Measure Retention in Residential New Construction

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ABSTRACT

The purpose of this study was to validate the lifetime estimates of energy measures installed under a residential new construction DSM program in accordance with California requirements for a 4th year evaluation. As part of this study, the authors undertook several efforts, including:

- Conducted on-site visits to verify the presence of installed measures;
- Conducted parallel phone survey to determine if the two survey methods developed different responses;
- Verified the fraction of measures removed or failed, and the dates of removal to estimate expected lifetimes; and
- Developed recommendations for improved data collection strategies to support the follow-up 9th year measure retention study.

We conducted a set of phone and duplicate on-site surveys to examine the comparability of results from the two data collection methods and found no difference in reported vs. verified removals. This finding allowed us to conduct the remaining retention inventory by telephone. Measure failures were relatively low for the program four to five years after installation – too few to recommend a different lifetime for the measures.

Based on the results of the 4th year retention study, we developed recommendations for a modified approach to meeting the 9th year study requirements. The program covered easy to identify measures, and the phone survey was very accurate in tracking removals. Therefore, a panel survey approach with alternate year phone surveys and periodic on-site verifications was recommended as an appropriate methodology to provide on-going, accurate, cost-effective data for estimating measure lifetimes for the 9th year retention study.

The Measure Retention Study

California's Protocols and Procedures for the Verification of Costs, Benefits, and Shareholder Earning from Demand Side Management Programs ("The Protocols") require measure retention studies in the 4th and 9th year of DSM programs.[1] These are designed to determine whether the estimated useful lifetimes (EULs) used for *ex ante* estimation of the savings from the program and shareholder incentives are an appropriate approximation for the *in-situ* lifetimes. The research approach entails examining the percent of measures that are still in place and operable, and calculating the estimated useful lifetime (EUL) of key measures. The results from these studies are used to support utility Annual Earnings Assessment Proceedings (AEAP). The protocols called for conducting appropriate statistical

[1] California Public Utilities Commission: Protocols and Procedures for the Verification of Costs Benefits, and Shareholder Earnings From Demand Side Management Programs. Revised January 1997. This study represents the 4th year retention study.

tests to determine whether the null hypothesis that the ex ante and estimated EULs are not significantly different at the 80% confidence level for any or all of the four measures. The revised EUL estimates, if found to be statistically different from the *ex ante* estimates, are used to recalculate estimated program savings and shareholder incentives. The study, therefore, can have significant monetary implications.

Program Description

The purpose of the PG&E Comfort Home (PCH) program was to encourage residential builders to construct homes that exceeded state energy efficiency standards. Initially, the elements of the program included: advertising, education, training seminars, and financial incentives for installing a specific set of energy efficiency measures. Both building owners and builders were eligible for the incentives.

The program was established in 1992, and targeted the following measures:

- Decreased Title 24 cooling by 10 percent
- Shell measure upgrades and evaporative coolers or whole house fans
- Natural gas appliances for cooking, clothes drying, space heating and water heating exceeding Title 24 by at least 10 percent,
- High efficiency ducts (optional bonus)
- Reduced size of central air conditioner (optional bonus), and
- Conventional single-speed or two-speed air conditioners that exceeded Title 24 standards for Seasonal Energy Efficiency Rating (SEER) by at least 1.5.

In 1994, the program was redesigned, and in 1995, the funds were shifted toward a higher emphasis on consumer-related advertising and away from incentives. The 1994 changes included:

- The target was changed to incent both builders and consumers – builders received financial incentives, and home buyers received coupons for efficient appliances,
- The target market was restricted to single family detached residential new construction in the Central Valley, the area of PG&E's territory with the highest cooling load, and
- Targeted measures were refined to include air conditioners, high efficiency ducts, natural gas cooking appliances, gas stubs in laundry rooms, as well as some lighting and energy efficient window measures.

A wide variety of measures were supported by the program. However, four key measures accounted for the majority of installed measure savings. These targeted measures were:

- Air conditioners: Enhanced case air conditioning units of 12.5 SEER or more, (or 15 SEER for an optional bonus) were eligible for the program. In areas where natural gas was unavailable, air-to-air heat pumps were allowed. Incentives were paid for only one unit per home, and for incentives in homes with more than one unit, the incentive was based on the one with the lowest SEER.

- High efficiency ducts: Duct systems that met specific standards in installation and material specification were incented through the program.
- Natural gas cooking appliances: Natural gas cooktops or ranges were required in areas where PG&E provided natural gas service to the dwelling, and homes in areas without natural gas service received a $50 lower incentive and were not required to install gas cooking appliances. For multi-home developments, the builders were eligible for the financial incentive if at least 75% of the homes built had natural gas cooking equipment installed.
- Gas stubs in laundry rooms: Natural gas dryer stubs were rebated, and were required in homes in areas served by PG&E gas service; the measures were not required in areas without PG&E gas service, and total incentives were lower.

Retention Study Background and Objectives

The 4th year retention study examined the measures installed under the program in program years (PY) PY93, PY94, and PY95, and reimbursed in PY94 and PY95. PG&E paid out incentives to approximately 20,000 homes for the two program years (PY) under study.

The principal objectives of the study were to:

- estimate the fraction of measures that were installed through the Comfort Home Program during the 1994 and 1995 program years that remains operable,
- provide PG&E with statistically-based Effective Useful Life (EULs) for each of the four measures included in the study,
- determine whether a phone sampling approach could achieve accurate data,
- determine whether analytic work could help narrow the shape of the measure survival function and help identify which year a follow-up study is needed to best "anchor" the function to develop a reliable estimate of median useful life, and
- provide recommendations regarding panel surveys and other approaches to support the follow-up 9th year study.

In compliance with the Protocols, PG&E determined that four measures represented the top 50% (or more) of the savings from the program. The end uses and their *ex ante* lifetimes are listed below. The measures not falling into these four key categories were treated as "miscellaneous" for the purposes of the measure retention study.

- high efficiency air conditioners 18 years
- natural gas cooktops and ranges 20 years
- high-efficiency duct installations 25 years
- gas dryer stubs 18 years

Analytical Needs and Approach

Under the Protocols, the purpose of a retention study is to collect data on the fraction of installed measures in place and operable in order to produce revised estimates of the (EUL). The ultimate goal, the estimation of the EUL (the median number of years that the measure is still in place and operable), can be estimated by identifying the measure's survival function. A survival function describes the percentage of measures installed that are still in place at a given time. The hazard rate is the rate at which measures fail or are removed.

This 4th year analysis focused on providing the first estimate of the EUL of the measures encouraged under the new construction program; the 9th year retention study is important in identifying the final shape of the decay function and resulting calculation of the EUL. Providing estimates for the two program years separately, (PY94 and PY95) provides information for two points in time and can help define the survival curve. Combining the two program years can result in improved estimates compared to what is obtained from analysis of only one program year.

Phone and on-site surveys provide data on the fraction and locations of measures installed in the program years that are still in place and operating. These data are used to estimate a survival function for each of the four identified measures. From the estimated survival function, we can determine the EUL, specifically that point at which it is estimated that "50% of the measures installed under the Program are still in place and in use". These estimates can be used to determine whether or not there is a significant difference at the 80% confidence level between the *ex ante* EUL which was used to compute earnings claims and the new estimate of the EUL for the measure. Two major types of computations form the core of the analysis:

- Estimate fraction of measures still in place and operable: As a first step, the percent of failures for the sample and the corresponding percent estimated for the full population would be computed, with its associated 80% confidence interval. This provides the estimated fraction of measures still in place in the homes.
- Estimate "survival curve" and develop EUL estimates: This step involves using statistical procedures to estimate the best fit for the "survival" function for the measures,[2] using the dates of failures found in the sample. The best fitting models could be calculated for each of the measure types, for combined and separate program years. The implications of important explanatory factors on the EUL estimates could also be examined.

The data needed to support these revised estimates are fairly limited. They include:

- the measures installed in the house
- the status of the measures
- date of failure of any measures no longer in place or operable
- date the measures were installed, and
- the program year and climate zone for the house.

Given the program's design (reliance on long-lived measures) and (relatively young) age, a number of challenges were anticipated in estimating the survival function.

- There are relatively long expected lifetimes of the measures installed. In this program, we addressed measures with 18-25 year lifetimes.
- The elapsed time since installation is short relative to the long measure lifetime. In this case, the measures have been in place less than 5 years.

[2] Estimated survival functions can take on a number of functional forms; discussions with another consultant team indicate that the authors of the Protocol suggested that the ex ante EULs may be based on a logistic survival function. The survival analysis procedures we have identified for use can support a number of functional forms, including, potentially, exponential, log-logistic, lognormal, gamma, and others.

- Relatively few failure points might be available to allow selection between "similar" distribution functions. Relatively few failures complicate fitting a curve through the data points.
- With measures with long lifetimes, estimated survival curves may not fall below 0.5, making it impossible to estimate the median survival time.

To try to reduce problems from these sources, we increased the sample size for the surveys (we completed 511 surveys), and identified a variety of statistical techniques to use in estimating the EULs.

Description of Analysis Techniques for Retention Work

Assuming sufficient failures, several procedures can be used to develop an estimate of the survival function and examine the results to determine the best "fit" and resulting estimate of EUL for each measure. Each of the modeling procedures has advantages and disadvantages as applied to this work. Several provide flexibility in the estimation of the distribution function, while others allow us to examine the "fit" of distributions we may believe, *a priori,* are most appropriate. Several models allow time dependent covariates (or explanatory factors), which can recognize and properly incorporate factors such as heating degree days. The results across approaches can be compared to determine the best models for each of the four types of measures.

- "LIFETEST" is a statistical procedure in SAS® that is appropriate for use with the type of "censored" data that are provided by a study of this type. The data from this study are "right-censored" in the fact that we can only say that the measures are around at <u>least</u> as long as they have been to date. This procedure takes this censorship into account generates a maximum likelihood estimate of the survival distribution given the observed test data. A confidence interval can be constructed around this curve, and estimates of the median expected survival of measures can be calculated from the estimated curve.
- "LIFEREG" lets the analyst select a preferred distribution for the failures from a list including exponential, gamma, loglogistic, lognormal, logistic, normal, and Weibull. Weighted and unweighted analyses can be supported.
- "PHREG" provides estimates without the requirement of a specific type of failure distribution. Phreg allows time varying covariates. Examples of a time-dependent covariate (or explanatory variable) that might be appropriate for the measures under consideration include cooling degree days. Phreg can appropriately account for the fact that more failures of air conditioners might be expected to fall in certain months, for example.

Using multiple analysis techniques for the data does not take significantly greater analytical time, but allows the analyst to examine the robustness of alternative specifications of the model. The 80% confidence intervals around the estimated EULs could be calculated and compared with the *ex ante* estimates, by measure. The implications of important explanatory variables could be examined and used in developing results for the regulatory filings. Depending on the results (e.g., apparent time dependence and other behavior), the analysis can be used to make stronger recommendations regarding on-going data collection efforts.

Sampling Plan and Data Collection

The most efficient, appropriate, and easily justified sampling strategy – and the strategies with well-known properties -- include simple random or stratified random designs. The types of information needed to support stratified designs can be fairly minimal, stratification leads to lower overall variance, and allows more efficient use of sample size. This sampling plan was used for both the on-site and phone survey portions of the project. The key strata used for this project included:

- ***Program year (2 strata)***: This study included sample points from two program years (per the Protocols). This helps support analysis jointly or on a PY basis.
- ***Climate zone (3)***: Newly constructed houses/developments in three climate zones were eligible for the program. Climate zone was used as a stratification variable because results by climate zone could be useful, and because climate zone might be expected to have an effect on measure lifetimes. Air conditioners are included in the study and since some of the climate zones have higher heating degree days than others, it may be that operating conditions are different between the climate zones. This was retained as both a stratification variable and a potential explanatory variable.
- ***Number of Measures***: We used number of measures installed (of the four of concern) as a stratification variable because of sample size issues. By drawing the sample of 500 entirely from households that contained at least three of the four measures of interest increases the number of measures inspected for retention. Maximizing the number of observations of measures maximizes the likelihood of finding potential measure failures and improves the accuracy of the estimates of the survival function. However, to justify this approach, it must be assumed that there would be no relationship between measure lifetimes and the number of measures installed – that households with only one measure installed would be expected to have the same lifetime as that measure installed in a house that had multiple eligible measures installed. It was determined that there was no reason to believe, *a priori*, that there would be behavioral, measure, or other differences between houses with one vs. more measures, or varying combinations of measures installed *that would affect the estimated useful life of the measures*.
- ***Geographic clustering***: We grouped the sample into geographic clusters of 20 nearby homes and selected from these clusters for our sample. This helped reduce travel costs for the on-site inspections.

Data Collection Approach and Results

For the first stage of the data collection work, we conducted both telephone interviews and on-site inspections for each household (a modified pre-test). This allowed us to determine if phone techniques were sufficient to collect reliable data on retention for the measures in question. A summary of the questions included in the telephone and on-site components is provided below in Table 1.

Table 1. Telephone and On-site Survey Research Components

Survey Component	Telephone Survey	On-site
Measure Status - Verbal	X	
Measure Status - Visual		X
Reason for removal	X	X
Date of failure / removal	X	X
Follow-up if gas cooktop missing	X	X
Occupant Questions	X	

During the month of October, 1998, surveys and on-sites were scheduled with a randomly-selected set of subcities/supercities. Phone survey recruitment and on-sites were conducted and we found that, for the most part, PG&E's records regarding installed measures are very accurate. As is usual in these types of surveys, the phone and address list included wrong numbers. The completed pre-test phone interviews and on-sites show that there were no measure database discrepancies. Data from the survey and on-site inspections showed:

- the equipment installed under the Comfort Home program 3-4 years previously was still installed,
- the households questioned knew that the equipment was still installed,
- the PG&E measure database was accurate, and
- phone number and address databases could be improved.

During the initial recruitment phases, it was found that customers were reluctant to accommodate on-site visits. In consultation with PG&E, the consultants added a monetary incentive to improve acceptance and to reduce recruitment labor costs. A figure of $20 was found to increase the percentage of customers agreeing to an on-site visit. Of the households that have been called or inspected, no measures have been removed or changed in any way. There were only one or two instances in which a household indicated problems with the installed measure. All others seemed very pleased with the equipment installed. Most customers were aware that their house was a "Comfort Home".

In the pre-test, phone surveys were accomplished with 78 households. A total of 64 households had both on-site and phone information. The research plan called for at least 50 on-site surveys to be completed to determine if the phone and on-site methods elicited the same information. If the results were comparable in accuracy, it was proposed that phone techniques be used to gather the data instead. The comparison found that the phone and on-site surveys found exactly the same results – the results from the on-site inspections were completely consistent with the information gathered via phone calls regarding measure retention and operability. This led us to recommend conversion to phone survey methods. This was justifiable because:

- these measures are very easily viewed, and are simple measures to identify, so we expected that residents could report the results with good accuracy,
- the measures have not been in place for long, and the majority of the residents would likely be the initial occupants, increasing their knowledge of whether the equipment was still in place, and
- not many failures in such long-lived equipment would be expected after only 4-5 years.

In total, we gathered retention information from 511 households, 242 respondents for PY94 and 269 for PY95. The surveys included checks on 1,749 measures. There were no failures for two measures (air conditioning and dryer stubs), and we found 3 failures/removal of high efficiency ducts, and 3 removals of gas cooktops. Figure 2 shows the failure rates by measure type.

Ducts were replaced because:

- faulty insulation installation led them to replace the return air duct with a fixed metal duct
- house suffered flood damage, and
- ducts were corroded.

Cooktops were replaced because:

- homeowner worked for an appliance manufacturer and replaced the cooktop with their own model prior to move-in,
- homeowner was displeased with the quality of the cooktop and replaced it before they moved in, and
- all appliances were removed (and sold) by the previous homeowner in association with repossession of the home prior to the new owner taking possession.

Table 2. Failure Rates

Measure Type	Ex Ante Estimate	Failures
Air Conditioners	18 years	0 of 280 / 0%
Gas Dryer Stubs	18 years	0 of 495 / 0%
High Efficiency Ducts	25 years	3 of 499 / 0.6%
Gas Cooktops	20 years	3 of 475 / 0.6%

All failures were found in Climate Zone 12, the zone with by far the largest number of participating homes. Two ducts were from PY 1994; and one cooktop failure was from PY 1994. The remainder of the failures were from PY1995.

The lack of failures made it impossible to estimate survival functions with any reliability, and the wide range for the 80% confidence intervals for the lifetimes of the measures (even using linear functions) included the ex ante estimates. Therefore, there was no evidence to change the ex ante EULs estimates.

Developing Recommendations for Follow-Up 9th Year Retention Study

Two key inputs lead to reliable estimates of survival functions and EULs:

- A reasonable number of failures, and
- Accurate data about the date for each of the failures (month and year).

These data help specify the shape of the hazard function, and that drives estimate of the point at which 50% of the measures are no longer in place and operable.

The fatal flaw in retention studies is the fact that "observations" only count when measures have failed or been removed ("failures"). Measures with long lifetimes will tend to have very few failures in the early years, so usable observations are scarce. In addition, information on the dates of failures or the time the measures were in place before failure is crucial to the estimation work, and failure dates can be hard to remember if it has been a long time since failure.

Low numbers of failures make it impossible to estimate survival functions if there are insufficient observations to anchor the functional form or distinguish between alternative forms. Different functional forms result in different estimate of EULs, or the point at which 50% have failed. Measures might fail slowly across time; alternatively, many may fail at roughly the same time with a few lasting considerably longer. Others may fail in an "S" shape. To clearly distinguish the shape requires the following types of information:

- a reasonable number of observations (failures) are needed,
- the observations need to accurately record the age at failure, and
- the observations need to cover a relatively long share of the measure's expected lifetime so estimates of any inflection points can be located or so the appropriate shape of the survival curve can be fitted.

This implies that the optimal situation would be one with:

- tracking of many houses to increase the chances to find failures,
- frequent data collection so EUL failure dates could be recalled with accuracy, and
- data collection over a period of time, providing sufficient time for failures to occur.

Advantages of Panel Surveys Approach for Retention Studies

For programs like the Comfort Home study, the *ex ante* estimates of EULs can be between 18 and 25 years. For long-lived measures, a 4 year study may not be expected to provide many failures. The 9th year study may be expected to show sufficient failures to allow a "fit" for the early portion of the curve. However, if 5 years elapse between data collection efforts, the fitted curve's accuracy will suffer if the respondents do not accurately recall dates for intervening failures.

Certain programs may be especially well suited to using a panel database for retention studies. General advantages of re-interview or panel databases, noted by statistical texts, include: lower cost for preparing the sample, gains in efficiency due to the elimination of variation between successive samples, savings from avoiding asking some questions twice, and increases in accuracy of report associated with the longer experience of residents with the interview situation.

Specific advantages for programs like the Comfort Home Program also include:

- the panel participants are homes for which we will have extra information about removal dates – even if a new resident says the measure is not there and has no idea when it was removed, we will know that it was in place *at least* through December 1998. This is very valuable information for a retention study.
- the panel homes have been cooperative once, and should the same residents be there, it may be relatively easier to gain cooperation. Those repeat respondents would also be familiar with the study and the process of reporting on the presence of their particular rebated equipment.

- the panel respondents represent a good, statistically-valid sample to support future work on the retention of measures from the PY94 and PY95 Comfort Home program.
- the panel participants could potentially be used as the basis for future periodic phone surveys to assess measure retention – modifying the data collection plan from the Protocols somewhat. This easy sample allows PG&E to collect relatively frequent data on retention, helping "nail down" hazard function shapes better than surveys that wait a long time between contacts.

The key considerations associated with establishing a panel are issues of *attrition* and *replacement*. When the unit of concern is a family, replacing households with similar households often gets into issues of trying to replace with households of similar demographics – information that is difficult to ascertain *a priori*. Programs similar in design to the PG&E Comfort Home program provides one of the easiest and best situations for a panel survey. Many complexities associated with panel surveys are avoided because in this case the *home* (and its house-bound equipment) is the participant of interest, not the actual occupant. In the case of the PG&E Comfort Home Measure Retention panel, we have two key advantages:

- **Low attrition:** Our panel survey units do not move or quit easily – and in fact, because they are *homes*, they will not easily disappear except in the case of fire, demolition, etc. The major source of attrition may be specific residents in homes electing not to participate in the future.
- **Straightforward replacement**: The homes are identified by criteria that do not change – program participation year (PY94 or PY95), the climate zone in which the home is located (3 options) and city/supercity designation. These are stratification criteria that are easily determined *a priori* and do not change. Replacing with valid homes (should replacement be necessary) is straightforward and can be done with minimal bias. We do not need to replace with similar residents, but instead with homes from the same stratification cell.

Given that some respondents will likely refuse to participate in the future, or that some of the dwellings will cease to exist (fire, etc.), replacement procedures will be needed, but are easily implemented by matching program year, climate, and other stratification variables. Replacing sample adds some sampling error (because you are introducing some new sample, with resulting variations), but helps improve the representativeness. For example, if attrition were to occur disproportionately in any climate zone, some effect on the pattern or years of air conditioning failures might result if these observations were not replaced or augmented.

Recommended Data Collection Approach for 9th Year Study

On-going, accurate data on measure failures or removals is very important in estimating measure lifetimes for retention studies. The specific characteristics of this new construction program (easy-to-identify and hard-to-remove measures), along with the match between the phone and on-site data collection efforts, led us to recommend a revised strategy for data collection for the required 9th year retention study for the program.

Periodic phone contacts with a well-selected panel sample can provide an excellent group for on-going longitudinal data collection efforts. Data could be gathered using a modified approach compared to the traditional 9th year study:

- every-other-year phone contact with the 500 households through year 9 – data which can be used for the follow-up 9th year study[3]
- potential increases to annual surveys for a period around when measures might be expected to increase in failure rate – perhaps starting in year 12.
- frequency of calls could then be reduced after failures would be expected to fall off.
- a second on-site might be considered at some point to re-validate the data.[4]

This provides higher precision information on failure dates, improving estimates of the survival functions underpinning derivation of the estimated useful lifetimes for the measures. This approach provides higher quality data for EUL estimates and does so with a reasonable, and potentially lower, budget.

Summary

The surveys showed between zero and three failures for the measures under study, even with 511 surveys completed, and between 239 and 434 observations per measure type in the survey. No revisions to ex ante EUL estimates were justified.

The findings demonstrated that good accuracy on the presence of measures and their failure dates could be obtained using phone techniques – on-site inspections do not appear to be necessary for these types of programs and measures. The reliability of the phone approach may be somewhat specific to this study. Recall that, unlike studies examining lighting measures, the households only need to be able to locate fairly unique and easily identified measures: [5]

- central air conditioners,
- gas stubs in laundry rooms,
- high efficiency ducts, and
- gas cooking equipment.

Further, these measures, unlike appliances, cannot be easily moved to another location with the resident. There is generally no need to determine whether the measure was taken with the resident, and whether that resident still resides in the service territory, etc. (as might be needed with appliance programs). Programs similar in design to the Comfort Home Program provide a special case that makes it especially appropriate for modified (telephone) measurement methods.

Programs similar to the Comfort Home program also provide excellent situations for a modified data collection plan that can be affordable, and provide high quality information for estimating the EULs of the measures being studied. We recommended implementing an

[3] Or alternating phone and on-site visits

[4] Perhaps at year 9, depending on requirements, etc.

[5] "Unique" referring here to the fact that there is not likely to be more than one of these items in the home, so no uncertainties occur over whether the removed or remaining item was the one that was installed through the program, etc. This differs significantly from lighting fixtures or bulbs measures, for example.

alternate year program of phone data collection in conjunction with periodic on-site verifications of the presence of the measures.

The respondents to the 4th year Retention Study of the Residential New Construction Comfort Home program provide a strong basis for a panel database. *Given the special characteristics of the types of measures under study from programs like the Comfort Home Residential New Construction program*, and the high degree of reliability for self-reports on the measures from telephone surveys, repeated phone interviews with a panel provides an excellent opportunity to modify data collection approaches for future retention work on this program. The modified approach can improve the recollection of dates of failures, and can support higher quality EUL estimates than the traditional isolated 4th and 9th year on-site inspections.

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