GROUP A

Residential HVAC and DHW Measure Effective Useful Life Study Final Report

California Public Utilities Commission
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Glossary of terms

C-20 Licensed Contractor – The C-20 HVAC License is a Class C Specialty Contractor License offered by the state of California, required to conduct legal operations in air conditioning projects, heating ventilation, and other climate control projects. A C-20 licensed contractor is a warm-air heating, ventilating, and air-conditioning contractor that fabricates, installs, maintains, services, and repairs warm-air heating systems, air conditioning systems, and water pumps.

C-36 Licensed Contractor – The C-36 Plumbing License is a Class C Specialty Contractor offered by the state of California, required to conduct legal operations in plumbing design, installation, repair, and inspection and maintenance. A C-36 plumbing contractor provides a means for a supply of safe water, ample in volume and of suitable temperature for the purpose intended, and the proper disposal of fluid waste from the premises in all structures and fixed works.

Effective Useful Life (EUL) – Effective useful life (EUL) is defined as an estimate of the median number of years that the measures installed under a program are still in place and operable.[1]

Measure – A product whose installation and operation at a customer's premises results in a reduction in the customer's on-site energy use, compared to what would have happened otherwise.[1]

Participant – An individual, household, business, or other utility customer that received a service or financial assistance offered through a particular utility program, set of utility programs, or aspect of a utility program in a given program year.[1]

Performance Degradation – Any over time savings degradation (or increases compared to standard efficiency operation) that includes both (1) technical operational characteristics of the measures, including operating conditions and product design, and (2) human interaction components and behavioral measures.[1]

Persistence Study – A study to assess changes in net program impacts over time (including retention and degradation).[1]

Precision – The indication of the closeness of agreement among repeated measurements of the same physical quantity. In econometrics, the accuracy of an estimator is measured by the inverse of its variance.[1]

Reliability – When used in energy evaluation refers to the likelihood that the observations can be replicated.[1]

Retention (Measure) – The degree to which measures are retained in use after they are installed.[1]

Rigor – The level of expected reliability. The higher the level of rigor, the more confident we are that the results of the evaluation are both accurate and precise, i.e., reliable.[1]

Sample Design – The approach used to select the sample units.[1]

Survival Analysis – Survival analysis is a class of statistical methods for studying the timing of events or time-to-event models. Originally these models were developed for medical research where the time to death was analyzed, hence the name survival analysis. These statistical methods are designed to work with time-dependent covariates and censoring. Time-dependent covariates are independent variables whose impacts on the dependent variable vary by not only their occurrence but also their timing. Censored data refers to not knowing when something occurred because it is before your data collection (left-censored) or has yet to occur at the time of data collection (right-censored).[1]

[1] CPUC. "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals. Appendix B: Glossary of Terms." April 2006.

1 EXECUTIVE SUMMARY

This report presents the findings of the effective useful life (EUL) evaluation study conducted by DNV on behalf of the California Public Utilities Commission (CPUC) of five residential heating, ventilation, and air conditioning (HVAC) and domestic hot water (DHW) heating technologies. This is the second of the two residential EUL studies with measure technologies selected by the joint staff (DNV and CPUC). For this study, DNV classified the residential HVAC and DHW technologies into two groups: nascent heat pump and established gas technologies. The nascent heat pump technologies include heat pump HVACs and heat pump water heaters, whereas the established gas technologies include gas furnaces, gas storage water heaters, and gas tankless water heaters.

1.1 Study background and objectives

An EUL is the estimate of the median number of years that a measure, or energy-efficient technology, installed under a program is still in place and operable. EUL values are critical in reliably estimating the lifetime energy savings that are used for program planning and evaluation activities, and therefore, need to be periodically re-assessed. The current Database for Energy Efficiency Resources (DEER) EUL values of residential HVAC and water heating technologies come from studies that were conducted 15 to 20 years ago. These EUL values need to be updated to reflect the impact of technology advancement, maintenance practices, occupancy, space remodeling, human interaction components, climate change, and many other factors that have shifted in recent years. Moreover, there is strong interest from stakeholders as the HVAC and DHW technologies, particularly the nascent technologies, support California's decarbonization and savings goals.

The objectives of this residential HVAC and DHW EUL Study were to:

- Revise or verify EUL estimates for the five residential nascent and established HVAC and DHW technologies.
- Conduct a retention study for residential nascent heat pump HVAC and heat pump water heaters. A retention study is performed through the development of a retention rate to assess what percent of impacted technologies installed over the last 15-20 years are still in-place and working.

1.2 Study methods and results

To arrive at EUL estimates, DNV adopted a primary data collection and analysis method that assessed the current status (if still in place), working condition (operable or not), and the age of a sample of impacted equipment. The sampled equipment was selected from a distribution of installation ages, ranging between 2006 and 2023, occurring through energy programs in California and from a subset of equipment, with ages ranging from 11 to 40 years, that DNV observed via non-participant surveys. Table 1-1 summarizes our targeted and achieved sample size for different age groups of the impacted HVAC and DHW technologies.

Table 1-1. Targeted and achieved sample size by age and technology

Age (Years)	Nascent heat pump technologies				Established gas technologies					
	Heat pump HVAC (central and ductless)		Heat pump water heater		Gas furnace (Central and wall)		Gas storage water heater		Gas tankless water heater	
	Target sample	Final Sample	Target sample	Final Sample	Target sample	Final Sample	Target sample	Final Sample	Target sample	Final Sample
1-3	150	123	153	264	30	139	20	232	20	1,108
4-5	12	5	42	65	30	43	20	170	20	480
6-7	4	1	62	95	93	72	20	67	20	112
8-10	17	14	44	35	101	43	20	-	20	1
11	7	8	-	-	3	206	3	2	3	-
12	6	9	1	3	5	251	6	2	6	-
13	3	3	-	-	-	507	2	2	2	4
15-17	-	-	-	-	125	516	-	-	-	3
11-40	4	4	-	-	29	10	68	62	68	3
Total	**201**	**167**	**302**	**462**	**416**	**1,787**	**163**	**537**	**163**	**1,711**

As the primary data collection approach, DNV conducted email surveys followed by phone calls and site inspections. We gathered in place and operable status information of the installed impacted equipment, and documented nameplate pictures. The nameplate photos in conjunction with customer-reported age information were used to estimate the age of impacted equipment. This information was then used to develop and predict the probability of survival of the impacted equipment – a survival analysis. An EUL is the amount of time that passes until 50% of the impacted equipment is still in place and working (surviving). Table 1-2 summarizes our data collection findings and our primary analysis results.

Table 1-2. Primary data collection and analysis summary

Residential technology	Total units observed	Count of units that were still in-place & working	Count of units that had failed/ were removed	Estimated EUL (years)
Nascent heat pump technologies				
Heat pump HVAC (ductless & central)	167	162	5	23
Heat pump water heater	437	437	25	38
Established gas technologies				
Gas furnace (central & wall)	1,787	1,652	135	36
Gas storage water heater	497	497	54	25
Gas tankless water heater	1,711	1,682	29	20

Because the heat pump technologies (heat pump HVAC and heat pump water heater) are nascent technologies, only a limited number of installations through energy programs between 2006 to 2023 were old enough to provide a good basis for a precise estimate of the EUL. So, we pursued a secondary method that assessed the age of a sample of equipment replaced by licensed C-20 HVAC and C-36 plumbing contractors and program implementors of the investor-owned utilities (IOUs), regional collaboratives (BayREN), public utilities (MCE), and local government joint power authorities (RCEA) during this study. This involved gathering nameplate pictures and age information of heat pump technologies removed between July to October 2023 through the current heat pump programs offered by the utilities in California and through C-20 and C-36 licensed contractors in California. The program implementors could not accommodate providing appropriate baseline equipment data, so we only relied on data gathered through C-20 and C-36 contractors to establish the age of heat pumps replaced during this study.

DNV reached out to 691 C-20 and C-36 licensed contractors and was able to recruit 43 contractors that had either replaced heat pump technologies in the past or anticipated replacing heat pumps. Among the recruited 43 contractors, only 5 contractors followed up with 10 nameplate photos of heat pump HVACs. No nameplate pictures for heat pump water heater replacements were provided by the contractors. For the 10 heat pump HVAC nameplate pictures we received from contractors, we estimated the installation date of the removed heat pump technologies by comparing nameplate manufacturing date with the contractor reported installation date. We then compared the verified installation date against the date of removal to estimate the age of heat pump HVACs at replacement. The age-at-replacement analysis of heat pump HVAC yielded a median age of 21.72 years and an average age of 20.03 years. This is consistent with the 23 year EUL estimated through our primarily analysis.

1.3 Key findings and recommendations

The key findings and recommendations from the residential EUL evaluation study are as follows.

Finding 1. Increases to the EUL values for heat pump HVAC, heat pump water heaters, and gas storage water heaters should be considered based on the results of this study.

As presented in

Table 1-3, this study developed EUL estimates of five residential HVAC and DHW technologies. For the heat pump HVAC and heat pump water heaters (nascent heat pump technologies), the EUL values estimated by this study are 23 years and 38 years, respectively, which are above the CPUC's 20-year EUL limit. [2] Similarly, for the established gas furnace and gas storage water heaters, the EUL values estimated by this study are well above the 20-year EUL cap. For gas tankless water heaters, the EUL value estimated by this study is exactly 20 years.

The CPUC has a 20-year cap on EUL of all energy efficiency measures [2]; however, per the criteria set forth by Decision 09-05-037[3], the 20-year EUL cap can be extended to 30 years if "substantiated by supporting measure empirical data and subjected to review by Energy Division". The evaluated EUL values for heat pump HVAC, gas furnaces, and gas storage water heaters in this study are backed by empirical data, affirming their eligibility for a 30-year cap extension. However, for heat pump water heaters, such an extension is not eligible due to limited data availability. We cannot confidently extrapolate

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[2] CPUC. cpuc.ca.gov D0111066 Energy Efficiency Policy Manual (ca.gov)

[3] Decision 09-05-037. May 21, 2009. Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plans and Associated Public Goods Charge (PGC) and Procurement Funding Requests.

longevity beyond 20 years for this technology. Therefore, heat pump water heaters should still be subjected to the 20-year cap.

Table 1-3. EUL results

Residential technology	Existing EUL (years)[4]	Estimated EUL (years)	Proposed EUL (years)
Nascent heat pump technologies			
Heat pump HVAC (ductless & central)	15	23	23
Heat pump water heater	10	38	20[1]
Established gas technologies			
Gas furnace (central & wall)	20	36	30[2]
Gas storage water heater	11	25	25
Gas tankless water heater	20	20	20

[1] Based on the available regional survival data, we can confidently project an EUL up to 20 years. However, we cannot confidently project an EUL longer than 20 years due to significant extrapolation of the available data.
[2] EUL extension to a maximum of 30 years is allowed per Decision 09-05-037.

Recommendation: Update the EUL values for the heat pump technologies, gas furnaces, and gas storage water heaters.

We recommend updating the EUL values for the following EUL Identifications (IDs) in the Database for Database for Energy Efficient Resources (DEER):

- 'HV-ResHP' with an EUL value of 23 years for heat pump HVAC
- 'WtrHt-HtPmp' with an EUL value of 20 years for heat pump water heaters
- 'HV-EffFurn' with an EUL value of 30 years for gas furnaces
- 'WtrHt-Res-Gas' with an EUL value of 25 years for gas storage water heaters.

Based on the comprehensive analysis conducted and supported by empirical data, we recommend extending the 20-year EUL cap for heat pump HVAC, gas furnaces, and gas storage water heaters to a 30-year EUL limit. The empirical evidence gathered indicates a strong case for the longevity of these technologies, justifying their eligibility for such an extension. However, for heat pump water heaters, due to limited data availability and the inability to confidently extrapolate longevity beyond 20 years, we recommend maintaining the 20-year cap. These recommendations align with the criteria set forth by Decision 09-05-037 and aim to ensure accurate and effective management of energy efficiency measures.

Finding 2. Heat pump technologies have a high retention rate.

[4] California Electronic Technical Reference Manual (terms). caetrm.com, 2023. https://www.caetrm.com/login/?next=/

Based on the in-place and operable data gathered for the sampled heat pump HVACs with age groups ranging from 1 to 20 years, we estimated that 93% of the heat pump HVACs that we observed were still working in 2023. In other words, the retention rate of heat pump HVACs stands at 93%. This high retention rate across different age groups suggests that the heat pumps HVACs are expected to last longer than the current EUL of 15 years.

Similarly, we gathered in-place and operable data for heat pump water heaters that were 1 to 12 years old and found that 95.1% of the observed units were still in place and working in 2023. While we did not have data for units older than 12 years old, based on this high retention rate of 12 years or newer heat pump water heaters, we can conclude that heat pump water heaters are expected to last longer than the current EUL of 10 years.

Recommendation: DNV has no specific recommendation for this finding.

2 INTRODUCTION

This report presents the findings of the EUL evaluation study of five residential HVAC and DHW technologies (measure and baseline) selected by the joint staff (DNV and CPUC). The measure names and the associated EUL identifications (ID) of the evaluated HVAC and DHW technologies in the database for energy efficient resources (DEER) are shown in Table 2-1.

Table 2-1. Measures selected by the joint staff for the EUL study

Measure name and ID	Technology		EUL ID[5]
Heat Pump Water Heater, Residential, Fuel Substitution (SWWH014-04)	Measure	Heat pump water heater	WtrHt-HtPmp
	Baseline	Storage gas water heater	WtrHt-Res-Gas
		Tankless gas water heater	WtrHt-Instant-Res
Ductless HVAC, Residential, Fuel Substitution (SWHC044-02)	Measure	Ductless heat pump	HV-ResHP
	Baseline	Gas wall furnace	HV-EffFurn
Heat Pump HVAC, Residential, Fuel Substitution (SWHC045-01)	Measure	Central heat pump	HV-ResHP
	Baseline	Gas central furnace	HV-EffFurn
Ductless Heat Pump, Residential (SWHC050-02)	Measure	Ductless heat pump	HV-ResHP
	Baseline		

This study classified the impacted five residential HVAC and DHW technologies into two groups: nascent heat pump technologies (central and ductless heat pump HVAC systems and heat pump water heaters), and established gas technologies (gas storage water heaters, gas tankless water heaters, and wall and central gas furnaces).

2.1 Background

Table 2-2 presents the current Database for Energy Efficiency Resources (DEER) EUL values and the EUL sources of the impacted five residential HVAC and DHW technologies. These current DEER EUL values come from studies that were conducted 15 to 20 years ago, and in some instances, from sources that are not robust (e.g., the current heat pump water heater EUL is based on engineering judgment). These EUL values need to be revised/verified to reflect the impact of technology advancement, climate, maintenance practices, occupancy, space remodeling, human interaction components, and many other factors that have shifted in recent years.

The CPUC currently has a cap of 20 years for the EUL of energy efficiency measures.[6] For the evaluated HVAC and DHW technologies, if supported by evidence, there is an opportunity to extend the current EUL up to a 30-year cap [7], allowing a more accurate assessment of both total system benefit and cost-effectiveness. Additionally, the heat pump energy efficiency measures, along with other energy efficiency measures, play a key role in the state's transition to limit greenhouse gas (GHG) emissions and decarbonization. Therefore, there is a strong interest from the stakeholders to understand the EUL of heat pump technologies and the underlying baseline gas technologies.

[5] California Electronic Technical Reference Manual (eTRM). caetrm.com, 2023. https://www.caetrm.com/login/?next=/

[6] CPUC. cpuc.ca.gov. D0111066 Energy Efficiency Policy Manual (ca.gov)

[7] Decision 09-05-037. May 21, 2009. Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plans and Associated Public Goods Charge (PGC) and Procurement Funding Requests.

Table 2-2. Current DEER EUL value and EUL source for the impacted HVAC and DHW measures

Technology	EUL ID	EUL value (years)	Current EUL source
Heat pump HVAC (ductless & central)	HVAC- ResHP	15	EUL ID was modified in 2014. The original source traces back to DEER2005[8]
Heat pump water heater	WtrHt-HtPmp	10	2004-05 DEER Update Study. Engineering Judgement [9]
Gas furnace (wall & central)	HV-EffFurn	20	Energy Policy Manual v2.0, 2003.[10] EUL of 25 years was capped at a maximum of 20 years.
Gas storage water heater	WtrHt-Res-Gas	11	EUL value comes from the Appliance Magazine, 09/2007 [11]
Gas tankless water heater	WtrHt-Instant-Res	20	2004-05 DEER Update Study.[9] US DOE Technical Brief: 1/6/2004

2.2 Study objectives

This study presents verified/revised EUL estimates of the impacted residential technologies. This study also assessed the retention rate of nascent technologies (heat pump HVAC and heat pump water heaters).

The study objectives by technology type are summarized in Table 2-3.

Table 2-3. Study objectives and technologies

Residential technology	Study objectives
Heat pump HVAC (central and ductless)	Revise or verify EUL estimates and develop retention rate of heat pump HVACs
Heat pump water heaters	Revise or verify EUL estimates and develop retention rate of heat pump water heaters.
Gas furnace (wall and central)	Revise or verify EUL estimates.
Gas storage water heater	Revise or verify EUL estimates.
Gas tankless water heater	Revise or verify EUL estimates.

8 2004-2005 DEER Update Study Final Report, Table 11-5: Non-Weather Sensitive – Other EULs. https://www.calmac.org/%5C/publications/2004-05_DEER_Update_Final_Report-Wo.pdf

9 2004-2005 DEER Update Study Final Report, Table 11-5: Non-Weather Sensitive – Other EULs. https://www.calmac.org/%5C/publications/2004-05_DEER_Update_Final_Report-Wo.pdf

10 Energy Policy Manual Version 2, Table 4.1. Effective Useful Lives of Energy Efficiency Measures, p. 17. https://www.calmac.org/events/Policy%20Manual%20V2.pdf

11 Appliance Magazine, September 2007. 30th Annual Portrait of the U.S. Appliance Industry.

2.3 CPUC EUL study protocol and terms

EULs are defined as the median number of years after installation that the measures installed under a program are still in place and operable – in other words, how long the measure persists. The EUL Evaluation Protocol section of the California Energy Efficiency Evaluation Protocols document outlines three types of EUL evaluation persistence studies: retention, degradation, and EUL analysis studies.[12]

The Protocols define a persistence study as one that "measures change in the net impacts that are achieved through installation/adoption of program-covered measures over time." These changes include retention and performance degradation. The EUL protocol defines retention as the "proportion of measures retained in-place and that are operable."[13] Performance degradation accounts for both time-related and use-related changes in energy savings over time.

To study the persistence of the residential nascent technologies, DNV conducted a retention study. As defined in the retention study protocol, "measure retention studies shall collect data to determine the proportion of measures that are in-place and operational."[14] Measure retention studies, per the retention study protocol, should address the following evaluation components: "research design, survey-site visit instrument design, establishing the definition of an operable status condition, identifying how this condition will be measured, and establishing the data collection and analysis approach."[15] Table 2-4 summarizes the required protocol methods for measure retention study by rigor level. Rigor is defined as the level of expected reliability. There are two levels of rigor (Basic and Enhanced) for the retention study. The higher the level of rigor, the more confident we are that the results of the evaluation are both accurate and precise.

Table 2-4. Retention study protocols

Rigor level	Retention evaluation allowable methods
Basic	➢ In-place and operable status assessment based upon on-site inspections. Sampling must meet the Basic Rigor Level requirements discussed in this Protocol and must meet the requirements of the Sampling and Uncertainty Protocol. ➢ Non-site methods (such as telephone surveys/interviews, analysis of consumption data, or use of other data, e.g., from EMS systems) may be proposed but must be explicitly approved by Joint Staff through the evaluation planning process. Sampling must meet the Basic Rigor Level requirements discussed in this Protocol and must meet the requirements of the Sampling and Uncertainty Protocol. ➢ Basic rigor requires that a 0.70 level of power be planned at a 90% level of confidence with 30% precision.
Enhanced	➢ In-place and operable status assessment based upon on-site inspections. Sampling must meet the Enhanced Rigor Level requirements discussed in this Protocol and must meet the requirements of the Sampling and Uncertainty Protocol. ➢ Enhanced rigor requires that a 0.80 level of power be planned at the 90% level of confidence with 10% precision.

[12] CPUC. "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals." April 2006.

[13] CPUC. "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals." Section: Effective Useful Life Evaluation Protocol (Retention and Degradation). April 2006.

[14] Ibid.

[15] Ibid.

3 METHODS

The objective of the EUL study was to develop EUL estimates of all nascent and established residential HVAC and DHW heating technologies, as well as to develop the retention rate of nascent heat pump technologies. This was accomplished by conducting online surveys, virtual follow-ups, and on-site follow-ups with HVAC and water heating technology adopting program participants between PY2006 and PY2021 and with 11–40-year-old non-participant units previously observed by DNV, distributed proportionately over climate regions. The equipment age and retention information gathered from historical program participants were then used to conduct a survival analysis to arrive at EUL estimates of the impacted nascent and established residential HVAC and DHW heating technologies.

Additionally, for the nascent technologies, we conducted a secondary data collection and analysis to assess the age of units replaced during this study. This involved gathering nameplate pictures and age information of heat pump technologies removed between July to October of 2023 through C-20 and C-36 licensed contractors in California. Details on EUL analysis methodology can be found in Section 3.3.

3.1 Sample design

3.1.1 Sample design overview

DNV delivered a sample design and data collection memo for the residential HVAC and DHW heating technologies of this EUL study to the CPUC. As shown in Table 3-1, this study used a combination of two different analysis approaches, combining different types of data.

Table 3-1. Analysis approaches and data sources

Analysis approach	Data sources	Technologies
Survival analysis (primary analysis)	DNV remote customer surveys and DNV onsite data collection (historical program participants and units observed by DNV in the past)	Heat pump HVAC (nascent) Heat pump water heaters (nascent) Gas furnaces (established) Gas storage water heaters (established) Gas tankless water heaters (established)
Average age at replacement	C-20 and C-36 contractors and program implementers	Heat pump HVAC (nascent) Heat pump water heaters (nascent)

Since heat pump HVAC and heat pump water heaters are nascent technologies, obtaining good precision for them was of high interest. At the same time, because they are nascent, only a limited number of installations were old enough to provide a good basis for a precise estimate of the EUL. We targeted an enhanced rigor study of heat pump technologies by targeting sufficient contractor/ program implementation cases to achieve good precision from the average age at replacement and using the survival analysis as a basis for triangulation. For gas furnaces and gas water heaters, which are established technologies, the sample size was designed to target a basic rigor EUL study. By following the sampling methodology explained in Section 6 and following the basic vs enhanced rigor sampling guidance provided in the Sampling and Uncertainty Protocol[16], we determined the following sample sizes (shown in Table 3-2) for the EUL study.

Table 3-2. EUL study sample size

Residential technology	Technology type	EUL study rigor	Survival analysis		Age-at-replacement analysis	
			Sample size	Projected EUL Precision at 90% Confidence	Sample Size	Projected EUL Precision at 90% Confidence
Heat pump HVAC	Nascent	Enhanced	201	50%	80	10%
Heat pump water heater	Nascent	Enhanced	302	29%	80	10%
Gas furnace	Established	Basic	416	30%	N/A	N/A
Gas storage water heater	Established	Basic	163	28%	N/A	N/A
Gas tankless water heater	Established	Basic	163	28%	N/A	N/A

Next, we discuss how we developed the sample sizes presented above for the survival analysis and the age-at-replacement analysis.

For the survival analysis, which is the primary analysis approach, the population used to design a sample is the list of downstream savings claims provided in the 2006 through 2021 program tracking data. In addition, we included equipment with ages ranging from 11 to 40 years that DNV had observed via non-participant surveys. Table 3-3 shows the breakdown of accounts and samples by technology and age bin, with the data source.

Table 3-3. EUL survival analysis population by technology and age bin

Age (Years)	Source	Heat pump HVAC	Heat pump water heater	Gas furnace	Gas storage water heater	Gas tankless water heater
1-3	2013-21 Tracking	15,398	1,534	34,072	4,762	35,964
4-5	2013-21 Tracking	117	416	3,881	2,102	4,378
6-7	2013-21 Tracking	37	621	1,856	9,836	11,922
8-10	2013-21 Tracking	165	441	2,015	1,320	874
11	2012 Tracking	66	-	34	15	12
12	2011 Tracking	55	5	50	35	25
13	2010 Tracking	34	1	9,446	20	2
15-17	2006-08 Tracking	-	-	9,619	-	2
11-40	Non-participant surveys	56	-	1,442	1,507	102
Total	**All**	**15,928**	**3,018**	**61,261**	**19,597**	**53,299**

[16] CPUC. "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals." April 2006.

By following the sampling methodology explained in Section 6, we determined the following sample sizes (shown in Table 3-4) for the EUL survival analysis.

Table 3-4. Sample size for EUL survival analysis

Age (Years)	Source	Heat pump HVAC	Heat pump water heater	Gas furnace	Gas storage water heater	Gas tankless water heater
1-3	2013-21 Tracking	150	153	30	20	20
4-5	2013-21 Tracking	12	42	30	20	20
6-7	2013-21 Tracking	4	62	93	20	20
8-10	2013-21 Tracking	17	44	101	20	20
11	2012 Tracking	7	-	3	3	3
12	2011 Tracking	6	1	5	6	6
13	2010 Tracking	3	-	-	2	2
15-17	2006-08 Tracking	-	-	125	-	-
11-40	Non-participant surveys	4	-	29	68	4
Total	**All**	**203**	**302**	**416**	**163**	**163**

For the age at-replacement analysis of heat pump HVAC and heat pump water heaters, our sampling target was to attempt to recruit 10 non-participating contractors to provide nameplate data with legible pictures for 8 replaced units each. Recruitment targets would be distributed over climate region groupings and types of customers served. Additionally, our sampling target was to attempt to gather program implementation data from nine different residential energy programs offered by the utilities in California (details provided in Table 6-3).

3.1.2 Data collection efforts, sample completions, and response rate

We designed the sample size for the EUL survival analysis shown in Table 3-2 assuming that recent and relevant contact information would be available for all the historical participant population data shown in Table 3-3. The population data shown in Table 3-3 includes some data points with incorrect and/or missing contact information. We made data requests with the PAs to gather the most recent and relevant contact information for those data points. We received responses from the PAs regarding our data requests, but not all the requested contacts were provided by the PAs. This essentially reduced our actual study population size (as shown in Table 3-5), limiting the data that we could theoretically collect from each age group and technology type.

Table 3-5. EUL survival analysis final population by technology and age bin

Age (Years)	Source	Heat pump HVAC	Heat pump water heater	Gas furnace	Gas storage water heater	Gas tankless water heater
1-3	2013-21 Tracking	1,578	1609	5,450	3,604	24,202
4-5	2013-21 Tracking	15	568	1,996	1,556	5,206
6-7	2013-21 Tracking	24	613	2,760	1,500	1,818
8-10	2013-21 Tracking	170	413	1,490	-	-
11	2012 Tracking	64	-	2,929	10	-
12	2011 Tracking	58	5	3,794	20	-
13	2010 Tracking	34	-	8,049	17	-
15-17	2006-08 Tracking	-	-	4,747	-	2

Age (Years)	Source	Heat pump HVAC	Heat pump water heater	Gas furnace	Gas storage water heater	Gas tankless water heater
11-40	Non-participant surveys	56	-	1,442	1,507	102
Total	**All**	**1,999**	**3,208**	**32,657**	**8,214**	**31,381**

We emailed web surveys to all the historical participants population with email contact information available (shown in Table 3-5). We sent five follow-up reminders to all the participants. For all the heat pump HVAC and heat pump water heater program participants, we completed six phone call follow-ups and relaunched the survey twice. The first relaunch included a $25 gift card incentive for participating in the survey, and the second relaunch included a $50 gift card incentive for participating in the survey. In addition to the above-mentioned efforts, for all 11–40-year-old non-participant units previously observed by DNV, we mailed a letter with instructions to complete the web survey and a $50 gift card incentive for each completion. We then conducted a door-to-door follow-up with 10 residents to gather the heat pump HVAC nameplate photos.

We categorized the survey responses that we gathered into two different categories: survey completed with a nameplate photo and survey completed without a nameplate photo. Table 3-6 shows the count by age group and technology type of completed surveys with nameplate photos. The percent complete shown in the table below compares the surveys completed with a nameplate picture (nameplate sample) to the sampling target shown in Table 3-4.

Table 3-6. Count of survey responses with nameplate photos

Age (Years)	Heat pump HVAC		Heat pump water heater		Gas furnace		Gas storage water heater		Gas tankless water heater	
	Final sample	% Complete	Final sample	% Complete	Final sample	% Complete	Final sample	% Complete	Final sample	% Complete
1-3	52	35%	124	81%	42	140%	110	550%	436	2,180%
4-5	1	8%	30	17%	3	10%	90	450%	195	975%
6-7	1	25%	41	66%	24	26%	36	180%	59	295%
8-10	2	12%	17	39%	11	11%	-	-	1	5%
11	2	29%	-	-	48	1,600%	2	67%	-	-
12	-	-	-	-	54	1,080%	1	17%	-	-
13	-	-	-	-	113	UD	1	50%	-	-
15-17	-	-	-	-	138	110%	-	-	2	UD
11-40	3	75%	-		1	3%	32	44%	1	1%
Total	**61**	**30%**	**212**	**70%**	**434**	**104%**	**272**	**167%**	**694**	**426%**

UD = undefined because the targeted sample size for this age group was zero.

We used the serial number and/or manufacturing date information from the gathered nameplate pictures to calculate the age of the equipment. We compared this nameplate age information with customer customer-reported equipment age and the equipment age estimated using the program participation data and found the nameplate age information to be consistent with the customer-reported age and the equipment age estimated using the program participation data. As such, we used all the survey responses (with or without a nameplate photo) as our final sample size for the survival analysis. Table 3-7 shows the count of the final sample completed by age group and technology types. The percent complete in Table 3-7 compares the final sample size with the targeted sample size presented in Table 3-4Table 3-4.

Table 3-7. Count of all survey responses

Age (Years)	Heat pump HVAC		Heat pump water heater		Gas furnace		Gas storage water heater		Gas tankless water heater	
	Final sample	% Complete	Final sample	% Complete	Final sample	% Complete	Final sample	% Complete	Final sample	% Complete
1-3	123	82%	264	173%	139	463%	232	1,160%	1,108	5,540%
4-5	5	42%	65	155%	43	143%	170	850%	480	2,400%
6-7	1	25%	95	153%	72	77%	67	335%	112	560%
8-10	14	82%	35	80%	43	43%	-	-	1	5%
11	8	114%	-	-	206	6,867%	2	67%	-	-
12	9	150%	3	300%	251	5,020%	2	33%	-	-
13	3	100%	-	-	507	UD	2	100%	4	200%
15-17	-	-	-	-	516	413%	-	-	3	UD
11-40	4	100%	-	-	10	34%	62	86%	3	4%
Total	**167**	**82%**	**462**	**153%**	**1,787**	**430%**	**537**	**329%**	**1,711**	**1,050%**

UD = undefined because the targeted sample size for this age group was a zero.

For the established gas technologies and heat pump water heater, while we were not able to complete the sampling target for some age groups, overall, our final sample size well exceeds our sampling target. Our final sample compensated the responses for age groups where we were not able to complete the sampling target by gathering significantly more than targeted responses from the other age groups. For heat pump HVAC, our final sample size was 82% of our sampling target. While the overall final sample size is lower than targeted, we were able to complete (and in some cases exceed) our sampling target for age groups older than 11 years. This is important because compared to the newer age group data, older age group data are more important for developing survival probability curves.

For the age of replacement analysis of heat pump technologies, as indicated in Table 3-1, we identified two data sources: a) program implementation data from the current residential heat pump HVAC and heat pump water heater programs offered by utilities in California, and b) C-20 and C-36 licensed contractors in California. DNV requested baseline equipment data for the current residential heat pump water heater and heat pump HVAC programs offered by the program implementors (IOUs, regional collaboratives, and public utilities) in California. We conducted two follow-up phone calls each with the program implementors, to discuss the requested baseline data and provided formal instructions for data gathering and submission; however, we did not receive the requested data. While some program implementors were able to provide equipment data, the critical baseline information was missing. In case of the IOUs, they could not accommodate collecting the requested data, citing that it was not a part of the measure package requirements. In some cases, the IOUs mentioned that the third-party data collection structure and the rigid contracting made it challenging for them to collect additional baseline data as it involved additional expenses. As such, we relied on C-20 and C-36 contractor data only for the age-of-replacement analysis of heat pump technologies.

We engaged C-20 and C-36 licensed contractors derived from a contractor listed on the California State License Board[17] to enlist them to provide 10 or more nameplate photos of heat pumps removed in the past year. We implemented a two-phase recruitment strategy. In phase one, we crafted a web-based survey, sent via email, inviting 691 contractors to submit nameplate photos. The emails were presented as a collaborative initiative on behalf of the CPUC and utilities PG&E, SDGE,

[17]Department of Consumer Affairs Contractors State License Board." CA.gov, https://www.cslb.ca.gov/.

and SCE. Unfortunately, this effort yielded less than a 1% response rate (7 surveys completed), prompting the initiation of phase two – telephone survey recruitment.

Under phase two, we placed telephone calls with the intent to explain the survey effort in greater detail and screen for eligible contractors. The starting population was 759 companies, of which only 471 had a phone or viable phone number. We telephoned all 471 and completed screener surveys with 139 companies (30% of the population).

Among the 139 surveyed, 96 contractors (69% of the population) did not remove or anticipated removing heat pumps in existing buildings and thus were not eligible to participate in the study. Among the eligible population, we asked what type of heat pump systems they worked with. The full range of responses is presented in Table 3-8. We also asked contractors about how many heat pump units they removed every few months, the counties served, and if they would be willing to help with the nameplate photo survey.

Table 3-8. Count of contractor responses regarding replacing heat pump technologies

Which of the following types of heat pumps do your company work with? Select all that apply	Response count	Response percent (n=43)
Heat pump water heating systems	14	33%
Central air heat pump systems	38	90%
Ductless heat pump systems	36	86%

Out of 43 contractors that had either removed in the past or anticipated removing heat pump technologies, only 37 contractors expressed willingness to participate in the nameplate photo survey. We followed up with instructions to complete the survey. Unfortunately, only a few contractors followed through with their verbal commitment. DNV placed numerous reminders by email and telephone, but often this resulted in refusals, citing reasons such as being no longer interested or insufficient incentive. The study concluded with 10 nameplate photos of heat pump HVACs from 5 individual contractor companies. We did not receive nameplate pictures for heat pump water heater replacements during this study. In general, there was not a big volume turnover for heat pump technologies during this study, possibly because not a lot of heat pumps have been installed in the past, and possibly because heat pump technologies are not failing as frequently as other technologies.

3.2 Data collection

3.2.1 Primary data collection

DNV conducted a combination of email surveys, phone calls, virtual inspections, and on-site inspections with HVAC and water heating technology program participants between PY2006 and PY2021 and with 11–40-year-old non-participant units previously observed by DNV, distributed proportionately over climate regions.

DNV gathered the following information for the EUL survival analysis:

- For equipment installed through residential programs, we verified the make/model of the installed equipment and verified the equipment measure installation date. *Note: If program-related equipment installation could be verified due to a change in home ownership or other reasons, we still conducted an in-place and operable status assessment.*
- Determined if the installed equipment is still in-place and operable.

- For installed equipment that has been replaced/failed, document the equipment replacement/failure date.
- Documented reasons for removal/failure if the installed equipment has been replaced or has failed.
- Gathered nameplate pictures and/or make/model of the removed equipment (if available) and the installed equipment.

The DNV data collection instruments for the EUL survival analysis are provided in Section 7.1.

Table 3-9 provides a breakdown of survey responses by technology type where the installed equipment was either in place and working or was removed. A summary of data collected for the EUL survival analysis can be found in Section 8.

Table 3-9. Summary of HVAC and DHW status assessment survey

Technology	Surveys completed	Survey responses where the installed equipment was:			
		In place and functioning	% of in place and functioning	Removed/replaced	% of removed/replaced
Heat pump HVAC	167	162	97.1%	5	2.9%
Heat pump water heater	462	437	94.5%	25	5.5%
Gas furnace (wall or central)	1,787	1,652	92.5%	135	7.5%
Gas storage water heater	537	497	92.5%	54	7.5%
Gas tankless water heater	1,711	1,682	98.3%	29	1.7%

For the age-at-replacement analysis, DNV, through C-20 and C-36 licensed contractors, gathered the following information:

- Make/model and type of existing residential HVAC and water heating equipment that has failed/is being replaced.
- Picture of equipment tag with installation date (if available)
- Name plate picture of existing failed/replaced residential HVAC and water heating equipment
- Existing equipment replacement/failure date
- Assessment of existing equipment condition
- Reasons for replacement/failure of existing equipment

3.2.2 Secondary research

There have been relatively few EUL studies conducted recently for residential HVAC and DHW technologies. We identified the 2023 X2001B: Connecticut Measure Life/EUL Update Study-Residential & Commercial Study [18] as our primary literature for the secondary research because of the recency and relevancy of the X2001B study. Similar to this EUL study, the X2001B EUL study employed the survival analysis approach to investigate EUL values of residential heat pump HVACs, heat pump water heaters, and gas furnaces, in addition to other residential and commercial technologies. DNV used the X2001B as the basis for our sample design and precision projections. The residential HVAC and DHW technology EUL findings of the X2001B study are summarized in Table 3-10.

[18] https://energizect.com/sites/default/files/documents/X2001BFINALReport_051523.pdf

Table 3-10. EUL results presented by the X2001B: Connecticut Measure EUL Study[19]

Residential measure	Estimated EUL (years)
Air source heat pump	20
Ductless heat pump	17
Heat pump water heater	15
Gas furnace	28

3.3 Analysis methods

This section of the report discusses the methods employed to estimate measure persistence to date. 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 employed a method commonly referred to as "survival analysis." The set of techniques referred to as survival analysis is widely employed to analyze data representing the duration between observable events. The tracking and verified data were fed into two models: a non-parametric Kaplan-Meier life test model and a parametric survival analysis, which are briefly explained below.

3.3.1 Kaplan-Meier (non-parametric) estimator

Combining the non-persistence data from multiple program years requires a way to take into consideration unknown future events conditional on current status. 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 unit operation vs. failure over a certain date range. The goal is to estimate a survival curve – i.e., what percent of installed units survive to any given age, plotting percent surviving vs age. With the non-parametric approach, that curve is calculated based on the percent of those that survive to a given year who also survive to the next (e.g., of those that survive to year 3, what percent survive to year 4).

If measures have been installed long enough that more than 50% 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 of the non-parametric approaches is that they cannot be projected beyond the limits of the maximum observed elapsed years. In many cases where estimates of measure persistence are sought, over 50% of the measures are still surviving 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.

3.3.2 Parametric survival analysis

Survival analysis generally tracks the binary options of "in place" and working or either of the opposites, not in place or not working. The parametric analysis allows an estimate of the percent that will survive to longer ages than are yet observable in the data, by assuming the decay in the survival curve follows a particular form. The same data used for the non-parametric KM estimator is used to estimate the parameters of a general form or distribution. With these parameters, we can draw the

[19] Ibid

projected survival rates for higher ages than have yet been observed. We can also calculate the EUL as the age at which 50% of the units will no longer be in place, that is, the median survival time.

For this study, DNV collected in-place and operable status information as well as information on if an equipment needed repair. Depending on the frequency of repair (if provided) and additional notes (if any) provided by the survey participants on the history of the equipment, we assigned binary (1 or 0) values when developing survival curves. DNV applied parametric models with multiple distributional assumptions to see which fit the data better. Of the parametric models that regularly successfully converge and provide results, the Weibull distribution is the most flexible. This means the Weibull model can produce a shape like many of the other distributions, if that is what the data prefers, but it can also take shapes the other distributions are not flexible to. As a result, the Weibull is broadly used for survival analysis both inside and outside the energy efficiency evaluation area. It has a general shape that is consistent with the way equipment failures tend to happen.

3.3.3 Age-at-replacement analysis

For the nascent heat pump technologies, we intend to use the baseline data from the current residential programs in conjunction with baseline equipment data from licensed contractors to analyze the age of units that were replaced during this study and to calculate a basic weighted average age that would provide another estimate of the EUL. As indicated in Section 3.1.2, we were not able to gather the baseline data from the IOUs for the current residential HVAC and DHW programs. While the residential program baseline data would have been valuable in conducting a rigorous age-at-replacement analysis, we were still able to conduct an EUL survival analysis – which is our primary EUL analysis approach – using the historical residential program participants' data. Although less rigorous, we conducted an age-at-replacement analysis using the baseline equipment data that we collected from the C-20 and C-36 licensed contractors. We received data for heat pump HVAC replacements only during this study, and therefore we were not able to conduct age-at-replacement analysis for heat pump water heaters.

The heat pump HVAC replacement data provided by the licensed contractors included the installation date of removed/replaced heat pumps, nameplate picture of removed/replaced heat pumps, and date of removal/replacement. We used the equipment serial number and/or manufacturing date information obtained from the nameplate pictures of the removed/replaced equipment in conjunction with the contractor-reported installation date of the removed/replaced equipment.

3.3.4 Retention analysis

A retention analysis estimates the percentage of installed equipment that is still in-place and working over a given timeframe. To understand the EUL of heat pump technologies, we developed retention rates of heat pump technologies for different age groups using the following formula:

$$Retention\ rate\ (\%) = \frac{Count\ of\ total\ units\ observed - Count\ of\ removed\ or\ replaced\ units}{Count\ of\ total\ units\ observed} \times 100$$

4 RESULTS

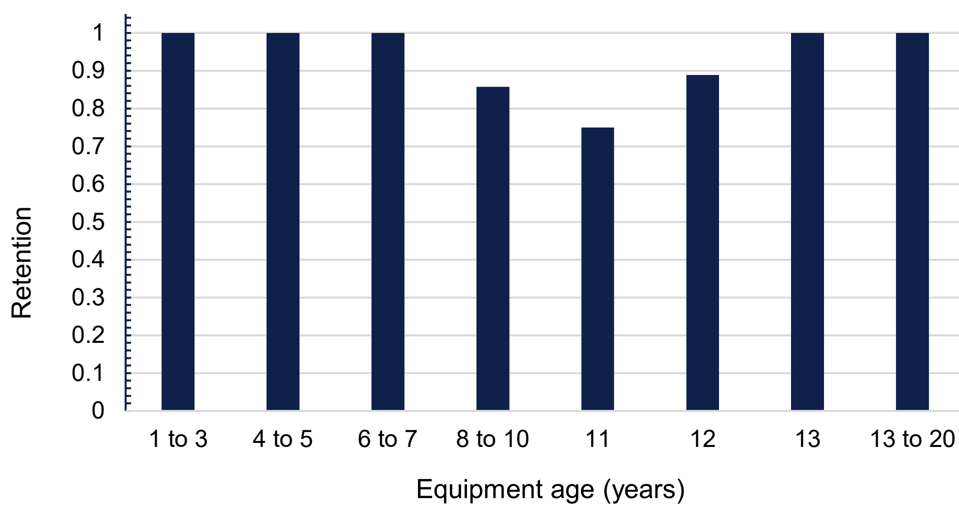
4.1 Nascent heat pump technologies

4.1.1 Heat pump HVAC (central and ductless)

4.1.1.1 Retention rate results

Figure 4-1 shows the retention rates of different age groups of the observed 167 heat pump HVAC units. The observed heat pumps belonging to age group 6 to 7 years and newer all had a 100% retention rate, suggesting that heat pump HVACs have a high survival probability for the first 7 years after installation. While we observed some instances of failure and/or removal of heat pump HVACs older than 7 years, the survival rate of those heat pumps was still greater than 75% (ranged from 75% to 100%). Overall, the observed heat pumps with age ranging from 0 to 20 years had an average retention rate of 93%. This high retention rate across different age groups suggests that the heat pumps units are expected to last longer than the current EUL of 15 years.

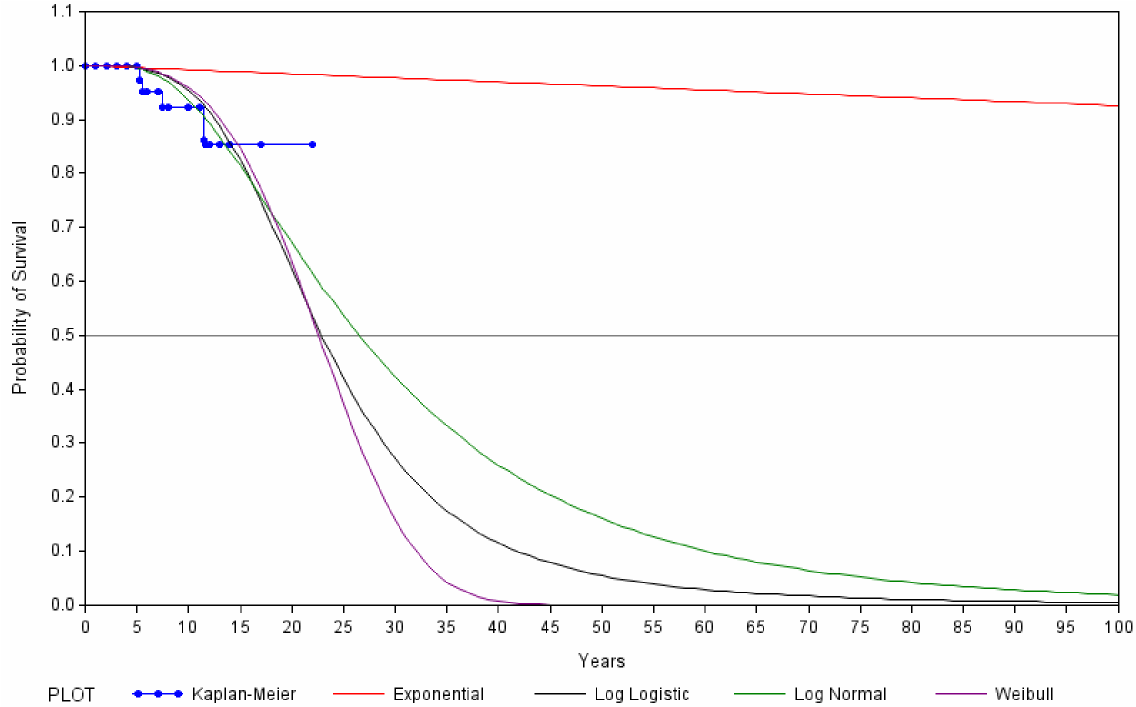
Figure 4-1. Heat pump HVAC retention by age



4.1.1.2 EUL survival analysis results

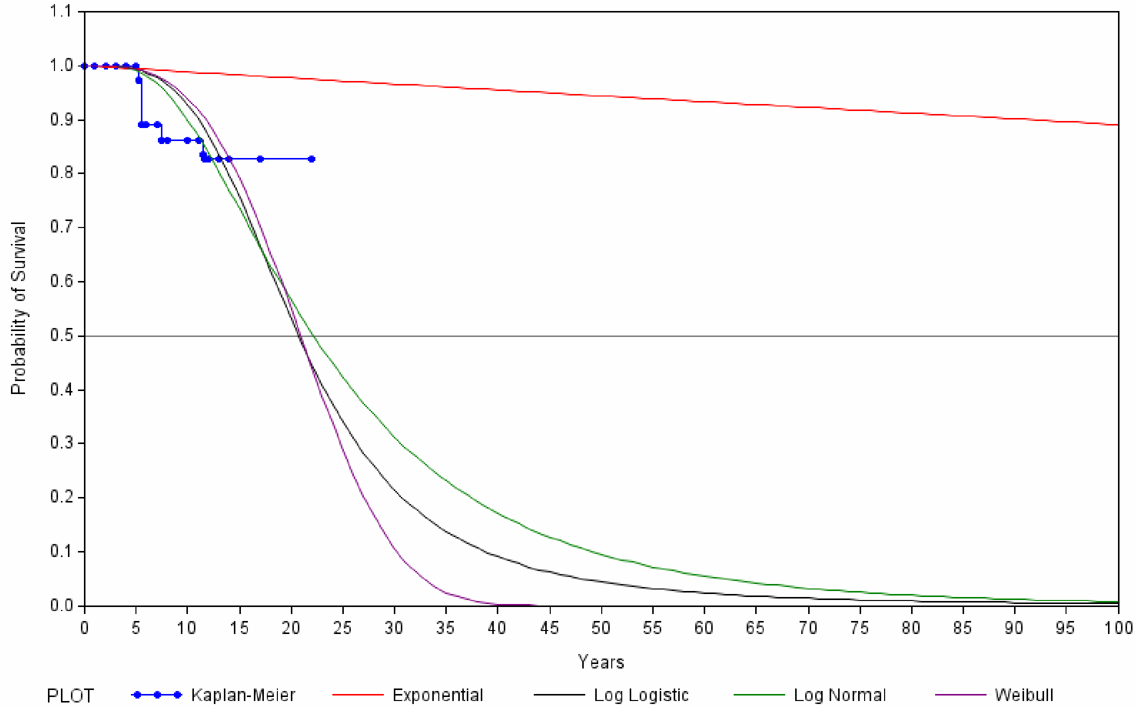
Our study developed survival analysis sample size aiming for an enhanced rigor EUL study and assuming the current heat pump HVAC EUL of 15 years to be accurate. We targeted heat pump HVAC program participation data for different age groups, with the oldest age group exceeding the current EUL. The heat pump survival data (effectively unforeseeable) showed that most of the observed heat pumps were still in good working condition. As such, the Kaplan-Meier analysis results (blue line in Figure 4-2) do not reach the median level because more than 50% of the observed heat pumps were still surviving. Log Logistic, Log Normal, and Weibull distribution are all close to the Kaplan-Meier results and provide possible EULs; however, the Weibull distribution is the closest to the Kaplan-Meier results and is the most flexible functional form that will still converge on the data. Therefore, Weibull distribution provides the heat pump HVAC EUL results. The predicted EUL for heat pump HVAC is 23 years with a 90% confidence interval of 20–25 years. This range represents an achieved precision of 12% at 90% confidence interval.

Figure 4-2. Kaplan-Meier and parametric survival models fit to the heat pump HVAC data



As mentioned in Section 3.1.2, while we were able to exceed our sampling target for the older age bins, we were not able to achieve our overall sampling target for different age groups for the survival analysis. We wanted to understand if and how the EUL value would be impacted had we completed our sampling target. As such, we conducted an additional EUL analysis assuming a more conservative scenario such that we got an additional 20 responses with 10 sites with failure at 5.5 years (the most conservative one we observed in the old sites) and 10 censored sites with duration proportional to what is in the observed data. As shown in Figure 4-3, the EUL would still only drop from estimated 23 years to 21 years (with a 90% confidence interval of roughly 10%) even if we had received additional data with the most conservative heat pump failure responses. Therefore, we feel confident with the 23-year EUL that we estimated using the equipment survival data.

Figure 4-3. Kaplan-Meier and parametric survival models fit to the heat pump HVAC data with conservative simulated additional 20 observations



Currently, the CPUC has a 20-year cap on the EUL of energy efficiency measures [20]. However, per Decision 09-05-037,[21] this cap can be extended from 20 to 30 years if "substantiated by supporting measure empirical data and subjected to review by Energy Division". We possess robust survival data of heat pump HVAC across various age groups, spanning up to 20 years, which serves empirical evidence. Furthermore, our report has undergone thorough review by the Energy Division. Consequently, we confidently recommend an EUL of 23 years for heat pump HVAC, aligning with Decision 09-05-037's 21 provision for extension based on substantiated empirical data and Energy Division review.

4.1.1.3 Age-at-replacement analysis results

Table 4-1 shows a summary of the age-at-replacement analysis for heat pump HVACs. We used the 10 nameplate pictures provided by C-20 and C-36 contractors of heat pump HVACs that were replaced during this study to estimate a median and an average equipment age at replacement. The median replacement age is 21.72 years, and the average age weighted by size (tons) is 20.03 years. This is consistent with the 23 year EUL that we established using the survival analysis.

Table 4-1. Heat pump HVAC age-at-replacement analysis

Description	Size (tons)	Verified installation date	Removal/replacement date	Age at replacement (years)
Central heat pump	2	05/22/1990	08/04/2023	33.22
Central heat pump	2	09/07/2010	09/12/2023	13.02

[20] CPUC. cpuc.ca.gov. D0111066 Energy Efficiency Policy Manual (ca.gov)

[21] Decision 09-05-037. May 21, 2009. Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plans and Associated Public Goods Charge (PGC) and Procurement Funding Requests.

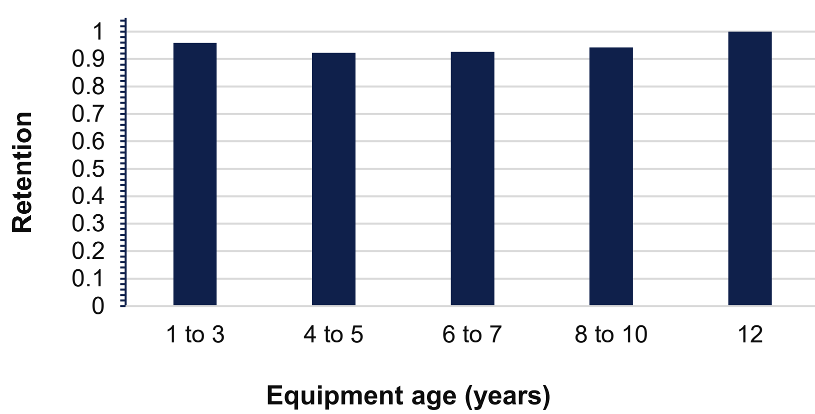
Description	Size (tons)	Verified installation date	Removal/replacement date	Age at replacement (years)
Central heat pump	3.8	12/1/2012	02/01/2023	10.17
Central heat pump	3	12/01/1998	08/03/2023	24.68
Central heat pump	2.5	11/01/1998	10/11/2023	24.95
Central heat pump	2.5	09/01/2017	05/22/2023	5.72
Central heat pump	3.5	12/01/2004	09/01/2023	18.76
Central heat pump	3	12/12/1996	11/01/2023	26.90
Central heat pump	4	07/18/1996	04/17/2023	26.76
Central heat pump	3	11/15/2005	02/24/2023	17.28

4.1.2 Heat pump water heater

4.1.2.1 Retention rate results

Figure 4-4 shows the retention rate for different age groups of the observed heat pump water heaters. The oldest available historical program participation data was for units that were 12 years old. The heat pump water heaters for all observed age groups (ranging from 1 to 12 years old) had a >90% retention rate with an average retention rate of 95.1%, suggesting that heat pump water heaters have a high survival rate. While we do not have retention data for units older than 12 years, we can conclude that heat pump water heaters are expected to last longer than the current EUL of 10 years.

Figure 4-4. Retention rate for heat pump water heaters by age group

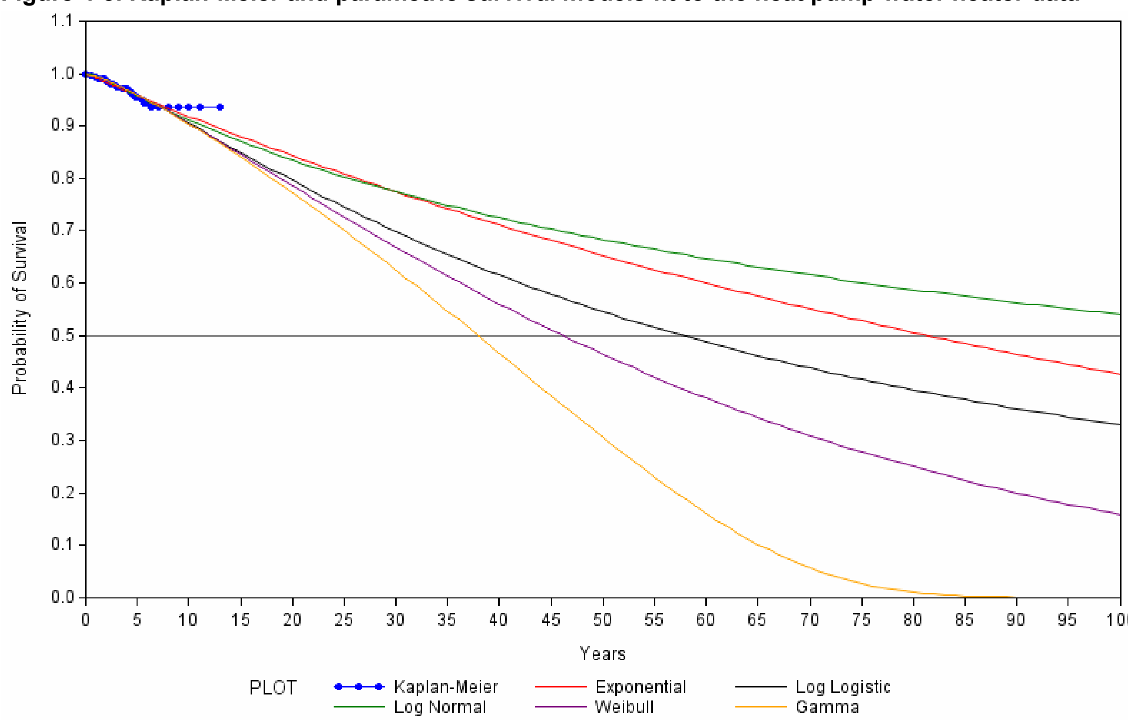


4.1.2.2 EUL survival analysis results

Our study developed survival analysis sample size aiming for an enhanced rigor EUL study. We targeted heat pump water heater program participation data for different age groups, with the oldest age available group exceeding the current EUL of

10 years. The heat pump water heater survival data (effectively unforeseeable) showed that most of the observed units were still in good working condition. As such, the Kaplan-Meier analysis results (the blue line in Figure 4-5) do not reach the median level because more than 50% of the observed heat pump water heaters were still surviving. An additional distribution model, the Gamma model, converge for these data. This distribution can fit a Weibull distribution but is more flexible and able to better fit the data. In this case, the Gamma distribution is the closest to the Kaplan-Meier results and provides the EUL result of 38 years with a 90% confidence interval of 27–48 years. While this range is significantly wider than our targeted precision, it is still sufficiently conclusive to support that the heat pump water heaters are expected to last at least up to the current 20-year EUL cap. However, to assert with confidence how well beyond 20 years heat pump water heaters can survive, additional data, particularly from the 12-20+ year old age bin, is imperative. Therefore, based on the best available regional survival data of heat pump water heaters, we recommend the EUL of heat pump water heaters to be updated to the 20-year EUL cap.

Figure 4-5. Kaplan-Meier and parametric survival models fit to the heat pump water heater data



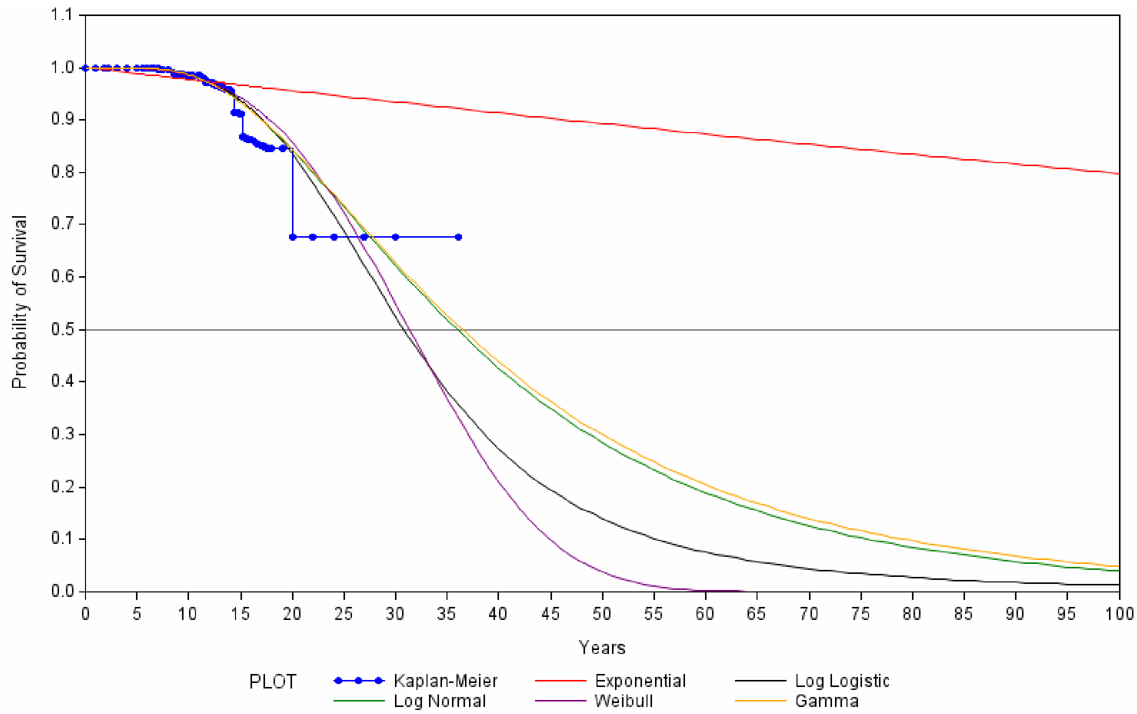
4.2 Established gas technologies

4.2.1 Gas furnace (wall and central)

4.2.1.1 EUL survival analysis results

Our study developed survival analysis sample size aiming for an enhanced rigor EUL study. We targeted gas furnace program participation data for different age groups, with the oldest age available group exceeding the current EUL of 20 years. The gas furnace data (effectively unforeseeable) showed that a majority of the observed units were still in good working condition. As such, the Kaplan-Meier analysis results (the blue line in Figure 4-6) do not reach the median level because more than 50% of the observed heat pump water heaters were still surviving. For gas furnaces, the parametric models offer slightly different results than the prior measures. As with the heat pump water heater data, the Gamma model converges for these gas furnace data. In this case, the Gamma model appears to indicate the log Normal distribution may provide a better basis for the gas furnace survival process. These models suggest an EUL of 36 years. This is roughly the age at which the KM algorithm indicates that more than 65% of units still survive. At the more conservative end of the estimates, the Weibull and Log Logistic models provide very similar EUL estimates of 31 years. All of these results significantly surpass CPUC's 20-year limit on EUL of energy efficiency measures, providing compelling empirical evidence that gas furnaces last longer than 20 years. In accordance with the criteria set forth in D.09-05-037 [22] for considering an EUL greater than 20 years, gas furnaces EUL results warrant recommending an EUL extension up to 30 years. Therefore, we propose extending the EUL of gas furnaces to 30 years.

Figure 4-6. Kaplan-Meier and parametric survival models fit to the gas furnace data



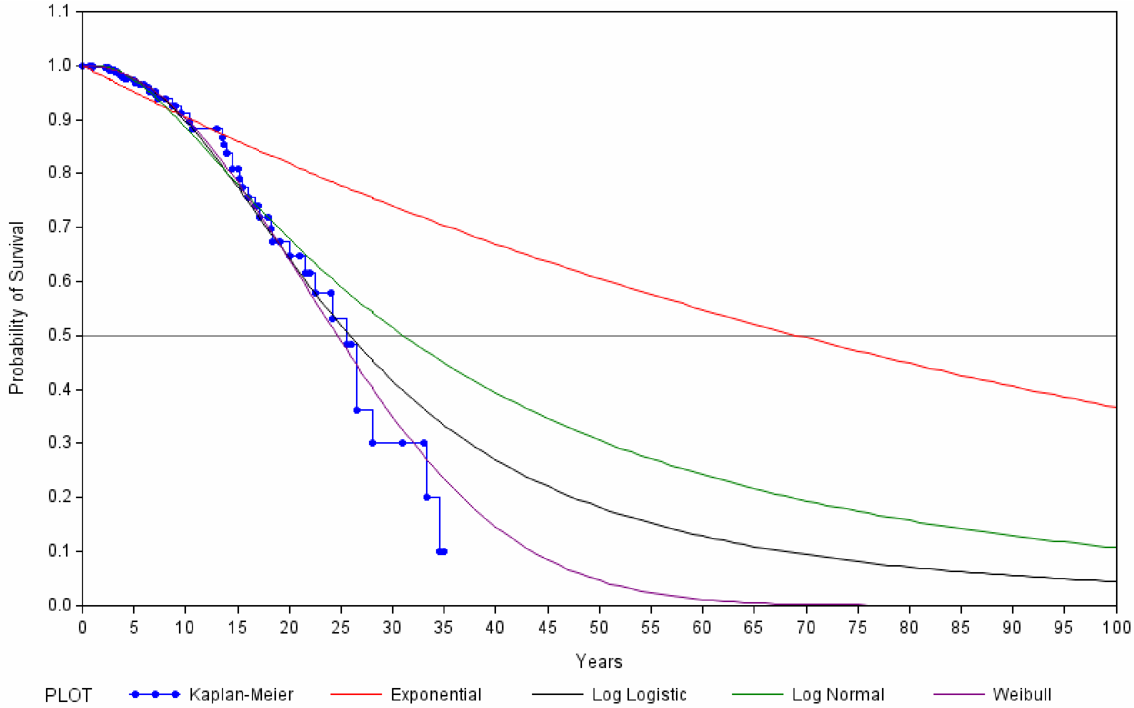
4.2.2 Gas storage water heater

4.2.2.1 EUL survival analysis results

Our study developed survival analysis sample size aiming for an enhanced rigor EUL study. We targeted gas storage water heater program participation data for different age groups with the oldest age available group exceeding the current EUL of 11 years. The gas storage water heater survival data, unlike measures discussed above, demonstrates units of an age where more than half of the units are not in good working condition. As such, the Kaplan-Meier analysis results (the blue line in Figure 4-7) do reach the median level. Because the Kaplan-Meier is not restricted to a specific distributional functional form, when it does cross the median level, it is generally considered the best available estimate. In this case, we can see that the Weibull distribution provides both a general shape and EUL results that are extremely close to the Kaplan-Meier results. The Kaplan-Meier EUL result is 26 years, and the Weibull is 25 years.

[22] Decision 09-05-037. May 21, 2009. Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plans and Associated Public Goods Charge (PGC) and Procurement Funding Requests.

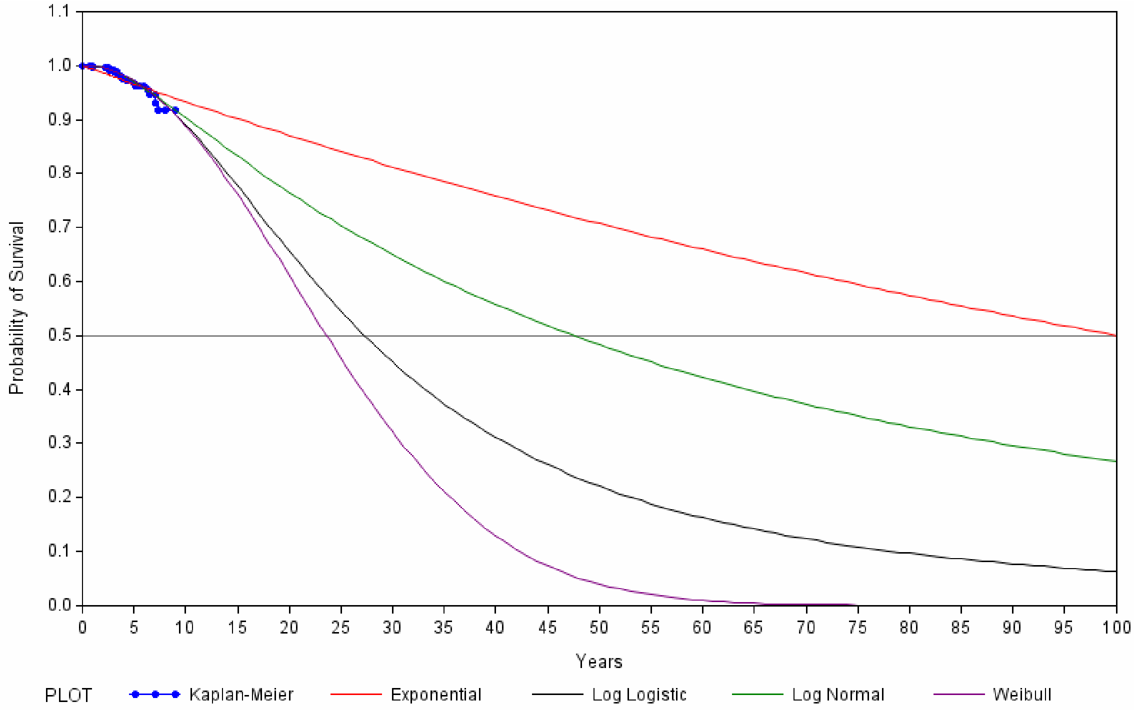
Figure 4-7. Kaplan-Meier and parametric survival models fit to the gas storage water heater data



The similarity of the KM and Weibull approaches demonstrates the ability of the parametric Weibull approach to approximate the robust, non-parametric KM approach. Recognizing the strength of the Weibull distribution on these data, we also wanted to test the implications of including the older data that was collected. The 11–40-years-old units previously observed by DNV had been in the field for a variable number of years. Because of this, those measures' survival to the present was conditional on them having survived to the point of that earlier research. For example, if those measures had all been initially assessed at 10 years of age, then there would have been zero probability of a measure having failed or having been removed prior to 10 years. Any measure that failed prior to 10 years could not have been included in that initial analysis sample. The conditional nature of these older data indicates that they could support an upwardly biased EUL estimate. To test this, we removed those longer-term conditional data and ran the same analysis. As illustrated in Figure 4-8, the shorter KM line, in blue, demonstrates the more limited range of ages of measures that could be assessed from the point of their original installation. The Weibull model fits these data points and produces an EUL of 24 years, only one year shorter than the Weibull-based EUL estimated from the full data. The confidence intervals are wider (±2 years) due to the necessity of projecting well outside of the existing data. These results give us further confidence in an EUL estimate of up to 24 years, while also providing evidence that in this case the bias inherent in the older, previously observed unit data was modest.

In light of our comprehensive analysis, which includes considerations of predicted EUL using the full available data and estimates excluding units aged 11-40 years, we have found that the expected lifespan of gas storage water heaters surpasses the typical 20-year EUL limit imposed by the CPUC. Our study benefits from robust survival data and empirical evidence gathered for gas storage water heaters. This data, coupled with the thorough review conducted by the Energy Division, solidifies our recommendation for an extension of EUL limit from 20 years to 30 years for gas storage water heaters. Therefore, in accordance with Decision 09-05-037's [23] provisions, we propose a 25 year EUL for residential gas storage water heaters.

Figure 4-8. Kaplan-Meier and parametric survival models fit to the gas storage water heater data without the 11–40-year-old non-participant units



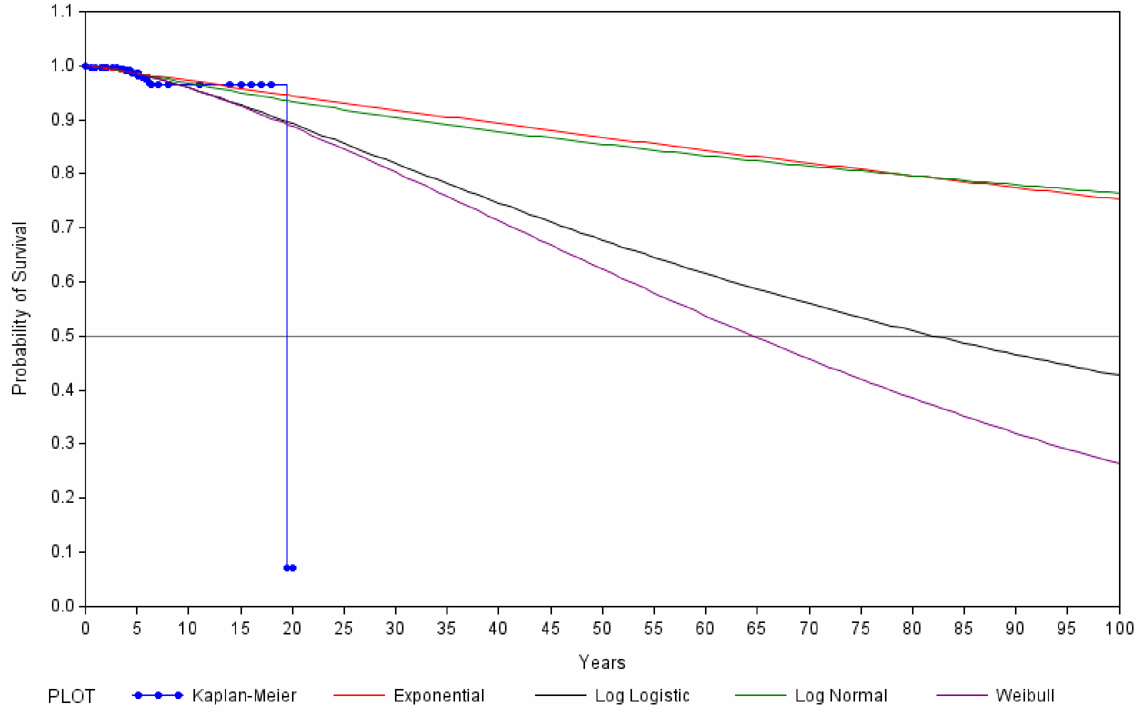
4.2.3 Gas tankless water heater

4.2.3.1 EUL survival analysis results

Our study developed survival analysis sample size aiming for an enhanced rigor EUL study. We targeted gas tankless water heater program participation data for different age groups with the oldest age available group exceeding the current EUL of 20 years. The gas tankless water heater survival data demonstrates units of an age where more than half of the units are no longer in good working condition. As such, the Kaplan-Meier analysis results (the blue line in Figure 4-9) do reach the median level. Because the Kaplan-Meier is not restricted to a specific distributional functional form, when it does cross the median level, it is generally considered the best available estimate. In this case, the Weibull distribution results diverge substantially from the Kaplan-Meier results. The Kaplan-Meier EUL result is 20 years, while the Weibull result is more than three times greater than that. In this case, the KM EUL estimate is preferred over the Weibull estimate.

[23] Decision 09-05-037. May 21, 2009. Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plans and Associated Public Goods Charge (PGC) and Procurement Funding Requests.

Figure 4-9. Kaplan-Meier and parametric survival models fit to the gas tankless water heater data



The tankless water heater data also include data of the 11–40-year-old non-participant units. Similar tests were applied as discussed in Section 4.2.3.1 for gas storage water heaters to assess the potential bias of these older data. Contrary to the gas storage water heaters, for tankless water heaters, removal of the older data increased the EUL to an even greater age. These results do not support a concern that the KM results might be biased upward by the inclusion of those data. We also explore the underlying data to better understand the unusual structure of the KM estimate. These data show extremely low failure or removal through year 19. The KM data included only a small number of units that were 19 years or older. Units representing half of the remaining units failed or were removed in that year. The weighting makes the removals at year 20 appear even more dramatic with respect to survival probability. With sparse data at higher ages, KM results become more variable, producing results of this sort. That said, the 20-year EUL estimated via the KM algorithm would likely be higher if more data were available as the KM algorithm smoothed. However, as a conservative estimate gas tankless EUL, it is a reasonable estimate.

5 CONCLUSIONS AND RECOMMENDATIONS

Based on the survival analysis using equipment-specific retention data, DNV estimated the EUL of the impacted five residential HVAC and DHW technologies. Table 5-1 summarizes the findings and recommendations of our EUL analysis.

Table 5-1. EUL analysis results

Residential technology	Evaluated unit counts	Estimated EUL (years)	90% confidence interval of EUL (years)	Relative precision achieved at 90% CI	Proposed EUL (years)
Heat pump HVAC (ductless & central)	167	23	20-25	12%	23
Heat pump water heater	437	38	27-48	28%	20[1]
Gas furnace (central & wall)	1,787	36	34-38	7%	30[2]
Gas storage water heater	497	25	N/A	N/A	25
Gas tankless water heater	1,711	20	N/A	N/A	20

N/A – Since confidence intervals and precision rates are based on underlying parameter models, they cannot be calculated in instances where the KM estimate is used. For tankless and gas storage water heaters, KM estimates were used to derive the EUL values and therefore, confidence intervals and precision rates are not applicable.

[1] Based on the available regional survival data, we project an EUL up to 20 years. However, we cannot confidently project an EUL longer than 20 years due to significant extrapolation of limited data.
[2] A 30-year maximum EUL is allowed per Decision 09-05-037.

Based on the evaluated equipment data ranging from age groups 1 to 20 years, DNV estimated the heat pump HVACs to have a retention rate of 93% on average. This suggested that the current EUL of 15 years was low. We applied a parametric model with a Weibull distribution (survival analysis) to estimate a 23-year EUL for heat pump HVACs. Since Decision 09-05-037[24] allows for extensions up to 30 years when supported by empirical data and Energy Division review, we recommend adopting a 23-year EUL for heat pump HVACs. We conducted an additional age at replacement of heat pump HVACs and estimated that the median age of 10 heat pump HVACs replaced by C-20 and C-36 contractors during the course of this study was 21.72 years. This is consistent with the 23 year EUL that we are recommending for heat pump HVACs.

For heat pump water heaters, based on evaluated equipment data from age groups 1 to 12 years, we estimated that heat pump water heaters have an average retention rate of 95%, suggesting that the current EUL of 11 years is low. We were limited by equipment retention responses for units older than 12 years, so we could only project the EUL of heat pump water heaters using the retention date of units newer than 12 years. We projected an EUL of 38 years with a 90% confidence interval of 27–48 years using a Gamma distribution. While this range is significantly wider than our targeted precision of 10%, it is still sufficiently conclusive to support that the heat pump water heaters are expected to last at least up to CPUC’s 20-year EUL cap. However, extension beyond 20 years would mean a significant extrapolation of the available survival data. Therefore, we recommend the EUL of heat pump water heaters be updated to the 20-year limit.

For gas furnaces, we gathered retention data for units ranging from 1 to 40 years, which is well above the current EUL of 20 years. Using the gathered retention data, we estimated an EUL of 36 years using a log normal distribution. This estimated

[24] Decision 09-05-037. May 21, 2009. Application of Southern California Edison Company (U338E) for Approval of its 2009-2011 Energy Efficiency Program Plans and Associated Public Goods Charge (PGC) and Procurement Funding Requests.

EUL is well above the current EUL cap of 20 years. Given Decision 09-05-037's[25] allowance for extensions up to 30 years when substantiated by empirical data and Energy Division review, there's a compelling case for adopting a 30-year EUL for gas furnaces. Therefore, we recommend updating the EUL of residential gas furnaces to 30 years.

For gas water heating technologies, we received sufficient equipment retention data from age groups well exceeding the current EUL values. Using the Kaplan-Meier analysis, we estimate that the EUL (or the age where more than 50% of the units failed) of gas storage water heaters and gas tankless water heaters to be 25 years and 20 years, respectively. Given that the predicted EUL of 25 years for gas storage water heaters exceeds the CPUC's 20-year cap and considering that the gas storage water heater EUL results justify an extension from a 20-year cap to a 30-year cap, as per the criteria outlined in D.09-05-037 [26], we recommend adopting a 25-year EUL for gas storage water heaters. For tankless gas water heaters, our study verified the current EUL of 20 years to be accurate.

[25] Ibid
[26] Ibid

6 APPENDIX A. SAMPLING METHODOLOGY FOR THE EUL STUDY

6.1 Survival analysis sample sizes

With a survival analysis, we estimate the percent of units surviving as a function of time, and from this survival function determine the EUL as the time at which 50% will remain. Estimating the necessary sample sizes to achieve a particular precision level for this type of study is challenging for several reasons:

1. The correct model form for the survival function is not known in advance and is typically determined by testing multiple models with the collected data.
2. Most of the data we obtain are "censored." That is, for most units in the sample, we don't know the age at which it fails or is removed or replaced, we only know whether that occurred prior to the time we observe it or is yet to occur as of that time.
3. The accuracy of the analysis depends in part on how many observations we have at an age near the EUL or later.

Rather than attempt to deal with each of these factors via explicit modeling assumptions, the approach taken here is to base our projections on a prior study with similar technology. There have been relatively few such studies for HVAC equipment. We use as the basis for our projections a relatively recent study conducted in Connecticut that includes several of the technologies of interest here.[27]

The strategy for using this study as the basis for the present sample design is as follows:

1. Attempt data collection for a census of the units in older age bins, except in cases where there are very large numbers of these. Assume a 10% success rate for the census-attempted bins.
2. Assume a design effect (DEFF) based on the rough distribution of the projected completed sample by age, compared to the distribution in the prior study. The design effect is a factor that reflects increased or decreased sampling variance compared to the original study. Essentially, if the prior study had better coverage of older units than will be possible with the present study, the design effect is greater than one, while if the planned study will have better coverage the design effect is less than one.
3. Calculated the sample size needed to attain the desired precision, based on the sample size and precision from the prior study and the assumed design effect. The formula for the desired sample size $n_{desired}$ is:

   $$n_{desired} = n_{prior} \times DEFF \times (p_{prior}/p_{desired})^2$$

   where

   p_{prior} and $p_{desired}$, respectively, are the precision at 90% confidence from the prior study and desired for this study

[27] X2001B: Connecticut Measure Life/EUL Update Study – Residential & Commercial. https://energizect.com/sites/default/files/documents/X2001BFINALReport_051523.pdf

n_{prior} = sample size from the prior study.

4. Allocate sample to the cells not addressed by #1, to get to the desired sample size from #3, if possible. The total sample size is distributed roughly uniformly across the age bins to the extent possible.
5. Re-assess the design effect after #4.

In some cases, there aren't enough older cases to get to the target precision. If a very large sample is allocated to younger units, a very large design effect has to be assumed, so that there is little value in increasing sample sizes substantially. For this reason, the projected sample size is sometimes less than the desired sample, and the achievable precision is worse than the desired level.

Table 6-1 shows the study distributions for the planned study compared to the prior study, the design effects assumed, and the projected overall sample sizes and precision. At the bottom of the table are the sample sizes that would be needed with the indicated design effect to reach the desired precision levels. However, it's only possible to achieve the desired sample sizes for DHW. For the other technologies, larger sample sizes would be possible only by adding substantially to the samples of newer units, in which case the indicated design effects would be increased.

Table 6-1. Sample distributions, design effects, and precision for prior study and planned study

Age Bin	Prior Study (Heat Pump Water Heater)	Planned Study		Prior Gas Furnace Study	Planned Gas Furnace Study	Prior Heat Pump HVAC Study	Planned Heat Pump HVAC Study
		Heat Pump Water Heater	Gas Water Heater				
	% of study sample						
1-3	16%	51%	12%	19%	7%	4%	75%
4-5	24%	14%	12%	28%	7%	6%	6%
6-7	14%	21%	12%	30%	22%	31%	2%
8-10	46%	15%	12%	23%	24%	59%	8%
11-13	-	0%	7%	-	2%	-	8%
15-17	-	0%	0%	-	30%	-	0%
11-40	-	0%	44%	-	7%	-	2%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Design effect	1	2	1	1	0.1	1	2
Planned sample size	326	302	163	510	416	280	201
Projected relative precision at 90% confidence	20%	29%	28%	87%	30%	30%	50%
Desired precision and sample sizes							
Relative precision at 90% confidence	-	10%	30%	-	30%	-	30%
Sample size needed	-	2,608	145	-	429	-	560
Reason if not achievable	-	Census attempt	-	-	Census attempt ages 6+	-	Census attempt ages 4+

6.2 Sample stratification

As described in the text, the HVAC and water heating samples are stratified by age bin and climate region.

Within each combination of technology and age bin, the sample is allocated proportionately to collapsed climate regions. This approach allows the final estimates to represent the actual distribution of climate regions, and to provide the best possible ability for the modeling to distinguish region effects for the most common regions for each technology.

The climate regions are groupings of California climate zones, as indicated in Table 6-2.

Table 6-2. Climate region classification

Climate Zone	Climate Region
CZ01	North Coastal
CZ02	North Coastal
CZ03	North Coastal
CZ04	Central Coastal

Climate Zone	Climate Region
CZ05	Central Coastal
CZ06	South Coastal
CZ07	South Coastal
CZ08	Inland
CZ09	Inland
CZ10	Inland
CZ11	Central Valley
CZ12	Central Valley
CZ13	Central Valley
CZ14	High and Low Desert
CZ15	High and Low Desert
CZ16	Mountain

6.3 Sample design for residential HVAC and water heater contractors

The overall budget allows for recruitment of a total of 20 contractors, providing nameplate photos and data for an average of 8 units each. We plan to split this effort roughly evenly between program implementation contractors and other contractors found from the licensing lists. For heat pumps, both HVAC and water heating, we project that the desired precision levels will not be achievable from the survival analysis. Accordingly, these are the technologies that will be targeted for the contractor/implementer data collection. We will distribute the contractor/implementer samples across climate zones.

A snapshot sample of heat pumps currently failing is likely to have a disproportionate number of units that failed early, because there were relatively few installations in earlier years and more installations in recent years. To avoid understating the average lifetime, the data analysis for the contractor/implementer samples will account for the changes in installation rates for technologies over time.

The projected precision for the contractor and implementer samples is based on these assumptions:

- The coefficient of variation of the age at death is 30%. For example, if the average age at death is around 15 years, the standard deviation is around 5 years, so that roughly 2/3 of units would last between 10 and 20 years. We believe this assumption is conservative, meaning it leads to projected precision worse than is likely to be achieved.
- The design effect for the sample is 3. The design effect in this case reflects the increase in variance due to the clustering of the sample, by collecting ages at failure/replacement for a sample of 20 contractors/implementers, rather than drawing a sample at random from all replaced units across the state. This assumption is also expected to be conservative.

The sample size and precision calculations are as follows:

$n_{desired}$ = DEFF x $(Z_5 \times CV / p_{desired})^2$

= 3 x $(1.645 \times 0.3/0.1)^2$

= 73

Where Z_5= 1.645 is the standard normal deviate that gives 90% confidence

Projected precision = Z_5 x CV x $(DEFF/n)^{1/2}$

= 1.645 x 0.3 x $(3/80)^{1/2}$

= 0.096.

For the data collection through program implementors, we identified the following direct install, downstream programs that currently deliver residential HVAC and water heating technologies.

Table 6-3. Residential programs for HVAC and DHW heating technologies

Program Name and ID	PA	Primary Sector	Implementation Type	Program Description
BayREN08	BAY	Residential - single family	Midstream Downstream Audit	BayREN's Home+ program, while available to all single-family residents, is targeted at underserved households, defined as those with a moderate income and/or where a language other than English is spoken. The Home+ program offers a menu of eligible measures including four fuel substitution measures: heat pump water heaters, heat pump heating and cooling, heat pump clothes dryers and induction cooktop/range
MCE08	MCE	Residential - single family	Direct Install Downstream Audit	Direct install program that provides no-cost health and energy savings kits, energy efficiency and building electrification ready home assessments, and home upgrades to eligible single-family (up to 4 attached units) homeowners and renters in MCE's service area
MCE01	MCE	Residential - multifamily	Downstream Direct Install	This Multifamily Energy Savings Program ("MFES") provides residential energy efficiency improvements to affordable multifamily properties in the MCE service territory.
RCEA02	RCEA	Residential	Direct Install Downstream Audit	This program offers rebates for residential heat pump HVAC installations
SCG3889	SoCalGas	RES-Multifamily	Direct Install Downstream	Central water heaters (water heating and hydronic space heating) through a Direct Install EE program
SCG3884	SoCalGas	RES-Mobile Home	Direct Install Downstream	The Comprehensive Manufactured Homes Program delivers natural gas energy efficiency, clean energy, and carbon emission solutions
SCG3702	SoCalGas	Residential single and multifamily	Downstream	The Residential Energy Efficiency Program (REEP) is a deemed, downstream gas measure rebate program that offers incentives to single and multifamily customers
PGE_Res_003	PG&E	Residential multifamily	Direct Install Downstream	PG&E offers this program to the owners and property managers of multifamily buildings. Given the unique energy needs of multifamily buildings, this program is tailored to provide opportunities to invest in EE, general energy management, and building decarbonization through common area and in-unit upgrades
SCE_3P_2020RCI_004	SCE	Residential Multifamily	Direct Install Downstream	This program offers deemed, customized calculated, and NMEC-based site-specific approach measures for energy- saving equipment for both common and in-unit areas of multifamily properties; end uses include HVAC and Lighting, and Water Heating, Pool pump, High efficiency kitchen appliances, Showerheads and Faucets and Energy Management Technologies

7 APPENDIX B. EUL STUDY DATA COLLECTION FORM

7.1 EUL survival analysis – DNV remote data collection survey instrument

Remote DC Survey Instrument

7.2 EUL survival analysis – DNV on-site data collection survey instrument

On-Site DC Survey Instrument

7.3 Age-at-replacement analysis – C-20 HVAC and C-36 plumbing contractors on-site data collection

C-20 and C-36 Plumbing Contractors On-Site DC Instrument

8 APPENDIX C. EUL STUDY DATA AND ANALYSIS

Table 8-1. Heat pump HVAC study data and analysis

Age (Years)	Source	Total survey responses	# of responses where equipment was in place & operable	# of responses where equipment was removed or replaced	Retention rate %
1-3	2013-21 Tracking	123	123	0	100%
4-5	2013-21 Tracking	5	5	0	100%
6-7	2013-21 Tracking	1	1	0	100%
8-10	2013-21 Tracking	14	12	2	56%
11	2012 Tracking	8	6	2	75%
12	2011 Tracking	9	8	1	89%
13	2010 Tracking	3	3	0	100%
15-17	2006-08 Tracking	-	-	-	-
11-40	Non-participant surveys	4	4	0	100%
Total	**All**	**167**	**162**	**5**	**97%**

Table 8-2. Heat pump water heaters study data and analysis

Age (Years)	Source	Total survey responses	# of responses where equipment was in place & operable	# of responses where equipment was removed or replaced	Retention rate %
1-3	2013-21 Tracking	264	253	11	96%
4-5	2013-21 Tracking	65	60	5	92%
6-7	2013-21 Tracking	95	88	7	93%
8-10	2013-21 Tracking	35	33	2	94%
11	2012 Tracking	-	-	-	-
12	2011 Tracking	3	3	0	100%
13	2010 Tracking	-		-	-
15-17	2006-08 Tracking	-	-	-	-
11-40	Non-participant surveys	-	-	-	100%
Total	**All**	**462**	**437**	**25**	**95%**

Table 8-3. Gas furnace study data

Age (Years)	Source	Total survey responses	# of responses where equipment was in place & operable	# of responses where equipment was removed or replaced
1-3	2013-21 Tracking	139	139	0
4-5	2013-21 Tracking	43	43	0
6-7	2013-21 Tracking	72	70	2
8-10	2013-21 Tracking	43	43	0
11	2012 Tracking	206	188	18
12	2011 Tracking	251	243	8
13	2010 Tracking	507	469	38
15-17	2006-08 Tracking	516	451	65
11-40	Non-participant surveys	10	6	4
Total	**All**	**1,787**	**1,652**	**135**

Table 8-4. Gas storage water heater study data

Age (Years)	Source	Total survey responses	# of responses where equipment was in place & operable	# of responses where equipment was removed or replaced
1-3	2013-21 Tracking	232	223	9
4-5	2013-21 Tracking	170	162	8
6-7	2013-21 Tracking	67	60	7
8-10	2013-21 Tracking	-	-	-
11	2012 Tracking	2	2	0
12	2011 Tracking	2	2	0
13	2010 Tracking	2	2	0
15-17	2006-08 Tracking	-	-	-
11-40	Non-participant surveys	62	32	30
Total	**All**	**537**	**485**	**54**

Table 8-5. Gas tankless water heater study data

Age (Years)	Source	Total survey responses	Count of responses where equipment was in place and operable	Count of responses where equipment was removed or replaced
1-3	2013-21 Tracking	1,108	1,098	10
4-5	2013-21 Tracking	480	466	14
6-7	2013-21 Tracking	112	108	4
8-10	2013-21 Tracking	1	1	0
11	2012 Tracking	-	-	-
12	2011 Tracking	-	-	
13	2010 Tracking	4	4	0
15-17	2006-08 Tracking	3	3	0
11-40	Non-participant surveys	3	2	1
Total	**All**	**1,711**	**1,682**	**29**

9 APPENDIX C. STAKEHOLDER COMMENTS AND EVALUATOR RESPONSES

Entity	Section	Page	Question or Comment	Evaluator Response	Notes/ Action:
SCE	2.1 Background	6	"The CPUC currently has a cap of 20 years for the EUL of energy efficiency measures. For heat pump technologies and gas storage water heaters, if supported by evidence, there is an opportunity to extend the current EUL to the 20-year cap, allowing a more accurate assessment of both total system benefit and cost-effectiveness. Additionally, the heat pump energy efficiency measures, along with other energy efficiency measures, play a key role in the state's transition to limit greenhouse gas (GHG) emissions and decarbonization. Therefore, there is a strong interest from the stakeholders to understand the EUL of heat pump technologies and the underlying baseline gas technologies." SCE notes that D.09-05-037 suggests that Energy Division studies can be a sufficient basis to increase the EUL above 20 years: • p. 31 "We agree that it is desirable to provide proper credit for measures that will provide long term savings even when the life of those savings exceeds our currently authorized maximum EUL of 20 years. However, we also agree with parties' comments that any increased EUL should be substantiated by supporting measure empirical data and subject to review by Energy Division." Does the evaluation team agree that this study provides "supporting measure empirical data" and	Thank you for your comment. The evaluation team acknowledges that this study aligns with the criteria set forth in D.09-05-037 for considering an EUL greater than 20 years. However, it's crucial to underscore that not all EUL results automatically warrant an increase beyond 20 years due to the significant extrapolation required. For example, let's consider the heat pump water heater EUL results derived from the best available region-specific data. The survival responses we gathered for heat pump water heaters indicate a proportionately higher occurrence in the <10 years old equipment age bin compared to the 10-20 year old age bin. This discrepancy can be attributed to the relatively new nature of heat pump technologies in California when compared to gas water heaters. Our EUL projection, based on the best available regional survival data, confidently suggests that heat pump water heaters can endure up to 20 years. However, to assert with confidence how well beyond 20 years heat pump water heaters can survive, additional data, particularly from the 10-20+ year old age bin, is imperative. Lacking a more robust estimation of the survival of heat pump water heaters well beyond 20 years, we approach the suggestion that the heat pump water heater EUL extend beyond 20 years with caution. While we can confidently affirm that the technology can last at least up to 20 years based on this data, projecting its longevity well beyond 20 years is challenging due to the inherent uncertainties involved in such extrapolations. That said, the empirical evidence gathered for heat pump HVAC, gas storage water heater, and gas furnaces indicates a strong case for the longevity of these technologies, justifying their eligibility for extension to a 30-year cap, aligning with criteria set forth in D 09-05-037.	We revised the report to acknowledge that this study aligns with the criteria set forth in D.09-05-037 for considering an EUL greater than 20 years. We revised our report to recommend extending the EUL cap for heat pump HVAC, gas furnaces, and gas storage water heaters from 20 to 30 years. The empirical evidence gathered indicates a strong case for the longevity of these technologies, justifying their eligibility for such an extension. However, for heat pump water heaters, due to limited data availability and the inability to confidently extrapolate longevity beyond 20 years, we recommend maintaining the 20-year cap. These recommendations align with the criteria set forth by Decision 09-05-037 and aim to ensure accurate and effective management of energy efficiency measures

Entity	Section	Page	Question or Comment	Evaluator Response	Notes/ Action:
			is "subject to review by Energy Division"?		
SCE	2.1 Background	6	Extending the comment above, stakeholders recognize the importance of EULs derived from solid research: p. 8 - "Also, regarding the Staff Proposal's discussion of the current 20-year cap on effective useful life, SBUA recommends removing this cap to improve the cost-effectiveness results of longer-lived measures such as insulation."	We agree that EULs derived from solid research warrant extending beyond 20 years; however, as we mentioned in our response to comment #1, not all EUL results warrant extending beyond 20 years because of the considerable extrapolation involved.	We revised the report to acknowledge that this study aligns with the criteria set forth in D.09-05-037 for considering an EUL greater than 20 years. We also revised our recommendation in section 1.2 on pages 3 and 4 to explicitly clarify that not all estimated EULs automatically warrant an extension beyond the 20-year cap.
SCE	Overall	N/A	Following this, the Decision states on page 34: "We believe; however, it is reasonable to consider allowing EUL values greater than 20 years for program cycles beyond the 2009-2011 cycle." SCE agrees that 2024 is far beyond the 2009-2011 cycle.	We recognize that the limitations concerning avoided costs have been addressed, allowing for the consideration of EULs exceeding 20 years. Consequently, adopting an EUL of up to 30 years is feasible, particularly where sufficient evidence, as observed in residential insulation, exists to support such an extension. However, it's important to note, as highlighted in our responses to comments #1 and #2 above, that we exercise caution regarding the widespread increase of EULs of all studied DHW and HVAC technologies beyond 20 years.	N/A

Entity	Section	Page	Question or Comment	Evaluator Response	Notes/ Action:
SCE	Overall	N/A	SCE notes that in eTRM, for commercial and residential measures, the only EULs higher than 20 years are those for non-weather-exposed envelop measures (e.g., insulation - total of 3 measures). Everything else (including equipment with moving parts/components), e.g., high efficiency chillers, boilers, etc., have an EUL <= 20 years. Does the evaluation team feel that increasing some Fuel Sub EULs would pose problems given the status quo?	As you noted, the current EUL values exceeding 20 years are specific to exempt insulation measures outlined in D.23-04-035 and detailed in the recent residential insulation EUL report. This study's recommendations are focused solely on adjusting the EUL values for studied residential DHW and HVAC technologies. It's crucial to clarify that these adjustments are not aimed at increasing the 'fuel-sub' EULs, given that the study's scope explicitly covers gas-fired equipment. In other words, our proposed changes are not aimed at increasing 'Fuel-Sub' EULs that could pose problems to the established status quo.	N/A
SCE	Overall	N/A	SCE also notes that the Avoided Cost Calculators now extend to 30 years. While this may have been a problem in the 2009 timeframe, the Calculator appears ready to handle EULs that have longer than 20 years in 2024.	As we have pointed out in our response to comment #3, we recognize that the limitations concerning avoided costs have been addressed, allowing for the consideration of EULs exceeding 20 years. However, as we mentioned in our response to comment #1, not all EUL results warrant extending beyond 20 years because of the considerable extrapolation involved.	N/A
SCE	4.1.2 Heat pump water heater	27	"For heat pump water heaters, based on evaluated equipment data from age groups 1 to 12 years, we estimated that heat pump water heaters have an average retention rate of 95%, suggesting that the current EUL of 11 years is low. We were limited by equipment retention responses for units older than 12 years, so we could only project the EUL of heat pump water heaters using the retention date of units newer than 12 years. We projected an EUL of 38 years with a 90% confidence interval of 27–48 years using a Gamma distribution. While this range is significantly wider than our targeted	As highlighted in the report, our projections for equipment survival beyond 12 years are based on data from the initial 12 years. We can assert that evidence supports an EUL of at least 20 years; however, to confidently estimate equipment survival well beyond 20 years, we require additional survival data for the 12-20+ year old age group. Without comparable survival rates in this age range, we cannot confidently assert that the equipment will consistently endure beyond 20 years. Gathering more data, especially for equipment aged 12-20 years as and when the data is available, is essential to strengthen our EUL estimates and support potential extensions beyond the 20-year mark. This is an important aspect for future studies to address.	N/A

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			precision of 10%, it is still sufficiently conclusive to support that the heat pump water heaters are expected to last longer than the CPUC's 20-year EUL cap. Therefore, we recommend the EUL of heat pump water heaters be updated to the 20-year cap." SCE sees these results as supporting an extension of the EUL per D.09-07-037.		
SocalGas	Table 1-1 - Primary data collection and analysis summary	2	SoCalGas respectfully requests that the methodology and the determined value of 20 years Estimated EUL for gas tankless water heaters be reexamined to reflect an EUL of at least 25 years. Table 1-1 states that out of 1,711 gas tankless units observed, 1,682 were operational and only 29 had been removed, but the EUL for this measure was the lowest out of all the measures in the report. In addition, the report stating that the EUL of the gas tankless water heater being 20 years warrants further insight into the methodology used to determine this figure since other measures had EUL ranges instead of being an exact figure. Additionally, SoCalGas has received responses from a number of gas tankless water heater manufacturers who state that tankless water heaters remain functional, with proper maintenance, for at least 20 years. One manufacturer of tankless water heaters, Bradford White, states that "With stainless steel heat exchangers, interchangeable service parts, and regular service and maintenance today's tankless waters can easily provide 20+ year EUL." Accordingly, we request the	Thank you for your comment. In Table 3.7 on page 12, we have provided a detailed breakdown of survey responses, emphasizing that over 99% of both the sample and failure responses fall within the <8 years equipment age group. Given the generally lower likelihood of failure in newer equipment, our survival rate estimation predominantly relies on data from these recent units. Consequently, asserting with confidence that older equipment would share a similar failure rate as newer ones lacks substantial support from our dataset. It's important to note that for tankless water heaters, the nature of the data reveals that the oldest sampled units exhibit very low survival rates (below 10%). This finding significantly influenced our analysis results and subsequent recommendations. Regarding the tankless water heater EUL methodology, our estimated 20-year EUL for tankless water heaters is based on Kaplan-Meier (KM) results because the results exceed the median. Even with the application of a gamma distribution curve (which would provide EUL ranges), the projected median EUL remains at 19 years, which is in line with the KM results. Regarding manufacturer's claim, the actual lifespan of equipment is influenced by various factors such as load, usage pattern, and maintenance, and may not align with manufacturers' claims or warranties. For instance, with storage water heaters, our region-specific survival data indicates a higher EUL than typically claimed by manufacturers. The California-specific survival data for tankless water heaters supports the estimated EUL of 20	N/A

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			Estimated EUL of the gas tankless water heater be amended to 25 years.	years, and without regional evidence of a higher survival, we cannot amend this estimate.	
SocalGas	Table 1-3 – EUL Results	4	SoCalGas respectfully requests DNV to recommend and the CPUC to consider that the cap of 20 years for gas measures be increased to up to 30 years, depending on the measure. SoCalGas acknowledges that current CPUC evaluation guidelines mandate a maximum useful life of 20 years except for exempt measures. However, D.09-05-037, Pp. 34 states, “We believe, however, it is reasonable to consider allowing EUL values greater than 20 years for program cycles beyond the 2009-2011 cycle.” Given the Estimated EUL of 36 years for gas furnaces and 25 years for gas storage hot water heaters, SoCalGas believes that increasing the cap from 20 years to 30 years be included to improve the value of this study.	Thank you for your comment. Per the criteria set forth in D.09-05-037 for considering an EUL greater than 20 years, we agree that gas storage water heaters and gas furnaces EUL results do warrant recommending values greater than 20 years. We have revised our recommendation to include a 25 year EUL for gas storage water heaters a 30 year EUL for gas furnaces.	We revised the report section 1.3 page 3 and 4 to recommend a 25 year EUL for gas storage water heaters and a 30 year EUL for gas furnaces.
SocalGas	Table 3-7 - Count of all Survey Responses	13	SoCalGas requests that the Estimated EUL of Heat Pump Water Heaters (HPWH) be reevaluated for accuracy. The number of survey responses for Heat Pump Water Heater (HPWH) units older than 10 years is 3 out of 462. Consideration should be given if this is a sufficient population of data to conclude an Estimated EUL of 38 years given that the results of the small sample size show 100% survival, which is not consistent with the previous years’ survival rates. SoCalGas observes that the secondary literature research cited in the study has materially different findings of 15 years	Thank you for your comment. While we acknowledge the limited number of Heat Pump Water Heater (HPWH) units observed beyond 10 years (3 out of 462), it's crucial to highlight that within the 8-10 years age range, we observed 35 units with a very high survival rate (>90%). Moreover, out of the 38 units observed in the 8-12 year old range, 35 were in-place and functioning properly, providing a strong basis for our estimate of a lifespan exceeding 12 years and at least 20 years through extrapolation. In response to the secondary literature research citing a 15-year Estimated Useful Life (EUL) for HPWH, we want to clarify that our study utilized an identical methodology to the Connecticut (CT) study, with the distinction being the use of California-specific survival data for estimating EUL values. Geography plays a significant role in these	N/A

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			for the EUL of Heat Pump Water heaters (HPWH). Further investigation and data collection should be done to confirm if adopting the findings in the current study of a EUL of 38 years for HPWH is requested.	estimates, and there is no evidence suggesting the CT study's results should supersede our region-specific findings. It's worth noting that the CT study recommended a 28-year EUL for gas furnaces, while our study, grounded in California-specific survival data, found a higher EUL of 38 years. We appreciate your concern and have ensured our methodology aligns with the region's unique characteristics.	
SocalGas	Table 3-10. EUL Results Presented by the X2001B: Connecticut Measure EUL Study	16	SoCalGas requests the EUL of Heat Pump HVAC measures for air source and ductless be assigned separate EUL values. The report states air source heat pumps have a 20 year EUL and ductless heat pumps have a 17 year EUL. These technologies would be better suited to have different EUL values in the current study since they are different technologies, and they currently use different EUL IDs in DEER as noted in Table 2-1 (HVAC-airHP vs HV-ResHP).	Based on the scope of our study, we collected equipment survival information without distinguishing between central and ductless heat pumps. This lack of separation during data collection makes it challenging to conduct separate EUL analyses for each technology. Furthermore, our combined data didn't meet our sampling target, preventing us from achieving a statistically meaningful analysis even if we had separated responses by technology type. Regarding the EUL ID, the ductless heat pump EUL ID actually changed from "HVAC-airHP" to "HVAC-ResHP" over the course of this study. Per the most recent eTRM, "HV-Res HP" EUL ID applies to residential heat pumps (both central and ductless), while the HVAC-airHP ID applies to commercial heat pumps.	N/A
SocalGas	Figure 4-9. Kaplan-Meier and Parametric Survival Models Fit to the Gas Tankless Water Heater Data	26	SoCalGas requests that fit curves be used rather than the Kaplan Meier Curve for the EUL of gas tankless water heaters. Using the Kaplan Meier method, the survival rates of tankless water heaters drop dramatically at year 20 from over 90% to 0%. Additional data collection should be conducted, with an emphasis on units older than 20 years.	The nature of survival data we gathered is such that the equipment survival dramatically drops at year 20. The EUL results are biased by the small number of failures in the observed data set along with the heavy weight assigned to the censored observations based on the sampling design. In the case of tankless water heaters, the KM data crosses the median for EUL estimation and therefore, the more robust KM estimate is preferred. Regarding using probability distribution curve instead of KM, please note that a gamma curve gives an EUL of 19 years, which is much more in line with the KM estimate.	N/A

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SocalGas	Table 5-1 – EUL Analysis Results	27	SoCalGas requests further clarification on the N/A values for the 90% confidence and 90% relative precision columns on Table 5-1 for gas storage and gas tankless water heaters. Please provide the explanation or reasons for these values in the report.	The EUL estimates for gas storage and tankless measures are based on the Kaplan-Meier results, not the parametric curves. Since confidence intervals and precision rates are based on underlying parameter models, they cannot be calculated in instances where the KM estimate is used. Hence, the "N/A" in the table. We have added additional explanation in the report.	We added explanation regarding precisions in Page 28 (Table 5-1 footnotes) of the report.
SoCalREN	Overall	N/A	The equipment used in this EUL study was within the residential sector, but the study would benefit from explaining if there were any disaggregation attempted for Single Family, Multifamily, and Mobile homes. This would better align with DEER building types.	Thank you for your comment. Our study data comes mostly from single family buildings. It was not within the scope of our study to develop and compare building type specific EUL values, but the EUL values that we have recommended would apply to all residential building types (single family, multifamily and double-wide mobile homes).	N/A
SoCalREN	3.3 Analysis Methods	16	The methodology discussed assessing the current status (equipment still in place) and working condition (operable or not); however, there is no mention if the number and types of repairs in the past had been captured, which could inform if water heaters/HVAC units are repaired indefinitely or if they are replaced upon failure. The report should clarify this.	As discussed on Page 14 and in the Appendix 7.1 EUL survival analysis – DNV remote data collection survey instrument, we did assess if an equipment was in need of a repair or not. A survival analysis only uses binary values, so depending on the status of equipment (if it went through frequent repairs) and the additional notes (if any) on the equipment provided by the survey participants, we assigned the working condition (failed or not) accordingly. We added a language in the report to clarify this.	In report section 3.3.2, page 15, we revised the language to clarify the process behind binary status assignments.
SoCalREN	3.3 Analysis Methods	16	Did the study consider binning the non-participant survey data from 11-40 years into smaller bins?	We had limited data from each age group between 11-40 years old to classify into smaller age bins, so the study did not classify 11-40 year old data into smaller bins.	N/A

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SoCalREN	4.2.2 Gas storage water heater	23	Page 23 finds that gas storage water heaters (tanked water heaters) have an EUL of up to 24 years, though the study recommends maintaining the capped 20-year EUL. Page 25 finds that for tankless water heaters the data show extremely low failure or removal through year 19 and recommends a 20-year EUL as a conservative estimate. It is not clear why the tankless gas water heaters, which are constructed differently (usually stainless steel) than tanked water heaters, do not show a higher projected life than the tanked heaters (even if capped). Is this due to other components (such as the blowers or controls) that fail?	Our EUL estimate for tankless water heaters is driven by the oldest observed units exhibiting a high failure rate compared to storage water heaters. Hence, the estimated EUL for tankless is 20 years, lower than the EUL of 25 years estimated for gas storage water heaters. We did not receive sufficient responses on reasons for failure to confidently compare why tankless water heaters exhibited a higher failure rate than storage water heaters.	N/A
SoCalREN	Overall	N/A	In SoCalREN's experience, EULs for tanked water heaters exceeding about 20 years are unrealistic unless the tanks are stainless steel. Most US manufactured tanked hot water heater warranties are 6-12 years. The study should adjust EULs accordingly based upon actual life and tank material. Were tank materials looked at relative to EUL? o Most US made tanks (for gas or electric heat pump units) are often carbon steel with a sacrificial anode, which are rarely replaced. o Additionally in hard water areas, sediment builds up which make the tanks functional poorly unless flushed annually, which if not flushed leads to tank failure. This flushing is also rarely done.	Our study did not specifically investigate the impact of tank materials on the EUL. The program installation tracking data used for our study sample lacked information on tank material and regions with hard water, so we were not able to stratify the sample sizes by tank materials and water hardness. Even if this information were available, it would require a substantially larger sample size and more resources. Unfortunately, we were unable to develop EUL estimates stratified by tank materials and water hardness due to these limitations. Our EUL estimates are based on best available regional survival data and the data indicates that storage water heaters survive much longer than manufacturer's warranty of 6-12 years.	N/A
SoCalREN	Overall	N/A	Were the lives of electric heat pumps (HP) and electric AC units compared? o Presumably they are similar unit	Our study primarily focused on assessing the EUL of heat pumps only, and as such, a direct comparison of the EUL between heat pumps and electric ACs fell outside the	N/A

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			designs (albeit with some additional controls and valves for the HP units and perhaps sized larger for HPs). o It seems the heat pumps would have longer run times and thus shorter lives. Did the study identify any data to measure this?	study's scope. Although we did not collect specific data for electric ACs, it is reasonable to consider their lifespan as comparable or potentially longer. We refrain from making explicit recommendations regarding updating AC EUL due to the absence of collected data. However, the DEER team could explore this aspect in light of the data gathered for heat pumps. Addressing concerns about potential shorter lives for heat pumps due to longer runtimes, our EUL analysis took this into account. We relied on the best available California-specific heat pump survival data, and the information gathered did not suggest that heat pumps have shorter lives compared to the 15-year EUL reported by DEER for electric Acs.	
SoCalREN	Overall	N/A	When comparing gas technologies vs electric technologies (both water heating and space heating) were the two factors below factored into EUL that site visits may alone not indicate: o Refrigerant obsolescence as older refrigerants (electric) are phased out and new ones are required, which may in extreme cases require new units and/in most cases would require refrigerant change outs (which could trigger a new unit) even in cases where the unit has not exceeded its EUL. This is less of an issue for units with CO2, but for older HVAC units with R22 or now R410, this could be an issue. Was existing refrigerant type looked at relative to EUL? o Electric heat pumps have quite a few more mechanical components than their gas counterparts (furnaces) which could fail over time or become obsolete. Site visits may yield this data over the	The scope of our study did not extend to investigating the impact of refrigerant types on the EUL. Our focus was on assessing the in-place and operable status of equipment to estimate the EUL, rather than delving into the specific influences of individual factors on EUL. Furthermore, we are not able to adjust the EUL of heat pump based on speculation of how expected regulation of refrigerants will affect market availability and so replacement rates. On the comment about mechanical components: while it's accurate to note that furnaces have fewer mechanical components than heat pumps, it's essential to recognize that a furnace alone doesn't offer the same service as a heat pump. When comparing a furnace paired with an electric AC to a heat pump, you're essentially considering a similar number of mechanical components in both systems. This ensures a more equitable assessment from a service perspective.	N/A

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			longer-term, but short-term there may be insufficient data for this as these units may still be available. Was this investigated?		

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