1994 Residential New Construction Fourth-Year Retention Evaluation
(Energy Advantage Home Program)

Study ID No. 716

Submitted to:

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Turning Data into Information

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Introduction

1.1 Overview

The objective of this measure retention study is to assess and verify useful lifetimes of the various measures installed through Southern Gas Company's 1994 Energy Advantage Home Program (EAHP). The EAHP is designed to induce builders to increase energy efficiency in new homes beyond the levels required by Title 20 and Title 24. The program offers informational and training workshops for builders and provides incentives for a variety of DSM measures.

Under the existing California Public Utilities Commission's Measurement and Evaluation Protocols (CPUC Protocols), The Gas Company is required to complete a fourth-year measure retention study. This study's objective is to conduct a retention study of the measures installed under the 1994 Energy Advantage Home Program. The results of this study are estimates of the effective useful life (EUL) for each of the measures installed under the 1994 EAHP.[1] These estimated EULs are then compared to *ex ante* estimates of measure lifetimes. If the *ex ante* estimates differ from the study estimates, then the program savings estimates should be adjusted accordingly.

Table 1-1 summarizes the DSM measures covered in the 1994 EAHP, including the number of installations and the *ex ante* per unit and annual savings in therms for each measure.

[1] EUL is defined as "...the time at which only 50% of the measures installed under the program are still in place and operable."

Table 1-1: Summary of DSM Measure in 1994 EAH Program

Program Measure	Number Installed	Per Unit Savings (therms)	Total Annual Savings (therms)
DSM Measures			
Duct Testing	7,159	22	157,498
Furnace (88% AFUE)	1,512	29	43,848
Water Heater (.60-.69 EF)	1,608	14	22,512
Water Heater (.70 EF)	7	30	210
Combination System (.58 EF)	1,095	23	25,185
Duct Insulation	10	5	50
Heat Traps	146	10	1,460
Recirculating Controls	1	405	405
MH Water Heaters (.60 EF)	0	21	0
MH Furnace (80%-87% AFUE)	34	14	476
MH Furnace (88+% AFUE)	0	37	0
All DSM Measures	-	-	**251,644**
Fuel Substitution Measures			
Furnaces	68	-147	9,996
Gas Ovens	1,529	-19	29,051
All Fuel Substitution Measures			**39,047**

1.2 Overview of Approach

The primary elements of the approach were as follows:

- ***Assessment of Primary and Secondary Data Sources.*** RER conducted a review of secondary sources in order to identify existing studies that may have completed similar research, or contains estimates of effective useful lives.[2]

[2] Note that care was taken to ensure that published lifetimes that were used for comparison had well documented definitions of the estimated lifetimes. That is, the lifetimes were not estimates of maximum life or some undefined average lifetime.

- **On-Site Survey.** An on-site survey of an attempted census of the 303 participant sites included in the first-year impact study was conducted in order to collect information on the program measures. The result of the completed census was 252 completed surveys. The approach to do on-site survey verification of participants included in the first-year study is consistent with the CPUC Protocols for SoCalGas retention studies (Table 9B). The survey was used to collect detailed information on whether installed measures are still installed and operational. In cases where the measure has been removed or is no longer operational, data were collected on why and when the measure was removed or ceased to work. Appendix A includes a copy of the survey instrument.

  Insofar as duct testing is a major portion of the savings from the EAH Program, a retention rate was estimated and duct blaster tests were conducted on a sub-sample of 20 homes to develop a degradation factor for duct integrity. The sub-sample of homes is the same as those that underwent duct blaster tests in the 1996 evaluation.

- **Statistical Analysis.** To estimate the EULs, RER utilized three specific statistical analyses:
  - ***Construct Summary Statistics.*** RER constructed summary statistics of measure lifetimes.
    - *Retention fraction,* which is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed.
    - *Average Measure Lifetime,* which is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure.

    These estimates of measure life can be subject to biases from measurement and censoring of the data. Because of these biases, the following two modeling approaches were used when feasible.
  - ***Life Table Method.*** This approach estimates survivor functions using estimates of hazard functions. In this analysis, RER used an estimator of the survivor function that is constructed from an estimate of the hazard function. The hazard is the probability that a program measure that is in place at month *t* will fail in the following month. The estimator of the hazard function accounts for censoring and individual differences in observation period (the interval between inspection and installation of the measure).
  - ***Parametric Models.*** For measures with long *ex ante* EULs, it is possible that more than half of the installed measures will exist and be operable at the time of the verification audits. In this case, estimates of EULs derived using the life table method will not be plausible since the median lifetime will not be observed. In this case, parametric specifications of the survivor function are required in order to extend beyond the censored lifetimes. Under this approach, RER *fit* the observed data to three alternative parametric specifications of the survivor function: log-normal, log-logistic and Weibull.

These estimated functions were then used to construct an 80% confidence interval around the estimated EUL.

Per the Protocols, the *ex ante* EUL will be compared to the estimated EUL to determine if the two values are statistically different—that is, to determine whether the *ex ante* EUL falls within the estimated 80% confidence interval. Because the above approach for developing estimates of EUL is subject to measurement error, estimates of EULS from other studies were also used to confirm the results of this study.

General Issues

A number of issues were discussed during the project initiation meeting in July. The following summarizes these issues:

- ***Existing Statewide Retention Studies.*** The CPUC protocols (Table 9B) indicate that the measures to be studied should not include any measures included in a statewide retention study. At the project initiation meeting, SoCalGas staff indicated that there have been no statewide residential new construction retention studies.
- ***Filing of DSM Measure Savings as Miscellaneous.*** The protocols also state in Table 9B that measures identified as miscellaneous (per Table C9) should be excluded. Again, SoCalGas staff indicated that no measures were identified as miscellaneous.
- ***EAHP Measure Breakdowns.*** The protocols (Table 9B) indicate that the analysis needs to be completed at the measure level (or sub-sets of closely related measures). RER developed measure categories consisting of like measures with the same assumed *ex ante* lifetimes. For instance, the EAHP-installed measures include water heaters with varying efficiency levels. Since these measures used the same *ex ante* lifetime to calculate savings, we grouped these as one measure for the retention analysis. To develop this categorization, RER reviewed the assumed measure lifetimes used in The Gas Company's earnings claim at the beginning of the project and grouped like measures.
- ***Duct Testing.*** Duct testing in the 1994 EAHP was the largest component of claimed savings. RER recognizes that the definition of retention in the context of duct testing is not clear. For example, discussions of this issue at recent CADMAC meetings have raised many issues, but the committee has not presented any formal conclusions. RER treated duct testing as duct sealing. In particular, RER determined if the duct sealing is still in place and operating effectively using a three-point visual inspection method. In addition, RER investigated whether a degradation factor (as per Table 9B in the CPUC protocols) should be included. This analysis involved the completion of roughly 20 duct blaster tests. No definitive answer to this issue was found. However, a recommendation for future analysis is provided in Section 3.

Compliance with CPUC Protocols

The CPUC Protocols (Table 9B) require that SoCalGas measure retention studies are based upon a sub-sample of the first-year impact on-site sample and that retention rates and EULs are estimated at the measure level. As mentioned above, RER's, on-site survey included participants included in the first-year study. RER estimated retention rates and EULs for all measures covered by the 1994 EAHP. Because of problems associated with small sample sizes of the on-site survey for some measures, RER grouped the 13 measures covered by the EAHP into 8 measure categories consisting of like measures with the same assumed *ex ante* lifetimes. Doing so, however, still meets the CPUC Protocol requirements, which allow for analysis "at the measure level (or sub-sets of closely-related measures)." RER also included an analysis of duct leakage degradation, an optional item in Table 9B of the Protocols.

Confidence intervals could be computed only for those measures covered by the statistical analysis. For the measures not covered by the analysis, there is no evidence that the *ex ante* EUL falls outside the 80% confidence interval range. Therefore, the *ex ante* EUL should be retained.

1.3 Preview of Results

Table 1-2 presents a summary of the retention fractions and EULs for each measure. In general, our analysis does not suggest changing any of the assumed EULs used by SoCalGas in their earnings claims with the exception of gas ovens. For gas ovens, we recommend the use of 18 years as compared to the 20 years that was used in previous earnings claims.

Table 1-2: Summary of Estimated Retention Fraction and a Comparison of Estimated EULs with Existing *Ex Ante* EULs

Measures	Retention Fraction	*Ex ante* EUL	Retention Study EUL
Duct Testing	0.976	25	25
Furnace (88% AFUE)	1.000	18	18
Water Heater (.60-.69 EF)	0.967	13	13
Water Heater (.70 EF)	0.967	13	13
Combination System (.58 EF)	1.000	20	20
Duct Insulation	1.000	25	25
Heat Traps	1.000	13	13
Recirculating Controls	1.000	15	15
MH Water Heaters (.60 EF)	0.967	13	13
MH Furnace (80%-87% AFUE)	1.000	18	18
MH Furnace (88+% AFUE)	1.000	18	18
Multi-Family Furnaces	1.000	18	18
Gas Ovens	1.000	20	18

In addition to the required findings presented in Table 1-2, two recommendations were developed as a result of the retention study. These recommendations are discussed below.

Use of Multiple Program Years to Estimate Survivor Functions

The use of a single program year necessitates the use of a relatively small sample and does not necessarily provide the needed variation in the observed lifetimes required to produce robust EUL estimates. RER recommends using multiple program year data in any future retention studies. The use of multiple program years is the suggested practice in the CPUC Protocols for the retention studies for the other California utilities.

RER recognizes that this recommendation needs to be balanced against the fact that the EAHP has changed significantly during the past few years. However, there is most likely some overlap between measures covered by the program across program years. For these measures, the use of multiple program year data could support a more robust retention modeling effort.

Further Research into Duct Leakage Degradation

Duct testing is a significant part of the 1994 EAHP and is receiving considerable attention in a number of state and national studies. The data gathered during this study provide a strong indication of degradation in the duct systems during the first four years of the program. However, there are a number of mitigating circumstances, such as small sample sizes and correct interpretation of the protocols, which suggest the need for more study before any definitive conclusion can be made about duct sealing degradation.

1.4 Organization of the Report

The remainder of the report is organized as follows:

- Section 2 discusses the data collected to support the analysis,
- Section 3 presents the methodology and results from the analysis,
- Appendix A contains a copy of the on-site data collection instrument,
- Appendix B contains a copy of the introductory letter used in the survey effort, and
- Appendix C contains a description of the duct testing program and procedures, in addition to a copy of the Duct Blower Door/Duct Blaster Data Collection Form.

2

Data

2.1 Overview

In order to meet the project objectives, the following three major data collection activities were completed:

- Assessment of secondary data on measure retention and measure lifetimes,
- Design and implementation of the on-site surveys,
  - Develop a draft of the on-site survey instrument
  - Conduct the pre-test and the finalize survey instrument
  - Compile sample list from the first-year impact study
  - Develop the on-site data collection protocol
  - Collect on-site data
  - Perform data entry and data review, and
- Duct Blaster tests.

Each of these activities is discussed below.

2.2 Assessment of Secondary Data on Measure Retention and Measure Lifetimes

A review of secondary sources of studies on equipment lifetimes was conducted. Sources of information were reviewed from various publications, government agencies, along with discussions with numerous manufacturers and associations. These included the following:

- Bradford White,
- Lennox,
- American Water Heater,
- Carrier,
- United McGill Corporation,
- Air-Conditioning and Refrigeration Institute (ARI),
- Association of Home Appliance Manufacturers (AHAM),

- Gas Appliance Manufacturers Association (GAMA),
- Lawrence Berkeley National Laboratory (LBNL),
- Electric Power Research Institute (EPRI),
- Residential End-Use Energy Planning System (REEPS),
- Appliance Magazine,
- Home Energy,
- Air Way,
- Rocky Mountain Institute,
- The Energy Outlet,
- U.S. Department of Energy (DOE),
- American Council for an Energy-Efficient Economy (ACEEE), and
- Federal Energy Management Program (FEMP).

In general, the numbers of studies conducted regarding lifetimes are few, and even fewer have clearly explicit definitions of effective useful lifetimes. Interestingly, GAMA, GRI, ACEEE, and DOE all recommended Appliance Magazine as the best source for lifetimes. The following is a final list of sources that had any information on lifetimes:

- REEPS,
- Appliance Magazine,
- DOE, and
- FEMP.

The REEPS national default database was developed for EPRI in 1995. Lifetime estimates were based on a compilation of sources that included studies conducted by DOE, AHAM, GAMA, LBNL, United Power Association (UPA), American Gas Association (AGA), the U.S. Department of Agriculture (USDA), Appliance Magazine, and individual utility studies.

Appliance Magazine bases lifetimes on first-owner use of the product. This does not necessarily mean the appliance is worn out. Estimates are based on expert judgement of Appliance Magazine staff based on input from many sources. Unfortunately, Appliance Magazine does not cover all of the measures contained in this study.

DOE produced a Technical Support Document in 1993.[1] This document presents the methodology, data, and results from the analysis of the energy and economic impacts of

[1] U.S. Department of Energy, Assistant Secretary, Energy Efficiency & Renewable Energy, Office of Codes and Standards, Washington, DC, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets, U.S.*, November 1993.

proposed standards. DOE does not document their methodology for determining lifetimes but discussions with staff indicate DOE's definition of average is simply the average number of years that an appliance survives.

FEMP promotes the purchasing of energy-efficient appliances. FEMP is a division of DOE. Marketing materials on how to buy energy efficient appliances were available on the Internet. Staff members at FEMP also state the definition of average is simply the average number of years that an appliance survives.

2.3 Design and Implementation of the On-Site Surveys

The design and implementation of the on-site surveys required the completion of six major tasks.[2]

- Develop an on-site survey instrument,
- Compile a sample list from the first-year impact study,
- Conduct the pre-test and finalized survey instrument,
- Develop the on-site data collection protocol,
- Collect on-site data, and
- Data entry and data review.

Each of these elements is discussed below. Included in the discussions are summaries of the survey response rate and the measures covered by the surveyed homes.

Develop a Draft of the On-Site Survey Instrument

The on-site survey instrument was designed to obtain the following information:

- To verify that the measure is in place,
- To verify that the measure is operational,
- To collect information relating to the reasons for removal of measures if the measures are not found,
- To collect information relating to the reasons for the measure no longer being operational, and
- If the measure is not found, to ascertain if the measure was ever installed.

[2] Insofar as an attempted census of all 1994 participants used in the first-year impact study is targeted, there was no call for a complex sample design.

A draft copy of the survey instrument was provided to SoCalGas staff and ASW staff for comments. RER developed a final draft survey instrument based on comments and edits provided by SoCalGas staff and ASW engineers.

Sample Lists

RER retrieved the databases used in the first-year impact analysis. From this database, all necessary contact data for the 303 participants visited during the first-year impact study was gathered. This list was submitted to ASW Engineering, who conducted the on-site visits.

Pre-Tests and Finalize Survey Instruments

ASW pre-tested the draft instruments on a group of 12 customers. These customers represented the full range of conservation measures. The pre-test sites also included a sample of sites requiring duct blaster tests. A comparison of duct leakage from the current tests and the tests conducted in 1996 were made on-site. In a few cases, significant differences existed and extra steps were taken to explain the increase in leakage. The causes of the deterioration in leakage were noted and, where appropriate, added to the checklist of duct integrity in the survey instrument. In particular, a three-point checklist based on the surveyor's visual inspection of the ducts was developed. This checklist required the surveyor to grade the quality of the duct sealing, plenum connection, and suspension system as good, fair, or poor.

ASW energy auditors performed the pre-test on-site surveys. The auditors documented questions and observations on the survey instrument and noted any additional information they thought should be included. RER reviewed the results of the pre-test from the perspective of their ultimate use in assessing measure retention, and made changes where necessary. The main changes to the survey document resulting from the pre-test related to developing a visual inspection checklist for each of the measures. RER conducted a number of conference calls with ASW on-site auditors to exchange ideas and obtain feedback on proposed changes before finalizing the survey instrument.

Once the on-site pre-tests were completed, RER issued a memorandum to the Study Manager that documented the results of the pre-test and described modifications that were made to the survey instrument. Approval was received from the Study Manager and the instrument was finalized. A copy of the final on-site survey is included in Appendix A.

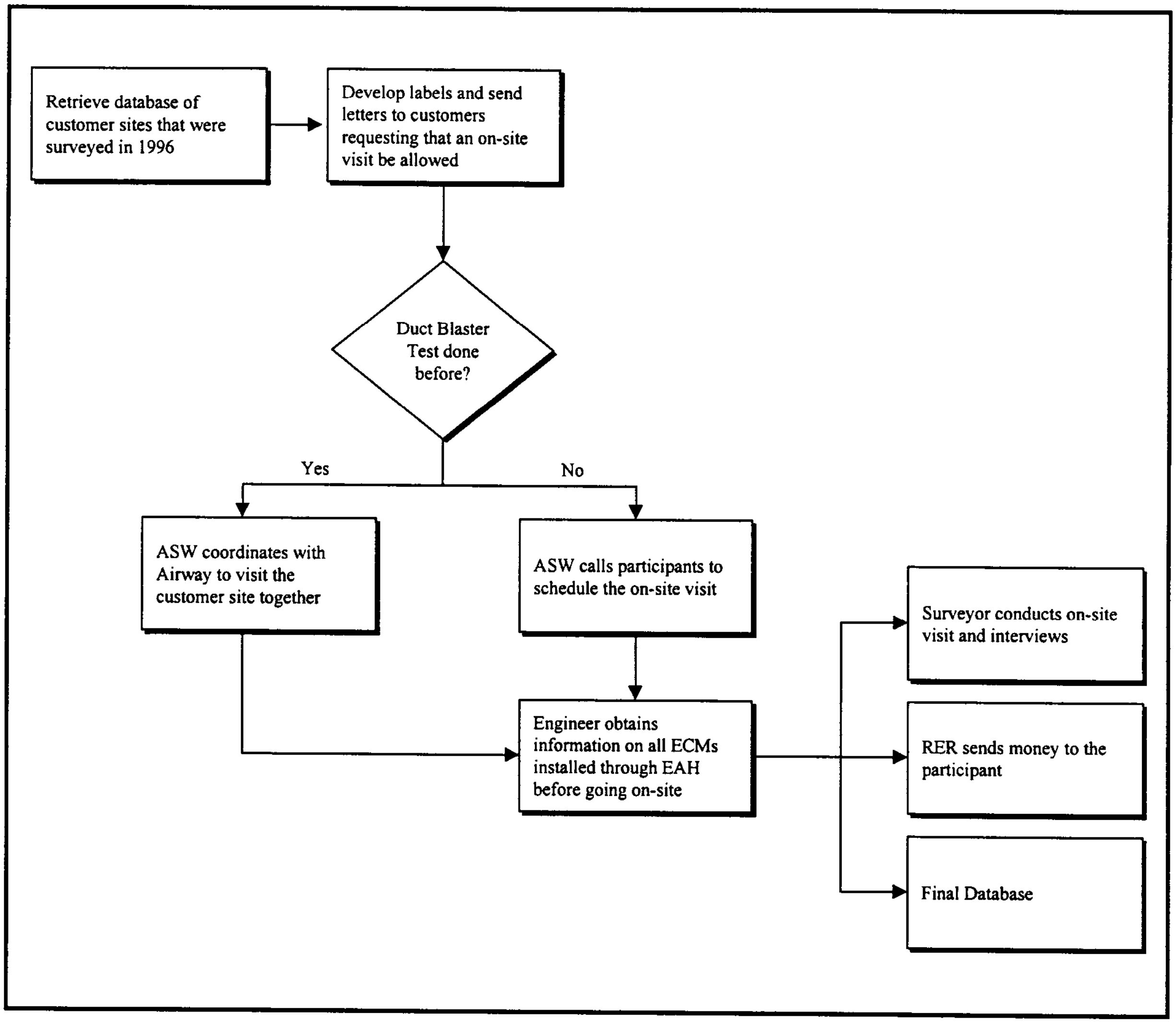
On-Site Data Collection Protocol

RER and ASW developed protocols and methods to complete the following five key steps of the data collection strategy in a professional and non-intrusive manner:

- Recruit customers in the sample,
- Schedule the on-site visits,
- Conduct on-site visits,
- Monitor the survey effort, and
- Data entry and data review.

Figure 2-1 presents an overview of the data collection process. Each of the key elements of the procedure is discussed below.

Figure 2-1 : Overview of On-site Data Collection Effort



Recruit Customers in Sample and Schedule On-Site Visits

The purpose of this task was to recruit as many of the 303 participant customers in the on-site sample for the follow-up retention analysis on-site survey and complete the on-site visit. Based on RER's experience with the first-year study, a $25 incentive was offered to each participating customer. An incentive of $50 was offered to the subsample of 20 customers that underwent duct blaster tests in the 1996 study. Introductory letters were sent to each customer in the sample. The letter explained the general purpose of the project, introduced the on-site company (ASW) to the customer, and explained that a $25 incentive was being offered to participate in the study. Each letter was sent on The Gas Company's letterhead and signed by the Study Manager. Copies of the letters are provided in Appendix B.

ASW staff was responsible for the recruiting customers and scheduling the on-site visits. The customer recruiting process used a five call-back protocol. In particular, each qualified number was called up to five times to make contact with the customer and identify the appropriate person for discussing participation in the study. If a customer was not contacted after five attempts, the number was dropped from the sample. After making contact, the ASW recruiter explained the project's purpose, indicated the amount of time needed during the visit from the contact person or other member of the household, offered the incentive for participation and, if the customer was willing to participate, arranged a mutually acceptable time for data collection. Contact calls were made at differing times of the day in an attempt to reach customers and to arrange the visit at the customer's convenience.

Conduct On-site Survey Effort and Develop Retention Analysis Database

After arranging the on-site visit, a field staff member visited the customer's home to conduct the survey. RER and ASW provided the Study Manager with weekly status reports on the progress of the on-site survey activities. ASW was responsible for data entry, along with performing verification and data quality review of the database.

Table 2-1 presents a summary of the completed on-site surveys by climate zone and residence type. Included in the table are the population of 1994 EAH participants and the response rate by residence type and weather zone. A total of 252 on-site surveys were completed, which represents a response rate of 83%.

Table 2-1: Completed On-Sites by Weather Zone and Residence Type

Residence Type	Weather Zone	Population	Target	Complete	Response (%)
Single Family	Mountain	5	1	0	0%
	Low Desert	197	5	3	60%
	Coastal	592	37	30	81%
	High Desert	879	40	33	83%
	Inland Valley	1,161	81	71	88%
	L.A. Basin	1,185	86	71	83%
Multi-Family	Mountain	0	0	0	0%
	Low Desert	0	0	0	0%
	Coastal	257	10	10	100%
	High Desert	97	4	2	50%
	Inland Valley	6	0	0	0%
	L.A. Basin	672	39	32	82%
All Single Family		4,019	250	208	83%
All Multi-Family		1,032	53	44	83%
Total		**5,051**	**303**	**252**	**83%**

The 252 surveyed sites contained a total of 457 program measures. Table 2-2 presents a breakout of measures, and compares the number of measures from the first-year impact study (*target*) to the number covered in the on-sites completed for this study (*complete*).

Table 2-2: Summary of Measure Coverage by Completed On-Site Survey

Measure	Target	Complete
Duct Testing	263	217
Furnace 88% + AFUE	69	58
Furnace 78% - 88% AFUE	1	1
Water Heater (.60 - .69 EF)	107	92
Water Heater (.70 + EF)	0	0
Ovens	79	73
Heat Traps	18	16
Combo Systems	19	18

2.4 Conduct Duct Blaster Tests

Duct blaster tests were completed for 20 participant homes during the first-year impact study. RER attempted to conduct follow-up duct blaster tests for the same 20 homes. RER offered an additional incentive of $25 to these 20 homeowners. Ultimately 19 of the original 20 homes participated in the duct blaster testing. New owners now occupy three of the homes.

The duct blaster tests followed the same protocols used during the previous study—that is, multi-point duct blaster tests at 25, 50, 75, and 100 pascals.[3] Airway was responsible for completing these tests. Appendix C provides a copy of the duct blaster test survey form and the protocols for completing the duct blaster test.

[3] All comparisons were made using the reading from the 50 Pascals test. This is necessary for comparison with the original program requirements of a minimum of 140 CFM of leakage at 50 Pascals.

3

Methodology and Results

3.1 Introduction

This section discusses the methodology used in the retention analyses and presents the results from the study. The methodology section provides a detailed discussion of the development of a retention fraction, average useful life, and effective useful lifetime. The results section is organized by measure. In particular, estimates of effective useful lifetimes from secondary sources, an estimated retention fraction and average lifetime, and, where possible, an estimate of effective useful lifetime, are provided for each measure.

3.2 Methodology

This section discusses the general analysis approach. The discussion covers the methods used to estimate the Effective Useful Life (EUL) for each of the measures. As stated in the DSM Protocols, a measure's Effective Useful Life (EUL) is "...the time at which only 50% of the measures installed under the program are still in place and operable." This study provides EUL estimates for each of the identified 1994 EAHP installed measures. Specifically, the analysis attempts to compute the following for each measure:[1]

- An estimate of the survivor curve, and
- An estimate of the EUL and corresponding standard error.

These statistics were then used to construct an 80% confidence interval around the estimated EUL. Per the Protocols, the *ex ante* EUL is compared to the estimated EUL to determine if the two values are statistically different—that is, to determine whether the *ex ante* EUL falls within the estimated 80% confidence interval. Because the proposed approach for developing EUL estimates is subject to measurement error, RER presents estimates of EUL from other studies to confirm the results of this study.

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1 Due to the relatively few number of failures, survivor functions were estimated for water heaters and gas ovens only. There were also a sufficient number of apparent duct failures to estimate a survivor function for duct testing. However, there was no knowledge on the part of the homeowner, nor is there any way to observe the time at which these failures occurred. Insofar as these data are essential for estimating the survivor functions, no survivor function for duct testing was estimated.

A natural first step in estimating a measure's EUL is to construct summary statistics of the program lifetimes. Two such statistics are described below:

- ***Retention Fraction,*** which is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed.
- ***Average Measure Lifetime,*** which is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (1) inspection and installation of the measure, or (2) date of failure and installation of the measure.

Program evaluations based on these statistics are subject to two important biases. The first bias is due to differing observation periods for the installed measures. In particular, differences in the estimated retention fractions across program years could be due to differing average observation periods.[2] The second bias is censoring bias; not all measure lifetimes are completed by the time of the on-site inspections. Estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. What is required is an estimation method that accounts for differing observation periods and for censoring.

Where possible estimates of each measure's survivor function was used to compute the EUL and corresponding confidence interval. The survivor function, call it $S(t)$, gives the probability that the survival of a measure exceeds length t; so $1\text{-}S(t)$ is the cumulative distribution function of the random variable t. Given estimates of $S(t)$, the measure's EUL and the confidence intervals around this estimate can be readily computed. The statistical methods used to estimate these functions are described below.

- ***Life Tables.*** Kalbfleish and Prentice, *The Statistical Analysis of Failure Time Data,* Wiley and Sons (1980) suggest an estimator of $S(t)$, which is constructed from an estimate of the hazard function, call it $h(t)$. The hazard is the probability of a program measure that is in place at month t will fail in the following month. The estimator of the hazard function accounts for censoring and individual differences in observation period (the interval between inspection and installation of the measure). Estimates of $S(t)$ are computed as follows:

  $$\hat{S}_{t+1} = \hat{S}_t\left(1 - \hat{h}_t\right) \qquad (1)$$

  where estimates of the hazard function are given below:

  $$\hat{h}_t = \frac{\text{Number of Measures with Lifetimes of Length } t}{\text{Number of Measures With Lifetimes of Length } t \text{ or Longer}} \qquad (2)$$

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2 Insofar as this is the study of only one program year, this might not be a significant factor.

The adjustment made for a measure with a censored lifetime of length *t* is to contribute one half to the denominator, rather than one. For example, the estimate of the hazard function for lifetimes of 18 months would be computed as follows. The numerator in equation (2) would contain the total number of measures with completed lifetimes of 18 months. The denominator would contain the sum of the total number of measures with completed lifetimes of 18 months or longer, plus half of the measures that have censored lifetimes of 18 months.

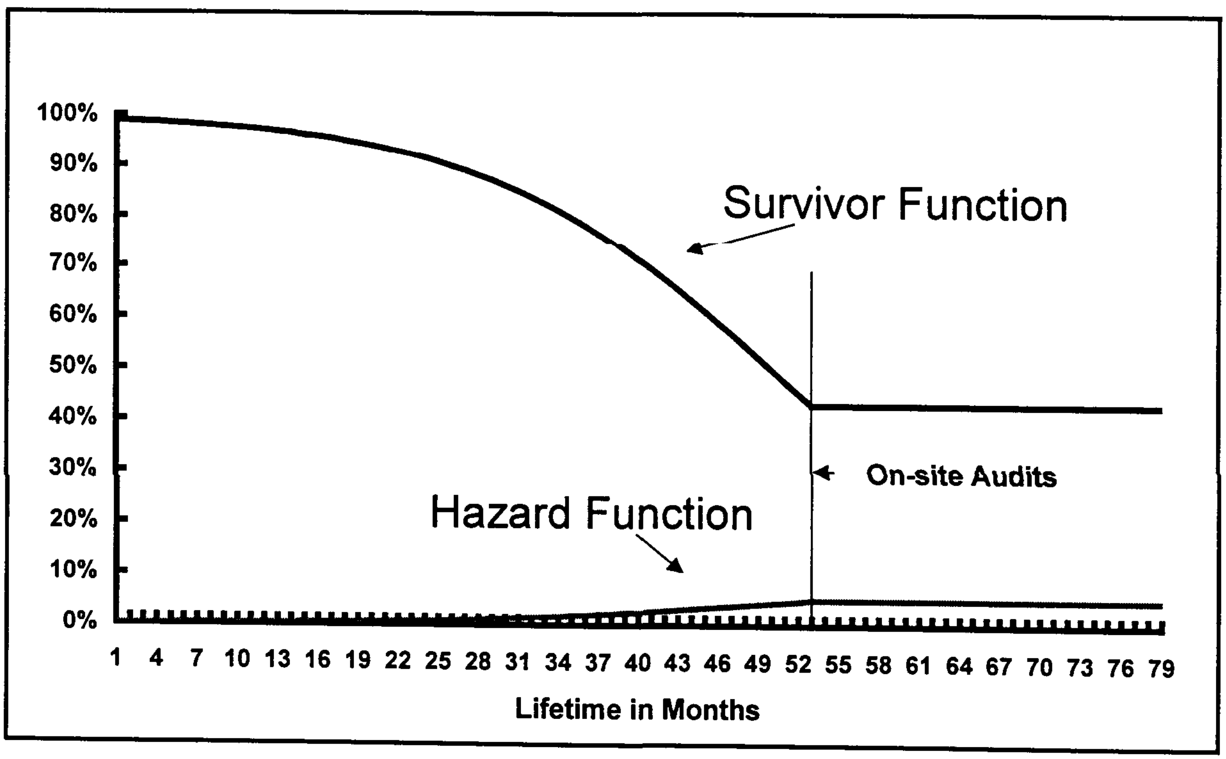
By construction, unless the longest observed measure lifetime is completed, the survivor curve will not go to zero. This is the case for the estimated survivor function depicted in Figure 3-1. In the case depicted, measure lifetimes are observed up to the time of the on-site audits. Measures that persist beyond the on-site visits are treated as censored.

Given an estimate of the survivor function, the estimated EUL is computed as follows:

$$\textit{Effective Useful Life} = \frac{t_{j-1} - t_{median} + \left[\dfrac{\hat{S}_{j-1} - \hat{S}_{median}}{2}\right]}{\hat{S}_{j-1} - \hat{S}_j} \qquad (3)$$

where the interval t_{j-1}, t_j is selected such that $\hat{S}_{j-1} \geq \hat{S}_{median}/2 \geq \hat{S}_j$.

Figure 3-1: Estimated Survivor and Hazard Function



The corresponding standard error is estimated by:

$$\hat{\sigma}_{EUL} = \frac{\hat{S}_{median}}{\left(2\hat{S}_j \hat{h}_j \sqrt{n_{median}}\right)} \tag{4}$$

where $\hat{h}_j$ is the estimate of the hazard function at month j.

The confidence interval around the estimated median measure life is given by:

$$\textit{Effective Useful Life} \pm z_{\alpha/2}\hat{\sigma}_{EUL} \tag{5}$$

where, $z_{\alpha/2}$ is the critical value for the normal distribution.

- ***Parametric Models.*** For measures with long *ex ante* EUL, it is possible that more than half of the installed measures will exist and be operable at the time of the verification audits. In this case, estimates of EULs derived using the life table method will not be plausible since the median lifetimes were not observed.[3] In this case, parametric specifications of the survivor function are required in order to extend beyond the censored lifetimes. Under this approach, the observed data were fit to three alternative parametric specifications of the survivor function: log-normal, log-logistic, and Weibull.

  Specifically:

  Log-Logistic Survivor Function,

$$S_t = \frac{1}{\left(1 + e^{\left(t-\mu/\sigma\right)}\right)} \tag{6}$$

  Log-Normal Survivor Function,

$$S_t = 1 - \Phi\left(\left(t-\mu\right)/\sigma\right) \tag{7}$$

  where Φ is the cumulative distribution function for the normal distribution.

  Weibull Survivor Function,

$$S_t = e^{\left(-e^{\left(t-\mu/\sigma\right)}\right)} \tag{8}$$

  Each of these functions has been widely used in the medical and unemployment duration literature and is documented in detail in Kalbfleish and Prentice (1980).

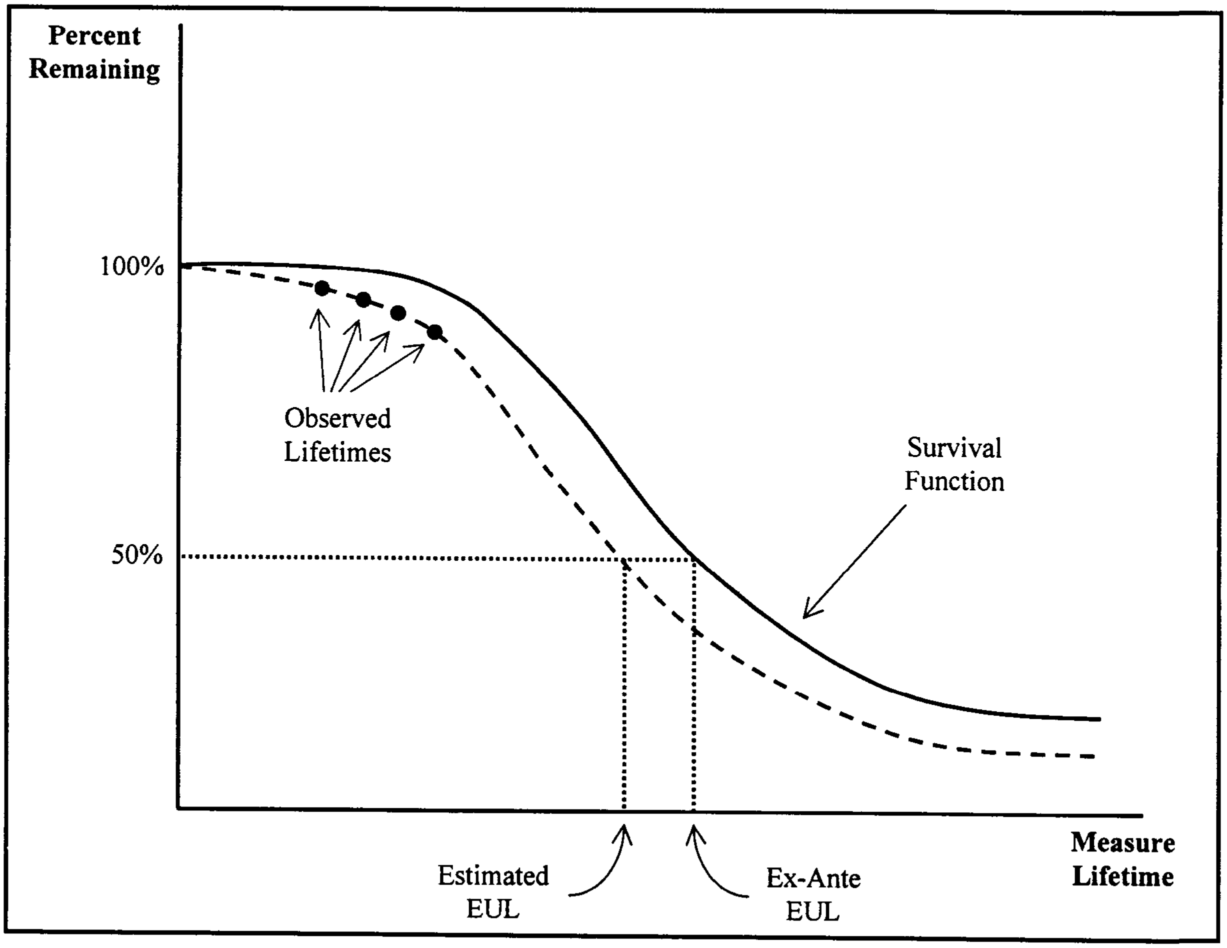
[3] The parametric method was the method used in this analysis since the median life of the measures were not observed. This is not surprising for a fourth-year new construction retention study of major appliances.

Because each function differs in the amount of weight that is placed in the upper tail of the estimated function, the implied estimated EUL differs. For estimates falling within the 80% confidence interval from the midpoint estimate, the midpoint estimate for the EUL was chosen. Estimated EULs that differ significantly were compared to estimates drawn from other studies in order to select the candidate EUL.

A survivor function was estimated for measures with an adequate amount of failures using data collected as part of the on-site verification audits.

Figure 3-2 presents an overview of the parametric approach. The *ex ante* EUL is derived from the assumed survival function. Using the observed lifetimes gathered in the on-site visit, a new survival function is estimated. The resulting EUL is then compared to the *ex ante* EUL using the criterion specified in the CPUC Protocols (Table 10).

Figure 3-2: Overview of Parametric Approach to Estimating Survival Function and EUL



3.3 Results

The major objective of the project is to provide estimates of effective useful lifetimes for measures covered in the 1994 EAH program. The potential problem of small sample sizes from the on-site retention survey for some of the measures was recognized during the development of the final workplan. The recommended solution for this problem was to collapse *like* measures that had the same assumed program *ex-ante* lifetimes. Table 3-1 presents the 13 measures covered in the EAH program and the assumed *ex ante* EULs.

Table 3-1: *Ex Ante* EULs for Measures Covered in the 1994 EAH Program

Measures	EUL
Duct Testing	25
Furnace (88% AFUE)	18
Water Heater (.60-.69 EF)	13
Water Heater (.70 EF)	13
Combination System (.58 EF)	20
Duct Insulation	25
Heat Traps	13
Recirculating Controls	15
MH Water Heaters (.60 EF)	13
MH Furnace (80%-87% AFUE)	18
MH Furnace (88+% AFUE)	18
Furnaces	18
Gas Ovens	20

The 13 measures covered in the EAH program were reduced for the examination of *ex ante* EULs to eight across like equipment type and with the same current lifetimes. The lifetimes estimated for these eight measures can be applied back to the original 13 by equipment type. The final list of measures includes the following:

- High efficiency furnaces,
- High efficiency water heaters,
- Duct testing,
- Combination system,
- Heat traps, and
- Gas ovens.

The following sections discuss the estimation of the EUL for the different measures and include the following:

- A summary of the secondary lifetime comparisons.
- An estimate of the retention fraction, which is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures, installed.
- An estimate of the average measure lifetime, which is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (1) inspection and installation of the measure, or (2) date of failure and installation of the measure.
- The estimated effective useful life which is defined to be "...the time at which only 50% of the measures installed under the program are still in place and operable."

3.4 High Efficiency Furnaces

This section discusses the estimation of the EUL for the installation of energy-efficient gas furnaces. This estimate covers two program measures

- Gas Furnaces with 88% + AFUE, and
- Gas Furnace with 78% - 88% AFUE.

The 1994 EAH program *ex ante* EUL for energy-efficient gas furnaces is 18 years or 216 months. Table 3-2 presents a summary of gas furnace failures by rebated (high-efficiency) and non-rebated (might or might not be high efficiency) measures.

Table 3-2: Summary of High Gas Furnace Failures

	Measures in Survey		Failed Measures	
	Rebated	Non-Rebated	Rebated	Non-Rebated
Gas Furnaces	50	193	0	0

Summary of Estimates of Measure Lifetimes from Secondary Data

Estimates of EUL from other studies are presented in Table 3-3. The range on expected lifetimes is from 13 to 35 years. The EUL from two independent sources, DOE and PG&E, provides estimates that match the 18 years used by SoCalGas as the *ex ante* EUL.

Table 3-3: Estimated Energy Efficient Gas Furnaces (Years)

Sources	Minimum	EUL	Maximum
Ex Ante EUL		18	
Appendix F – PG&E		18	
REEPS 1987 Default Database	13		23
Appliance Magazine – September 1998[4]	15	25	35
DOE – FEMP – October 1998[5]		18	

Retention Fraction

The retention fraction is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed. A total of 50 energy-efficient gas furnaces were installed in the 1994 EAH program year. Of these, all were in place and working at the time of the on-site survey. The estimated retention fraction for the installed gas furnaces is 100%.

Average Measure Lifetime

Average Measure Lifetime is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure. Due to censoring bias, estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. As a result, the best that can be concluded is the EUL for gas furnaces is at least 44 months.

Effective Useful Lifetime

Insofar as no failures have been observed, no EUL can be estimated using either the life table or parametric methods.

Summary of Findings for High-Efficiency Gas Furnaces

Data from the on-site survey are inconclusive with regard to estimating the EUL of high-efficiency gas furnaces. However, the literature search and review of secondary data supports the current assumed EUL of 18 years.

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4 Appliance Magazine – Listed as Gas Furnace - Low, high, and average years are based on first-owner use of the product and do not necessarily mean the appliance is worn out. Estimates are based on expert judgement of Appliance Magazine staff based on input from many sources.

5 Federal Energy Management Program. "*How to Buy an Energy-Efficient Gas Furnace.*" October 1998.

3.5 High Efficiency Gas Water Heaters

This section discusses the estimation of the EUL for the installation of energy-efficient gas water heaters. This analysis covers two program measures:

- Gas water heaters (.60 - .69 EF), and
- Gas water heaters (.70 + EF).

The 1994 EAH program *ex ante* EUL for energy-efficient gas water heaters is 13 years or 156 months. Table 3-4 presents a summary of gas water heater failures by rebated (high-efficiency) and non-rebated (might or might not be high efficiency) measures.

Table 3-4: Summary of Gas Water Heater Failures

	Measures in Survey		Failed Measures	
	Rebated	Non-Rebated	Rebated	Non-Rebated
Gas Water Heaters	92	158	3	4

Summary of Estimates of Measure Lifetimes from Secondary Data

Table 3-5 presents a summary of the EUL for gas water heaters from secondary sources. The range on expected lifetimes is from 4 to 19 years. Three independent estimates by PG&E, SDG&E, and DOE support the SoCalGas *ex ante* estimate of 13 years.

Table 3-5: Estimated Water Heater Lifetimes (Years)

Sources	Minimum	EUL	Maximum
Ex Ante EUL		13	
Appendix F – PG&E		13	
Appendix F – SDG&E		13	
REEPS 1987 Default Database	8		18
Appliance Magazine – September 1998[6]	4	12	19
DOE – Technical Support Document 1993		13.86	
DOE – FEMP – October 1998[7]		13	

EUL is the average expected lifetime.

Retention Fraction

The retention fraction is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed. A total of 92 energy-efficient water heaters were installed during the 1994 program year. Of these, 89 were in place and working at the time of the on-site survey. The estimated retention fraction for the installed water heater measures is 96.7%.

Average Measure Lifetime

The average measure lifetime is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure. The average measure lifetime for this group of measures is estimated to be 43 months.

Program evaluations based on the above two summary statistics are subject to two important biases. The first is the bias due to differing observation periods for the installed measures. In particular, differences in the estimated retention fractions across program years could be due to differing average observation periods. The second bias is censoring bias; not all measure lifetimes are completed by the time of the on-site inspections. Estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. As a result, the best that can be concluded is the EUL for water heaters is at least 43 months.

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6 Appliance Magazine – Low, high, and average years are based on first-owner use of the product and do not necessarily mean the appliance is worn out. Estimates are based on expert judgement of Appliance Magazine staff based on input from many sources.

7 Federal Energy Management Program. "*How to Buy an Energy-Efficient Gas Water Heater*" October 1998.

Effective Useful Lifetime

Life Tables

To account for differing observation periods and for censoring, RER uses the estimated survivor function to compute the EUL and corresponding confidence interval. The survivor function, call it *S*(*t*), gives the probability that the survival of a measure exceeds length *t*; so *1*-*S*(*t*) is the cumulative distribution function of the random variable t. Given estimates of *S*(*t*), the EUL of a measure and confidence intervals around this estimate can be readily computed.

An estimator of *S*(*t*) which is constructed from an estimate of the hazard function, call it *h*(*t*) was attempted. The hazard is the probability that a program measure that is in place at month t will fail in the following month. The estimator of the hazard function accounts for censoring and individual differences in observation period (the interval between inspection and installation of the measure). Estimates of *S*(*t*) are computed as follows:

$$\hat{S}_{t+1} = \hat{S}_t\left(1 - \hat{h}_t\right) \tag{9}$$

where estimates of the hazard function are given below:

$$\hat{h}_t = \frac{Number\ of\ Measures\ with\ Lifetimes\ of\ Lenght\ t}{Number\ of\ Measures\ With\ Lifetimes\ of\ Lenght\ t\ or\ Longer} \tag{10}$$

The adjustment made for a measured with a censored lifetime of length t is to contribute one half to the denominator, rather than one. By construction, unless the longest observed measure lifetime is completed, the survivor curve will not go to zero. This is the case with the water heater measures. In this case, water heater lifetimes are observed up to the time of the on-site audits. Water heaters that persist beyond the on-site visits are treated as censored.

Given an estimate of the survivor function, the estimated EUL is computed as follows.

$$Effective\ Useful\ Life = \frac{t_{j-1} - t_{median} + \left[\dfrac{\hat{S}_{j-1} - \hat{S}_{median}}{2}\right]}{\hat{S}_{j-1} - \hat{S}_j} \tag{11}$$

where the interval t_{j-1}, t_j is selected such that $\hat{S}_{j-1} \geq \hat{S}_{median}/2 \geq \hat{S}_j$. Specifically, the EUL is that point at which half of the measures have failed. If less than half of the measures have failed, then this estimate will be biased downward. This is the case with the water heater measures, where only three of the 92 installations had failed at the time of the audits. The resulting EUL estimate of 47.7 months is therefore an underestimate of the true EUL for this measure.

Parametric Models

In the case where less then half the measure lifetimes are observed, all of the above methods provide estimates of EUL that are biased downward. In order to develop estimates that extend beyond the censored lifetimes parametric specifications of the survivor function are required. Under this approach, the observed data are used to estimate three alternative parametric specifications of the survivor function: log-normal, log-logistic and Weibull.

The estimated EUL and upper and lower confidence bounds are presented in Table 3-6. As can be seen, the estimated EUL range from 94.4 months to 134.0 months. Under an assumption that water heater lifetimes follow a pattern suggested by a log-normal distribution, the *ex ante* EUL of 156 months does fall within the 80% confidence interval required by the Protocols. This is not the case for the log-logistic and Weibull distribution assumptions.

Table 3-6: Estimate High Efficiency Gas Water Heater EUL and 80% Confidence Bounds (Months)

Distribution	EUL	Upper Bound	Lower Bound
Log-Logistic	101.9	116.8	89.0
Log-Normal	134.0	159.4	112.5
Weibull	94.4	106.8	83.3

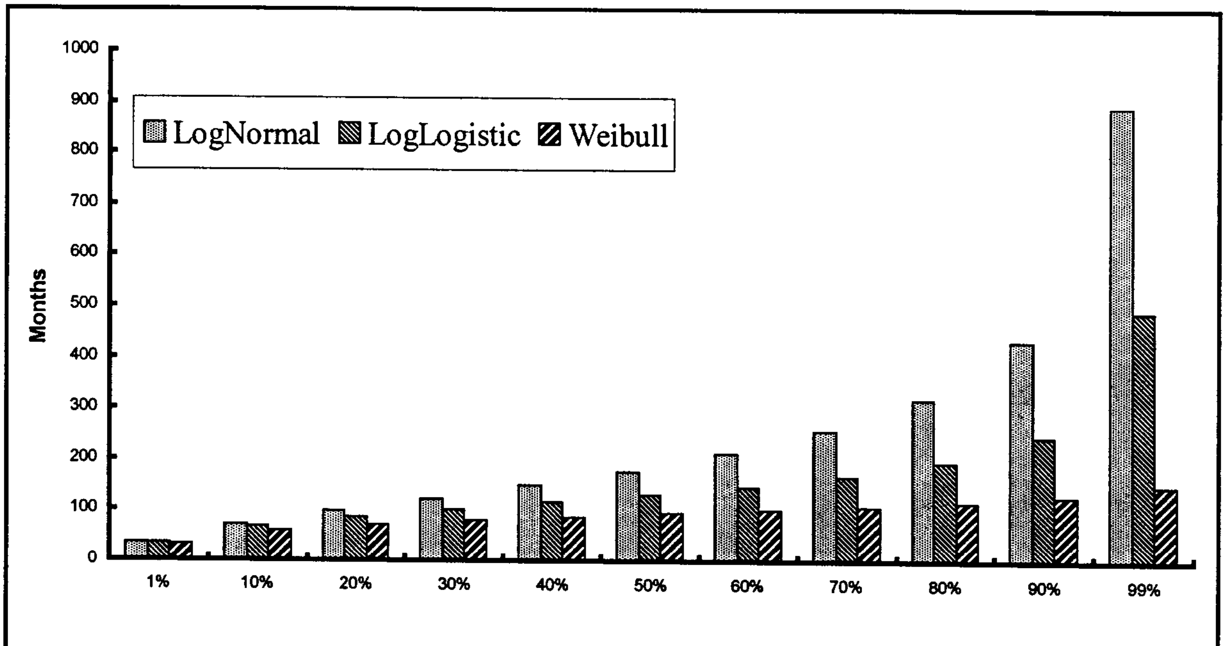
The range in estimated EUL suggested by the three distribution assumptions reflect the fact that each distribution differs in the amount of weight that is placed in the upper tail of the estimated function. The differences in the estimated functions can be seen in Table 3-7. In this table, 1% of the water heaters are estimated to fail by about 35 months. Ten percent of the water heaters are expected to fail between 60 to 72 months. Up to this point, the three distributions are roughly the same because they are forced to fit the 3% of water heaters that did fail. By the time 30% of the water heaters are expected to fail, the log-normal distribution is predicting significantly longer lifetimes.

Without observed lifetimes in the upper tail of the distribution, it is not possible to choose one distribution assumption over another, which implies that the log-normal distribution is just as likely to be the correct functional form as the log-logistic and Weibull.

Table 3-7: Comparison of Estimated Survivor Functions for High Efficiency Gas Water Heaters (Months)

Percent Failed	Log-Logistic	Log-Normal	Weibull
1%	34.9	35.1	33.4
10%	69.4	72.6	59.5
20%	87.6	98.6	71.5
30%	102.2	122.9	80.2
40%	116.0	148.4	87.6
50%	130.3	177.0	94.4
60%	146.4	211.0	101.0
70%	166.2	254.8	108.0
80%	194.0	317.6	116.0
90%	244.7	431.2	126.6
99%	486.8	891.1	150.1

Figure 3-3: Comparison of Estimated Survivor Functions for High Efficiency Gas Water Heaters (Months)



Summary of Findings for High-Efficiency Gas Water Heaters

The evidence provided from a review of the secondary sources and the parametric approach supports the use of 13 years as the assumed *ex ante* EUL for high efficiency water heaters. In particular, using the parametric approach and assuming a log-normal distribution the assumed estimate of 13 years falls inside the 80% confidence interval around the estimated median lifetime.

3.6 Gas Ovens

This section discusses the estimation of the EUL for the installation of energy-efficient gas ovens. The 1994 EAH program *ex ante* EUL for energy-efficient gas ovens is 20 years or 240 months. Table 3-8 presents a summary of gas oven failures by rebated and non-rebated measures. Insofar as ovens were a fuel switching measure, the total number of installed ovens, whether they were rebated or not, were used to develop EUL estimates. However, only those ovens for which an incentive was given are used to develop retention fraction estimates.

Table 3-8: Summary of High Efficiency Gas Oven Failures

	Measures in Survey		Failed Measures	
	Rebated	Non-Rebated	Rebated	Non-Rebated
Gas Ovens	73	113	0	4

Summary of Estimates of Measure Lifetimes from Secondary Data

The *ex ante* EUL for energy-efficient ovens is 20 years or 240 months. Estimates of EUL from other studies are presented in Table 3-9. The range on expected lifetimes is from 10 to 30 years, which is consistent with the *ex ante* value of 20 years.

Table 3-9: Estimated Oven Lifetimes (Years)

Sources	Minimum	EUL	Maximum
Ex Ante EUL		20	
Appendix F – PG&E		20	
REEPS 1987 Default Database	10		30
DOE – Technical Support Document 1993		19	
Appliance Magazine – September 1998[8]	12	19	26

Retention Fraction

The retention fraction is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed. A total of 73 gas ovens were installed by program participants during the 1994 program year. Of these, 73 were in place and working at the time of the on-site survey. The estimated retention fraction for the installed ovens is 100%.

Average Measure Lifetime

The average measure lifetime is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure. The average measure lifetime for this group of measures is estimated to be 43 months.

Measure lifetime evaluations based on the above two summary statistics are subject to two important biases. The first is due to differing observation periods for the installed measures. In particular, differences in the estimated retention fractions across program years could be due to differing average observation periods. The second bias is censoring bias; not all measure lifetimes are completed by the time of the on-site inspections. Estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. Therefore, the best that can be concluded is the EUL for ovens is at least 43 months.

Effective Useful Lifetime

<u>*Life Tables*</u>

The use of the life table method suffered from the same biases as the high efficiency water heaters. In particular, if less than half of the measures have failed, then this estimate will be

8 Appliance Magazine – Listed as Gas Range - Low, high, and average years are based on first-owner use of the product and do not necessarily mean the appliance is worn out. Estimates are based on expert judgement of Appliance Magazine staff based on input from many sources.

biased downward. This is the case where only three of the 107 oven installations had failed at the time of the audits. The resulting EUL estimate of 39.9 months is, therefore, an underestimate of the true EUL for this measure.

Parametric Models

In the case where less then half the measure lifetimes are observed, all of the above methods provide estimates of EUL that are biased downward. In order to develop estimates that extend beyond the censored lifetimes, parametric specifications of the survivor function are required. Under this approach, the observed data are used to estimate three alternative parametric specifications of the survivor function: log-normal, log-logistic and Weibull.

The estimated EUL and upper and lower confidence bounds are presented in Table 3-6. As can be seen, the estimated EUL range from 119 months to 177 months. The *ex ante* EUL of 240 months falls outside the 80% confidence interval required by the Protocols.

The range in estimated EUL suggested by the three distribution assumptions reflect the fact that each distribution differs in the amount of weight that is placed in the upper tail of the estimated function. The differences in the estimated functions can be seen in Table 3-7. In this table, 1% of the ovens are estimated to fail by about 36 months. Ten percent of the ovens are expected to fail by about 73 months. Up to this point, the three distributions are roughly the same because they are forced to fit the 3% of ovens that did fail. (Both rebated and non-rebated ovens are used for this phase of the analysis.) By the time 30% of the ovens are expected to fail, the log-normal distribution is predicting significantly longer lifetimes.

Without observed lifetimes in the upper tail of the distribution, it is not possible to choose one distributional assumption over another, which implies that the log-normal distribution is just as likely to be the correct functional form as the log-logistic and Weibull.

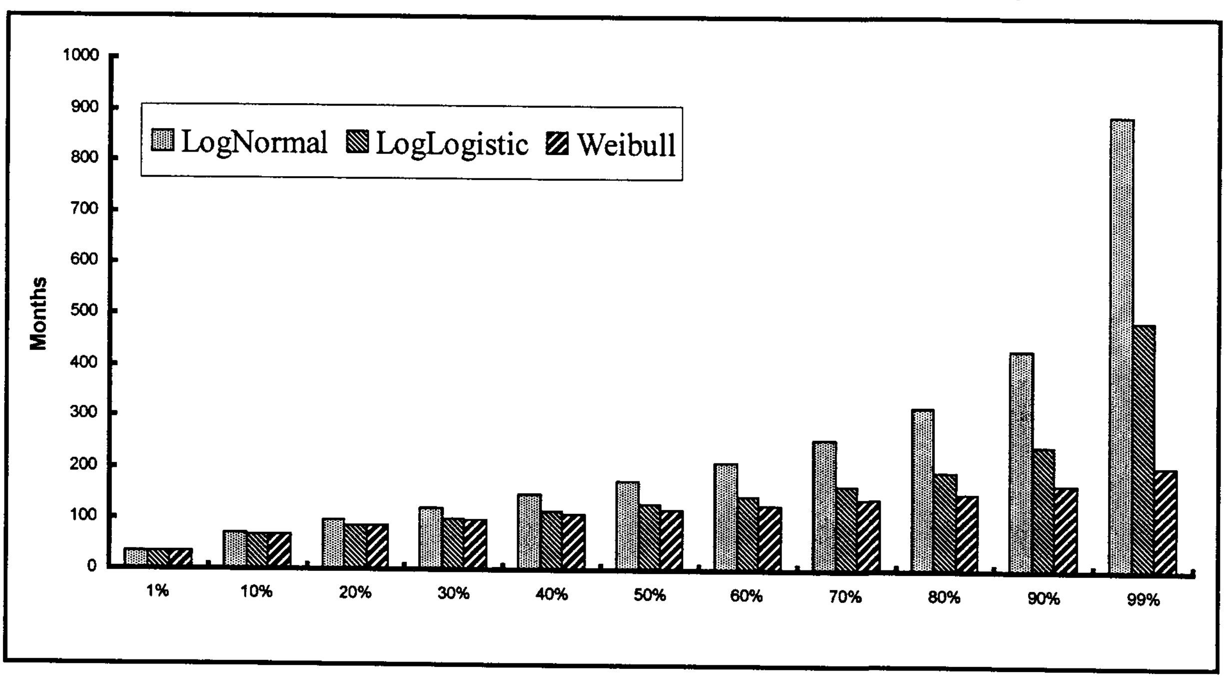
Table 3-10: Estimate High Efficiency Gas Oven EUL and 80% Confidence Bounds (Months)

Distribution	EUL	Upper Bound	Lower Bound
Log-Logistic	130.3	151.5	112.1
Log-Normal	177.0	213.6	146.6
Weibull	119.0	136.7	103.6

Table 3-11: Comparison of Estimated Survivor Functions for High Efficiency Gas Ovens (Months)

Percent Failed	Log-Logistic	Log-Normal	Weibull
1%	34.9	35.1	34.9
10%	69.4	72.6	69.0
20%	87.6	98.6	85.7
30%	102.2	123.0	98.1
40%	116.0	148.4	109.0
50%	130.3	177.0	119.0
60%	146.4	211.0	129.0
70%	166.2	254.8	139.7
80%	194.0	317.6	151.9
90%	244.7	431.1	168.5
99%	486.8	891.1	204.0

Figure 3-4: Comparison of Estimated Survivor Functions (Months)



Summary of Findings for High Efficiency Gas Ovens

The evidence provided from a review of the secondary sources supports the use of 20 years as the assumed *ex ante* EUL for high efficiency gas ovens. However, using the parametric approach and assuming any one of three distributions, there is insufficient statistical evidence to support the *ex ante* EUL. That is, the assumed estimate of 20 years does not fall within an 80% confidence interval around the estimated median lifetime.

The estimated EUL from the parametric analysis suggests an EUL of 15 years ± 2.7 years with 80% confidence. Information from secondary sources indicates 19 to 20 years. Given the relatively small sample sizes, RER recommends the use of 17.5 years as the measure lifetime. This is a simple average of the estimated EUL from the parametric method and the SoCalGas-assumed EUL. This EUL would fall within an 80% confidence interval of the parametric method, does not rely totally on the estimated EUL from a relatively small sample, and would still be somewhat consistent with secondary estimates of lifetime.

3.7 Duct Testing

This section discusses the estimation of the EUL for the performance of duct testing. The duct testing measure required that ducts be tested using a standardized protocol (see Appendix D) and that the duct system must achieve duct leakage rates of less that 140 CFM at 50 pascals.

Duct testing in the 1994 EAHP was the largest component of claimed savings. RER recognizes that the definition of retention in the context of duct testing is not clear. For example, discussions of this issue at recent CADMAC meetings have raised many issues, but the committee has not presented any formal conclusions. For the purpose of this study, RER has treated duct testing as duct sealing

In order to define measure lifetime, RER assumes that the duct sealing vis-a-vis duct testing *is still in place and operating effectively* if the following is true:

1) There are no catastrophic failures, or
2) Based on a three-point visual inspection system developed and used during the on-site survey, there are no signs of severe failure of the duct system. Particular attention was paid to aspects of the system that are more failure prone, such as connections at the plenum and duct joints.

In addition, RER investigated whether a degradation factor (as per Table 9B in the CPUC Protocols) is appropriate for this measure. This analysis was designed as a preliminary indicator of degradation and involved the completion of roughly 20 duct blaster tests.

The 1994 EAHP *ex ante* EUL for duct testing is 25 years or 348 months. Table 3-2 presents a summary of duct testing failures as defined above.

Table 3-12: Summary of Duct Testing Failures

	Measures in Survey		Failed Measures	
	Rebated	Non-Rebated	Rebated	Non-Rebated
Duct Testing	217	35	5	0

Summary of Estimates of Measure Lifetimes from Secondary Data

A review of the secondary literature indicates that the duct lifetime is associated to the lifetime of the house, which is typically assumed to be roughly 30 years. This assumption is somewhat consistent with the assumed lifetime for 25 years for duct testing. The literature also indicates that the typical flex ducting is rated to last 15 years, which is considerably lower than the assumed EUL for duct testing.[9] The dialogue on duct leakage centers on the effectiveness of different types of duct sealants. In particular, it is recognized that even though the duct system itself can last 15 to 30 years, the effectiveness of leakage protection is directly related to the type of fasteners and sealants used during installation.

The most comprehensive analysis of duct sealant is under an ongoing accelerated testing program at Lawrence Berkeley National Laboratory (LBNL).[10] These tests have provided a good indication of which sealants and tapes last and which are most likely to fail, but do not provide any real indication of lifetimes at this time. Three different types of test procedures are being used: baking, cycling, and aging.

The baking test uses a simple oven. One of the hardest joints to seal is constructed and sealant is applied according to manufacturer's instructions, if applicable. The duct section is placed in an oven set to the temperature of a hot attic or heating system (140°F - 180°F). Leakage is measured before and at various intervals during baking. Only tapes with rubber-based adhesives have shown degradation. Duct tapes are cloth-backed with rubber adhesives. Some foil tapes contain rubber adhesives.

The cycling apparatus was funded by the U.S. Environmental Protection Agency (EPA) in 1995. In the cycling test, temperature and pressure changes are added. This test has several limitations: the cycles take 20 minutes and there is an inability to test for the colder

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9 Home Energy, Volume 15 Number 4, Berkeley California.

10 Walker, J., et al. *Leakage Diagnostics, Sealant Longevity, Sizing, Technology Transfer.* Ernest Orlando Lawrence Berkeley National Laboratory. January 1998.

temperatures that one would expect during the winter months. Only the aerosol sealant has been put through the cycling test.

The aging apparatus was built with funding from the California Institute for Energy Efficiency in 1997. The aging test was designed to overcome the limitations of the cycling test by including hot and cold air sources. The aging apparatus may also be used for potential longevity tests. Some of the duct tapes failed in only a matter of days. Rapid failures have only occurred for cloth duct tapes with rubber adhesives.

Retention Fraction

The retention fraction, which is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures, installed. A total of 217 homes had their ducts tested during the 1994 EAH program year. Of these, 212 showed no signs of catastrophic failure, were repaired for catastrophic failure, or showed severe degradation during the on-site inspection. Therefore, the estimated retention fraction for duct testing is 97.6%.

Average Measure Lifetime

The average measure lifetime is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure. The average measure lifetime for this group of measures is estimated to be 42 months.

Measure lifetime evaluations based on the above two summary statistics are subject to two important biases. The first is due to differing observation periods for the installed measures. In particular, differences in the estimated retention fractions across program years could be due to differing average observation periods. The second bias is censoring bias; not all measure lifetimes are completed by the time of the on-site inspections. Estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. As a result, the best that can be concluded is the EUL for duct sealing is at least 42 months.

Effective Useful Lifetime

The data from the on-site inspections provide information on whether there are any catastrophic failures or, using the three point visual inspection method, any obvious degradation. This approach presents the problem of not knowing exactly when the ducting system failed. Further, the in-person interviews during the on-site visits were of no value to identify failure times. This is not surprising given the likelihood that homeowners are unaware of the timing of duct failures.

As stated above, there were five cases of duct sealing failures. Without the knowledge of when these occurred, RER made the following assumptions about the timing of the failures to test the sensitivity of the EULs to failure times. In particular, the following assumptions were made:[11]

- All failure happened in the month of the on-site survey,
- All failures happened at the midpoint between the installation of the ducts and the on-site visit, and
- The failures were randomly distributed in the period from installation to the time of the onsite visits.

As shown in Table 3-13, the estimated EUL varies from just over 5 years to 156 years. This result illustrates the sensitivity of the estimation method to the observed lifetimes and relatively small sample.

Table 3-13: EULs by Assumed Failure Times

Assumed Failure timing	EUL	Upper Bound	Lower Bound
Midpoint	958.6	1,437.2	639.4
Within one month of on-site visit	62.8	64.5	61.2
Random	1,882.0	3,028.1	1,169.7

Summary of Findings for Duct Testing

Based on our analysis, there is no statistically significant evidence to suggest a change in the existing assumption for duct testing lifetime. However, there is considerable discussion in the literature that indicates that duct testing lifetimes should be linked to the degradation in duct leakage rates. This issue is explored in more detail below.

Analysis of Duct Leakage Degradation

The analysis of duct leakage degradation involved the completion of 20 duct blaster tests on a sample of participant homes also tested in the first-year impact study, a review of the literature on duct sealing practices, an interview with the contractor who performed the initial verification of the duct testing, and a review of the initial requirements for duct testing in the 1994 program.

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11 An additional assumption that all of the failures occurred within six months of the ducts being installed was also analyzed. This assumptions resulted in implausibly long estimates of EUL.

1994 Program Requirements

The criterion for passing the duct inspection measure in the 1994 EAH residential new construction program was for the tests to exhibit leakage rates of less than 140 CFM at 50 pascals. Further, there were strict protocols for administering the duct blaster tests. A copy of the protocol is provided in Appendix D.

Duct Blaster Tests

Table 3-14 presents a summary of the duct blaster tests performed on the 18 homes that were tested in the first-year impact analysis. The leakage values are presented in CFM, and CFM per square feet of floor area.

Table 3-14: Summary of Duct Blaster Test Results (CFM/SF)

Survey	Average Leakage (CFM)	Average Leakage (CFM/SF)
1994 First-Year Impact Study (1996)	364 *(SE 204)*	.20 *(SE .19)*
1994 Fourth-Year Retention Study (1999)	381 *(SE 192)*	.21 *(SE 16)*

The results presented in Table 3-14 suggest two key findings:

- ***No degradation between the first-year impact study and the retention study duct blaster tests.*** The duct blaster tests on the same sample of 18 homes reveal that there is no significant degradation in duct leakage over the period between the first-year impact study (late 1996) and the current round of duct blaster tests (late 1998). This period roughly represents the second through fourth year after installation. This result is based on a statistical test for the difference in the mean leakage between the two test samples.[12]
- ***Significant degradation between the initial program year and the first-year impact study.*** The average leakage rates from the duct blaster tests indicate that, *on-average*, the homes tested have leakage rates significantly higher than the duct testing criterion of leakage (less than 140 CFM) required in the 1994 EAH program. In particular, only three of the homes tested would pass the program requirement.

[12] See Statistics: Decision and Applications in Business and Economics, Moshe Ben-Horim and Haim Levy, Random House, New York, 1984.

Secondary Data Sources

As discussed above, LBL is conducting an ongoing study in the reliability of differing types of duct sealant. One of the major findings from this research is that almost any type of sealant, except for cloth backed rubber adhesive (common duct tape), can be used to seal ducts.

Summary of Results

The results of the duct blaster tests raise the issue of degradation for the duct testing measure. It is not surprising that there is no significant difference between the first-year and retention study leakage rates. However, the substantial increase in leakage rates over the first two years of the program needs some further review. In particular, these results can be attributable to four major issues:

- ***Small Sample Sizes.*** The sample size for the duct blaster tests is relatively small. Increased sample sizes could certainly increase the precision of the estimates of leakage.
- ***Use of Cloth-Backed Duct Tape.*** RER's review of secondary data sources indicates that the use of cloth-backed duct tape can result in substantial increases in leakage rates over a relatively short period. Cloth-backed duct tape was allowed in program year 1994. Further, Table 3-15 presents a breakout by tape type for the 18 homes receiving duct blaster tests. The majority of these homes were sealed using standard duct tape. For this reason, it is not surprising to see increased leakage rates. As a further indication of the extent of the use of duct tape, Table 3-16 presents the breakout by tape type for all homes in the retention sample that received the duct testing measures.

Table 3-15: Type of Duct Sealing Tape in Homes Completing Duct Blaster Tests

Tape Type	Count
Butyl Tape	3
Duct Tape	14
Mastic	
Metal Tape	
Metal/Duct	1
NA	1

Table 3-16: Type of Duct Sealing Tape for Homes Receiving the Duct Testing Measure

Tape Type	Count
Butyl Tape	45
Duct Tape	137
Mastic	5
Metal Tape	15
Metal/Duct	6
NA	9

- ***Inconsistent Use of Protocols.*** The first-year and retention studies followed the same set of protocols and were conducted by separate contractors. However, in discussions with the contractor who completed the initial verification analysis, there may be some need to review more thoroughly the interpretation of these protocols. This is an issue in the treatment of the supply and return ducts under certain conditions. These include the treatment of unducted returns and open platform returns.
- ***Field Conditions.*** Our review of secondary sources also points to the failure of some types of sealant due to the poor field conditions under which the sealants are installed. In particular, most tests conducted allow for factory recommended installation procedures. These procedures may not be possible in the field. For instance, if the ducts are not cleaned sufficiently before installation, failures may occur regardless of sealant type.

Given the substantial use of duct tape, small sample sizes and the need to review the Protocols more closely, it is recommended that further study into the impacts from duct leakage be performed to develop a duct testing degradation factor.

3.8 Combination System

This section discusses the estimation of the EUL for the installation of multi-family combination heating and water heating units. The 1994 EAHP *ex ante* EUL for these combination units is 20 years or 240 months. Table 3-17 presents a summary of combination unit failures by rebated and non-rebated measures.

Table 3-17: Summary of Combination Heating and Water Heating System Failures

	Measures in Survey		Failed Measures	
	Rebated	Non-Rebated	Rebated	Non-Rebated
Combination Units	18	0	0	0

Summary of Estimates of Measure Lifetimes from Secondary Data

There are no reliable estimates of lifetimes from secondary sources. Interviews with combination unit manufacturers were conducted in addition to the review of secondary sources used to investigate lifetimes for the other measures. The manufacturers also had no reliable estimates of measure lifetimes.

Retention Fraction

The retention fraction is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed. Eighteen energy-efficient gas furnaces were installed in the 1994 EAH program year. All were still in place and working at the time of the on-site survey. The estimated retention fraction for the installed water heater measures is 100%.

Average Measure Lifetime

Average Measure Lifetime is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure. Due to censoring bias, estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. Consequently, the best that can be concluded for the gas furnace EUL is at least 43 months.

Effective Useful Lifetime

Insofar as no failures have been observed, no EUL can be estimated using either the life table or parametric methods.

Summary of Findings for High Efficiency Gas Furnaces

Insofar as there have been no failures, data from the on-site survey are inconclusive with regard to estimating combination system EUL. In addition, a review of secondary data did not provided any insights into measure lifetimes. Therefore, there is insufficient information to recommend a change in the assumed measure EUL.

3.9 Heat Traps

This section discusses the estimation of the EUL for the installation of gas water heater heat traps. The 1994 EAHP *ex ante* EUL for heat traps is 13 years or 156 months. Table 3-18 presents a summary of gas water heater heat trap failures by rebated and non-rebated measures.

Table 3-18: Summary of Heat Trap Failures

	Measures in Survey		Failed Measures	
	Rebated	Non-Rebated	Rebated	Non-Rebated
Heat Traps	16	236	0	0

Summary of Estimates of Measure Lifetimes from Secondary Data

There is no reliable secondary estimate of EUL for heat traps. Typically, the assumed lifetime is the same as the assumed lifetime of the water heater.

Retention Fraction

The retention fraction is computed as the ratio of the number of measures that exist at the time of inspection over the total number of measures installed. A total of 16 gas water heater heat traps were installed as part of the 1994 EAH program year. Of these, all were still in place and working at the time of the on-site survey. The estimated retention fraction for the installed water heater measures is 100%.

Average Measure Lifetime

Average Measure Lifetime is computed as the average lifetime of the measures. Here, a measure lifetime is defined as the lessor of the time interval between (a) inspection and installation of the measure, or (b) date of failure and installation of the measure. Due to censoring bias, estimates of average measure lifetimes based on data on completed lifetimes, as defined above, are underestimates of the true mean duration. Therefore, the best that can be concluded for the gas furnace EUL is at least 41 months.

Effective Useful Lifetime

Insofar as no failures have been observed, no EUL can be estimated using either the life table or parametric methods.

Summary of Findings for Heat Traps

Data from the on-site survey are inconclusive concerning estimating the EUL of gas water heater heat traps. In addition, a review of secondary data did not provided any insights into measure lifetimes. Therefore, there is insufficient information to recommend a change in the assumed measure EUL.

3.10 Summary of Findings

Table 3-19 presents a summary of the retention fractions and EULs for each measure. In general, this analysis does not suggest changing any of the assumed EULs used by SoCalGas in their earnings claims with the exception of gas ovens. For gas ovens, RER recommends the use of 18 years as compared to the 20 years used in previous earnings claims.

In addition to the required findings presented in Table 3-19, a number of recommendations relating to these findings are included in the following section.

Table 3-19: Summary of Measure Lifetimes

Measures	Retention Fraction	Ex-Ante EUL	Retention Study EUL
Duct Testing	.976	25	25
Furnace (88% AFUE)	1.00	18	18
Water Heater (.60-.69 EF)	.967	13	13
Water Heater (.70 EF)	.967	13	13
Combination System (.58 EF)	1.00	20	20
Duct Insulation	1.00	25	25
Heat Traps	1.00	13	13
Recirculating Controls	1.00	15	15
MH Water Heaters (.60 EF)	.967	13	13
MH Furnace (80%-87% AFUE)	1.00	18	18
MH Furnace (88+% AFUE)	1.00	18	18
Multi-Family Furnaces	1.00	18	18
Gas Ovens	1.00	20	18

3.11 Recommendations

Two major recommendations were developed as a result of the retention study and are discussed below.

Use of Multiple Program Years

The use of a single program year necessitates the use of a relatively small sample and does not necessarily provide the needed variation in the observed lifetimes required to produce robust EUL estimates. It is recommended that multiple program year data be used in any future retention studies. The use of multiple program years is the suggested practice in the Protocols for the retention studies for the other California utilities.

RER recognizes that this recommendation needs to be balanced against the fact that the EAHP has changed significantly during the past few years. However, there is most likely some overlap between measures covered by the program across program years. For these measures, the use of multiple program year data could support a more robust retention modeling effort.

Further Research into Duct Leakage Degradation

Duct testing is a significant part of the 1994 EAHP and is receiving considerable attention in a number of state and national studies. The data gathered during this study provide a strong indication of degradation in the duct systems during the first four years of the program. However, there are a number of mitigating circumstances, such as small sample sizes and correct interpretation of the Protocols, that suggest the need for more study before any definitive conclusion can be made about duct sealing degradation.

Appendix A

On-Site Survey Instrument

SoCalGas Energy Advantage Home Program

On-Site Data Collection Instrument

RER, Inc. and ASW, Inc

Name: ______________________________

Street Address: ______________________________

City, State: ______________________________

Zip Code: ______________________________

Phone: ______________________________

Track Number: ______________________________

Premise ID: ______________________________

Survey Date: ______________________________

Surveyor: ______________________________

ECMs installed through the Energy Advantage Program (*Check All That Apply)*

Measure	Installed		Comments
Furnace	Yes	N.A.	If Yes, details to be filled on page
Water Heater	Yes	N.A.	If Yes, details to be filled on page
Heat Trap	Yes	N.A.	If Yes, details to be filled on page
Recirculating Controls	Yes	N.A.	If Yes, details to be filled on page
Duct Testing sealing	Yes	N.A.	If Yes, details to be filled on page
Duct Insulation	Yes	N.A.	If Yes, details to be filled on page
Duct Blaster Test	Yes	N.A.	If Yes, details to be filled on page
Gas Oven	Yes	N.A.	If Yes, details to be filled on page

N.A. Not Applicable

General Information

1. What type of residence is this?

- ☐ Single Family
- ☐ Condominium
- ☐ Townhouse
- ☐ Apartment (building has fewer than 5 units)
- ☐ Apartment (building has greater than 5 units)
- ☐ Other

2. When did you move into this residence? ________/________ ☐ Don't know
   Year Month

3. Are you the original owner of this house?

- ☐ Yes → ***Skip to question 5***
- ☐ No

4. When was this residence built? ________/________ ☐ Don't know
   Year Month

5. Have you added any square feet to your home since you moved in?

- ☐ Yes ***(Measure the added square feet)*** → ________Square Feet ☐ Don't know
- ☐ No

Now I would like to inspect the measure(s) and come back and ask you a few questions.

Water Heating Measures

6a Water Heating Equipment Verification

Technology Details	Existing Information	New Information	Change
Model Number:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Efficiency Rating:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Manufacturer:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Tank Size (gallons):			☐ Same ☐ Different ☐ N.A. ☐ Not There
Hot water tank insulated: ☐ Yes ☐ No			☐ Same ☐ Different ☐ N.A. ☐ Not There
Hot water pipes insulated: ☐ Yes ☐ No			☐ Same ☐ Different ☐ N.A. ☐ Not There
Hot Water Temperature:	N.A.		☐ Same ☐ Different ☐ N.A. ☐ Not There
Heat Trap: ☐ Yes → __ (1 = integral / 2 = added) ☐ No			☐ Same ☐ Different ☐ N.A. ☐ Not There
Year of Manufacture:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Location:			☐ Same ☐ Different ☐ N.A. ☐ Not There

6b. Water Heating Equipment Performance Verification

Is the equipment in good working condition?

6b1. Water Heating	☐ Yes ☐ No → Describe the problem:
Visual Inspection Look for rust and Other signs of degre- Dation.	______ ______ ______ ______ ______
6b2. Heat Trap	☐ Yes ☐ No → Describe the problem:
Visual Inspection Check if traps are still In place and functional When water heater is on.	______ ______ ______ ______

Additional Surveyor Notes:

______

______

Furnaces

7a. Furnace Equipment Verification

Technology Details	Existing Information	New Information	Change
Furnace Model Number:			☐ Same ☐ Different ☐ N.A. ☐ Not There
AFUE:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Manufacturer:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Thermostat (automatic or manual)			☐ Same ☐ Different ☐ N.A. ☐ Not There
Thermostat Setting:	N.A		☐ Same ☐ Different ☐ N.A. ☐ Not There
Year of Manufacture:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Location			☐ Same ☐ Different ☐ N.A. ☐ Not There

7b. Furnace Equipment Performance Verification

Is the equipment in good working condition?

7b1. Furnace	☐ Yes ☐ No → Describe the problem:
Check the condition of the Filters. Are they blocked?	____________________ ____________________ ____________________ ____________________

Additional Surveyor Notes:

____

____

Duct Sealing/Insulation

8a. Duct Equipment Verification

Technology Details	Existing Information	New Information	Change
Duct Seal Type: (Ma) Mastic (B)Butyl Tape (Me) Metal Tape (D)Duct Tape	☐ Ma ☐ B ☐ Me ☐ D		☐ Same ☐ Different ☐ N.A. ☐ Not There
Duct Insulation R- Value			☐ Same ☐ Different ☐ N.A. ☐ Not There
Location of Ducts: (C)crawl space (A) attic (O)other	☐ C ☐ A ☐ O		☐ Same ☐ Different ☐ N.A. ☐ Not There

8b. Duct Equipment Performance Verification

Is the equipment in good working condition? 1). The surveyor needs to check visually where the duct work connects to the plenum. 2). A visual check of the suspension of the ducting, noting crushed or damaged areas. 3). Any observable degredation of the duct sealing at joints or seams shall be noted. If a fair or poor condition is noted, surveyor shall photograph condition.

8b1. Duct Sealing	☐ Yes	☐ No → Describe the problem: Plenum Connection: ___ Condition: Good ☐, Fair ☐, poor ☐ Suspension Observations: ___ Condition: Good ☐, Fair ☐, poor ☐ Duct Sealing: ___ Condition: Good ☐, Fair ☐, poor ☐
8b2. Duct Insulation Check visually for Material degredation.	☐ Yes	☐ No → Describe the problem: ___ ___ ___ ___

Additional Surveyor Notes:

___

___

Gas Ovens

9a. Gas Oven Equipment Verification

Technology Details	Existing Information	New Information	Change
Model Number:			☐ Same ☐ Different ☐ N.A. ☐ Not There
AFUE:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Manufacturer:			☐ Same ☐ Different ☐ N.A. ☐ Not There
Age of Equipment:			☐ Same ☐ Different ☐ N.A. ☐ Not There

9b. Gas Oven Equipment Performance Verification

Is the equipment in good working condition?

9b1. Gas Ovens	☐ Yes ☐ No → Describe the problem:
Check if burners are Clogged.	____________________ ____________________ ____________________ ____________________

Additional Surveyor Notes:

____

____

Differences In Customer Usage

10. I noticed the following changes in equipment from what we saw the last time. What month and year were they changed?
(If the resident is unsure of the date, please probe to find out if there is a warranty or an invoice that can be used to check the date)

<u>**Check All That Apply**</u>

Measure	Status	Month	Year	Primary reason for removing/replacing measure:
Water Heater	☐ Replaced → ☐ Removed → ☐ N.A.			☐ Equip. failed ☐ Other → Describe:
Furnace	☐ Replaced → ☐ Removed → ☐ N.A.			☐ Equip. failed ☐ Other → Describe:
Gas Oven	☐ Replaced → ☐ Removed → ☐ N.A.			☐ Equip. failed ☐ Other → Describe:
Other	☐ Replaced → ☐ Removed → ☐ N.A.			☐ Equip. failed ☐ Other → Describe:

N.A= NOT APPLICABLE

Other Factors

11. What thermostat settings do you use?

Season	Day (degrees F)	Night (Degrees F)
Summer		
Winter		

Maintenance Programs

12. Are you participating in any maintenance program for measure(s)?
(Ask this question about all the relevant measures)

Measure	Type of Maintenance	Frequency of Maintenance
12a: Water Heater	☐ Self – maintain equip. myself ☐ Service agreement w/ mfr./dist./retail store ☐ Call service store when needed ☐ Other → ____________________ ☐ None ☐ N.A.	☐ Once/year ☐ Twice/year ☐ Monthly ☐ Never ☐ Do not know
12b: Furnace	☐ Self –maintain equip. myself ☐ Service agreement w/ mfr./dist./retail store ☐ Call service store when needed ☐ Other → ____________________ ☐ None ☐ N.A.	☐ Once/year ☐ Twice/year ☐ Monthly ☐ Never ☐ Do not know

Equipment Repair

13. Has the ________ equipment ever been repaired?
(Ask this question about all the relevant measures)

Measure		When? (month/year)
13a. Water Heater	☐ Yes → ☐ No ☐ N.A.	______/______
13b. Water Heater Heat Trap	☐ Yes → ☐ No ☐ N.A.	______/______
13c. Furnace	☐ Yes → ☐ No ☐ N.A.	______/______
13d. Duct Insulation	☐ Yes → ☐ No ☐ N.A.	______/______
13e. Duct Sealing	☐ Yes → ☐ No ☐ N.A.	______/______
13f. Gas Oven	☐ Yes → ☐ No ☐ N.A.	______/______
13g. Furnace	☐ Yes → ☐ No ☐ N.A.	______/______

Additional Surveyor Notes:

____
____
____
____

Demographics

13. How many people of the following ages live at this residence at least nine months of the year, including yourself?

Under 2 years ________
2-5 years ________
6-21 years ________
22-39 years ________
40-64 years ________
65 years and over ________
Refused ☐

14. Have there been any changes in the number of people living at this residence since 1996?

☐ Yes → *Go to Q18*
☐ No → *Skip to Q19*

15. Please describe the changes.

Persons	Age	Added/Left	Year	Month
		☐ Added ☐ Left		
		☐ Added ☐ Left		
		☐ Added ☐ Left		
		☐ Added ☐ Left		
		☐ Added ☐ Left		

15. What is your household's current annual income before taxes?

☐ Under $20,000
☐ $20,000 - $39,999
☐ $40,000 – $59,999
☐ $60,000 – $79,999
☐ $80,000 – $120,000
☐ Over $120,000
☐ Refused
☐ Don't know

Thanks for your time.

Appendix B

Introductory Letters

The Gas Company®

Melissa S. Cuaycong
Market Consultant
Consumer Marketing

February 12, 1999

«Customer_Name»
«Address»
«City», CA «Zip»

Southern California Gas Company

555 W. Fifth Street
Los Angeles, CA
90013-1011

Mailing Address:
Box 3249
Los Angeles, CA
90051-1249
ML. 25D1

tel 213-244-3922
fax 213-244-8251

Dear «Customer_Name»:

The Southern California Gas Company (The Gas Company) encourages energy efficiency in newly constructed homes through its Energy Advantage Home Program. This program offers incentives to builders and contractors who install energy efficient gas appliances and other conservation measures in new homes. Occupants of these homes benefit from lower energy bills and increased comfort levels.

We understand that your home was equipped with energy efficient gas measure(s) as part of the Energy Advantage Home (EAH) Program. Our records also indicate that your home was one of the 300 homes we visited to inspect such measure(s) during 1996-97.

It is important that we collect similar information from the 300 houses that we inspected during 1996-97, in order to identify the performance of the measure(s) and the effectiveness of the EAH program. We are offering a $25.00 incentive to households that allow us to inspect the measures on-site and answer a few questions about the performance of these measures. As before, the survey consists of a qualified energy surveyor coming to your home for a very short time to collect this information. This information will be invaluable in helping us improve the Energy Advantage Home Program and in bringing you quality products and services.

A representative of ASW Engineering Consultants will contact you sometime during the next two weeks inviting you to participate in this study. We hope that you participate. If you have any questions regarding this survey, please contact Kavita Maini from Regional Economic Research at 800-755-9585.

Sincerely,

Melissa S. Cuaycong

Market Consultant
Consumer Marketing

The Gas Company®

Melissa S. Cuaycong
Market Consultant
Consumer Marketing

February 12, 1999

«Customer_Name»
«Address»
«City», CA «Zip»

Southern California
Gas Company

555 W. Fifth Street
Los Angeles, CA
90013-1011

Mailing Address:
Box 3249
Los Angeles, CA
90051-1249
ML 25D1

tel 213-244-3922
fax 213-244-8251

Dear «Customer_Name»:

The Southern California Gas Company (The Gas Company) encourages energy efficiency in newly constructed homes through its Energy Advantage Home Program. This program offers incentives to builders and contractors who install energy efficient gas appliances and other conservation measures in new homes. Occupants of these homes benefit from lower energy bills and increased comfort levels.

We understand that your home was equipped with energy efficient gas measure(s) as part of the Gas Company's Energy Advantage Home Program. Our records also indicate that your home was one of the twenty homes that underwent comprehensive tests to check the effectiveness of insulation levels.

In order to evaluate the performance of our Energy Advantage program, it is important that we conduct similar tests in the same twenty houses that we inspected a couple of years ago. We would like to conduct a follow-up visit and are offering a $50 incentive to households that allow us to perform tests and inspect measures that were installed through our program. As before, the survey consists of a qualified energy surveyor being in your home for approximately 45 minutes. This visit will be invaluable in helping us improve the Energy Advantage Home Program and in bringing you quality products and services.

A representative of ASW Engineering Consultants will contact you sometime during the next two weeks inviting you to participate in this study. We hope that you participate. If you have any questions regarding this survey, please contact Kavita Maini from Regional Economic Research at 800-755-9585.

Sincerely,

Melissa S. Cuaycong

Market Consultant
Consumer Marketing

Appendix C

Duct Testing Program

SOUTHERN CALIFORNIA GAS COMPANY
ENERGY ADVANTAGE HOME
DUCT TESTING PROGRAM

Ducts are quickly gaining a reputation as one of the hottest (and coolest) sources of residential energy loss. Heating systems in nine out of ten new homes now use ducted air distribution systems. Duct systems, including the entire air distribution and return system, have the potential to substantially increase or reduce a home's heating and cooling energy usage and cost. Studies have shown that duct system air leakage in homes in America has tremendous energy conservation potential. [1]

The Gas Company's Energy Advantage Home Duct Testing Program provides a financial incentive to builders to assist them in inspecting duct systems installed in their single family and townhome developments. Builders participating in The Gas Company's Energy Advantage Home Program are required to participate in the duct testing element of the program for single family and townhome developments. To participate, builders must complete and submit The Gas Company's Energy Advantage Home Program application and receive approval from The Gas Company prior to installing any measures contained in the program.

PERFORMANCE METHOD

The Gas Company's Energy Advantage Home Duct Testing Program is performance based. The program does not specify any installation or material standards. Rather, The Gas Company depends upon builders and HVAC contractors to install duct systems in compliance with the Uniform Mechanical Code, Air Diffusion Council Guidelines and/or local codes and ordinances. The Gas Company specifies the degree of air tightness of the duct system, not how to install duct systems. It is not the objective of The Gas Company to create new installation standards. It is the intention of the program to provide a financial incentive to encourage the installation of the more energy efficient air distribution systems.

The performance criteria establishes the maximum allowable air leakage at a specific duct pressure. **At 50 pascals (0.2 inches water column) of pressure in the duct system, the maximum allowable air leakage is 140 cfm.** The Certificate of Completion requires that the duct system be tested at four specific pressures, but 50 pascals (0.2 inches water column) is the only pressure which has a specific air leakage standard.

---

1 Home Energy Magazine, September/October 1993

CERTIFICATION

The Duct Testing Program requires that builders certify that the HVAC duct system in each home complies with the allowable duct air leakage. Builders must use approved duct pressurization testing equipment and follow the Duct Testing Procedure described in Appendix A. The Duct Testing Procedure includes a Certificate of Completion which must be completed and submitted with the Energy Advantage Home Program contract. The purpose of the Duct Testing Procedure is to ensure that all homes are tested using a standard procedure for determining the relative air tightness of the duct system.

DUCT PRESSURIZATION TEST EQUIPMENT

Three duct pressurization tester (duct blasters) have been approved for use in this program. The three are listed below with manufacturer's name, address and phone number. The use of any other equipment must receive prior approval by The Gas Company.

Berkeley Duct Blaster
Fathom Engineering
20 El Paseo
Walnut Creek, CA 94956

(510) 947-1836

Minneapolis Duct Blaster
The Energy Conservatory
5158 Bloomington Ave., S.
Minneapolis, MN 55417

(612) 827-1117

Airflow Low Leakage Tester
Airflow Development LTD
Lancaster Rd. Highwycomb
Buckinghamshire HP123QP
England
0494 25252/443821

DUCT LEAKAGE TEST PROCEDURE

The Duct Leakage Test Procedure is describe in Appendix A. This test procedure is used to assure comparability and repeatability of test data. The test procedure includes a Certificate of Completion which must be completed by a certified technician (certification described in following section), signed by both the technician and the builder and submitted to The Gas Company. The Gas Company will not process the incentive application for any Energy Advantage Home Program measure without a complete Certificate of Completion.

INSPECTION OF SYSTEM

The Gas Company or its representatives will test a percentage of duct systems to insure compliance with the program guidelines. Testing conducted by The Gas Company will:

- Verify compliance with the Performance Guidelines including duct leakage
- Verify information provided in the Certificate of Completion including job site information, construction details and HVAC system description.

The Gas Company inspectors will use the same duct leakage procedure described Appendix A.

BUILDERS INCENTIVE

Builders will qualify for a $250 per unit incentive if the duct system meets the program duct leakage criteria. The incentive is available for each HVAC system that is installed in a home. A Certificate of Compliance is required for each HVAC system tested within a home. If the duct system in a unit within the project fails the inspection by The Gas Company, the project will be disqualified and the incentive will be disallowed for that project.

HVAC TECHNICIAN TRAINING

The HVAC technicians performing the duct test and completing the Certificate of Completion are required to attend a half day training seminar presented by The Gas Company. The training seminar includes classroom and laboratory training to familiarize technicians with program guidelines, duct pressurization testing equipment and testing protocol. Training classes are held throughout the year.

HVAC technicians will be allowed to test duct systems qualifying under the Energy Advantage Home Duct Testing Program after they have successfully completed the training seminar conducted by The Gas Company authorized representative.

APPENDIX A

DUCT LEAKAGE TEST PROCEDURE

NOTE: The following Duct Leakage Test Procedure is for calendar year 1994 only. It is the intention of The Gas Company to modify these guidelines for calendar years 1995 and 1996. In 1995 and 1996, the platform return and return air chases will be included within the air distribution system that must meet the maximum air leakage guidelines.

DUCT LEAKAGE TEST

The objective of the duct leakage test is to determine the integrity or air tightness of the forced air unit (FAU) air distribution system **excluding** platform returns and return air chase spaces. In order to perform the duct leakage test, the entire system is sealed at all supply registers and return grilles and then pressurized using one of the approved duct testers (duct blasters). Excluding the platform return and/or return air chases from the distribution system being tested requires using different sealing and testing configurations depending upon the type of FAU installed and the return air system.

The following guidelines are intended to provide guidance for builders, HVAC contractors or other individuals performing duct leakage tests, regardless of the type of system installed. If the configuration of the HVAC system being tested precludes the use of these guidelines, please contact your SoCalGas Marketing Account Executive for additional guidance.

GENERAL CONDITIONS

The duct leakage test may only be performed after all components of the HVAC system are installed and connected. This includes the FAU, supply duct system and return air system. It is best if the supply registers are in place, since the testing by SoCalGas will be performed with the supply registers installed, but the test can be performed prior to the registers being installed.

The duct leakage test is designed to measure the duct leakage in cubic feet per minute (cfm) at specific pressure differentials between the house and the duct system. The following conditions are necessary to perform reliable tests:

- Insure that the FAU blower will not turn on unexpectedly during the test by turning the thermostat to the off position, disconnecting the power supply or other means as necessary.

- Open all interior doors in the house.

- If the FAU is located within the house, close all exterior doors and windows except for one open door or window. It is best, but not essential, to close the attic access door and crawl space access.

- If the FAU is located in the attic and the testing equipment is used in the house, close all exterior doors and windows except for one open door or window. It is best, but not essential, to close the attic access door and crawl space access.

- If the FAU is located in the garage, close the large garage door but leave one small door or window in the garage open. The door between the house and garage may be left open.

The intention of these guidelines is to accurately measure the air leakage from the duct system while reducing the impact of wind upon the test gauges.

HVAC SYSTEMS

The set-up of the duct testing equipment depends upon both the type of HVAC system and the return air system. Guidelines have been provided for the following types of systems:

- FAU's with Platform Return or Return Air Chase

- FAU's without Platform Return

- Attic FAU's with Return Air Chase

- FAU's with Sealed Blower Compartments

If the configuration of the system being tested does not fit any of these descriptions, please contact your SoCalGas Marketing Account Executive for additional guidance.

FAU's WITH PLATFORM RETURNS OR RETURN AIR CHASE

These guidelines apply to furnaces typically installed in closets or garages. The return air flows directly from the house into the furnace platform, or the return air is ducted from the house to a return air platform or the return air is drawn through a chase space from the house to a return air platform. The platform, return air ducts and chases may be included or they may be excluded from the duct pressurization testing. If the platform or return air system is included, the testing is the same as described below for **FAU' without Platform Return**. If the platform and return air system is excluded from the testing, the following guidelines apply. **NOTE:** If the furnace has a sealed blower compartment, see the section below for **Furnaces with Sealed Blower Compartment**.

- Seal all outlet registers by taping blanking panels over the registers or cover the entire face of each register with tape.

- Remove the blower door compartment cover and furnace filter, if a filter is in place.

- Seal the bottom of the blower compartment using rigid plastic or cardboard and tape. The integrity of this seal is important since any leakage around the seal will count against the overall duct system leakage. By sealing the bottom of the FAU, the return air portion of the system should be eliminated from testing.

- Cut a piece of rigid plastic or cardboard into place instead of the blower compartment cover. Tape this plastic or cardboard into place instead of the blower compartment cover. Cut a round hole in the plastic or cardboard the approximate size of the hole in the duct tester transition assembly (approximately 10" diameter). NOTE: Cut the hole in the plastic or cardboard as low as practical so that the air flow stream is directed into the compartment
not directly at the blower housing.

- Tape the transition assembly onto the plastic or cardboard, aligning the hole in the transition assembly with the hole in the plastic or cardboard.

- Tape the plastic or cardboard, with the attached transition assembly, onto the blower compartment cover opening.

- Proceed as described in **Performing the Duct Leakage Test.**

FAU's WITHOUT PLATFORM RETURN

These guidelines apply to horizontal attic units, package heating and cooling units or any FAU without a platform return system. The testing guidelines for these systems is based on one premise: both the supply and return are connected to the FAU by sheet metal or duct board plenums.

- Seal all outlet registers by taping blanking panels over all registers or cover the entire face of each register with tape.

- Connect the duct tester transition assembly to the return air grille closest to the furnace. The return air grille must be at least as large (1 foot square) as the transition assembly. If there are additional return air grilles, seal them with blanking panels or tape over the entire grille.

- Proceed as described in Performing the Duct Leakage Test.

ATTIC FAU's WITH RETURN AIR CHASE

These guidelines apply to attic furnace where the return air is drawn through a chase space from the house to the attic FAU. If the attic FAU has the return air system ducted directly to the return plenum, see the guidelines for **FAU's Without Platform Return.** The return air chase may be included or it may be excluded from the duct pressurization testing. If the return air system is included, the testing is the same as described for **FAU's Without Platform Return.** If the return air system is excluded from the testing, the following guidelines apply. NOTE: If the furnace has a sealed blower compartment, see the section below for **FAU's With Sealed Blower Compartment.**

- These guidelines allow the duct pressurization test to be conducted within the house, but sealing of the furnace must be performed in the attic. At the preference of the tester, the duct test could be performed in the attic following the guidelines for **FAU's With Platform Return Or Return Air Chase.**
- Connect the duct blaster transition piece to a supply register that is at least as large as the transition piece (one foot square). Connect the duct blaster to the transition piece.
- Seal all the other outlet registers by taping blanking panels over all registers or cover the entire face of each register with tape.
- Remove the blower door compartment cover and furnace filter, if a filter is in place.
- Seal the bottom (return air side) of the blower compartment using rigid plastic or cardboard and tape. The integrity of this seal is important since any leakage around the seal will count against the overall duct system leakage. by sealing the bottom (side) of the FAU, the return air portion of the system should be eliminated from testing.
- Replace the blower compartment cover.
- Proceed as described in **Performing the Duct Leakage Test.**

FAU's WITH SEALED BLOWER COMPARTMENTS

If the system being tested has a sealed blower compartment, the duct pressurization testing will vary depending upon the type of FAU system. If the system does NOT have a platform return, use the guidelines for FAU's Without Platform Return. If the system has a platform return, use the following guidelines.

- Seal all supply registers exactly the same as with any platform return system.

- The transition assembly cannot be connected to the front of the blower door compartment, so it must be installed through the platform on the bottom of the blower compartment.

- Cut a piece of rigid plastic or cardboard the approximate size of the bottom of the blower compartment. This plastic or cardboard will be taped into place on the bottom of the blower compartment. Cut a round hole in the plastic or cardboard the approximate size of the hole in the duct tester transition assembly (approximately 10" diameter). NOTE: Cut the hole in the plastic or cardboard so that the air flow stream is directed into the compartment not directly at the blower housing.

- Tape the transition assembly onto the plastic or cardboard, aligning the hole in the transition assembly with the hole in the plastic or cardboard.

- Tape the plastic or cardboard, with the attached transition assembly, onto the blower compartment opening.

- Proceed as described in **Performing the Duct Leakage Test.**

PERFORMING THE DUCT LEAKAGE TEST

- Insure that the power to the FAU blower is disconnected.

- Connect the duct testing equipment blower and gauges in accordance with the manufacturer's specification.

- Perform the duct pressurization test at the four prescribed duct pressures and enter the results in the "Test Data" section of the Certificate of Completion.

The four duct pressures are:

- Test 1 — 25 Pascals (0.10 in. wg)
- Test 2 — 50 Pascals (0.20 in. wg)
- Test 3 — 100 Pascals (0.40 in. wg)
- Test 4 — 125 Pascals (0.50 in. wg)

- Convert each fan pressure reading into cfm using the conversion tables provided by the equipment manufacturer. Enter the results into the "Test Data" section of the Certificate of Completion.

CERTIFICATE OF COMPLETION: SIGNATURE AND VERIFICATION

The technician performing the test must complete all required information in the Certificate of Completion. Both the technician and the builder must sign and date the Certificate of Completion and return it with the Energy Advantage Home Program contract. The Gas Company will not process the incentive without a completed Certificate of Completion.

TEST EQUIPMENT REMOVAL AND FINAL WALK THROUGH

- Disconnect and remove the testing equipment
- Remove any plastic or cardboard from the FAU
- Return all HVAC system components to same condition as before testing
- Replace the furnace filter if appropriate
- If the thermostat was adjusted, return it to its original setting
- Remove all tape and/or blanking panels from the supply registers and return air supply
- Perform final walk through to ensure that all conditions within the house and garage are in the same condition as prior to the Duct Leakage Test

TEST RESULTS	TEST SEQUENCE
	SHUT DOWN EQUIPMENT * Shut down Blower Door, remove from house. * Shut Down Duct Blaster, leave set up. * Exterior door must be open for next test.
DUCT BLASTER MULTI-POINT TEST *25 Pascals:* ________ **Fan Pressure** 1 2 3 **Flow Ring** ________ **Fan Flow** *50 Pascals:* ________ **Fan Pressure** 1 2 3 **Flow Ring** ________ **Fan Flow** *75 Pascals:* ________ **Fan Pressure** 1 2 3 **Flow Ring** ________ **Fan Flow** *100 Pascals:* ________ **Fan Pressure** 1 2 3 **Flow Ring** ________ **Fan Flow**	**CONDUCT MULTI-POINT DUCT BLASTER TEST** * Zero pressure gauge on Duct Blaster (off/on). * Check all registers for tape blow out, correct as needed. * Take readings at 25,50,75 and100 pascals, with reference to outside (house not pressurized). **ADDITIONAL COMMENTS / DIAGRAM**
	TAKE DOWN ALL EQUIPMENT / CLEAN UP * Remove all equipment and load in vehicle. * Remove all tape from registers and returns. * Return all appliances to original settings. * Return all dampers to original settings. * Replace HVAC air filter.
	CLOSE WITH CUSTOMER * Inform the customer that you are finished and that the home is restored to pre test conditions.

Blower Door / Duct Blaster Data Collection Form

Customer Name:	**Customer Phone #** **Home:**	**Customer job #:**
Customer Address:	**Customer Phone #** **Work:**	**Test Performed by:**
City, Zip:		**Date test performed:**

TEST RESULTS	TEST SEQUENCE
	CUSTOMER INTRODUCTION / OVERVIEW * Briefly explain process to customer. * Make them aware of test conditions.
	SIZE UP / PREPARE HOUSE FOR BLOWER DOOR TEST * Tour home making sure each register is open. * Check for combustion appliances (shut them off). * Shut off HVAC equipment , remove air filter. * Close all dampers (fireplaces, wood stoves, etc.). * Close all windows and exterior doors, open interior doors.
BLOWER DOOR TEST ***(single point)*** ________ **Fan Pressure** A B C **Flow Ring #** ________ **Fan Flow**	SET UP / CONDUCT BLOWER DOOR TEST * Set up Blower Door, zero gauges. * Run single point blower door test @ 50 pascals with reference to outside.
	SHUT DOWN BLOWER DOOR * Leave Blower Door equipment in place.
	PREPARE FOR DUCT LEAKAGE TEST * Tape all supply registers and any secondary returns. * Mount Duct Blaster to primary return. * Install one input hose to fan. * Install one input hose to register between 5-10 feet from air handler.
DUCT BLASTER TEST ***(single point, with house pressurized to 50 pascals)*** ________ **Fan Pressure** 1 2 3 **Flow Ring** ________ **Fan Flow**	CONDUCT TEST * Using the Blower door, pressurize the HOUSE to 50 pascals with reference to outside. * Pressurize DUCTS to zero pressure with reference to house. * Check and adjust as necessary the Blower Door making sure it's reading 50 pascals. * Check Duct Blaster Pressure gauge , take readings at zero pascals with reference to house.

Appendix D

CPUC M&E Protocols Tables 6 and 7

CPUC M&E Protocols

Table 6

Results Used to Support PY94 Third-Earnings Claim
for
Residential New Construction Program
Fourth-Year Retention Evaluation

March 1999

Study ID No. 716

TABLE 6 for RETENTION STUDIES
PROGRAM: Residential New Construction
YEAR(S): PY94

1. End Use	1. Measure	2. *ex-ante* EUL	2. *ex-ante* EUL Source	3. *ex-post* EUL from Study	4. *ex-post* EUL for 3rd & 4th claim	5. Std. Error	6. Upper & lower bounds @ 80% Conf Int		7. P Value	8. Realization Rate	9. "Like" Measures to be Adjusted
HVAC	Duct Testing	25	1994 EAH Filing	25	25	n/a	n/a	n/a	n/a	1.00	none
HVAC	Furnace (88%+ AFUE)	18	1994 EAH Filing	18	18	n/a	n/a	n/a	n/a	1.00	none
Water Heat	Water Heater (.60 -.69 EF)	13	1994 EAH Filing	13	13	see Table 3-6				1.00	none
Water Heat	Water Heater (.70 EF)	13	1994 EAH Filing	13	13	see Table 3-6				1.00	none
HVAC/WHT	Combination System (.58 EF)	20	1994 EAH Filing	20	20	n/a	n/a	n/a	n/a	1.00	none
HVAC	Duct Insulation	25	1994 EAH Filing	25	25	n/a	n/a	n/a	n/a	1.00	none
Water Heat	Water Heater Heat Traps	13	1994 EAH Filing	13	13	n/a	n/a	n/a	n/a	1.00	none
Water Heat	Recirculating Controls	15	1994 EAH Filing	15	15	see Table 3-6				1.00	none
Water Heat	MH Water Heaters (.60 EF)	13	1994 EAH Filing	13	13	see Table 3-6				1.00	none
HVAC	MH Furnace (80% - 87% AFUE)	18	1994 EAH Filing	18	18	n/a	n/a	n/a	n/a	1.00	none
HVAC	MH Furnace (88%+ AFUE)	18	1994 EAH Filing	18	18	n/a	n/a	n/a	n/a	1.00	none
HVAC	Multi-family Furnaces	18	1994 EAH Filing	18	18	n/a	n/a	n/a	n/a	1.00	none
Cooking	Gas Ovens	20	1994 EAH Filing	17.5	17.5	see Table 3-10				0.88	none

"n/a" indicates failures were not observed

CPUC M&E Protocols

Table 7

Data Quality and Processing Documentation
for
Residential New Construction Program
Fourth-Year Retention Evaluation

March 1999

Study ID No. 716

1 Overview Information

a) **Study Title and Study ID:** 1994 Residential New Construction Program – Fourth Year Retention Evaluation, March 1999, Study ID No. 716.

b) **Program, Program Year(s), and Program Description (Design):** Residential New Construction Program for the 1994 program year. The Program was designed to induce builders to increase energy efficiency in new homes beyond Title 20 and Title 24 requirements. The program offerred informational and training workshops for builders and provided incentives for a variety of DSM measures.

c) **End Uses and Measures Covered:** Duct testing, gas furnaces (88% AFUE), gas water heaters (.60 - .69 EF), gas water heaters (.70 EF) combination heating and water heating systems, duct insulation, water heater heat traps, recirculating controls, MH water heaters (.60 EF), MH furnaces (80% - 87% AFUE), MH furnaces (88%+ AFUE), multi-family furnaces, and gas ovens.

d) **Methods and Models Used:** See Section 3.2 and Sections 3.4 through 3.9.

e) **Analysis sample size:**

Program Year	Measure	# of Customers in Program	# of Installations in Program	# of Measures Installed in Program	# of Measures in Sample Frame	Date of Retention Study
DSM Measures						
1994	Duct Testing	1994 EAH[1]	1994 EAH[1]	7,159	217	1998
1994	Furnace (88% AFUE)	1994 EAH[1]	1994 EAH[1]	1,512	58	1998
1994	Water Heater (.60-.69 EF)	1994 EAH[1]	1994 EAH[1]	1,608	92	1998
1994	Water Heater (.70 EF)	1994 EAH[1]	1994 EAH[1]	7	0	1998
1994	Combination System	1994 EAH[1]	1994 EAH[1]	1,095	18	1998
1994	Duct Insulation	1994 EAH[1]	1994 EAH[1]	10		1998
1994	Heat Traps	1994 EAH[1]	1994 EAH[1]	146	16	1998
1994	Recirculating Controls	1994 EAH[1]	1994 EAH[1]	1		1998
1994	MH Water Heater (.60 EF)	1994 EAH[1]	1994 EAH[1]	0		1998
1994	MH Furnace (80% - 87% AFUE)	1994 EAH[1]	1994 EAH[1]	34		1998
1994	MH Furnace (88%+ AFUE)	1994 EAH[1]	1994 EAH[1]	0		1998
Fuel Substitution Measures						
1994	Furnaces	1994 EAH[1]	1994 EAH[1]	68		1998
1994	Gas Oven	1994 EAH[1]	1994 EAH[1]	1,529	73	1998

1. See SoCalGas' 1994 EAHP program filing.

2 DATABASE MANAGEMENT

a) **Data sources:** the data came from the following sources:

- The on-site survey database from the 303 program participants covered under the first-year program impact study was retreived. The on-site survey collected detailed information on whether installed measures were still in the home and if they were still operational.
- Duct blaster tests were conducted for 19 of the 20 homes tested for the first-year impact study.
- In addition, estimates of EULs were derived from secondary sources. See Sections 2 for a list of the secondary sources evaluated.

b) **Data Attrition:** A census of the 303 participant sites of the first-year impact study was attempted with a result that 252 on-site surveys were completed.

c) **Data Quality Checks:** RER and the on-site contractor ASW developed protocols and methods to ensure a high level of data quality. A survey pre-test was used to to test the survey instrument, customer recruitment, survey and data entry protocols. Prior to the statistical analysis steps, the on-site survey database was subject to a series of statistical and manual data checks to ensure completeness of the data.

d) **Analysis Database.** All of the data collected on the on-site survey instrument has been entered into the analysis database. A copy of the survey instrument is included in Appendix A.

3 SAMPLING

a) **Sampling Procedures and Protocols:** RER attempted a census of the 303 participant sites of the first-year impact study. The on-site data collection protocol is discussed in Section 2.3.

b) **Survey Information:** Appendix A includes a copy of the on-site survey. A total of 252 of the targeted 303 on-site surveys were completed, giving a survey response rate of 83%. The completed on-site survey sample by weather zone and residence type is presented in Table 2-1. Completed on-site surveys by measure is presented in Table 2-2. Given the relatively high response rates, we did not attempt to test for non-response bias.

c) **Statistical Descriptions:** The key variable of interest is the measure lifetime which is summarized in Section 3. No comparison group was used as part of this analysis.

DATA SCREENING AND ANALYSIS

a) **Treatment of Outliers and Missing Data Points.** The main problem in computing estimates of the EULs for the measures studied is that the majority of the measures had not failed at the time of the on-site survey. Thus, the observed lifetimes are censored. To control for censoring a series of statistical models were estimated for three of the measures. The statistical method employed is described in Section 3.2.

b) **Background Variables.** Whether a measure had failed or not at the time of the on-site survey is independent of economic and political activity.

c) **Screened Data.** The measures studied were based on the first year impact study sample. No additional screens were employed.

d) **Model statistics:** See Table 6 for estimates of EULs and upper and lower confidence bounds.

e) **Specification:** Where possible survivor functions were estimated for the measure. In these cases, three alternative model specifications were estimated: Log-logistic, log-normal and Weibull survivor functions. The EUL and 80% upper and lower confidence bounds are presented in Section 3. A detailed description of the model specifications are presented in Section 3.2. Because of the small sample sizes it was not feasible to include factors that would account for heterogeneity of customers.

- **Heterogeneity:** Because of the small sample sizes it was not feasible to include factors that would describe the heterogenity of the customers..
- **Omitted Factors:** All relevant data were used.

f) **Error in Measuring Variables:** The key statistical problem is that the observed measure lifetimes are censored. That is, for those measures that were still in place and operating at the time of the on-site survey, the true lifetime was not observed. When possible, the analyis was extended to control for this censoring. See Section 3.2 for a detailed description of the method used.

g) **Influential Data Points:** Not applicable.

h) **Missing Data:** Not applicable.

i) **Precision:** See Section 3.2 for a description of how the standard errors were calculated.