## APPENDIX 8-E. FURNACE FAN LIFETIME DETERMINATION

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# APPENDIX 8-E. FURNACE FAN LIFETIME DETERMINATION

## 8-E.1 INTRODUCTION

DOE defines lifetime as the age when a product is retired from service. DOE used national survey data, along with manufacturer shipment data, to calculate the distribution of furnace fan lifetimes. Furnace fan lifetimes are considered to be equivalent to furnace lifetimes, so DOE modeled furnace fan lifetime based on estimated furnace lifetimes, which were developed for the recent HVAC rulemaking. DOE assumed that the lifetime of a fan is the same at different efficiency levels.

## 8-E.2 METHODOLOGY

DOE's lifetime methods are based on "Using national survey data to estimate lifetimes of residential appliances" paper.[1]

EIA's RECS[2] surveys occupied primary housing units, noting the presence of a range of appliances and placing the age of each appliance into several-year bins. The U.S. Census's *American Housing Survey* (AHS)[3] surveys all housing, including vacant and second homes. Using the AHS data allowed DOE to adjust the RECS data to reflect some appliance use outside of primary residences. AHS also has a larger sample size, with correspondingly smaller sampling error. By combining these survey results with the known history of appliance shipments (collected from manufacturer trade associations) DOE estimated the fraction of appliances of a given age still in operation. This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an estimate of the average and median appliance lifetime.

The Weibull distribution is a probability distribution function commonly used to measure failure rates.[4] Its form is similar to an exponential distribution, which would model a fixed failure rate, except that it allows for a failure rate that changes over time in a particular fashion. The cumulative distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \quad \text{for } x > \theta \text{ and } P(x) = 1 \text{ for } x \leq \theta,$$

Where:

$P(x)$ = probability that the appliance is still in use at age $x$,
$x$ = appliance age,
$\alpha$ = the scale parameter, which is the decay length in an exponential distribution,
$\beta$ = the shape parameter, which determines the way in which the failure rate changes in time, and
$\theta$ = the delay parameter, which allows for a delay before any failures occur.

When $\beta = 1$, the failure rate is constant over time, and this distribution takes the form of a cumulative exponential distribution. For the case of appliances, $\beta$ is commonly greater than 1, which results from a rising failure rate as the appliance ages. A plot of a Weibull distribution (DOE's calculated furnace fan survival function) is shown as Figure 8-E.2.1.

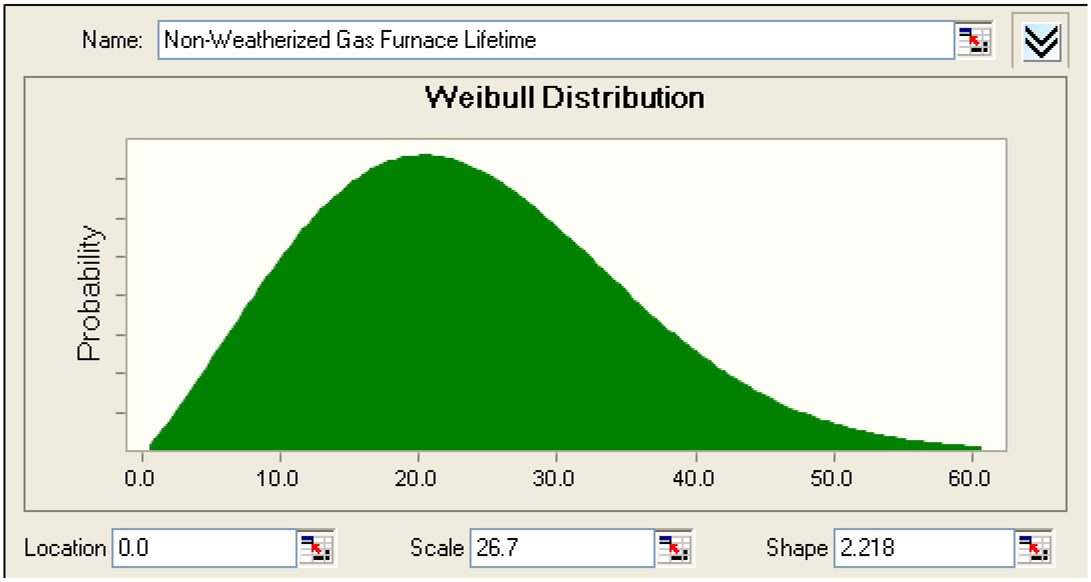


**Figure 8-E.2.1 Lifetime Distribution for Non-Weatherized Gas Furnaces**

The RECS survey is DOE's primary resource for furnace ages. For several appliances, including furnaces, the survey asks respondents to place the appliance's age into one of these bins:

- less than 2 years;
- 2 to 4 years;
- 5 to 9 years;
- 10 to 19 years and
- more than 20 years.

The RECS survey has been conducted every 3 or 4 years for the last several decades. For this analysis, DOE used the surveys conducted in 1990, 1993, 1997, 2001, and 2005. The AHS survey is conducted every other year, and DOE used the surveys conducted from 1991 to 2007. DOE used the AHS count of housing units with furnaces to scale the RECS data to better match the total installed stock. DOE used the surveys' household-level micro-data to count households with shared or multiple furnaces. Households that did not know the age of their appliances were allocated among the remaining age bins according to the distribution of respondents who did report their appliance age.

DOE used RECS appliance age data, AHS total installed stock data, and the history of appliance shipments to generate an estimate of the survival function. For example, DOE summed the total shipments from 5 to 9 years prior to the RECS survey, and compared this number with the number of units of those ages still in use, to calculate one approximation of the surviving appliance fraction within that age bin. The AHS total stock acts as an "all ages" bin. By combining the age bins from five RECS surveys and nine AHS surveys with shipments data, DOE had enough data to build a fit to a Weibull distribution and find the parameters ($\alpha$, $\beta$, $\theta$) that best approximate the surviving units, using a least-squares method. Because the first two (youngest) RECS bin data tend to have a large scatter relative to the shipments in those years, DOE combined the RECS and shipments data in the first two bins. Generally, appliances do not tend to fail in large numbers during this period, so combining bins does not appreciably lower the accuracy of the shape of the distribution. DOE weighted each bin's contribution to the sum of squares by the inverse of the variance in the survey results, which controls for the changes in sample size between RECS bins, between RECS and AHS, and within each survey over time.[4] RECS and AHS have complicated error models; DOE used only the error due to finite sample size to determine the variance used to weight each data point's contribution. The error due to sampling is less than 1% for AHS survey data and is typically about 5% for RECS age bins. The equation for the sum of squares DOE minimized is therefore:

$$\sum_i \frac{\left(\boldsymbol{RECS}_i - \boldsymbol{Surv}_i\right)^2}{\sigma^2_{i,RECS}} + \sum_j \frac{\left(\boldsymbol{AHS}_j - \boldsymbol{Surv}_j\right)^2}{\sigma^2_{j,AHS}}$$

Where:

| | |
|---|---|
| $i$ = | the identifier for a bin from a single RECS, |
| $j$ = | the identifier for a single AHS survey, |
| $RECS_i$ = | the number of appliances reported by RECS in bin $i$, |
| $AHS_j$ = | the number of appliances reported by AHS in survey year $j$, |
| $Surv_i$ = | the number of surviving appliances in bin $i$ predicted by the Weibull distribution applied to the number of appliances shipped (a function of $\alpha$, $\beta$, and $\theta$), |
| $\sigma_{i,RECS}$ = | the standard error (square root of the variance) of the RECS data point for bin $i$, and |
| $\sigma_{j,AHS}$ = | the standard error (square root of the variance) of the AHS data point for year $j$. |

DOE adjusted the RECS and AHS survey data in several ways to place it on an even footing with the historical shipment data. In particular, DOE adjusted for the fact that the RECS survey is scaled to July of its reference year, the AHS survey is conducted in the middle portion of the year, and shipment data is provided for each calendar year. Adjustments included:

- DOE modeled the additional retirement of older appliances and their replacement by new ones that took place in the latter half of the survey year (after a given respondent had been surveyed), using the survival function. This had the effect of moving households from the older RECS age bins to the youngest age bin.

- For appliances installed directly in new construction, such as furnaces, DOE added units to the youngest RECS age bin and to the AHS total stock to represent half of the new construction for the final year of the survey, which were known to have installed the appliance type in question, using data from the U.S. Census for new construction starts.

### *Assumptions*

DOE's lifetime-calculation technique depends on several assumptions:

- Appliance lifetime can be modeled by a survival function. In particular, a Weibull distribution is an appropriate survival function.
- The appliance survival function does not change over time.
- The survival function is independent of other household factors (such as household size, region, etc.) as well as product class (within furnaces).
- The age bin for the appliance as reported by the RECS respondent is correct.
- The historical shipment data is correct.
- The Weibull delay parameter, $\theta$, is limited to between 1 and 5 years.

Three of these assumptions are of particular importance. The first is the assumption that a Weibull distribution is the correct distribution to use for appliance retirement rates. This distribution is the standard distribution for use in lifetime analysis, but it is not guaranteed to reflect actual consumer behavior. The second assumption is that consumer behavior and mechanical appliance lifetime have not changed over time. This assumption required DOE to treat all data from different RECS surveys on an equal footing. Using only recent surveys (to potentially better reflect recent consumer behavior and appliance lifetime) would result in attempted least-squares fits using a small number of data points, leading to large statistical uncertainty.

DOE limited the delay parameter to between 1 and 5 years to reflect the range of common appliance warranties. A delay of less than 1 year would imply that some appliances fail or are replaced within their initial year of use, a period during which they are commonly covered by parts and labor warranties. A delay of greater than 5 years implies that no appliances are replaced for some length of time after the end of the longest standard warranty. Fits with $\theta > 5$ also commonly show nonsensical behavior with sharp changes in consumer behavior or appliance survival immediately following the "delay" period.

## REFERENCES


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