GROUP A

Commercial HVAC and Water Heating Measure Effective Useful Life Study Final Report

California Public Utilities Commission
CALMAC Study ID: CPU0368.03

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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 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]

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[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 commercial heating, ventilation, and air conditioning (HVAC) and water heating technologies selected by the joint staff (DNV and CPUC). For this study, DNV classified the commercial HVAC and water heating technologies into two groups: nascent heat pump technologies and established technologies. The nascent heat pump technologies include HVAC heat pumps and heat pump water heaters, whereas the established technologies include air conditioners, gas storage water heaters, and gas tankless water heaters.

1.1 Study background and objectives

EUL represents the median number of years that a measure or energy-efficient technology remains operational after installation. EUL values play a crucial role in accurately estimating the lifetime energy savings used for program planning and evaluation. Consequently, periodic reassessment of EUL values is imperative. The current Database for Energy Efficiency Resources (DEER) EUL values for commercial HVAC and water heating technologies stem from studies conducted 15-20 years ago, necessitating updates to reflect technological advancements, maintenance practices, occupancy patterns, space renovations, human interaction elements, climate change, and other contemporary factors. Additionally, stakeholders exhibit significant interest in these HVAC and domestic hot water (DHW) technologies, particularly given their pivotal role in supporting California's decarbonization and energy savings objectives.

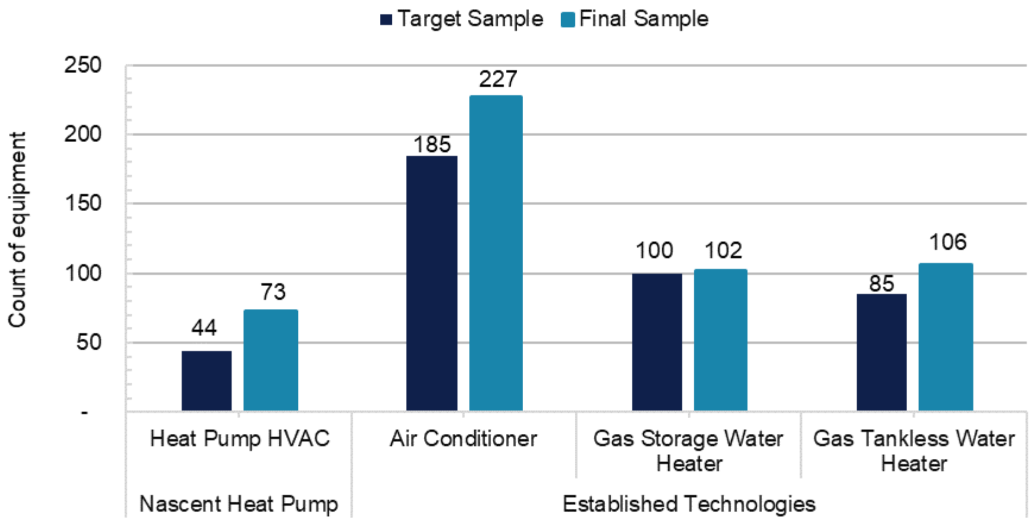
The objectives of this study are to revise or update the EUL estimates of the five nascent and established commercial HVAC and water heating technologies and to evaluate the retention rate of nascent heat pump technologies. A retention rate estimate involves assessing the percentage of impacted technologies installed over the past 10-15 years that remain in place and operational.

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. We selected sampled equipment from a distribution of installation ages, ranging between 2010 and 2021, occurring through energy programs in California. Figure 1-1 below presents our targeted and achieved sample size for the impacted commercial HVAC and water heating technologies.

As the primary data collection approach, DNV conducted site inspections supplemented by email surveys. We gathered in-place and operable status information of the installed impacted equipment and documented nameplate photos. We used the nameplate photos and customer-reported age information to estimate the age of impacted equipment. We then used this information to develop and predict the probability of survival of the impacted equipment—a survival analysis. EUL is defined as the amount of time that passes until only 50% of the impacted equipment is still in place and working (surviving).

Figure 1-1. Targeted vs achieved sample size by technology



Because the HVAC heat pump technologies are nascent technologies, only a limited number of installations through energy programs between program year (PY)2010-PY2021 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 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 five contractors followed up with seven nameplate photos of HVAC heat pumps. For the seven HVAC heat pump nameplate photos we received from contractors, we estimated the installation date of the removed heat pump technologies by comparing the 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 HVAC heat pumps at replacement. The age-at-replacement analysis of HVAC heat pumps yielded a median age of 24.9 years and an average age of 23.4 years.

The in-place and operable status information we obtained from on-site inspections of HVAC heat pumps indicated that all observed units were in place and in good working condition, with zero failures observed. Consequently, the survival analysis results were inconclusive, rendering the EUL indefinite. Therefore, we relied on the secondary age-at-replacement method to inform us on the EUL of HVAC heat pumps. Based on the projection using the 100% survival rate for the first 8 years and the findings of the secondary analysis indicating a median EUL of 24.9 years, we can conclude that HVAC heat pumps can last up to CPUC's 20-year EUL cap.

Similar to HVAC heat pumps, all of the observed air conditioner units with ages spanning from 1-8 years old were still in place and in good working condition. As none of the observed air conditioner units had failed, a survival analysis resulted in an indefinite EUL. Considering the high survival rate of 1-8-year-old air conditioner units and considering the technological parallels of air conditioners with HVAC heat pump systems, we recommend considering a 20-year EUL for commercial air conditioners. However, to understand the longevity of both HVAC heat pumps and air conditioners beyond 20 years, we recommend expanding current data collection efforts in 5 years to include equipment data from installations carried out through the new program's direct installations. This expansion will provide a more comprehensive understanding of the longevity and performance of HVAC heat pumps and air conditioners, incorporating data from installations conducted under the latest program initiatives.

For gas storage water heaters, we observed enough failures of units with ages spanning from 1-15 years to conduct a survival analysis. By developing survival curves based on the gathered equipment failure data, we estimated the point at which 50% of failures are anticipated, providing us with an EUL of 13 years for gas storage water heaters.

For gas tankless water heaters, based on the failure rate of the observed units, a survival analysis suggests an EUL that is much higher than the current EUL of 20 years. However, it is crucial to acknowledge that our dataset was restricted to tankless units up to 8 years old. Considering that our data was limited to 8-year-old units and considering the CPUC's 20-year cap on the EUL of energy efficiency technologies, we confidently affirm that gas tankless water heaters can endure up to 20 years.

Table 1-1 summarizes our data collection findings and our primary analysis results.

Table 1-1. Primary data collection and analysis summary

Commercial technology	Total units observed	Count of units that were still in place and working	Count of units that had failed/ were removed	Estimated EUL (years)
Nascent heat pump technologies				
HVAC heat pump	73	73	0	20
Established technologies				
Air conditioner	227	227	0	20
Gas storage water heater	102	26	76	13
Gas tankless water heater	106	102	4	20

Due to insufficient claims for commercial heat pump water heaters between PY2010 and PY2021, primary data collection and analysis were not feasible, as outlined in the previously communicated workplan addendum with the CPUC. Leveraging residential heat pump water heater EUL results from the CPUC Group A Residential HVAC and DHW Measure Effective Useful Life Study Final Report[2], we extrapolated the results to establish the EUL for commercial heat pump water heaters.

Commercial and residential water heaters differ in terms of the number of hours the water heater runs and the extent to which the water heater’s capacity is used when it runs. To understand these differences, we analyzed the hourly operating profiles of commercial and residential water heaters in California, as presented in DEER Water Heater Calculator v5.1[3]. Our analysis showed that commercial water heaters run approximately 288 more equivalent hours, which is 63% higher loading each year than residential water heaters. We scaled the residential heat pump water heater EUL results to calculate the EUL of commercial heat pump water heaters, accounting for differences in run hours and load. This adjustment ensures our analysis accurately reflects the operational disparities between residential and commercial heat pump water heaters. Based on our analysis and the aforementioned comparison, we recommend a 13-year EUL for heat pump water heaters in commercial buildings. The substantial difference in equivalent annual load between commercial and residential contexts underscores the importance of understanding the unique operational demands of each setting when determining equipment lifespan.

[2] California Public Utilities Commission. GROUP A Residential HVAC and DHW Measure Effective Useful Life Study Final Report. April 9, 2024. https://pda.energydataweb.com/api/view/3952/CPUC%20Group%20A%202023%20Res%20HVAC%20and%20DHW%20EUL%20Study%20Final%20Report.pdf

[3] DEER Water Heater Calculator, v5.1. https://cedars.sound-data.com/deer-resources/tools/water-heaters/

1.3 Key findings and recommendations

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

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

As presented in Table 1-2, this study developed EUL estimates of commercial HVAC and water heating technologies. For the HVAC heat pumps and air conditioners, considering we observed zero failures in the sampled units and considering the age-at-replacement data for HVAC heat pumps show an average age of >20 years, we estimated an EUL of at least 20 years. In light of CPUC's 20-year cap[4] for the EUL of energy efficiency technologies, the joint staff recommends a 20-year EUL for commercial HVAC heat pumps and air conditioners.

Table 1-2. EUL results

Commercial technology	Existing EUL (years)[5]	Estimated EUL (years)	Proposed EUL (years)
Nascent heat pump technologies			
HVAC heat pump	15	20	20
Heat pump water heater	10	13.8	13
Established technologies			
Air conditioner (packaged and split with gas heating)	15	20	20
Gas storage water heater	15	13	13
Gas tankless water heater	20	20	20

Based on our analysis of water heater load factors and leveraging insights from the residential heat pump water heater EUL results, we recommend a 13-year EUL for commercial heat pump water heaters, reflecting their distinct operational demands in commercial settings.

Considering the survival rate observed among 1-8 year-old gas tankless water heaters and in light of CPUC's 20-year EUL cap[6], the joint staff recommends a 20-year EUL for commercial gas tankless water heaters.

Recommendation	**Update the EUL values for the HVAC heat pumps and air conditioners to 20 years, and the EUL of heat pump water heater to 13 years.**

We recommend updating the EUL values for commercial HVAC heat pump, air conditioner, and heat pump water heater measures corresponding to the following EUL Identifications (ID) in the DEER:

- 'HVAC-airHP' with an EUL value of 20 years
- 'WtrHt-HtPmp-Com' with an EUL value of 13 years
- 'HVAC-airAC' with an EUL value of 20 years

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

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

[6] Ibid

For gas tankless water heaters (WtrHt-Instant-Com), this study verified the current DEER EUL value of 20 years to be reasonable.

Currently, DEER does not have an EUL ID for commercial heat pump water heaters and the measure package on eTRM uses EUL ID of 'WtrHt-HtPmp', which is assigned the residential sector label. As a part of the heat pump water heater EUL update, the joint staff recommends establishing an EUL ID of 'WtrHt-HtPmp-Com' specifically for commercial heat pump water heaters.

Finding 2	**Reduction in the EUL of commercial gas storage water heaters should be considered based on the findings of this report.**

Assessing the failure rate of observed gas storage water heaters with ages spanning from 1-15 years and employing survival analysis models, this study estimates a 13-year EUL for gas storage water heaters. Additionally, the secondary analysis, which considers water heater load factors and insights from residential gas storage water heater EUL results, corroborates a 12-year EUL estimate for gas storage water heaters, aligning closely with our primary survival analysis.

Recommendation	**Update the EUL of commercial gas storage water heaters to 13 years.**

The joint staff recommends updating the EUL of commercial gas storage water heaters (WtrHt-Com) from the existing 15 to 13 years. Furthermore, we recommend updating the EUL ID from 'WtrHt-Com' to 'WtrHt-Com-Gas' to prevent any potential confusion that may arise.

2 INTRODUCTION

This report presents the findings of the EUL evaluation study of five commercial HVAC and water heating technologies (measure and baseline) selected by the joint staff (DNV and CPUC). The measure names and the associated EUL IDs of the evaluated HVAC and water heating technologies in the 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[7]
Heat Pump Water Heater, Commercial, Fuel Substitution (SWWH027-04)	**Measure**	Heat pump water heater	WtrHt-HtPmp
	Baseline	Storage gas water heater	WtrHt-Com
		Tankless gas water heater	WtrHt-Instant-Com
Packaged Heat Pump Air Conditioner Commercial, Fuel Substitution (SWHC046-03)	**Measure**	Three-phase package or split heat pumps	HVAC-airHP
	Baseline	Commercial packaged or split-system AC with electric DX cooling and gas heating	HVAC-airAC
Unitary Air-Cooled Air Conditioner or Heat Pump, Commercial (SWHC014-04)	**Measure**	Air-cooled AC or heat pump with a cooling capacity < 65 kBtu/hr and SEER > 14	HVAC-airHP
	Baseline	Air-cooled AC or heat pump with a cooling capacity < 65 kBtu/hr and SEER value of 14	HVAC-airHP

This study classified the impacted five commercial HVAC and DHW technologies into two groups: nascent heat pump technologies (packaged or split HVAC heat pump systems and heat pump water heaters), and established technologies (gas storage water heaters, gas tankless water heaters, and split and central air conditioners).

2.1 Background

The current DEER EUL values and the EUL sources presented in Table 2-2 for the five impacted commercial HVAC and DHW technologies come from studies that were conducted 15 to 20 years ago. In some instances, the EUL sources are not robust (e.g., the current heat pump water heater EUL is based on engineering judgment rather than a robust study). 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. 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 technologies.

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

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

Technology	EUL ID	EUL value (years)	Current EUL source
HVAC heat pump (packaged and split)	HVAC-airHP	15	Energy Policy Manual v2.0, 2003[8]
Heat pump water heater	WtrHt-HtPmp	10	2004-05 DEER Study. Engineering Judgement[9]
Air conditioner (packaged and split with gas heating)	HVAC-airAC	15	Energy Policy Manual v2.0, 2003[8]
Gas storage water heater	WtrHt-Com	15	Energy Policy Manual v1.0, 2001[10]
Gas tankless water heater	WtrHt-Instant-Com	20	Energy Policy Manual v1.0, 2001[10]

2.2 Study objectives

This study presents verified/revised EUL estimates of the impacted commercial HVAC and water heating technologies. This study also assessed the retention rate of nascent HVAC heat pump technologies. The study objectives by technology type are summarized in Table 2-3.

Table 2-3. Study objectives and technologies

Commercial technology	Study objectives
HVAC heat pump (packaged and split)	Revise or verify EUL estimates and develop retention rate of HVAC heat pumps
Heat pump water heater	Revise or verify EUL estimates
Air conditioner (packaged and split with gas heating)	Revise or verify EUL estimates
Gas storage water heater	Revise or verify EUL estimates
Gas tankless water heater	Revise or verify EUL estimates

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.[11]

[8] CPUC. "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

[9] Itron, Inc. "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] CPUC. "Energy Policy Manual Version 1," Table 4.1. Effective Useful Lives of Energy Efficiency Measures, p. 21. https://docs.cpuc.ca.gov/published/Graphics/11474.pdf

[11] 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.

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."[12] 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 commercial nascent and established 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 for the retention study: Basic and Enhanced. The higher the level of rigor, the more confident we are that the results of the evaluation are both accurate and precise. DNV aimed for a basic rigor retention study of established technologies and an enhanced rigor for nascent heat pump technologies.

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." Section: Effective Useful Life Evaluation Protocol (Retention and Degradation). April 2006.

[13] Ibid.

[14] Ibid.

[15] Ibid.

3 METHODS

The primary objective of this study was to develop EUL estimates of commercial HVAC and water heating technologies. This was accomplished by conducting site inspections, supplemented by online surveys with HVAC and water heating technology adopting program participants between PY2010 and PY2021, 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 commercial HVAC and water heating technologies.

Additionally, for HVAC heat pumps, DNV 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 commercial HVAC 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

In conducting the study sample design, DNV reviewed the available historical commercial downstream installation program claims between PY2010 and PY2015 and found that only two HPWHs were claimed between PY2010 and PY2021. DNV also reached out to the investor-owned utilities (IOUs) in California requesting baseline equipment data from their current commercial and HVAC and water heater programs, but the IOUs were not able to accommodate the requested data. Based on the findings of our program tracking data review and the responses from the IOUs regarding the baseline equipment data request, we submitted a workplan addendum to the CPUC outlining the following scope changes:

- Commercial heat pump water heater EUL to be based on the residential EUL study results
- DNV will not rely on baseline equipment data from current programs

For the remaining heat pump and established technologies, DNV delivered a sample design and data collection memo 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 onsite data collection (primary) and DNV remote customer surveys	• HVAC heat pump (nascent) • Air conditioner (established) • Gas storage water heaters (established) • Gas tankless water heaters (established)
Average age at replacement	C-20 and C-36 contractors	• HVAC heat pump (nascent)

Since HVAC heat pumps are a nascent technology, obtaining good precision for it was of high interest. At the same time, because it is 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 HVAC heat pump technologies by targeting sufficient contractor cases to achieve good precision from the average age at replacement and using the survival analysis as a basis for triangulation. For air conditioners and gas storage and tankless 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 versus 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

Commercial 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
HVAC heat pump	Nascent	Enhanced	44	50%	80	10%
Air conditioner	Established	Basic	185	30%	N/A	N/A
Gas storage water heater	Established	Basic	100	30%	N/A	N/A
Gas tankless water heater	Established	Basic	80	30%	N/A	N/A

N/A = not applicable

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 PY2010-PY2021 program tracking data. We filtered out historical downstream savings claims with missing customer identifier information (name, address, phone, email, and service account number, etc.) and claims where distributors were listed as the program participant. Historical program tracking data indicated one measure installation claim per commercial customer for only about 10% of the participants. The remaining 90% of the participants have claimed two or more measures per address. As such, DNV used the count of unique program participants as the basis for designing the study sample. Table 3-3 shows the count of unique commercial participants by technology and age.

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

Age (years)	Source	HVAC heat pump	Air conditioner	Gas storage water heater	Gas tankless water heater
2	2010-21 Tracking	-	-	33	301
3	2010-21 Tracking	-	-	53	212
4	2010-21 Tracking	259	1,331	258	234
5	2010-21 Tracking	7	492	260	215
6	2010-21 Tracking	36	934	435	290
7	2010-21 Tracking	82	271	573	150
8	2010-21 Tracking	172	625	10	8
9	2010-21 Tracking	219	20	-	-
10	2010-21 Tracking	100	-	-	-
11	2010-21 Tracking	1	22	-	-
12	2010-21 Tracking	2	15	-	-
Total	**All**	**878**	**3,710**	**1,622**	**1,410**

[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	HVAC heat pump	Air conditioner	Gas storage water heater	Gas tankless water heater
2-4	2010-21 Tracking	9	40	15	35
5-6	2010-21 Tracking	10	100	85	45
7-8	2010-21 Tracking	25	45	-	-
9-12	2010-21 Tracking	-	-	-	-
Total	**All**	**44**	**185**	**100**	**80**

For the age-at-replacement analysis of HVAC heat pumps, our sampling target was to attempt to recruit 10 non-participating contractors to provide nameplate data with legible pictures for eight replaced units each. Recruitment targets would be distributed over climate region groupings and types of customers served.

3.1.2 Data collection efforts, sample completions, and response rates

Table 3-5 shows the count of the final sample completed by age group and technology types. While we were not able to complete the sampling target for some age groups, overall, our final sample size well exceeded our sampling target. Our final sample compensated for 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. Furthermore, except for air conditioners, we were able to significantly exceed our sampling requirements for older age groups. This is important because compared to the newer age group data, older age group data are more important for developing survival probability curves.

Table 3-5. Count of all survey responses

Age (years)	HVAC heat pump		Air conditioner		Gas storage water heater		Gas tankless water heater	
	Final sample	% complete	Final sample	% complete	Final sample	% complete	Final sample	% complete
2-4	-	0%	43	108%	14	93%	46	131
5-6	18	180%	150	150%	49	58%	44	98%
7-8	55	220%	34	76%	26	UD	16	UD
9-15	-	-	-	-	13	UD	-	-
Total	**73**	**166%**	**227**	**123%**	**102**	**102%**	**106**	**133%**

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

We engaged C-20 and C-36 licensed contractors derived from a contractor listed on the California State License Board[17] 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 Pacific Gas and Electric Company

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

(PG&E), San Diego Gas & Electric (SDGE), and Southern California Edison (SCE). Unfortunately, this effort yielded less than a 1% response rate (seven 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 anticipate 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 3-6. 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 3-6. Count of contractor responses regarding replacing heat pump technologies

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

Out of 43 contractors that had either removed 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 seven nameplate photos of HVAC heat pumps. There was not a big volume turnover for heat pump technologies during this study, possibly because there were not many heat pumps 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 on-site inspections as the primary data collection method, supplemented by a combination of email surveys and phone calls, with participants of the HVAC and water heating technology program between PY2010 and PY2021. We gathered the following information for the EUL survival analysis:

- For equipment installed through commercial programs, we verified the make/model of the installed equipment and verified the equipment measure installation date.
- Determined if the installed equipment is still in-place and operable.
- For program-installed equipment that had failed or was replaced, we documented the equipment replacement/failure date.
- We documented reasons for removal/failure if the installed equipment had failed or was replaced.
- We gathered nameplate pictures and/or make/model of the removed equipment (if available) and the installed equipment.

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

Table 3-7 provides a breakdown of survey responses by technology type where the installed equipment was either in place and working or was removed. We included a summary of data collected for the EUL survival analysis in Section 8.

Table 3-7. 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
HVAC heat pump	73	73	100%	0	0%
Air conditioner	227	227	100%	0	0%
Gas storage water heater	102	76	74.5%	26	25.5%
Gas tankless water heater	106	102	96.2%	4	3.8%

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 commercial HVAC equipment that failed/was being replaced
- Picture of existing HVAC equipment tag with installation date (if available)
- Nameplate picture of existing failed/replaced HVAC equipment
- Existing equipment replacement/failure date
- Assessment of existing equipment condition
- Reasons for replacement/failure of existing equipment

3.2.2 Secondary research

DNV 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. The X2001B study investigated the EUL of commercial HVAC technologies using a similar survival analysis approach as utilized in this study. The X2001B study gathered in-place and operable status of 42 commercial HVAC units and found that all 42 units were in place and functioning. The study concluded that the survival analysis results were inconclusive and suggested an additional sample with failure data is required to conduct a meaningful EUL analysis. The study suggested that, based on the failure rate of the observed 42 units, the EUL could be closer to 24 years. However, due to the lack of additional data, the study recommended maintaining the existing EUL of 15 years.

For commercial water heaters, we conducted a literature review, synthesizing insights from various sources on the EUL of commercial water heaters. Manufacturers assert an impressive EUL of up to 20 years for tankless water heaters, alongside a guaranteed minimum EUL of at least 10 years for storage water heaters.[19] Energy Star[20] and the New York State Energy Research and Development Authority (NYSERDA)[21] provide specific EUL estimates for heat pump water heaters, ranging from 13-15 years, with NYSERDA pinpointing a 15-year duration. Conversely, the American Society of Heating,

[18] Michaels Energy & Evergreen Economics. "X2001B: Connecticut Measure Life/EUL Update Study-Residential & Commercial." 5/11/2023. https://energizect.com/sites/default/files/documents/X2001BFINALReport_051523.pdf

[19] Intellihot. "How Long Do Commercial Water Heaters Last?" https://www.intellihot.com/how-long-do-commercial-water-heaters-last/

[20] ENERGY STAR. "What Goes Into the Cost of Installing a Heat Pump Water Heater?" https://www.energystar.gov/products/ask-the-experts/what-goes-cost-installing-heat-pump-water-heater#:~:text=In%20contrast%2C%20heat%20pump%20water,replace%20your%20existing%20water%20heater.

[21] NYSERDA. "All About Heat Pump Water Heaters." https://www.nyserda.ny.gov/Featured-Stories/All-About-Heat-Pump-Water-Heaters

Refrigerating and Air-Conditioning Engineers (ASHRAE)[22] cites a slightly shorter EUL of 13 years for gas storage water heaters. However, broader statistical analysis reveals that, on average, commercial water heaters exhibit a longer operational lifespan, typically spanning from 15-20 years, as per independent market research platforms and statistical data.[23]

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 (KM) 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 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 versus 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, more than 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 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 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 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 survival data

[22] ASHRAE Equipment Life Expectancy Chart. https://www.naturalhandyman.com/iip/infhvac/ASHRAE_Chart_HVAC_Life_Expectancy.pdf
[23] Gitnux. "Average Life of Water Heater." https://gitnux.org/average-life-of-water-heater/

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. The Weibull distribution has a general shape that is consistent with the way equipment failures tend to happen.

3.3.3 Age-at-replacement analysis

For the HVAC heat pumps, we used baseline equipment replacement data provided by licensed contractors to analyze the age of units that were replaced during this study and to calculate a median and a basic weighted average age that would provide another estimate of the EUL. The commercial HVAC heat pump 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 nameplate photos of the removed/replaced equipment in conjunction with the contractor-reported installation date of the removed/replaced equipment to verify the heat pump installation date. We compared the verified installation date against the contractor-reported date of removal to estimate the age of the removed heat pumps.

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 HVAC heat pumps, we developed retention rates 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

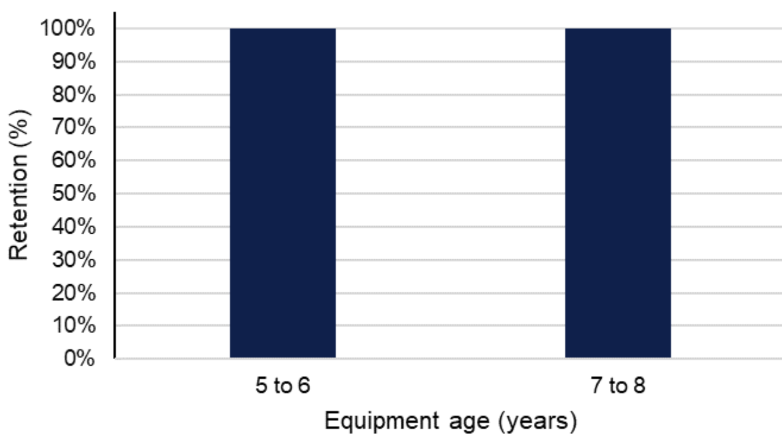
4.1 Nascent heat pump technologies

4.1.1 HVAC heat pump (central and ductless)

4.1.1.1 Retention rate results

Figure 4-1 shows the retention rates of different age groups of the observed 73 HVAC heat pump units. The observed heat pumps all had a 100% retention rate, suggesting that HVAC heat pumps have a high survival probability for the first 8 years after installation. Based on the extrapolation of this high retention rate for the first 8 years, heat pump units are expected to have a prolonged EUL.

Figure 4-1. HVAC heat pumps retention by age



4.1.1.2 EUL survival analysis results

Of the 73 observed HVAC heat pump units, with ages up to 8 years old, none experienced failure or replacement, indicating a 100% survival rate of the observed units. Consequently, survival analysis results were inconclusive, with the estimated EUL deemed indefinite. To gain insight into the upper bound of the EUL, we turned to secondary age-at-replacement analysis results.

4.1.1.3 Age-at-replacement analysis results

Table 4-1 shows a summary of the age-at-replacement analysis for HVAC heat pumps. By analyzing the seven nameplate pictures provided by C-20 and C-36 contractors of HVAC heat pumps replaced during this study, we determined both a median and an average equipment age at replacement. The median replacement age stands at 24.9 years, while the average age is 23.4 years. Taking into account the median replacement age of 24.9 years alongside the 100% survival rate for the first 8 years, we can project that HVAC heat pumps could last up to 20 years. However, without additional survival data, particularly from ages 10-20 years old, we cannot confidently project how long HVAC heat pumps could last beyond 20 years. Therefore, based on the age-at-replacement analysis and projections for the longevity of HVAC heat pump systems using the available survival data and considering the CPUC's 20-year EUL cap[24] for energy efficiency measures, we recommend a 20-year EUL for HVAC heat pumps.

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

Description	Verified installation date	Removal/replacement date	Age at replacement (years)
Central heat pump	6/1/2006	7/28/2023	17.2
Central heat pump	5/1/1995	8/5/2023	28.3
Central heat pump	10/23/2007	10/18/2023	16.0
Central heat pump	9/26/1993	7/6/2023	29.8
Central heat pump	11/10/1998	10/3/2023	24.9
Central heat pump	10/31/2008	1/17/2023	14.2
Central heat pump	4/17/1990	12/27/2023	33.7

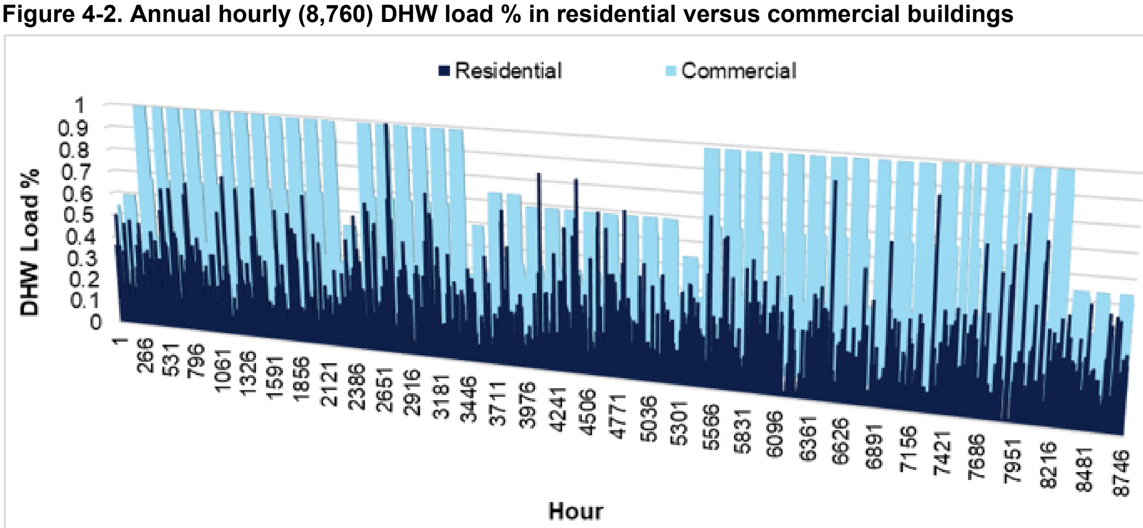
Table 4-1. HVAC heat pump age-at-replacement analysis

4.1.2 Heat pump water heater

As mentioned in Section 3.1.1, there were not enough historical program installations of heat pump water heaters and therefore, we did not conduct a primary data collection and EUL survival analysis for commercial heat pump water heaters. Instead, we leveraged the results of the recently completed CPUC Residential HVAC and DHW Measure Effective Useful Life Study[25], which we conducted as a part of the broader EUL effort.

Utilizing the hourly hot water demand profiles from the DEER Water Heater Calculator[26] for various building types alongside their respective normalizing weights, we computed the average hourly hot water demand for both residential and commercial sectors. Assuming 100% DHW load at peak hourly flow, we derived the 8760 average hourly DHW load percentages for residential and commercial sectors, as illustrated in Figure 4-2. Notably, commercial buildings exhibited considerably greater hot water demands in contrast to residential ones, suggesting higher operational load factor for water heaters in commercial settings. Because of the higher operating load factor and extended operational periods, it is expected that water heaters in commercial buildings last for fewer years than in residential buildings.

Figure 4-2. Annual hourly (8,760) DHW load % in residential versus commercial buildings



[25] California Public Utilities Commission. GROUP A Residential HVAC and DHW Measure Effective Useful Life Study Final Report. April 9, 2024. https://pda.energydataweb.com/api/view/3952/CPUC%20Group%20A%202023%20Res%20HVAC%20and%20DHW%20EUL%20Study%20Final%20Report.pdf

[26] DEER Water Heater Calculator, v5.1. https://cedars.sound-data.com/deer-resources/tools/water-heaters/

On average, water heaters in commercial buildings are projected to have a total annual hourly load factor of 45.22%, contrasting with a 5.21% annual hourly load factor for residential buildings. However, it is crucial to acknowledge that commercial buildings typically employ multiple water heaters, unlike residential buildings, which typically have one water heater per building. Understanding the average annual hourly load factor per water heater is essential for a direct comparison of water heater deterioration between commercial and residential settings. To understand the load factor per water heater, we utilized the peak load and a sizing factor of 1.2, adhering to the capacity sizing calculation methodology outlined in the DEER Water Heater Calculator.[27]

We estimated that six 50-gallon heat pump water heaters would be required to meet the average commercial building hot water demand, whereas only one 50-gallon heat pump water heater would suffice for residential building use. This means the average annual load factor, per water heater, is 7.54% in commercial buildings, compared to 5.21% in residential buildings. This suggests that 50-gallon heat pump water heaters in commercial buildings are projected to operate 45% on average more compared to operation in residential buildings. Considering data from the Residential HVAC and DHW EUL Study Final Report[28], which indicates a 20-year EUL for heat pump water heaters in residential settings, their EUL is projected to reduce to approximately 13.84 years due to the increased usage in commercial contexts.

4.2 Established technologies

4.2.1 Air Conditioner (split and central)

4.2.1.1 EUL survival analysis results

Our study targeted air conditioner program participation data for different age groups, with the oldest age available group exceeding 8 years. The air conditioner data showed that all of the observed 227 units were still in place and in good working condition. Consequently, the survival analysis results, which are based on projection of the survival of the observed units, were inconclusive, with the estimated EUL deemed indefinite. As mentioned in the Section 3.2.2 , the CT X2001B EUL study [29] also found similarly inconclusive survival analysis results. While the X2001B study suggested, based on the failure rate of the observed 42 units, the EUL could be closer to 24 years than 15 years, it still recommended maintaining the existing EUL of 15 years due to the lack of a sufficient sample size and age.

Considering that our study observed more units than the X2001B study and considering that for heat pump technologies, which is expected to have a similar operation to air conditioners, are expected to last at least up to 20 years, we can project that air conditioners may also have a similar life span of up to 20 years. However, further research with a larger sample size and longer observation period would be necessary to confidently estimate the longevity of air conditioners beyond 20 years.

4.2.2 Gas storage water heater

4.2.2.1 EUL survival analysis results

Our study developed a survival analysis sample size plan aiming to meet the criteria for an enhanced level of rigor for the gas storage water heater measures. We targeted gas storage water heater program participation data for different age groups with the oldest age available group equal to the current EUL of 15 years. The gas storage water heater survival data,

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[27] DEER Water Heater Calculator, v5.1. https://cedars.sound-data.com/deer-resources/tools/water-heaters/

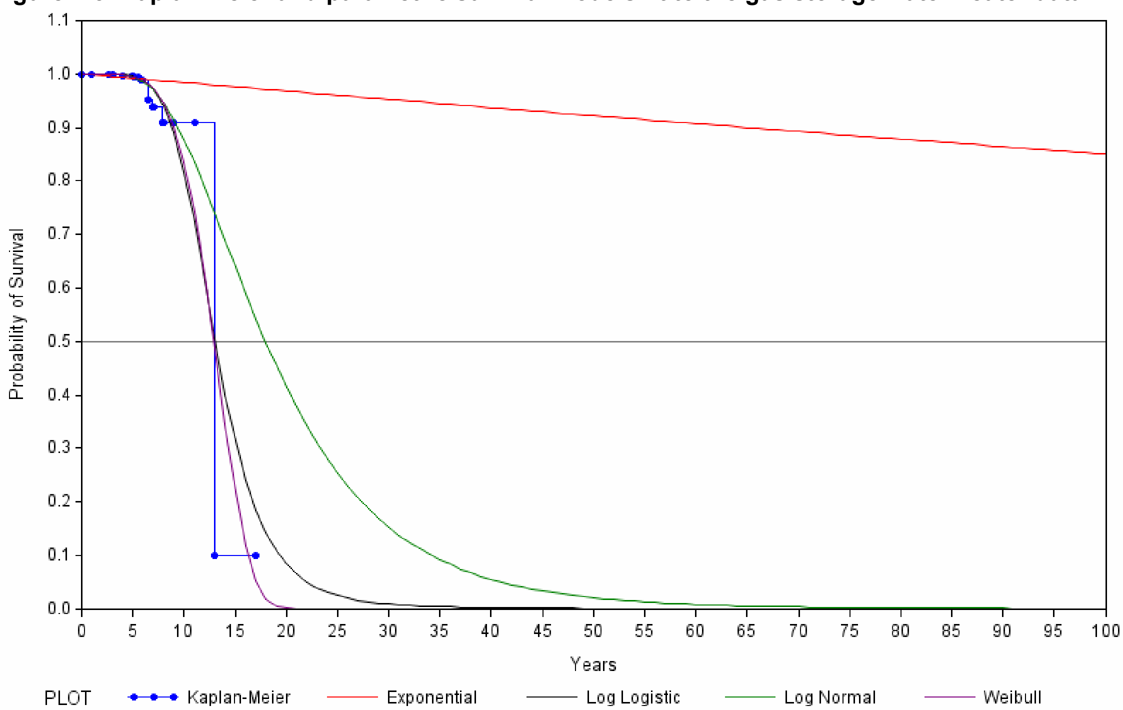
[28] California Public Utilities Commission. GROUP A Residential HVAC and DHW Measure Effective Useful Life Study Final Report. April 9, 2024. https://pda.energydataweb.com/api/view/3952/CPUC%20Group%20A%202023%20Res%20HVAC%20and%20DHW%20EUL%20Study%20Final%20Report.pdf

[29] Final Evaluation Report for: X2001: Connecticut Measure Life/EUL Update Study Residential & Commercial. https://energizect.com/sites/default/files/bulk-media/CT_X2001_EUL_Measure_Report_FINAL_051523_forPosting.pdf

unlike measures discussed above, demonstrates units of an age where majority of units between 8-15 years old had failed. As such, the KM analysis results (the blue line in Figure 4-3) do reach the median level or 50% probability of survival in Figure 4-3. Because the KM 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 both Weibull and Log Logistic distributions provide both a general shape and EUL results that are extremely close to the KM results. Between the KM, Log Logistic, and Weibull models, we can say the EUL estimate is 13 years with 90% confidence interval ranging from 12-14 for storage water heaters.

Using the EUL projection methodology based on load profile discussed in Section 4.1.2 and considering the 25-year EUL for gas storage water heaters estimated by the Residential HVAC and DHW Measure Effective Useful Life Study Final Report[30], we estimate that a 50-gallon gas water heater is expected to last around 12 years in commercial settings due to their increased usage. This is comparable with the 13-year EUL that we established for commercial gas storage water heaters using the parametric survival model.

Figure 4-3. Kaplan-Meier and parametric survival models fit to the gas storage water heater data



4.2.3 Gas tankless water heater

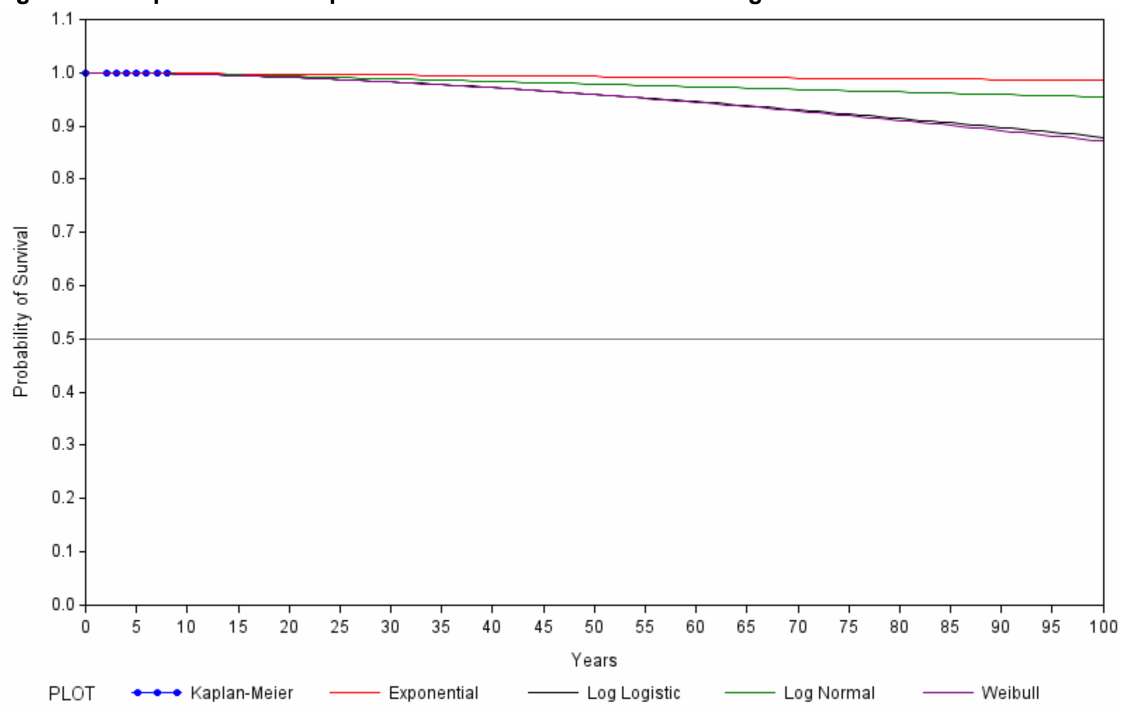
4.2.3.1 EUL survival analysis results

Our study targeted gas tankless water heater program participation data for different age groups with the oldest age available group equal to 8 years. The gas tankless water heater survival data, see Figure 4-4, demonstrates more than 90% of the observed units were in place and in good working condition. Because there were not enough observed failures for the first 8 years after installation, the survival analysis EUL results are infinitely large. While we cannot confidently estimate how

[30] California Public Utilities Commission. GROUP A Residential HVAC and DHW Measure Effective Useful Life Study Final Report. April 9, 2024. https://pda.energydataweb.com/api/view/3952/CPUC%20Group%20A%202023%20Res%20HVAC%20and%20DHW%20EUL%20Study%20Final%20Report.pdf

long exactly gas tankless water heaters can last, we can at least say that there is no evidence that the EUL is lower than the CPUC's 20-year cap. As such, we recommend retaining the existing 20-year EUL value for gas tankless water heaters.

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



5 CONCLUSIONS AND RECOMMENDATIONS

Using the retention evidence shown by evaluated equipment specific data, DNV estimated the EUL values of the five commercial HVAC and DHW technologies. Table 5-1 summarizes the findings from this EUL study, with our recommendations provided below.

Table 5-1. EUL analysis results

Commercial technology	Evaluated unit counts	Estimated EUL (years)	90% confidence interval of EUL (years)	Relative precision achieved at 90% CI	Proposed EUL (years)
HVAC heat pump (ductless and central)[1]	73	20	N/A	N/A	20[3]
Air Conditioner (packaged and split with gas heating)[1]	227	20	N/A	N/A	20[3]
Heat pump water heater[2]	N/A	13	N/A	N/A	13
Gas storage water heater	106	13	12-14	8%	13
Gas tankless water heater[1]	102	20	N/A	N/A	20[3]

N/A = not applicable

[1] Because of the high survival rate of the observed units, the survival analysis results were indefinitely high. As such, confidence intervals and relative precision values could not be estimated.

[2] Based on secondary research

[3] Capped at CPUC's 20-year EUL cap

5.1 HVAC heat pumps

Based on the evaluated equipment data ranging from age groups 1-8 years, DNV estimated the HVAC heat pumps to have a 100% retention rate. While this suggested that HVAC heat pumps have a high survival rate for the first 8 years, we could not conclusively estimate the exact EUL of HVAC heat pumps through a parametric survival analysis. As such, we relied on the secondary age-at-replacement analysis to understand the EUL of HVAC heat pump technologies. We estimated that the median age of 7 HVAC heat pumps replaced by C-20 and C-36 contractors during the course of this study was 24.9 years. Using this median age of units replaced in 2023 in conjunction with the high survival rate of 1-8-year-old units, we can conclude that HVAC heat pump technologies can last up to at least the CPUC's cap of 20 years. Therefore, we recommend a 20-year EUL value for commercial HVAC heat pumps.

5.2 Air conditioners

Similar to HVAC heat pumps, we observed 227 air conditioner units with ages ranging from 1-8 years old and saw zero failures. We could not conclusively estimate the EUL of air conditioners using parametric survival analysis. Considering the high survival rate of 1-8-year-old air conditioner units and the technological parallels of air conditioners with HVAC heat pump systems, we recommend considering a 20-year EUL for commercial air conditioners. However, further research with a larger sample size and longer observation period is warranted to provide more definitive conclusions.

5.3 Heat pump water heaters

While our study did not involve primary data collection, based on our analysis and comparison of average annual hourly load factors for water heaters in commercial and residential settings, we recommend a 13-year EUL for water heaters in commercial buildings. The substantial difference in load factors between commercial and residential contexts underscores the importance of understanding the unique operational demands of each setting when determining equipment lifespan. Leveraging insights from the Residential HVAC and DHW Measure Effective Useful Life Study final Report[31] results, our recommendation aligns with the projected lifespan of heat pump water heaters operating in commercial environments. As a part of the EUL update, we also recommend establishing an EUL ID of 'WtrHt-HtPmp-Com' specifically for commercial heat pump water heaters.

5.4 Gas storage water heaters

For gas storage water heaters, based on evaluated equipment data from age groups 1-15 years, we estimated that heat pump water heaters have a high failure rate with units 8-15 years old, suggesting that the current EUL of 15 years is high. Between the KM, Weibull, and Log Logistic models, we can conclude that the estimate EUL is 13 years with a 90% confidence interval of 12-14 years old. This range represents an achieved precision of 8% at 90% confidence interval. Therefore, we recommend a 13-year EUL for commercial gas storage water heaters. As a part of the EUL update, we also recommend updating the DEER EUL ID of commercial gas storage water heaters from 'WtrHt-Com' to 'WtrHt-Com-Gas' to prevent any potential confusion that may arise.

5.5 Gas tankless water heaters

We found that the retention data for units 1-8 years old showed a high survival rate. Due to the lack of failures within the first 8 years after installation, the survival analysis yields infinitely large EUL results. While the exact longevity of gas tankless water heaters cannot be confidently estimated, there is no evidence to suggest that the EUL is lower than the CPUC's 20-year cap. Therefore, we recommend a 20-year EUL for gas tankless water heaters.

[31] California Public Utilities Commission. GROUP A Residential HVAC and DHW Measure Effective Useful Life Study Final Report. April 9, 2024. https://pda.energydataweb.com/api/view/3952/CPUC%20Group%20A%202023%20Res%20HVAC%20and%20DHW%20EUL%20Study%20Final%20Report.pdf

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 do not know the age at which it fails or is removed or replaced, we only know whether that occurred prior to the time we observed 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.

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. Assume a 2% success rate for the census-attempted bins.
2. Since age group 1-3 participants give minimal information about the measure life and since there are not enough 8+ year old installations in the historical tracking data, the useful data for the survival analysis primarily comes from participants in the age group 4-7, i.e., the “middle aged” equipment.
3. Assume a design effect (DEFF) of 3 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.
4. Calculate the sample size for each age bin as follows:

   n = 2% x DEFF x N_customers

   where

   N_customers is the count of unique customers shown in Table 3-3

   DEFF = 3

6.2 Sample design for commercial HVAC and water heater contractors

The overall budget allows for the recruitment of a total of 10 contractors, providing nameplate photos and data for an average of eight units each. For HVAC heat pump technologies, 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 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 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 $(Z_5 \times CV / p_{desired})^2$

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

= 73

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

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

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

= 0.096.

7 APPENDIX B. EUL STUDY DATA COLLECTION FORM

7.1 EUL survival analysis – DNV remote data collection survey instrument

Com Web Survey.pdf

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

CPUC Group A
Commercial EUL Stud

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

CPUC Group A
Commercial EUL Stud

8 APPENDIX C. EUL Study data and analysis

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

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	Retention rate %
2-4	2019 to 2021 tracking	0	0	0	-
5-6	2017 to 2018 tracking	18	18	0	100%
7-8	2015 to 2016 tracking	55	55	0	100%
Total	**All**	**73**	**73**	**0**	**100%**

Table 8-2. Air conditioner 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	Retention rate %
2-4	2019 to 2021 tracking	43	43	0	100%
5-6	2017 to 2018 tracking	150	150	0	100%
7-8	2015 to 2016 tracking	34	34	0	100%
9-15	2014 and older	-	-	-	-
Total	**All**	**227**	**227**	**0**	**100%**

Table 8-3. Gas storage 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
2-4	2019 to 2021 tracking	14	14	0
5-6	2017 to 2018 tracking	49	40	9
7-8	2015 to 2016 tracking	26	20	6
9-15	2014 and older	13	2	11
Total	**All**	**102**	**76**	**26**

Table 8-4. 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
2-4	2019 to 2021 tracking	46	46	0
5-6	2017 to 2018 tracking	44	42	2
7-8	2015 to 2016 tracking	16	14	2
9-15	2014 and older	-	-	-
Total	**All**	**106**	**99**	**4**

9 APPENDIX D. EUL SCALING METHODOLOGY

Below, we provide a detailed explanation of how load factor values for residential and commercial buildings were utilized to scale the residential heat pump water heater and gas storage water heater EUL values to establish commercial EUL values.

1. We collected 8,760 hourly gallons per minute (GPM) flow data for various residential and commercial building types form the DEER Water Heater Calculator v5.1.[32] Utilizing the building weights supplied in the same calculator for each commercial and residential building type, we computed a blended average hourly GPM for both residential and commercial buildings.

2. Next, we computed hourly load factor (%) values by dividing the hourly GPM by the maximum 8760 GPM. The average hourly load factor for residential buildings is 5.21%, while for commercial buildings, it is 45.22%.

3. Using the maximum 8760 hourly GPM, we estimated the water heater capacity that would be required for the peak draw (shown in Table 9-1) using the equation below.

$$Required\ capacity\ for\ peak\ volume, \frac{Btu}{hr} = \ Peak\ flow\ \times Conversion\ factor\ \times 100$$

Table 9-1. Capacity sizing calculations

Description	Commercial	Residential
Peak flow, gallons/hr	255	33.21
Conversion factor, Btu/gal-°F	8.22	8.22
Required capacity for peak volume, Btu/hr	209,796	27,305

4. Using the capacity sizing calculation methodology outlined in the DEER Water Heater calculator[32], we estimated the quantity of water heaters needed to meet the peak volume capacity estimated in Table 9-1. We used the following technology parameters for sizing calculations:

Table 9-2. Technology parameters [32]

Parameters	Heat pump water heater technology		Gas storage heater technology	
	Values	Units	Values	Units
Type	PkHP	-	Stor	-
UEF/EF	3.52	-	0.65	-
Fuel	Elec	3413	Gas	1000
Volume	50	gallons	50	gallons
Cap	4.5	kW or kBtu/h	40.1	kW or kBtu/h
RE/TE	N/A	TE for Com. WHs	0.78	TE for Com. WHs
Draw Pattern	MD-HI	-	MD	-
Tank UA	4.37	Btu/hr-F	5.075	Btu/hr-F
Aux W	0	watts	0	watts
Vent W	0	watts	0	watts
Aux Btu	0	Btu/hr	350	Btu/hr
Aux Eff	0	-	0.67	-

[32] DEER Water Heater Calculator, v5.1. https://cedars.sound-data.com/deer-resources/tools/water-heaters/

5. For heat pump water heaters, we estimated that six 50-gallon systems, each with a uniform energy factor of 3.5, would be necessary to fulfill the commercial peak capacity. We divided the average commercial load of 45.22% by six to ascertain the average load per water heater, resulting in 7.54%. In contrast, residential buildings were assumed to utilize a single heat pump water heater per building, resulting in an average load of 5.22%. By dividing the average load per water heater for commercial buildings by that of residential buildings, we derived a commercial to residential usage factor ratio of 1.45. Subsequently, we divided the residential heat pump water heater EUL of 20 by the ratio of 1.45 to calculate a 13.84-year EUL for commercial heat pump water heaters.

6. For gas storage water heaters, based on DEER Water Heater Calculator capacity sizing calculations, we estimated that four 50-gallon gas storage water heaters, each with a uniform energy factor of 0.64, would be necessary to fulfill the commercial peak capacity as outlined in Table 9-1. Dividing the average commercial load of 45.22% by four yielded an average load per water heater of 11.31%. In contrast, residential buildings were assumed to use a single heat pump water heater per building, resulting in an average load of 5.22%. By dividing the average load per water heater for commercial buildings by that of residential buildings, we obtained a commercial to residential usage factor ratio of 2.17. Subsequently, we divided the residential heat pump water heater EUL of 25 by the ratio of 2.17 to calculate a 11.53-year EUL for commercial gas storage water heater.

10 APPENDIX E. STAKEHOLDER COMMENTS AND EVALUATOR RESPONSES

Entity	Section	Page	Question or comment	Evaluator response	Notes / action:
SoCalREN	4.1.2	17	SoCalREN appreciates California Public Utilities Commission (CPUC) and DNV's efforts to evaluate 11 program years' worth of data to develop the comprehensive draft report. SoCalREN offers its comments on the study below. Due to insufficient claims data for commercial heat pump water heaters (HPWHs), the study extrapolated residential heat pump water heater effective useful life (EUL) results to establish the commercial HPWH EUL. The recommendation to reduce commercial HPWH EULs based on residential results, due to increased load experienced within commercial sector facilities inaccurately represents the EUL applicable to HPWHs installed in public sector facilities. SoCalREN performed an analysis using data from the DEER Water Heater Calculator. As shown in the attached excel file, a comparison of the average Equivalent Full Load Hours (EFLH) between public sector and commercial sector building types reveals a notable 31% increase in EFLH for the latter. This significant variance suggests that HPWHs deployed in public sector facilities should theoretically exhibit a longer EUL compared to commercial HPWHs. In light of this analysis, SoCalREN respectfully requests within the final report that DNV segregate the building types utilized within public sector programs from those within commercial sector programs, as detailed in Table 1 below. Furthermore, it is recommended that the California Public Utilities Commission (CPUC) consider establishing distinct EUL guidelines for commercial sector HPWHs and public sector (or non-residential) HPWHs separately, based on this analysis. If parsing out for the inclusion of public sector in the study is not feasible, SoCalREN recommends that EULs are applied differently to different building types so public sector facilities can benefit from more accurate EULs.	Thank you for your comment. While there are observable differences in equivalent full load hours (EFLH) between the public and commercial sector building type groupings provided by SoCalREN, DEER and the eTRM has not afforded a level of granularity in EUL between these building types. The joint staff does not desire to make a recommendation that would set such a precedent in part because it would create even more DEER table permutations, which has presented challenges to system and its users. Additionally, scaling for the "Public" sector alone would result in an EUL value that exceeds what we can confidently extrapolate from the residential EUL results. Therefore, we maintained recommending a single EUL value for all commercial building types.	N/A
SDG&E	Overall	Overall	The current DEER EUL support tables for commercial water heater "WtHt-Com" does not distinguish between heat pump and gas water heating. The report lists this EUL ID as a "Gas storage water heater" in Table 2-2 and subsequently throughout the document, but that does not match the EUL description on eTRM. SDG&E recommends creating a new DEER EUL ID for gas "WtHt-Com-Gas" (version DEER2026). This will help prevent any potential confusion that could arise.	Thank you for your comment. The joint staff agrees with the recommendation to upgrade the DEER EUL ID to "WtrHt-Com-Gas" to avoid potential confusion in the future. We have updated the recommendation in the final report version.	DNV added a recommendation in the report to update DEER EUL ID for commercial gas water heaters.
SDG&E	Table 2-2	7	The draft report lists 5 EUL ID's that were impacted by this research but does not provide all the various sub-categories for commercial HVAC air-conditioners and heat pumps. SDG&E would like the evaluators to confirm if it is possible to also include the legacy commercial HVAC types that are listed in the DEER Effective Useful support tables within eTRM, which include but are not limited to Package Terminal AC "HVAC-PTAC", Package Terminal Heat Pump "HVAC-PTHP", High Efficiency Water Source Heat Pump "HVAC-WSHP", and air conditioners (water cooled, split and unitary) "HVAC-wtrAC". This information is helpful for eTRM 2026 measure package planning.	Our study's scope did not include the mentioned subcategories, such as packaged terminal air conditioners or water source units. Therefore, the joint staff cannot determine whether these subcategories have comparable EULs, particularly due to potential differences in maintenance practices, usage patterns, and the human interaction component for package terminal units or differences in equipment components and technology for the requested water source HVAC units. At this time, we are recommending updating EUL for only air source heat pump HVAC (EUL ID of HVAC-airHP) and air-cooled packaged and split ACs (EUL ID of HVAC-airAC).	N/A
SDG&E	Table 2-2	7	According to eTRM CPUC Support Table for Effective Useful Life (https://www.caetrm.com/cpuc/table/effusefullife/), the EUL ID associated with heat pump water "WtrHt-HtPmp" is a residential EUL ID (version = DEER20214). SDG&E suggests adding a recommendation to create new a DEER EUL ID "WtrHt-HtPmp-Com" (version DEER2026).	The joint staff agrees with the recommendation to use "WtrHt-HtPmp-Com" EUL ID for commercial heat pump water heaters. We have updated the recommendation in the final report version.	DNV added a recommendation in the report to update DEER EUL ID for commercial heat pump water heaters.

Entity	Section	Page	Question or comment	Evaluator response	Notes / action:
SoCalGas	1.3	4	SoCalGas requests DNV to sustain commercial storage water heating EUL at 15 years since the sample size used to establish the Kaplan Meier analysis may be too small to allow the model to provide a reliable result. To provide a more accurate distribution over time on a Kaplan Meier model, the sample size should consist of permutations that reflect the age of existing equipment being sampled in the market and be large enough compared to the number of available units. In the circumstances presented in the report, the sample used to establish storage water heater EUL did not account for storage water heaters older than 15 years, although that data is likely available, and the sample is relatively small compared to the number of storage water heaters available in the commercial market. For these considerations, EUL for storage water heaters should remain at 15 years while a more reliable sample can be used to conduct a Kaplan Meier analysis.	Thank you for your comment. The joint staff agrees that a larger sample size generally yields more reliable results. However, this study meets the CPUC's minimum sampling requirements for a basic rigor EUL study, with 30% precision at a 90% confidence interval. The modeled results achieved a precision of 8% at a 90% confidence interval, demonstrating reliability for the targeted basic rigor EUL study. Regarding the age distribution of our sample, the oldest sample points are 15 years, which matches the current EUL for gas storage water heaters. The Kaplan-Meier analysis, based on data up to 15 years old, indicates a survival rate of only 13 years. Therefore, sample data older than 15 years, while helpful, isn't strictly necessary for estimating the expected EUL at the targeted rigor level. Given that this study uses the best available regional failure data and meets the requirements for a basic rigor EUL study, the joint staff is confident in recommending a 13-year EUL for commercial gas storage water heaters.	N/A
SoCalGas	4.2.2	18	SoCalGas requests DNV to sustain commercial storage water heating EUL at 15 years. Although a 50-gallon water heater, in a commercial setting, may be used more than a residential water heater as mentioned on page 19 of the report, water heaters in a commercial setting are likely to undergo maintenance schedules and are likely to last analogous to a residential water heater. The difference between the proposed commercial and finalized residential EUL is material, which further warrants a request for the commercial EUL for storage water heater to remain at 15 years	Thank you for your comment. As mentioned in our response to comment #5, the joint staff's recommendation of a 13-year EUL is based on the analysis of equipment failure rates observed at commercial locations. In other words, this study sample accounts for any regular maintenance that commercial water heaters typically undergo. Additionally, we conducted a secondary analysis to scale the EUL of a 50-gallon residential storage water heater based on usage profiles. While the joint staff acknowledge that commercial water heaters are likely to follow maintenance schedules more rigorously than residential units, they also operate more frequently and under higher loads, as observed on site, which results in a lower EUL. Therefore, despite the maintenance schedules, the increased operational frequency and load in commercial settings justify our recommendation of a 13-year EUL for commercial water heaters, rather than sustaining the 15-year EUL.	N/A

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