Life-Cycle Costs and Payback Periods for Central Air Conditioners and Heat Pumps – Assumptions and Results

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Introduction

This report describes the life-cycle cost (LCC) and payback period (PBP) results associated with increased efficiency levels for split system and single package central air conditioners and heat pump. Two sets of LCC and PBP results are presented based on two different sets of manufacturer cost increases that are associated with increased efficiency. The two sets of manufacturer costs increases are identified as:

- **ARI** (Air-Conditioning & Refrigeration Institute) – ARI collected incremental cost estimates from individual manufacturers and calculated industry averages, and

- **Rev Eng** (Reverse Engineering) – cost estimates developed from current products through a reverse engineering analysis conducted by Arthur D. Little, Inc. (ADL).

The LCC and PBP results are generated as a distribution using a simulation based on "Monte-Carlo" methods where inputs to the analysis consist of probability distributions rather than single-point values. As a result, the Monte Carlo analysis produces a distribution of LCC and PBP results rather than single-point values. A distinct advantage of this type of approach is that the percentage of consumers achieving LCC savings or attaining certain PBP values due to an increased efficiency standard can be identified in addition to the average LCC savings or average PBP for that standard.

The LCC and PBP Monte Carlo uncertainty analysis is conducted using data from the 1993 Residential Energy Consumption Survey (RECS). The 1993 RECS consists of over 7000 surveyed households, statistically weighted to represent the entire housing population of the United States. Of the over 7000 households surveyed in RECS, 2550 households representing 35.6% of the housing population have a central air conditioner while 651 households representing 8.3% of housing population have an electric heat pump[1]. Using the households in RECS that utilize a central air conditioner or heat pump, LCC and PBP analyses were performed on a household-by-household basis to determine whether an increase in the minimum efficiency standard is economically justified.

[1] The number of households actually used in the central air conditioner and heat pump LCC and PBP analyses were 2164 and 613, respectively. Some central air-conditioned households were dropped from the analysis for one or more of the following reasons: 1) the central air conditioner was not used, 2) a room air conditioner was present and used, or 3) marginal energy prices could not be determined for the household. With regard to households with heat pumps, they were dropped from the analysis for one or more of the following reasons: 1) the heat pump was not used or 2) marginal energy prices could not be determined for the household.

The two basic outputs for the consumer impacts analysis are:

- Distributions of LCC for the baseline level and each standard level and distributions of the change in LCC (i.e., the difference between the baseline LCC and the LCC for a given standard level) for each standard level.

- Distributions of Payback Periods for each standard level.

Results Summary

Tables 1 and 2 and Figures 1 through 8 depict the LCC results for split system air conditioners, split system heat pumps, single package air conditioners, and single package heat pumps based upon ARI and reverse engineering manufacturer cost data. The tables and figures show the LCC mean values at the baseline (10 SEER) level and each standard level. In addition, the percentage of households that achieve a reduction in LCC are reported for each standard level.

Table 3 and Figures 9 through 12 depict the PBP results for split system air conditioners, split system heat pumps, single package air conditioners, and single package heat pumps based upon ARI and reverse engineering manufacturer cost data. The table and figures show the mean and median PBP values for each standard level. PBPs exceeding 35 years are represented graphically as a 35 year payback.

A detailed discussion of the inputs for the LCC and PBP analysis follow the results summary. After the discussion of the inputs, more detailed LCC and PBP results are presented.

Table 1 Life-Cycle Cost Results for Split System Central Air Conditioners and Heat Pumps

	Split Air Conditioners				Split Heat Pumps			
	ARI		Rev Eng		ARI		Rev Eng	
SEER / HSPF	Mean LCC	Percent with reduced LCC	Mean LCC	Percent with reduced LCC	Mean LCC	Percent with reduced LCC	Mean LCC	Percent with reduced LCC
10 / 6.8	$4,837	-	$4,828	-	$10,086	-	$10,001	-
11 / 7.1	$4,827	39%	$4,786	48%	$9,915	74%	$9,695	99%
12 / 7.4	$4,886	31%	$4,770	45%	$9,852	63%	$9,533	90%
13 / 7.7	$5,229	12%	$4,931	27%	$10,119	36%	$9,850	49%
14 / 8.0	$5,659	6%	$5,246	15%	$10,311	28%	$10,246	27%
15 / 8.2	$6,052	4%	$5,456	11%	$11,079	11%	$10,534	20%
16 / 8.4	-	-	$5,533	11%	-	-	$10,679	18%
17 / 8.6	-	-	$5,672	10%	-	-	-	-

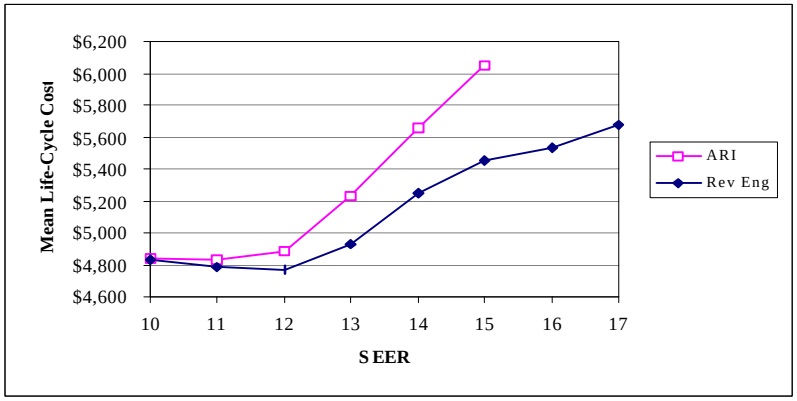

Figure 1 Split A/C: Mean Life-Cycle Costs – ARI vs. Rev Eng

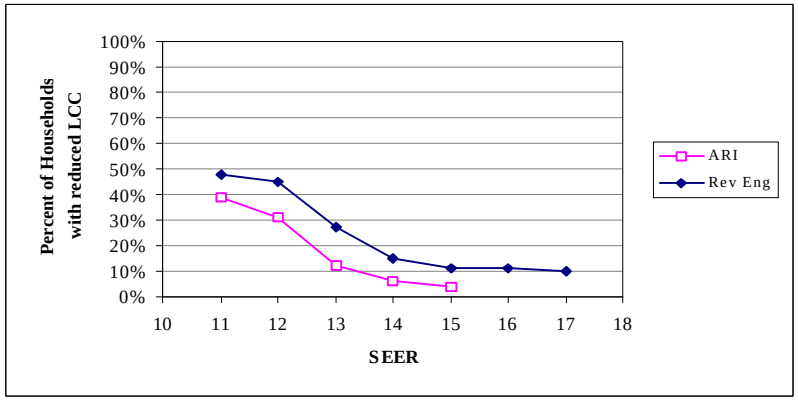

Figure 2 Split A/C: Percent with reduced LCC – ARI vs. Rev Eng

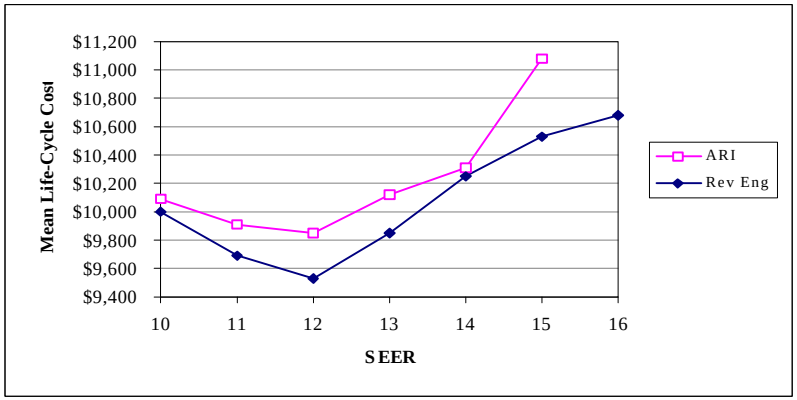

Figure 3 Split HP: Mean Life-Cycle Costs – ARI vs. Rev Eng

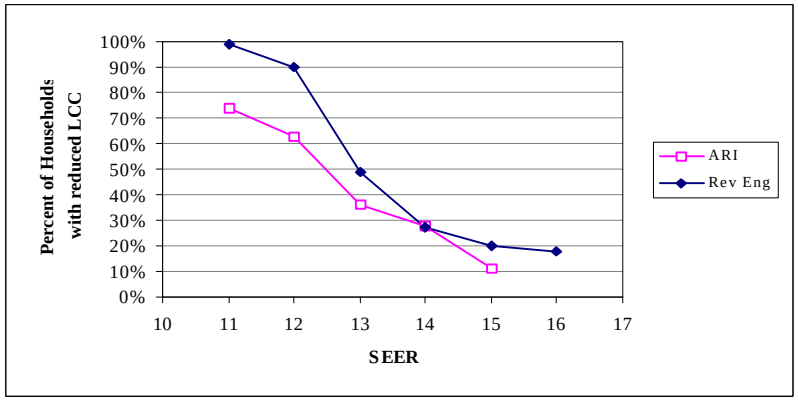

Figure 4 Split HP: Percent with reduced LCC – ARI vs. Rev Eng

Table 2 Life-Cycle Cost Results for Single Package Central Air Conditioners and Heat Pumps

	Single Package Air Conditioners				Single Package Heat Pumps			
	ARI		Rev Eng		ARI		Rev Eng	
SEER / HSPF	Mean LCC	Percent with reduced LCC	Mean LCC	Percent with reduced LCC	Mean LCC	Percent with reduced LCC	Mean LCC	Percent with reduced LCC
10 / 6.8	$5,341	-	$5,324	-	$10,025	-	$9,912	-
11 / 7.1	$5,429	20%	-	-	$9,906	61%	-	-
12 / 7.4	$5,433	26%	$5,194	58%	$9,835	58%	$9,551	80%
13 / 7.7	$6,031	5%	$5,598	17%	$10,342	22%	-	-
14 / 8.0	$6,362	4%	-	-	$10,425	21%	-	-
15 / 8.2	$6,921	2%	-	-	$11,031	10%	-	-

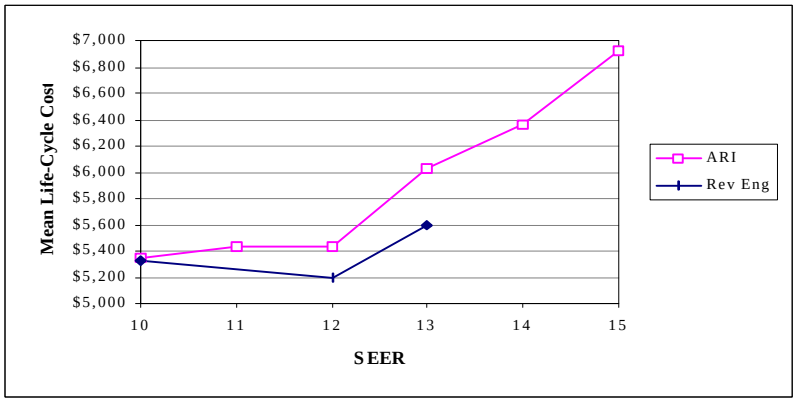

Figure 5 Package A/C: Mean Life-Cycle Costs – ARI vs. Rev Eng

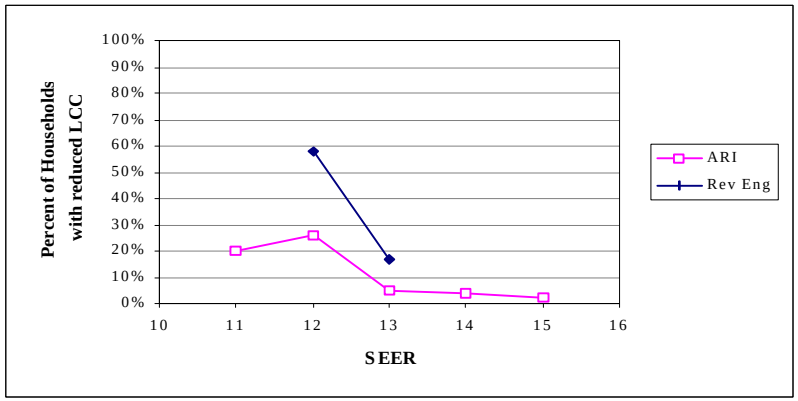

Figure 6 Pack. A/C: Percent with reduced LCC – ARI vs. Rev Eng

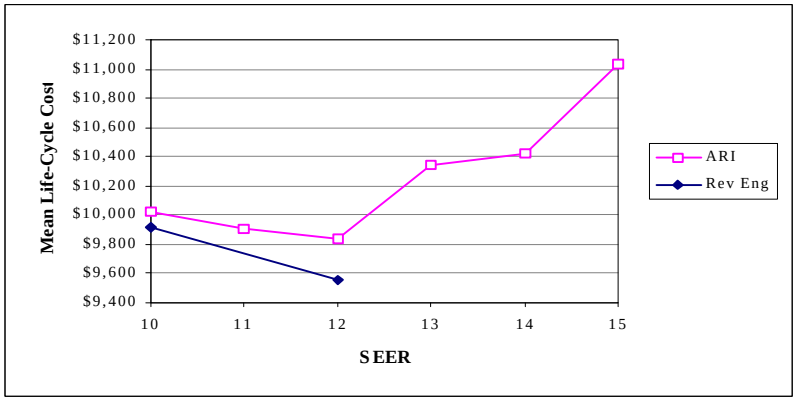

Figure 7 Package HP: Mean Life-Cycle Costs – ARI vs. Rev Eng

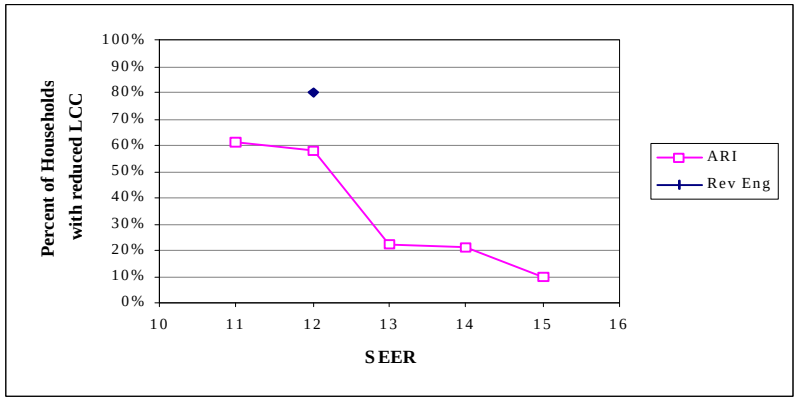

Figure 8 Pack. HP: Percent with reduced LCC – ARI vs. Rev Eng

Table 3 Payback Period Results for Central Air Conditioners and Heat Pumps (years)

	Split Air Conditioners				Split Heat Pumps				Package Air Conditioners				Package Heat Pumps			
	ARI		Rev Eng		ARI		Rev Eng		ARI		Rev Eng		ARI		Rev Eng	
SEER / HSPF	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
11 / 7.1	33	13	26	10	10	6	1	1	36	20	-	-	13	8	-	-
12 / 7.4	28	15	20	11	13	8	5	3	42	17	15	8	14	9	8	5
13 / 7.7	440	41	204	20	129	13	81	10	486	84	288	30	183	20	-	-
14 / 8.0	546	80	375	35	131	17	119	17	531	133	-	-	134	20	-	-
15 / 8.2	1104	137	352	43	219	31	142	21	645	559	-	-	218	31	-	-
16 / 8.4	-	-	1086	46	-	-	151	22	-	-	-	-	-	-	-	-
17 / 8.6	-	-	855	49	-	-	-	-	-	-	-	-	-	-	-	-

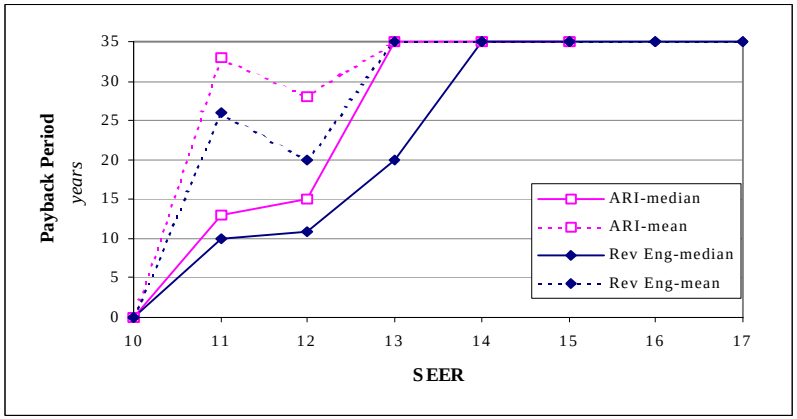

Figure 9 Split A/C: Mean and Median Payback Periods

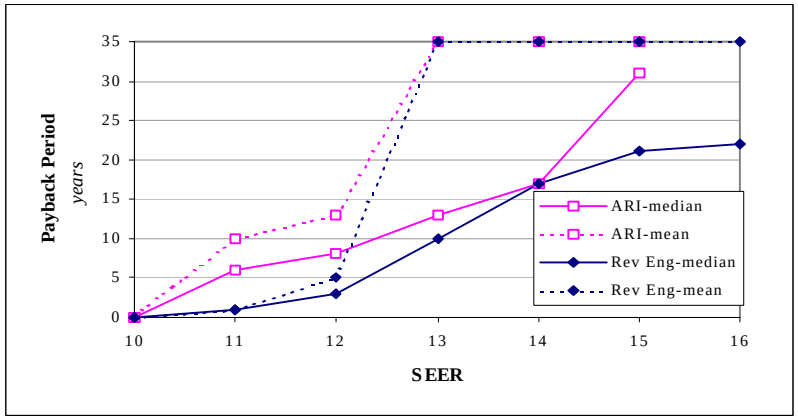

Figure 10 Split HP: Mean and Median Payback Periods

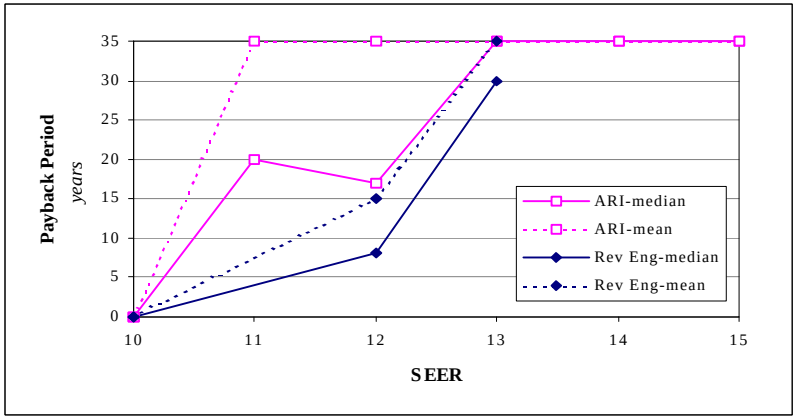

Figure 11 Package A/C: Mean and Median Payback Periods

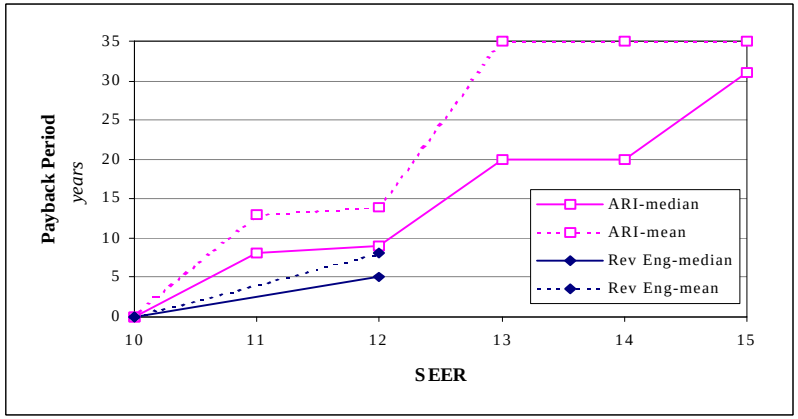

Figure 12 Package HP: Mean and Median Payback Periods

Inputs

LCC is the total consumer expense over the life of the appliance, including purchase expense and operating expenses (including energy expenditures). Future operating expenses are discounted to the time of purchase and summed over the lifetime of the appliance. The PBP is the change in purchase expense due to an increased efficiency standard divided by the change in annual operating expense that results from the standard.

Inputs to the LCC and PBP analysis are categorized as follows: (1) inputs for establishing the purchase expense, otherwise known as the installed consumer cost, and (2) inputs for calculating the operating expense.

The primary inputs for establishing the installed consumer cost are:

- *Baseline manufacturer production cost*: The cost to manufacture equipment meeting existing minimum efficiency standards. Baseline manufacturer costs were developed from a reverse engineering analysis and described in the accompanying Engineering Analysis reports.

- *Standard level incremental manufacturer costs*: The incremental manufacturer cost associated with producing equipment with an efficiency higher than the existing minimum standard. Two sets of incremental manufacturer costs are analyzed; one set submitted by ARI and another set developed through reverse engineering. Details of the reverse engineering production cost analysis are provided in the spreadsheets accompanying the Engineering Analysis .

- *Markups and Sales Tax*: The markups associated with converting the manufacturer cost to a consumer price. Three sets of markups were assumed for the LCC and PBP analysis: *manufacturer markup* – markup for converting the manufacturer cost to the cost distributors or wholesalers pay for the equipment, *distributor markup* – markup for converting the distributor or wholesaler cost to the cost contractors or dealers pay for the equipment, and *dealer markup* – markup for converting the dealer or contractor cost to the price which consumers pay for the equipment. In addition to the markups, a *sales tax* was developed. All the markups and sales tax were developed through an analysis performed by ADL.

- *Installation price*: The cost to the consumer of installing the equipment. The installation price represents all costs required to install the equipment other than the marked-up equipment cost. The installation price includes labor, overhead, and any miscellaneous materials and parts such as linesets. The installation price was developed from public sources and phone calls to HVAC contractors. Thus, the total installed consumer cost equals the consumer equipment price (manufacturer cost multiplied by the various markups plus sales tax) plus the installation price.

The primary inputs for calculating the operating expense are:

- *Annual energy consumption*: For central air conditioners, the annual energy consumption is the annual site energy use associated with providing space-cooling. For heat pumps, the annual energy consumption is the annual site energy use associated with providing both space-cooling and space-heating. The annual energy consumption was based on data from the 1993 RECS. For each household with a central air conditioner and heat pump, RECS estimates the equipment's annual energy consumption from the household's energy bills. It is important to note that the estimated annual energy consumption corresponds to the household's stock equipment, specifically its capacity and efficiency.

- *Equipment efficiency*: The seasonal energy efficiency ratio (SEER) is the efficiency descriptor for central air conditioners. For heat pumps, the cooling efficiency is represented with the SEER while the heating efficiency is represented with the heating seasonal performance factor (HSPF). Central air conditioner and heat pump efficiencies in existing households were based on two pieces of information: (1) the equipment's age and (2) ARI disaggregated shipments data providing shipment-weighted distributions of efficiency by year. For each household in the 1993 RECS with either a central air conditioner or heat pump, the survey records the equipment's age. Knowing the age establishes the equipment's year of manufacture which in turn, using the disaggregated shipments data, allows for the determination of the equipment's most probable efficiency. It is important to note that the established equipment efficiency corresponds to the household's stock equipment. To estimate the annual energy consumption associated with a particular standard level, the ratio of the household's stock efficiency to the standard level efficiency is multiplied by the household's annual energy consumption.

- *Average electricity prices*: The average price per kWh paid by each household for electricity.

- *Marginal electricity prices*: The marginal price per kWh paid by each household for electricity. Marginal electricity prices were deduced from household electricity bills from the 1993 RECS. A complete discussion of how marginal electricity prices were determined are detailed in a forthcoming Lawrence Berkeley National Laboratory report.

- *Electricity price trends*: The Annual Energy Outlook 1999 (AEO99) was used to forecast electricity prices into the future. For the results presented here, the AEO99 Reference case was used to forecast future electricity prices.

- *Maintenance costs*: The cost associated with maintaining the operation of the equipment (e.g., cleaning heat exchanger coils, checking refrigerant charge levels).

Data from Service Experts, an HVAC service company, were used to establish service costs.

- *Repair costs*: The cost associated with repairing or replacing component failures. Repair costs for minimum efficiency equipment (10 SEER) and equipment with efficiencies greater than 12 SEER were assumed to equal ½ the equipment price divided by the mean equipment lifetime. Equipment with efficiencies of 11 and 12 SEER were assumed to incur a 1% increase in repair cost over the minimum efficiency (10 SEER) level.

- *Lifetime*: The age at which the central air conditioner or heat pump is retired from service. A 1990 ASHRAE technical paper entitled "Heat Pump Life and Compressor Longevity in Diverse Climates" by M.E. Bucher, C.M. Grastataro, and W.R. Coleman was used to establish a survival function for both heat pumps and central air conditioners. The mean service life from the retirement function is 18.4 years, with a range of 1 to 24 years.

- *Discount rate*: The rate at which future expenditures are discounted to establish their present value. A distribution of discount rates was derived to represent the variability in financing methods consumers use in purchasing central air conditioners and heat pumps. The real (excluding inflation) discount rates used in the LCC analysis ranged from 0% to 19% with a mean value of 6.5%.

Figure 13 graphically depicts the relationships between the installed cost and operating expense inputs for the calculation of the LCC and PBP.

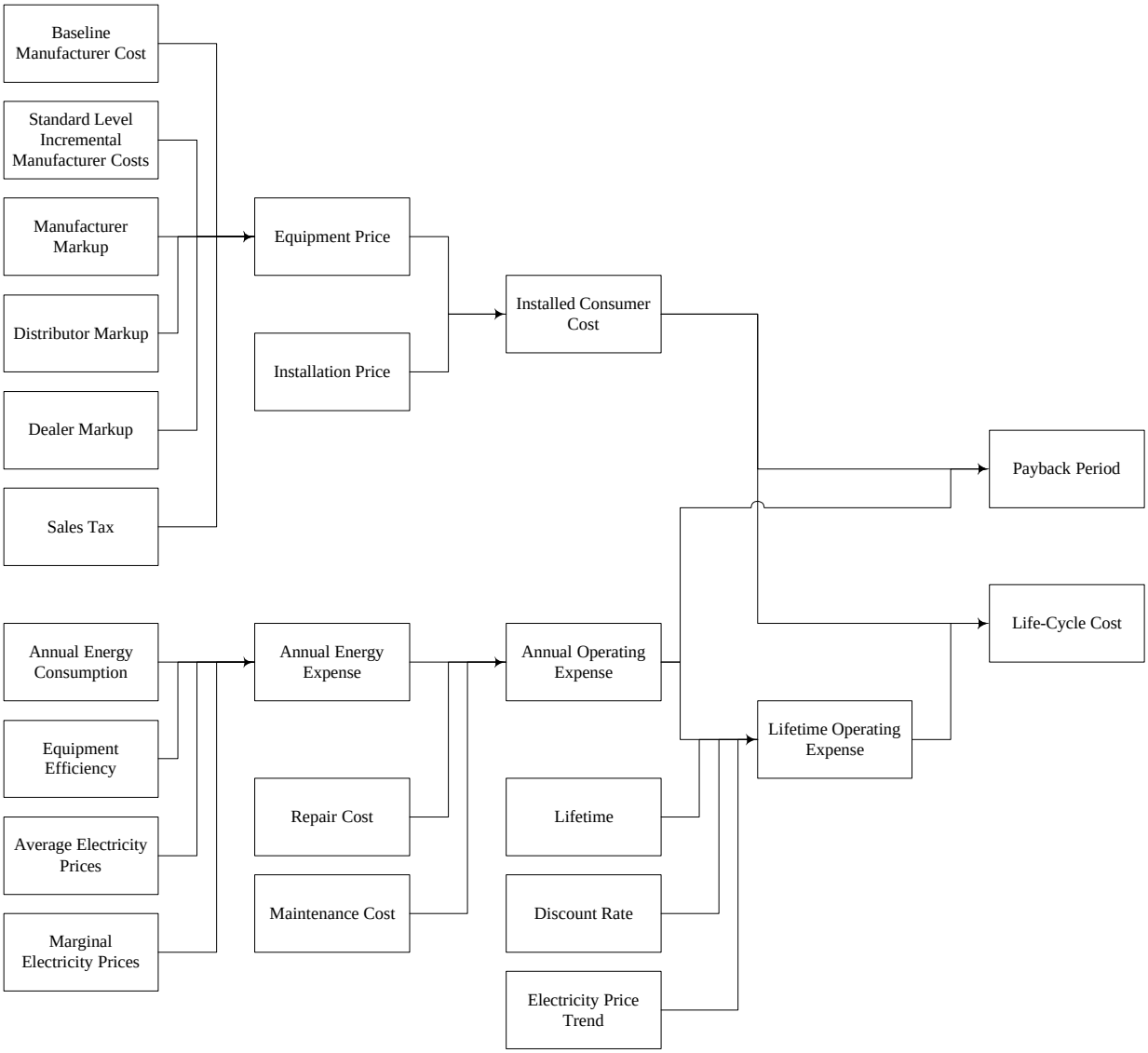

Figure 13 Flow Diagram of Life-Cycle Cost and Payback Period Inputs

Input Summary

The following tables and figures summarize the input values used for determining the installed consumer costs and operating expenses in the LCC and PBP analysis.

Installed Consumer Cost Inputs

Table 4 presents the baseline manufacturer cost. Tables 5 through 8, respectively, show the incremental manufacturer cost multipliers for the four primary product classes; split-type air

conditioners, split-type heat pumps, single package air conditioners, and single package heat pumps. As noted earlier, two sets of manufacturer production cost multipliers (ARI and Rev Eng) are presented for each class. Low, average, and high values are shown for each manufacturer cost multiplier. The incremental production cost multipliers are used to determine the manufacturer costs for each standard level. For example, the *average* manufacturer cost for the 11 SEER standard level for split system air conditioners with a blower based on ARI data equals the baseline production cost of $454 times the *average* multiplier (1.16) or $527. Because the probability distribution of ARI values was unknown, only average values from the ARI data were used in the LCC analysis. With regard to the reverse engineering data, probability distributions rather than single-point values were used in the LCC analysis. The low and high values for the reverse engineering cost multipliers shown in Tables 5 through 8 represent the 10th and 90th percentiles, respectively. Of note, the reverse engineering cost multipliers listed in Tables 5 through 8 differ slightly than what is presented in the Engineering Analysis documentation. The costs presented in the Engineering Analysis differ in two respects from those used in the LCC analysis. First, the Engineering Analysis costs calculate outbound freight in a manner that bases fixed rate on cabinet volume. Second, for ease of use, the Engineering Analysis costs have not been subjected to a Monte Carlo analysis to determine their uncertainty. Hence, the Engineering Analysis costs represent *most likely* rather than *mean* or *average* estimates. The LCC analysis uses the more appropriate *mean* cost estimates. The differences between *most likely* and *mean* estimates are usually subtle.

Table 4 Baseline Manufacturer Costs

Class	w/o Blower	w/ Blower
Split A/C	$367	$454
Split Heat Pump	-	$615
Package A/C	-	$534
Package Heat Pump	-	$589

Table 5 Split A/C Manufacturer Cost Multipliers

	ARI			Rev Eng		
SEER	low	avg	high	low	avg	high
10	-	1.00	-	0.96	1.00	1.05
11	1.03	1.16	1.30	1.08	1.13	1.18
12	1.09	1.36	1.55	1.20	1.25	1.31
13	1.30	1.63	1.90	1.35	1.42	1.48
14	1.60	2.03	3.00	1.65	1.73	1.81
15	1.81	2.40	3.50	1.87	1.95	2.04
16	-	-	-	1.98	2.07	2.17
17	-	-	-	2.13	2.23	2.33

Table 6 Split Heat Pump Manufacturer Cost Multipliers

		ARI			Rev Eng		
SEER	HSPF	low	avg	high	low	avg	high
10	6.8	-	1.00	-	0.96	1.00	1.05
11	7.1	1.05	1.10	1.15	0.97	1.01	1.06
12	7.4	1.11	1.24	1.35	1.05	1.10	1.15
13	7.7	1.17	1.44	1.66	1.29	1.35	1.41
14	8.0	1.30	1.64	1.88	1.57	1.65	1.72
15	8.2	1.75	2.09	2.52	1.79	1.87	1.96
16	8.4	-	-	-	1.92	2.01	2.10

Table 7 Package A/C Manufacturer Cost Multipliers

	ARI			Rev Eng		
SEER	low	avg	high	low	avg	high
10	-	1.00	-	0.96	1.00	1.05
11	1.03	1.19	1.27	-	-	-
12	1.15	1.30	1.40	1.08	1.14	1.19
13	1.40	1.63	1.75	1.33	1.40	1.46
14	1.59	1.87	2.00	-	-	-
15	1.89	2.23	2.92	-	-	-

Table 8 Package Heat Pump Manufacturer Cost Multipliers

		ARI			Rev Eng		
SEER	HSPF	low	avg	high	low	avg	high
10	6.8	-	1.00	-	0.96	1.00	1.05
11	7.1	1.06	1.14	1.25	-	-	-
12	7.4	1.06	1.28	1.50	1.11	1.16	1.22
13	7.7	1.45	1.60	1.90	-	-	-
14	8.0	1.65	1.75	2.30	-	-	-
15	8.2	1.93	2.13	2.47	-	-	-

Table 9 summarizes the remaining input values necessary for determining total installed consumer cost as multipliers. Low, average, and high values are shown for the markups, sales tax, and installation price. Triangular input distributions rather than point-values were used to represent the markups and installation price for the LCC analysis with the low and high values representing the end-points of the distribution and the most likely value representing the apex. The sales tax was assumed to have a unique distribution as shown in Figure 14. The same markups and sales tax were used for all product classes. With regard to the installation price, although there are differences in the price with regard to air conditioners and heat pumps, the same prices were used for split and single package systems. It is especially important to note that the markups, sales tax, and installation prices were assumed to remain constant with increasing efficiency.

As an example at how to arrive at the installed consumer cost, the calculation procedure is demonstrated for 11 SEER split system air conditioners with a blower based on ARI data. From above, the *average* manufacturer cost equals $527. The *average* equipment price to the consumer equals the *average* manufacturer cost times the product of the *most likely* manufacturer (1.18),

distributor (1.36), and dealer markups (1.55), and the *average* sales tax (1.07). The resulting *average* equipment price is $1403. The *average* installed consumer cost equals the *average* equipment price plus the *average* installation price ($1190) or $2593.

Table 9 Inputs to Installed Consumer Cost

Installed Consumer Cost Input	low	most likely	high
Manufacturer Markup (Multiplier)	1.10	1.18	1.27
Distributor Markup (Multiplier)	1.36	1.36	1.36
Dealer Markup (Multiplier)	1.37	1.55	1.63
Sales Tax (Multiplier)	1.05	1.07 [1]	1.08
Installation Price [2]	$952 / $1,628	$1,190 / $2,035	$1,428 / $2,422

[1] Represents the average rather than the most likely value.

[2] First value for air conditioners; second value for heat pumps.

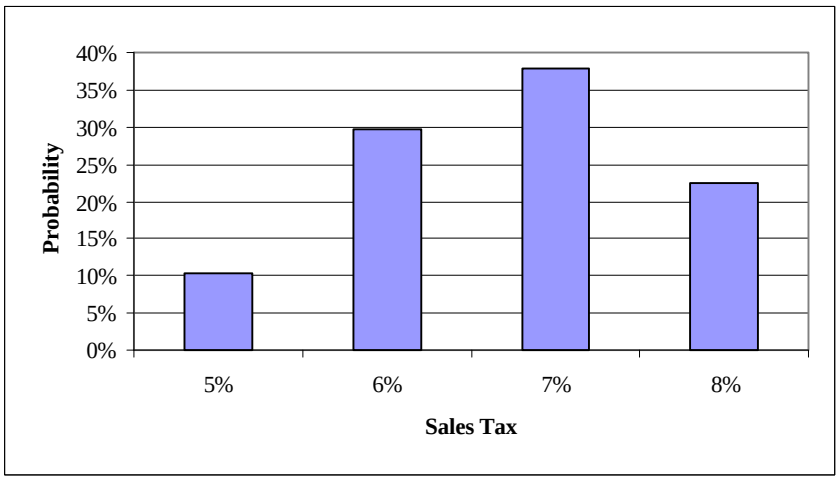

Figure 14 Sales Tax Distribution

Operating Expense Inputs for Central Air Conditioners

With the exception of repair costs, Table 10 summarizes the input values necessary for determining operating expenses for central air conditioners. The data in Table 10 applies both to split and single package systems.

Table 10 Inputs to Operating Expense for Central Air Conditioners

Operating Expense Input	low	weighted-average	high
RECS Annual Energy Use (kWh/yr)	174	2,629	12,929
RECS Efficiency (SEER)	5.30	8.58	15.20
RECS Marginal Electricity Price (cent/kWh)	0.58	8.74	19.42
RECS Average Electricity Price (cent/kWh)	2.70	8.49	16.50
Annual Maintenance Cost	$0	$36	$135
Discount Rate	0%	6.5%	19%
Lifetime (years)	1	18.4	24

Table 11 shows the repair costs by standard level for split and single package systems. As noted earlier, the 10 SEER efficiency level as well as standard levels with efficiencies of 13 SEER and greater were assumed to have a repair cost equal to one-half its corresponding equipment price divided by the assumed mean lifetime (18.4 years). Because the repair cost was assumed to be a function of equipment price, there are two sets of repair costs for each product class; one based on the ARI manufacturer costs and the other based on the reverse engineering costs. For 11 and 12 SEER levels, the repair cost was assumed to increase by 1% over the 10 SEER level. Although the repair costs were assumed to increase with efficiency, the maintenance costs were assumed to remain constant with increasing efficiency.

Table 11 Repair Costs for Central Air Conditioners

	Repair Cost			
Efficiency	**Split Systems**		**Single Package**	
SEER	**ARI**	**Rev Eng**	**ARI**	**Rev Eng**
10	$28	$28	$38	$38
11	$29	$29	$39	-
12	$29	$29	$39	$39
13	$46	$40	$63	$54
14	$58	$49	$72	-
15	$68	$56	$86	-
16	-	$59	-	-
17	-	$63	-	-

The annual operating expense for a standard level is the sum of the annual energy cost, the annual repair cost, and the annual maintenance cost. The annual energy cost for a standard level is determined by multiplying the average electricity price by the baseline (10 SEER) annual energy use and subtracting from it the product of the marginal electricity price and the annual energy savings associated with the standard level.

As an example at how to arrive at the annual operating expense, the calculation procedure is demonstrated for 11 SEER split system air conditioners based on ARI manufacturer cost data . First, the *average* annual energy use for the baseline (10 SEER) level is determined. This is accomplished by taking the ratio of the *weighted-average* SEER (8.58) and the baseline SEER (10) and multiplying it by the *weighted-average* annual energy use (2629 kWh/yr). This results in an *average* baseline annual energy use of 2255 kWh/yr. Next, the average annual energy use for the 11 SEER level is determined. This is accomplished with the same procedure as used for the baseline level expect that 11 SEER is substituted for 10 SEER. The resulting *average* 11 SEER annual energy is 2050 kWh/yr. The annual energy cost is then determined by multiplying the *average* baseline annual energy use (2255 kWh/yr) by the *weighted-average* average energy price (8.74 ¢/kWh) and subtracting from it the product of the *annual* energy savings associated with the 11 SEER standard level (2255 - 2050 = 205 kWh/yr) and the *weighted-average* marginal electricity price (8.49 ¢/kWh). The resulting annual energy cost for the 11 SEER standard level is $180. Adding the annual repair ($29) and maintenance ($36) costs results in an *average* annual operating expense of $245.

Although low, average, and high values are presented for the operating expense inputs in Table 10, the distribution of values are empirical and do not necessarily correspond to simple triangular, normal, or uniform distributions. For example, since annual energy consumption, average electricity prices, and marginal electricity prices are all based on RECS household data, the distributions are very unique. Figures 15 through 17 show the distributions of annual energy consumption and electricity prices that were used in the LCC analysis for central air conditioners.

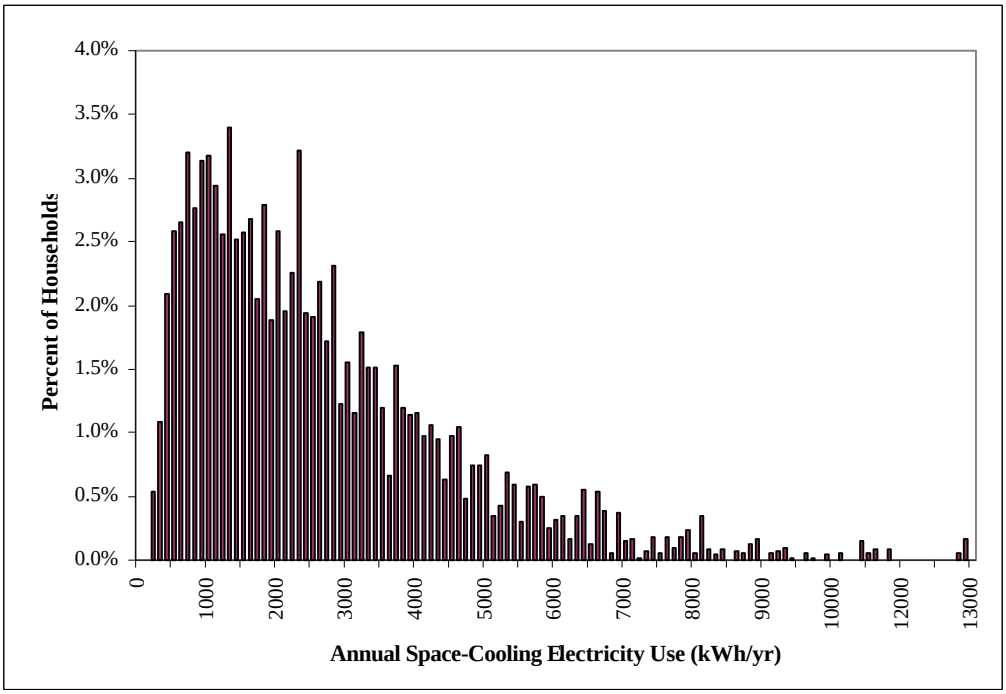

Figure 15 Percent of Households with Central Air Conditioners by Annual Electricity Consumption for Space-Cooling
(Source: EIA, 1993 RECS)

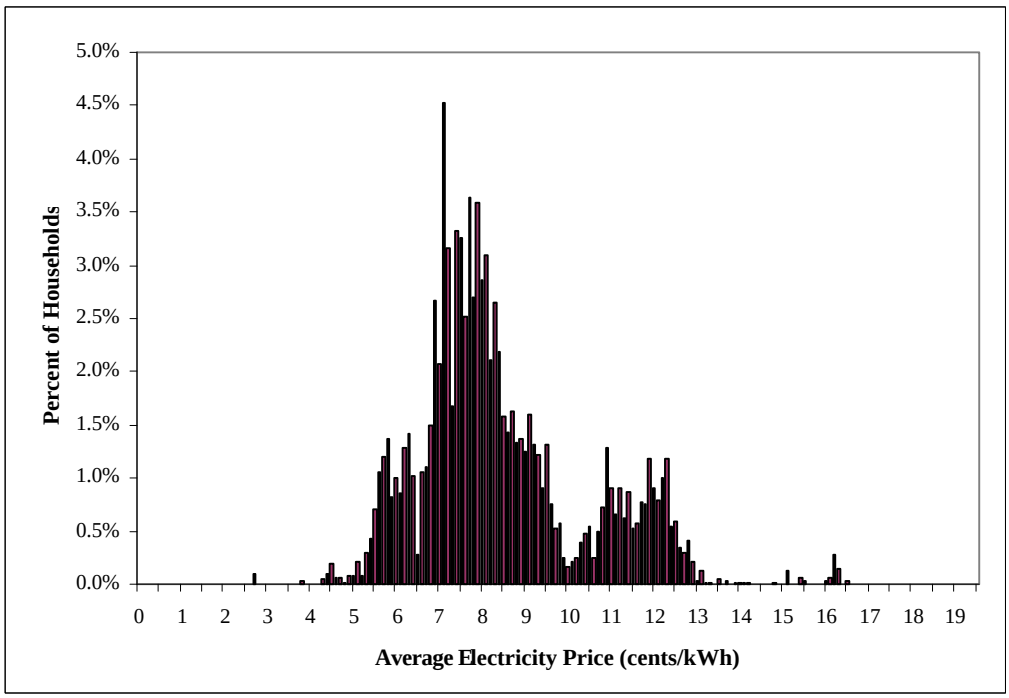

Figure 16 Percent of Households with Central Air Conditioners by Average Electricity Prices (Source: EIA, 1993 RECS)

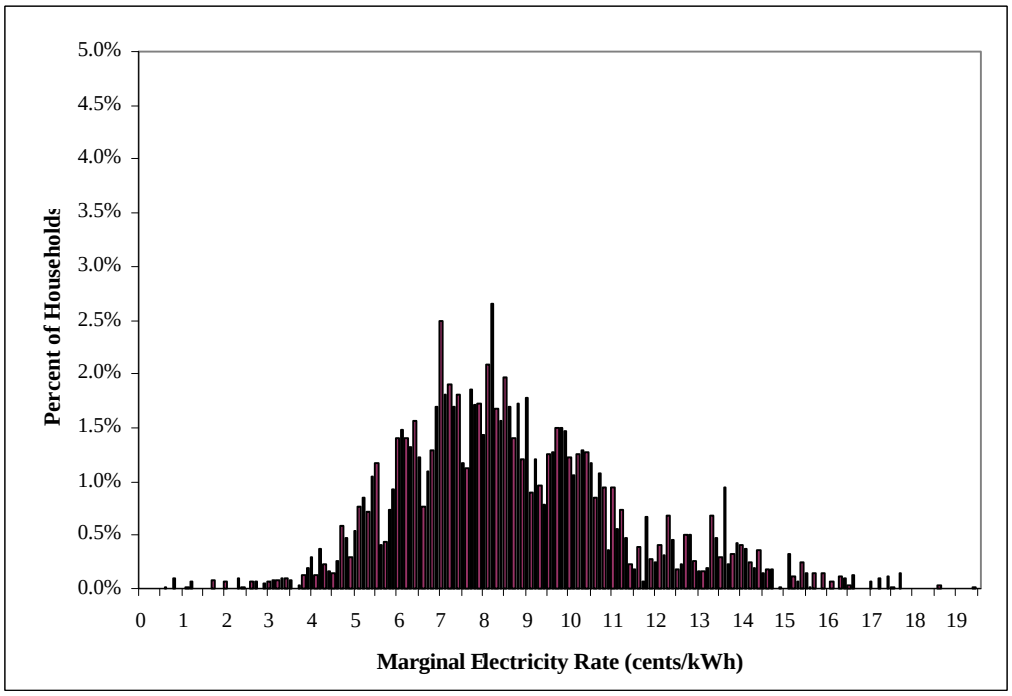

Figure 17 Percent of Households with Central Air Conditioners by Marginal Electricity Prices (Source: EIA, 1993 RECS)

As noted earlier, the RECS-based annual energy consumption and efficiency are associated with stock household equipment. Thus, for any single RECS household, the annual energy consumption associated with a particular standard level must be calculated by taking the ratio of the household's stock efficiency to the standard level efficiency and multiplying it by the household's annual energy consumption. This calculation can be represented with the following expression:

$$AEC_{std} = AEC_{stock} \frac{SEER_{stock}}{SEER_{std}}$$

where:

AEC_{std} =	Annual energy consumption of the standard level,
AEC_{stock} =	annual energy consumption of the stock household equipment,
$SEER_{stock}$ =	efficiency of the stock household equipment, and
$SEER_{std}$ =	efficiency of the standard level.

Based on the use of the RECS ***weighted-average*** annual energy consumption and efficiency, Table 12 presents the annual energy consumption values associated with each of the standard levels (i.e., 10 through 17 SEER). The values presented in Table 12 provide an idea of the relative magnitude of the annual energy consumption associated with each standard level.

Table 12 Central Air Conditioner Annual Energy Consumption, scaled to SEER

	Efficiency *SEER*	**Annual Energy Consumption** *kWh/yr*
Survey	8.58 [1]	2629 [1]
Scaled	10	2255
	11	2050
	12	1879
	13	1735
	14	1611
	15	1503
	16	1409
	17	1327

[1] RECS-based weighted average values for household equipment in use in 1993.

Figure 18 shows the survival function that was assumed for central air conditioners. As stated earlier, the survival function is based on an ASHRAE technical paper from 1990 entitled "Heat Pump Life and Compressor Longevity in Diverse Climates" by M.E. Bucher, C.M. Grastataro, and W.R. Coleman.

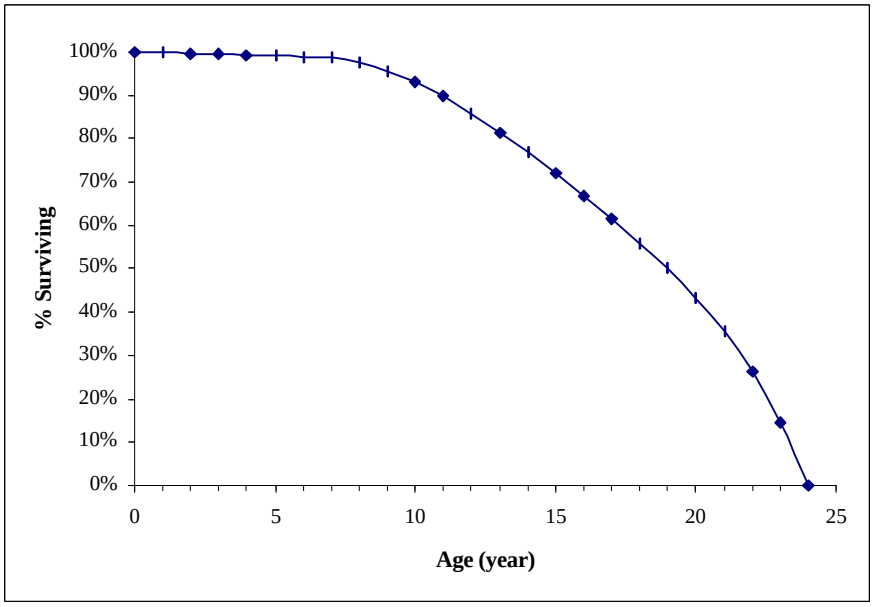

Figure 18 Percent of Central Air Conditioners and Heat Pumps surviving by years since installation

Consumer real discount rates were based upon assumed consumer finance methods for purchasing central air conditioning and heat pump equipment and the interest rates that correspond to each of the financing methods. Table 13 shows the assumed financing methods with their corresponding interest rates. The share attributed to new home purchases was based on shipments data showing that approximately 30% of central air conditioner and heat pump purchases go to the new construction market. Shares for the other financing methods were based on information provided by ARI. Minimum and maximum interest rates for new home, second mortgage, and credit card financing methods were based on a range of recently available rates. The maximum interest rate associated with cash purchases was based on typical returns available from mutual funds. As indicated in Table 13, the weighted-average mean discount rate equals 6.51%.

Table 13 Finance Methods with corresponding Interest Rates

		Nominal interest rate			Real Interest Rate [1]		
Finance Method	**Share**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
New home	30%	5.00%	8.89%	6.94%	1.60%	4.40%	3.00%
Cash	10%	-	-	-	0.00%	6.00%	3.00%
Credit card	35%	-	-	-	6.00%	19.00%	12.50%
Second mortgage	25%	6.00%	10.00%	8.00%	2.32%	5.20%	3.76%
Mean Weighted-Average							6.51%

[1] New home and second mortgage rates are after taxes of 28%. Inflation rate of 2% assumed.

Operating Expense Inputs for Heat Pumps

With the exception of repair costs, Table 14 summarizes the input values necessary for determining operating expenses for heat pumps. The data in Table 14 applies both to split and single package systems.

Table 14 Inputs to Operating Expense for Heat Pumps

Operating Expense Input	low	weighted-average	high
RECS Annual Energy Use (kWh/yr) [1]	0 / 162	2,987 / 4,658	14,771 / 29,839
RECS Efficiency (SEER / HSPF)	5.30 / 4.88	8.72 / 6.52	15.20 / 9.67
RECS Marginal Electricity Price (cent/kWh)	0.82	7.99	18.62
RECS Average Electricity Price (cent/kWh)	2.60	7.86	13.00
Annual Maintenance Cost	$0	$36	$135
Discount Rate	0%	6.5%	19%
Lifetime (years)	1	18.4	24

[1] First value is for space-cooling; Second value is for space-heating

Table 15 shows the repair costs by standard level for split and single package systems. As with central air conditioners, the 10 SEER efficiency level as well as standard levels with efficiencies of 13 SEER and greater, were assumed to have a repair cost equal to one-half its corresponding equipment price divided by the assumed mean lifetime (18.4 years). Because the repair cost was assumed to be a function of equipment price, there are two sets of repair costs for each product class; one based on the ARI manufacturer costs and the other based on the reverse engineering costs. For 11 and 12 SEER levels, the repair cost was assumed to increase by 1% over the 10 SEER level. Although the repair costs were assumed to increase with efficiency, the maintenance costs were assumed to remain constant with increasing efficiency.

Table 15 Repair Costs for Heat Pumps

	Repair Cost			
Efficiency	**Split Systems**		**Single Package**	
SEER	**ARI**	**Rev Eng**	**ARI**	**Rev Eng**
10	$44	$44	$42	$42
11	$45	$45	$43	-
12	$45	$45	$43	$43
13	$64	$60	$68	-
14	$73	$73	$74	-
15	$93	$83	$91	-
16	-	$89	-	-

As with central air conditioners, although low, average, and high values are presented for the operating expense inputs in Table 14, the distribution of values are empirical and do not correspond to simple triangular, normal, or uniform distributions. Figures 19 through 22 show the distributions of annual energy consumption and electricity prices that were used in the LCC analysis for heat pumps.

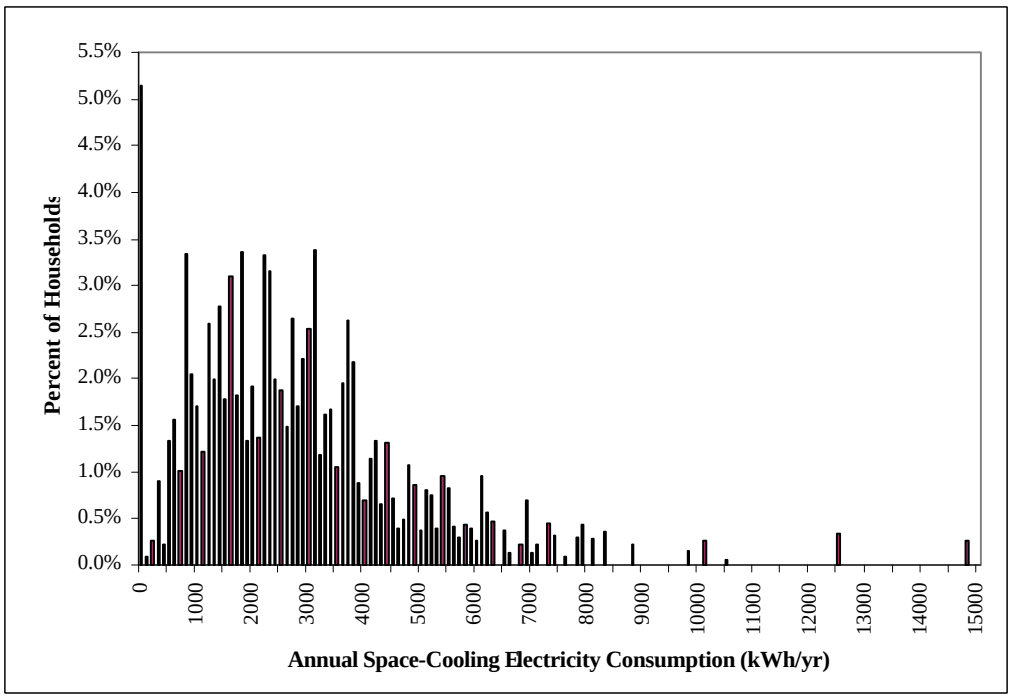

Figure 19 Percent of Households with Heat Pumps by Annual Space-Cooling Energy Consumption (Source: EIA, 1993 RECS)

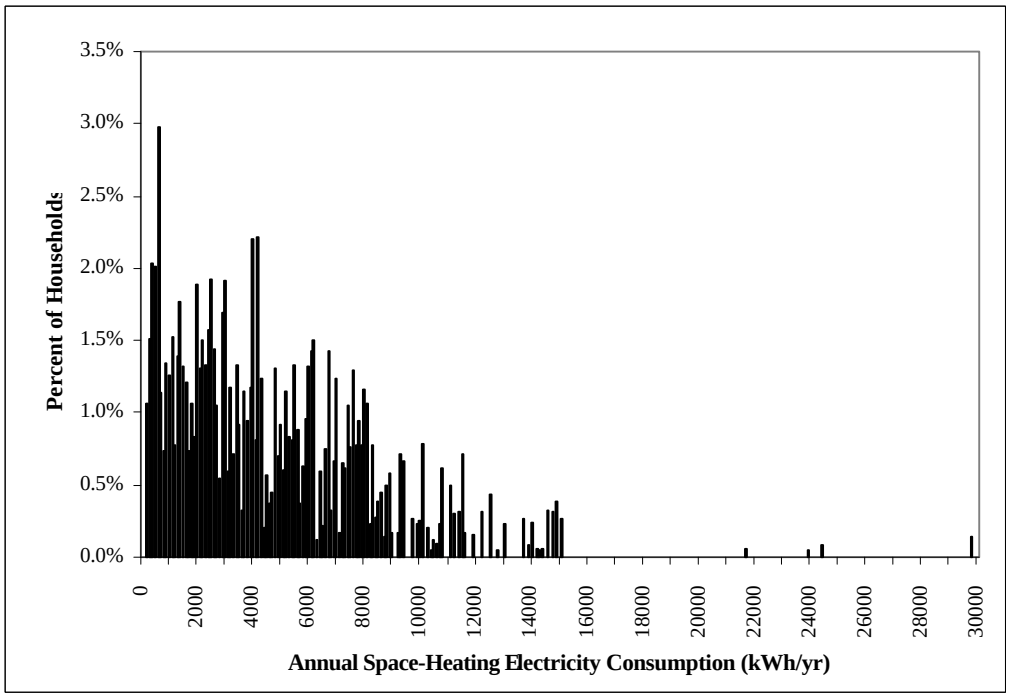

Figure 20 Percent of Households with Heat Pumps by Annual Space-Heating Energy Consumption (Source: EIA, 1993 RECS)

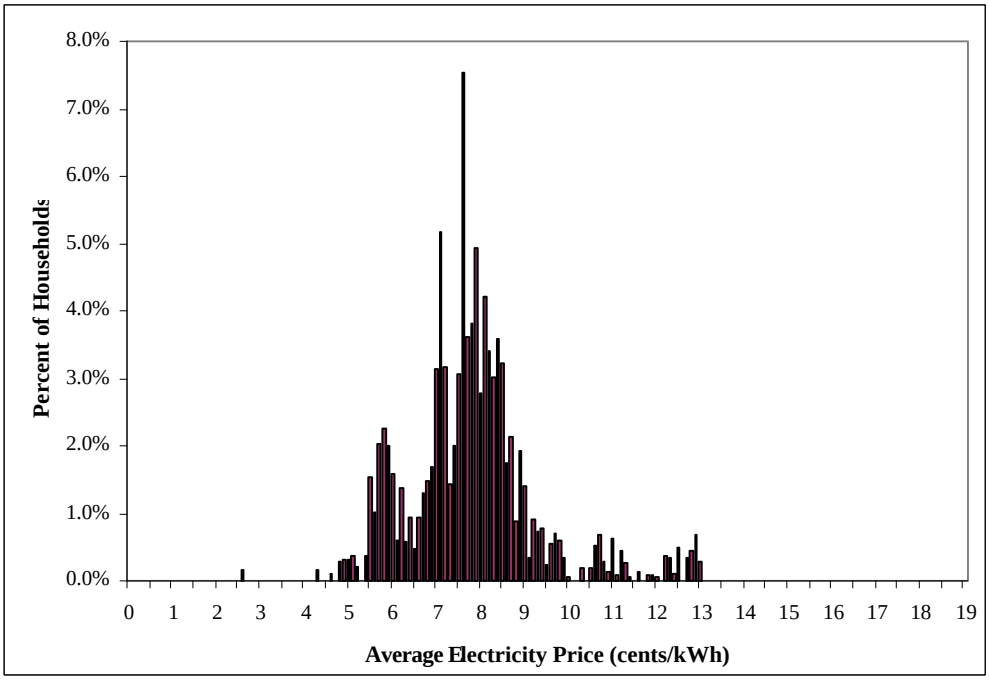

Figure 21 Percent of Households with heat Pumps by Average Electricity Prices (Source: EIA, 1993 RECS)

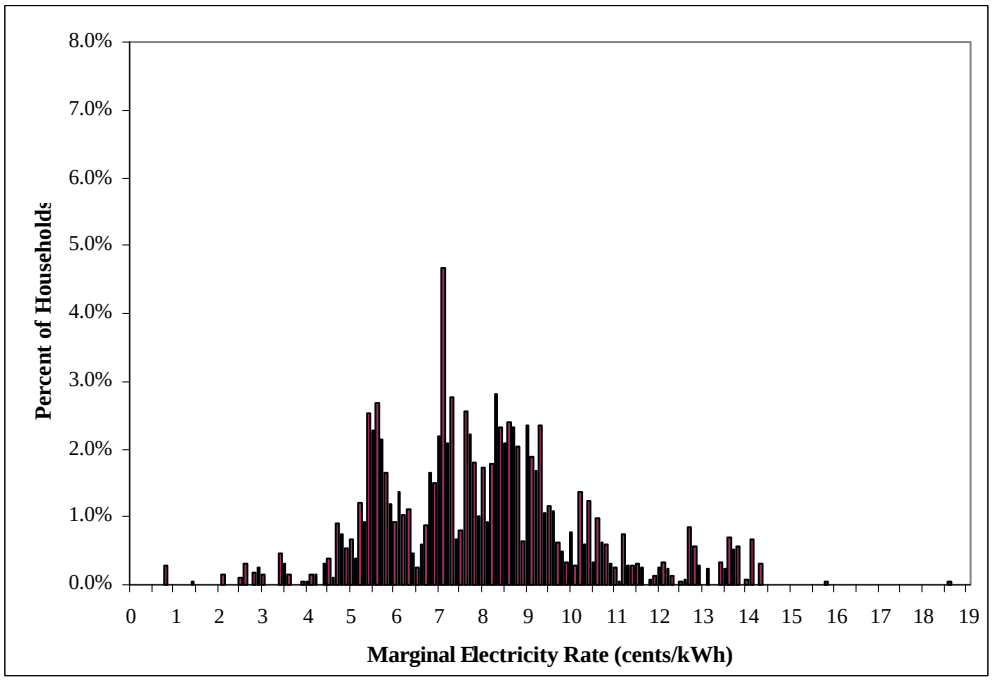

Figure 22 Percent of Households with Heat Pumps by Marginal Electricity Prices (Source: EIA, 1993 RECS)

As with central air conditioners, the RECS-based annual energy consumption and efficiency are associated with stock household heat pump equipment. Thus for any single RECS household, the annual energy consumption associated with a particular standard level must be determined by taking the ratio of the household's stock efficiency to the standard level efficiency and multiplying it by the household's annual energy consumption. This calculation can be represented for heat pumps with the following expression:

$$AEC_{std} = AEC_{stock_cool} \cdot \frac{SEER_{stock}}{SEER_{std}} + AEC_{stock_heat} \cdot \frac{HSPF_{stock}}{HSPF_{std}}$$

where:

AEC_{std} = Annual energy consumption of the standard level,
AEC_{stock_cool} = space-cooling annual energy consumption of the stock household equipment,
$SEER_{stock}$ = cooling-efficiency of the stock household equipment,
$SEER_{std}$ = cooling-efficiency of the standard level,
AEC_{stock_heat} = space-heating annual energy consumption of the stock household equipment,
$HSPF_{stock}$ = heating-efficiency of the stock household equipment, and
$HSPF_{std}$ = heating-efficiency of the standard level.

Based on the use of the RECS ***weighted-average*** annual energy consumption and efficiency, Table 16 presents the annual energy consumption values associated with each of the heat pump standard levels. The values presented in Table 16 provide an idea of the relative magnitude of the annual energy consumption associated with each standard level.

Table 16 Heat Pump Average Annual Energy Consumption, scaled to efficiency

	Efficiency		Annual Energy Consumption		
			Cooling	**Heating**	**Total**
	SEER	*HSPF*	*kWh/yr*	*kWh/yr*	*kWh/yr*
Survey	8.72 [1]	6.52 [1]	2987 [1]	4658 [1]	7645
Scaled	10	6.8	2604	4465	7069
	11	7.1	2366	4277	6643
	12	7.4	2169	4104	6273
	13	7.7	2002	3944	5946
	14	8.0	1859	3796	5655
	15	8.2	1735	3704	5439
	16	8.4	1627	3615	5242

[1] RECS-based weighted average values for household equipment in use in 1993.

The survival function (Figure 18) and the distribution of discount rates (Table 13) presented earlier for central air conditioners were also used for heat pumps.

Detailed Results Summary

Uncertainty

We are using a Monte Carlo method of analysis (i.e. random sampling from distributions) in conducting the life-cycle cost and payback period analysis. The results in this report are based on 10,000 samples per Monte Carlo run.

Baseline Life-Cycle Cost

The ***baseline*** life-cycle cost is based on ***average*** electricity prices from each RECS household, in agreement with the household energy bill. The change in LCC is based on ***marginal electricity prices***. Figures 23 through 26 below show the frequency distributions for the baseline life-cycle cost for the four primary product classes. Table 17 shows the mean, median, minimum, and maximum life-cycle cost from the baseline distributions for each of the product classes.

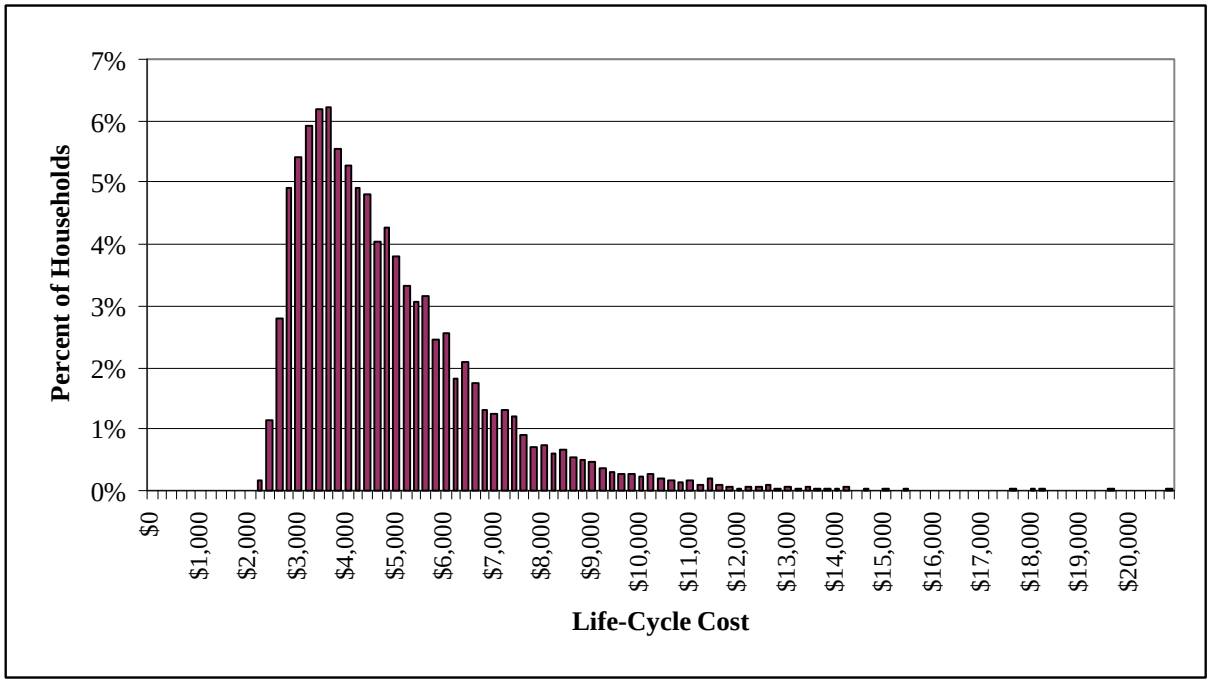

Figure 23 Split A/C: Percent of Households by Life-Cycle Cost, Baseline

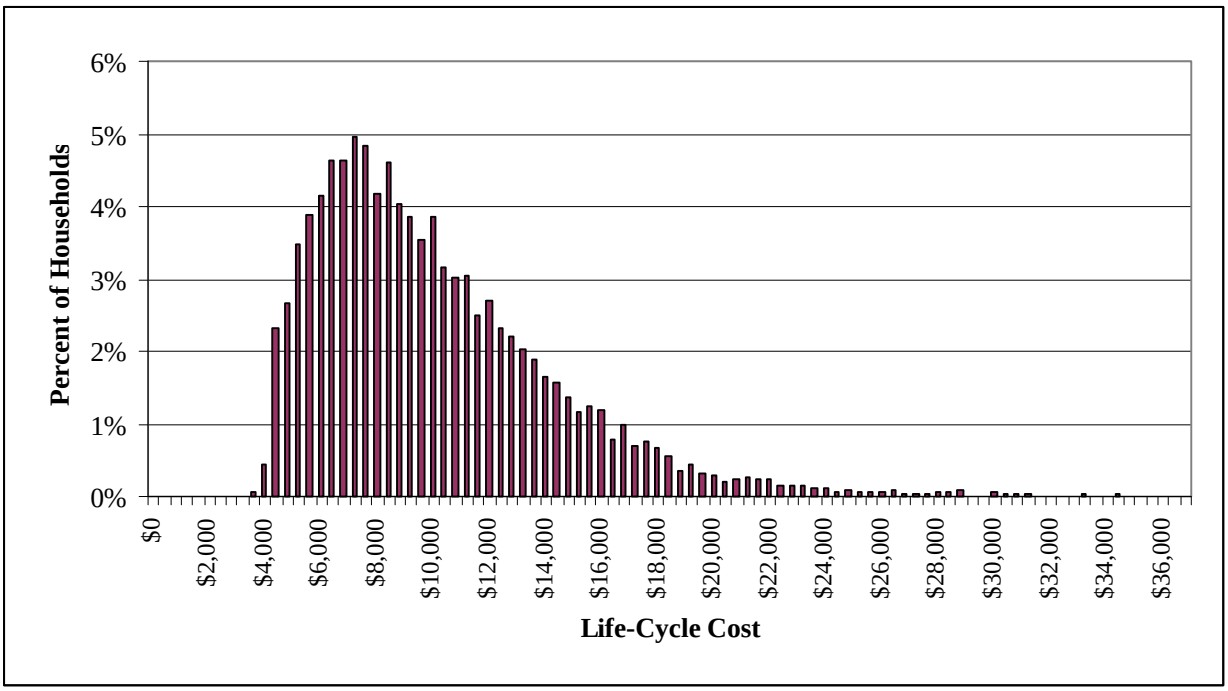

Figure 24 Split Heat Pump: Percent of Households by Life-Cycle Cost, Baseline

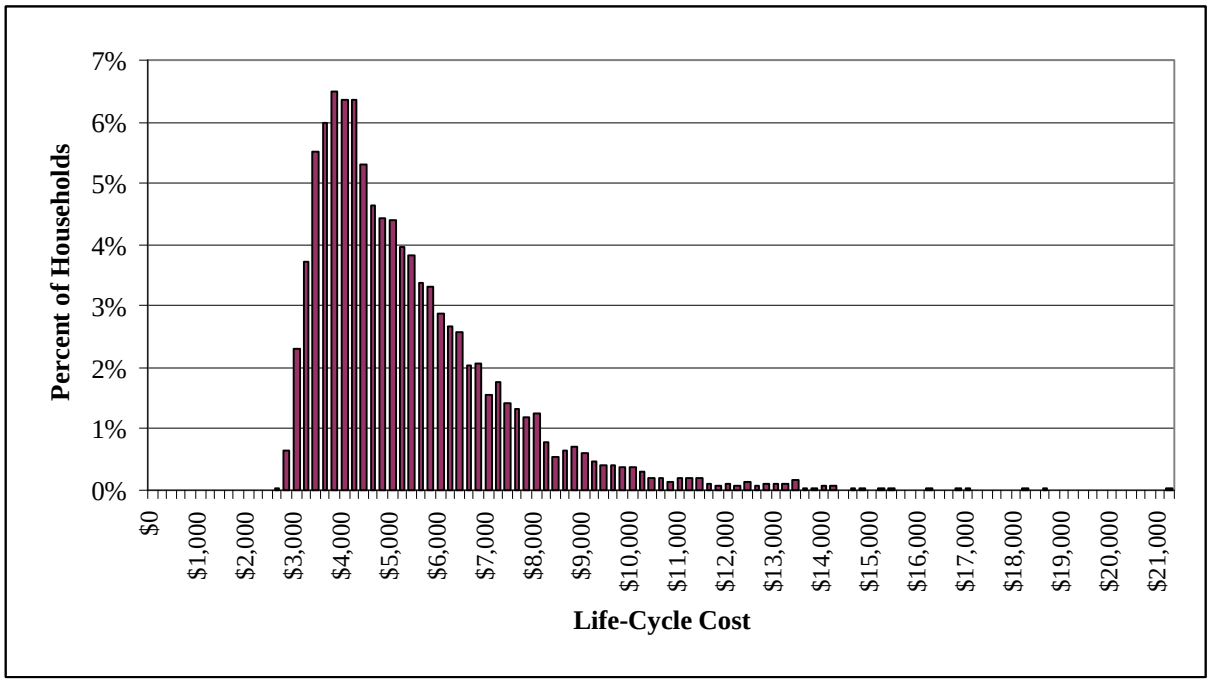

Figure 25 Single Package A/C: Percent of Households by Life-Cycle Cost, Baseline

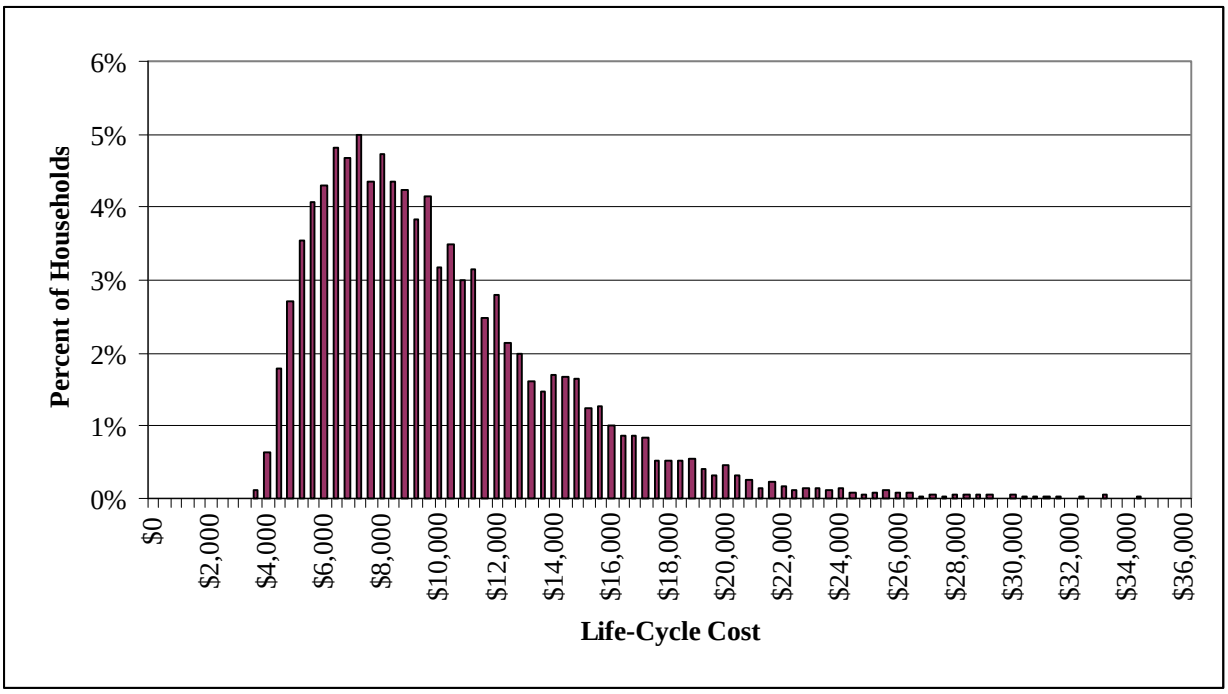

Figure 26 Single Package HP: Percent of Households by Life-Cycle Cost, Baseline

Table 17 Baseline LCC: Mean, Median, Minimum, and Maximum Values

Product Class	Minimum	Median	Mean	Maximum
Split A/C	$2,097	$4,367	$4,837	$20,808
Split Heat Pump	$3,382	$9,175	$10,086	$36,718
Package A/C	$2,475	$4,843	$5,341	$21,293
Package Heat Pump	$3,287	$9,031	$10,025	$44,870

Life-Cycle Cost Breakdown

Figures 27 through 50 show how the installed consumer costs, annual operating expenses, and life-cycle costs vary with efficiency for each of the four product classes. For each product class, the results based upon ARI manufacturer cost data and reverse engineering cost data are shown side-by-side in order that direct comparisons can be made. The figures for installed cost are segmented into equipment and installation price. The figures for annual operating expense are segmented into annual electricity, repair, and maintenance costs. The figures for life-cycle cost are segmented into installed consumer cost and lifetime operating expense. Although the following figures are based on mean or average values rather than results from the Monte Carlo analysis, they serve to demonstrate how the various inputs ultimately impact life-cycle cost and payback.

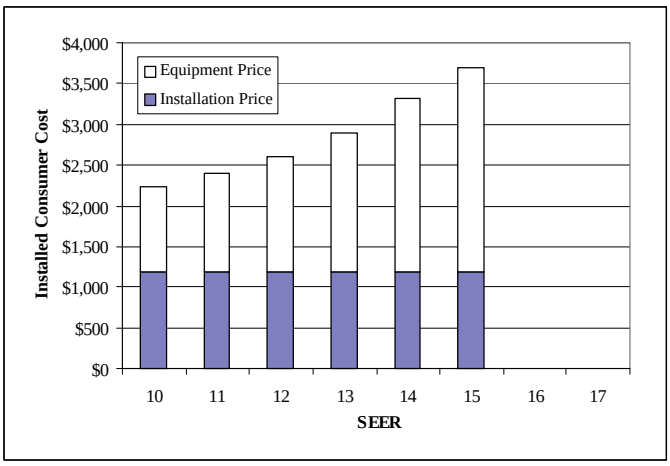

Figure 27 Split A/C: Mean Installed Consumer Costs – ARI

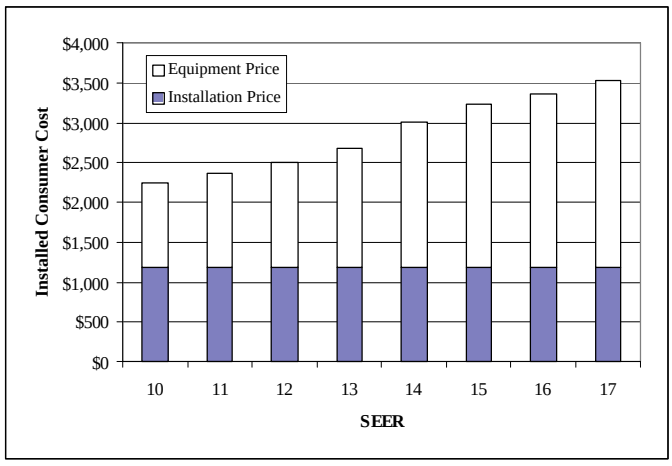

Figure 28 Split A/C: Mean Installed Consumer Costs – Rev Eng

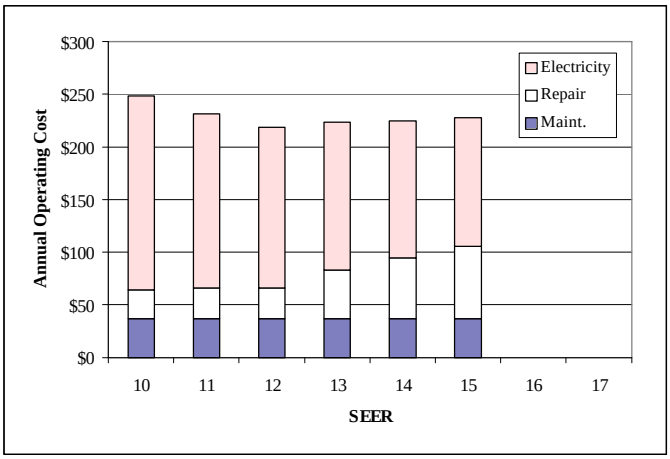

Figure 29 Split A/C: Mean Annual Operating Expenses – ARI

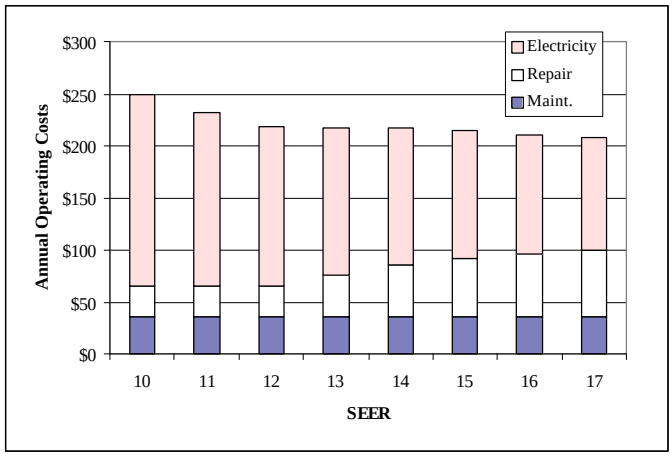

Figure 30 Split A/C: Mean Annual Operating Expenses – Rev Eng

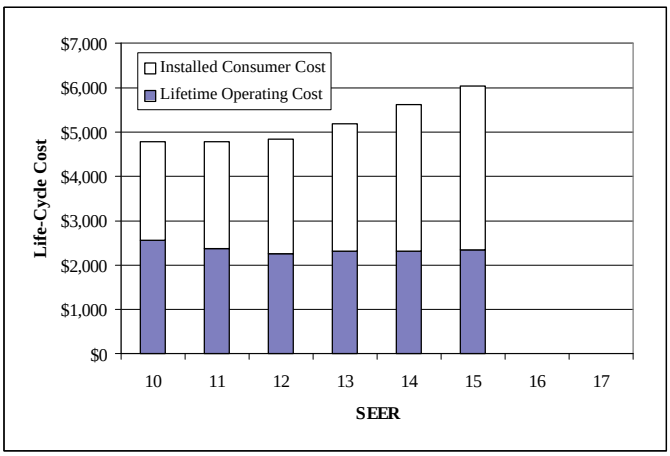

Figure 31 Split A/C: Mean Life-Cycle Costs – ARI

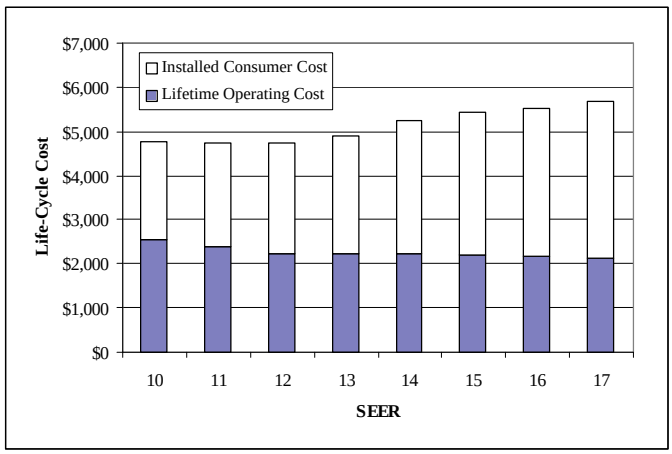

Figure 32 Split A/C: Mean Life-Cycle Costs – Rev Eng

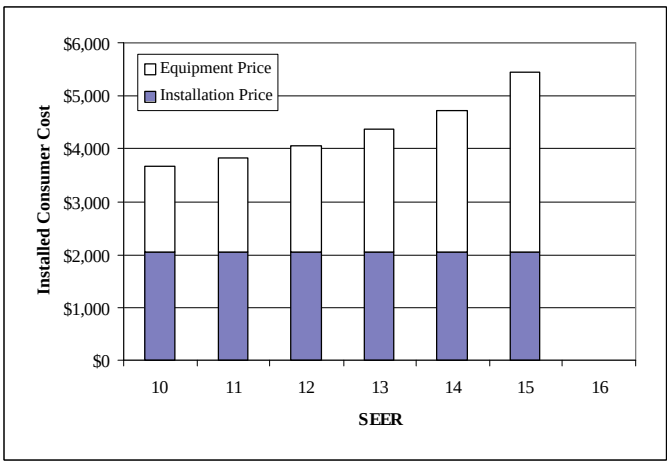

Figure 33 Split HP: Mean Installed Consumer Costs – ARI

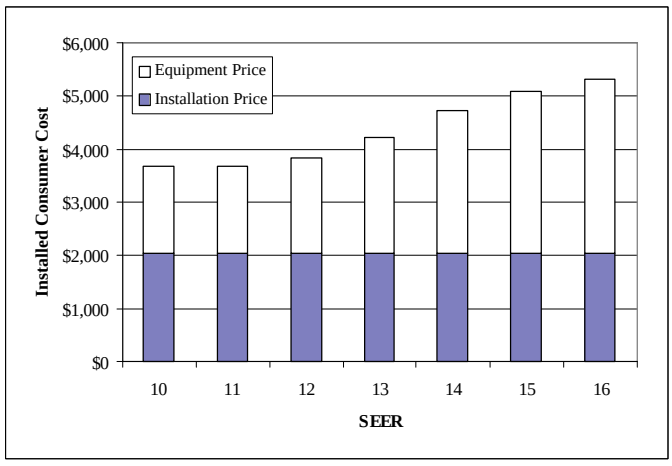

Figure 34 Split HP: Mean Installed Consumer Costs – Rev Eng

Figure 35 Split HP: Mean Annual Operating Expenses – ARI

Figure 36 Split HP: Mean Annual Operating Expenses – Rev Eng

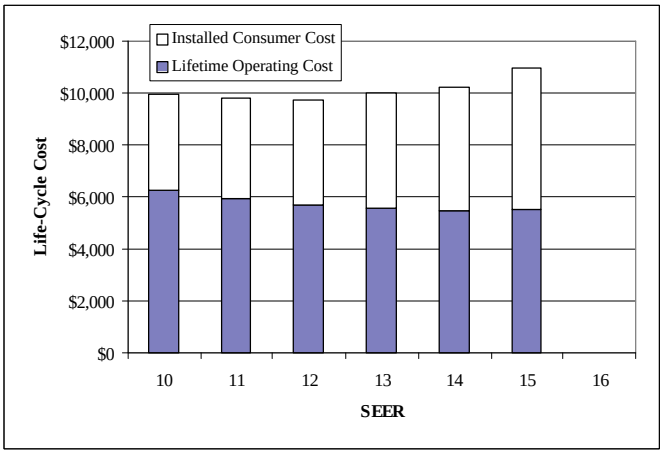

Figure 37 Split HP: Mean Life-Cycle Costs – ARI

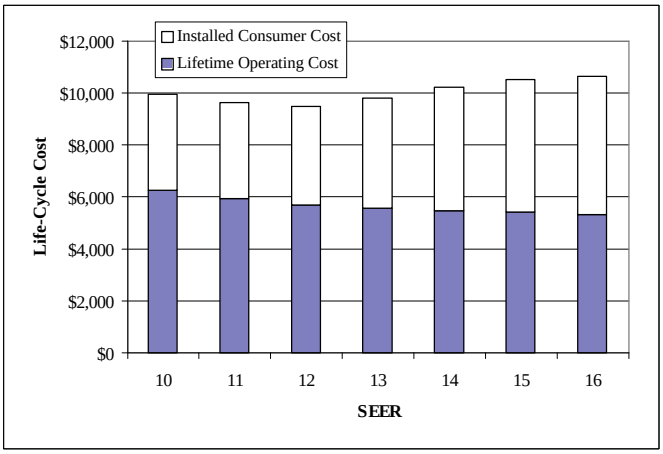

Figure 38 Split HP: Mean Life-Cycle Costs – Rev Eng

Figure 39 Package A/C: Mean Installed Consumer Costs – ARI

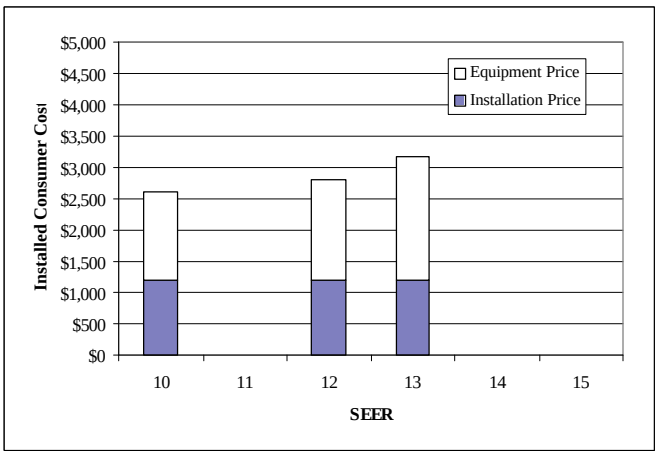

Figure 40 Package A/C: Mean Installed Consumer Costs – Rev Eng

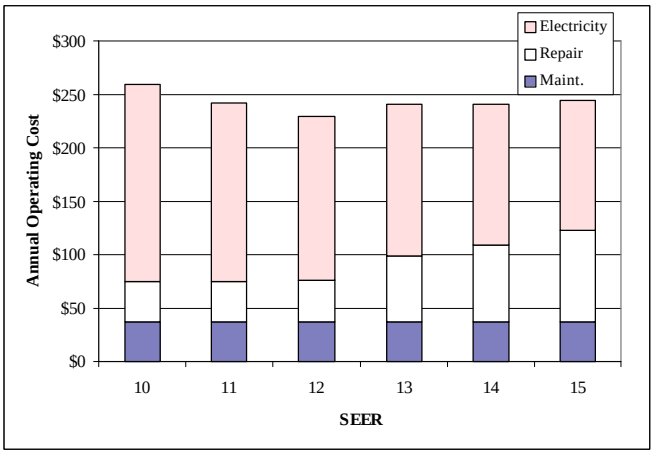

Figure 41 Package A/C: Mean Annual Operating Expenses – ARI

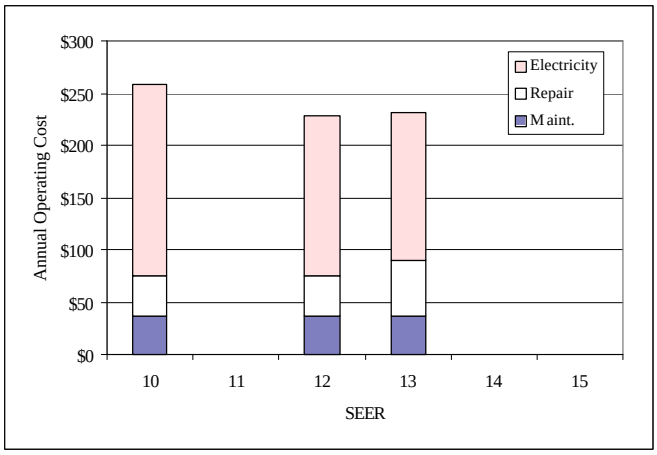

Figure 42 Package A/C: Mean Annual Operating Expenses – Rev Eng

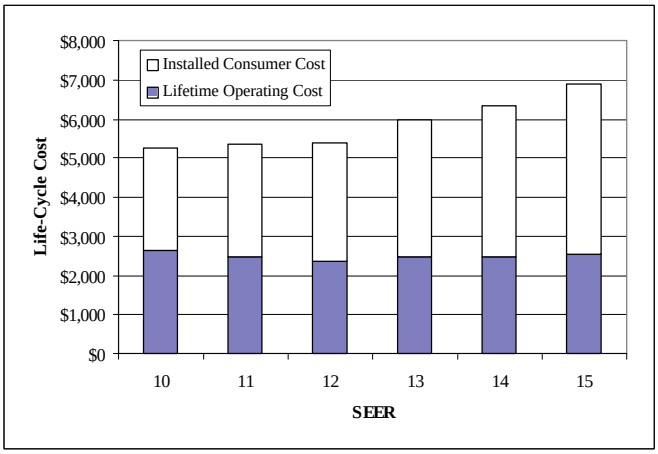

Figure 43 Package A/C: Mean Life-Cycle Costs – ARI

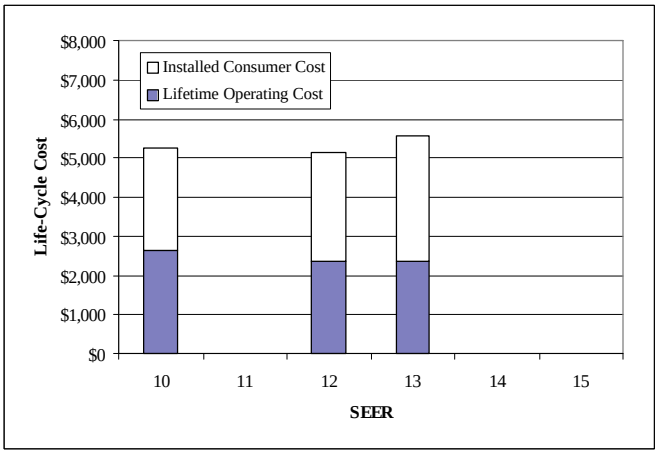

Figure 44 Package A/C: Mean Life-Cycle Costs – Rev Eng

Figure 45 Package HP: Mean Installed Consumer Costs – ARI

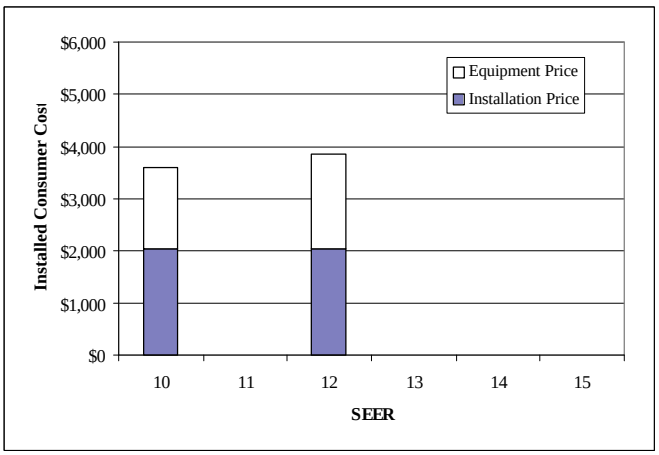

Figure 46 Package HP: Mean Installed Consumer Costs – Rev Eng

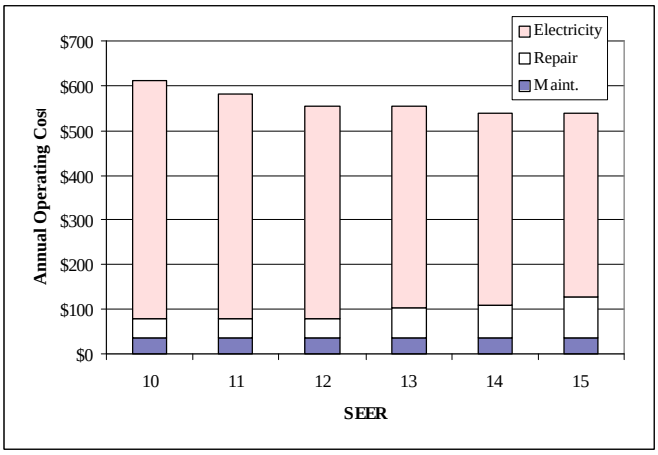

Figure 47 Package HP: Mean Annual Operating Expenses – ARI

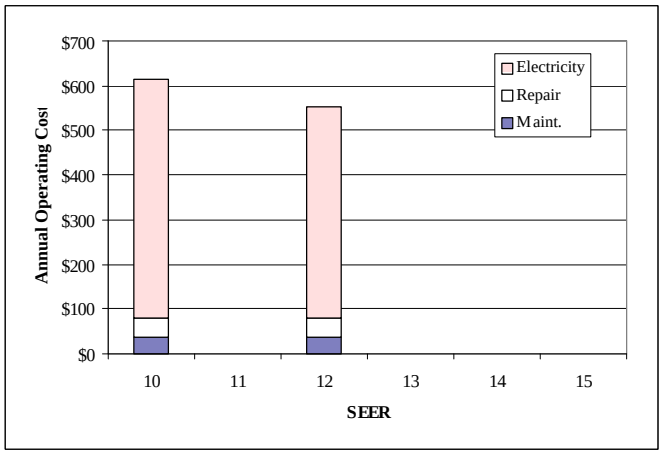

Figure 48 Package HP: Mean Annual Operating Expenses – Rev Eng

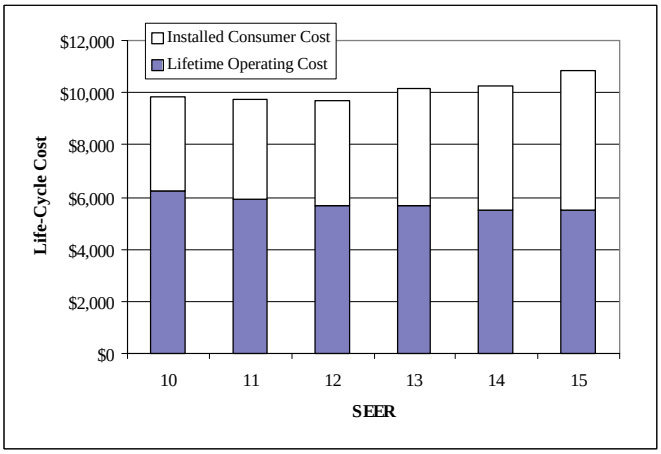

Figure 49 Package HP: Mean Life-Cycle Costs – ARI

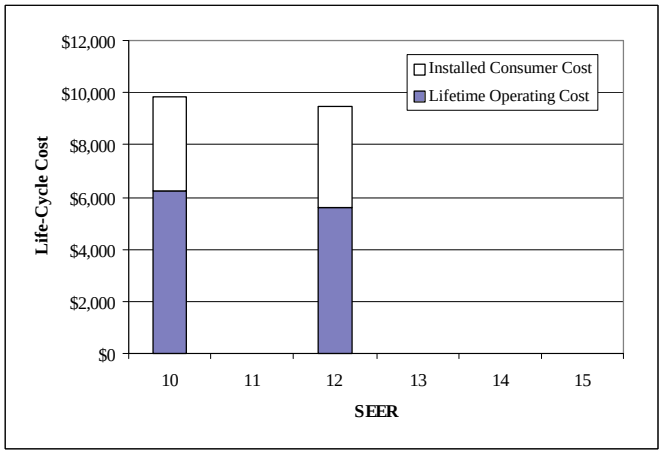

Figure 50 Package HP: Mean Life-Cycle Costs – Rev Eng

Change in Life-Cycle Costs

Tables 18 through 21 show the LCC results for each of the four primary product classes. Results are summarized for the change in LCC from the baseline by percentile groupings (i.e., percentile of the distribution of results). The mean and the percent of LCCs that are reduced for each standard level are also shown.

Example: In Table 18 for split system air conditioners based on ARI cost data, the 11 SEER efficiency level (row 1) shows that the maximum (zero percentile column) change in LCC is savings of $1,586. (Negative values are net savings.) For 90% of the cases studied (90th percentile), the change in LCC is a cost of $130 or less. The largest increase in LCC is $197 ($100^{th}$ percentile). The mean change in LCC is a net savings of $10. The last column shows that 39% of the sample have reduced LCC (i.e., change in LCC less than or equal to zero).

Figures 51 through 58 graphically compare the ARI and reverse engineering LCC results. In this way, direct comparisons can be made as to how the different sets of cost data impact life-cycle cost. The first figure for each product class shows the mean LCCs while the second figure shows the percentage of households at each standard level with reduced LCCs.

Table 18 Summary of LCC Results for Split Air Conditioners

Efficiency Level (SEER)	Change in LCC from Baseline Shown by Percentiles of the Distribution of Results (values in 1998$)												Percent of Households with reduced LCC
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean	
ARI													
11	$-1,586	$-205	$-97	$-40	$2	$38	$64	$87	$108	$130	$197	$-10	39%
12	$-2,948	$-322	$-113	$-9	$73	$135	$182	$226	$266	$306	$433	$49	31%
13	$-4,045	$-76	$179	$318	$417	$499	$562	$613	$667	$750	$1,062	$392	12%
14	$-5,599	$248	$550	$717	$836	$935	$1,014	$1,085	$1,166	$1,283	$1,793	$822	6%
15	$-4,884	$528	$897	$1,079	$1,218	$1,329	$1,429	$1,521	$1,634	$1,795	$2,551	$1,215	4%
Rev Eng													
11	$-1,750	$-240	$-128	$-71	$-29	$4	$31	$55	$76	$98	$157	$-42	48%
12	$-3,625	$-416	$-226	$-117	$-36	$29	$78	$123	$159	$199	$317	$-68	45%
13	$-4,211	$-393	$-122	$32	$137	$221	$288	$341	$393	$450	$710	$103	27%
14	$-4,785	$-165	$138	$319	$449	$549	$629	$697	$768	$862	$1,402	$418	15%
15	$-5,947	$-45	$313	$509	$654	$766	$864	$943	$1,029	$1,155	$1,757	$626	11%
16	$-5,609	$-71	$362	$575	$740	$866	$971	$1,060	$1,153	$1,290	$1,951	$705	11%
17	$-7,245	$0	$455	$698	$882	$1,021	$1,135	$1,230	$1,336	$1,491	$2,329	$844	10%

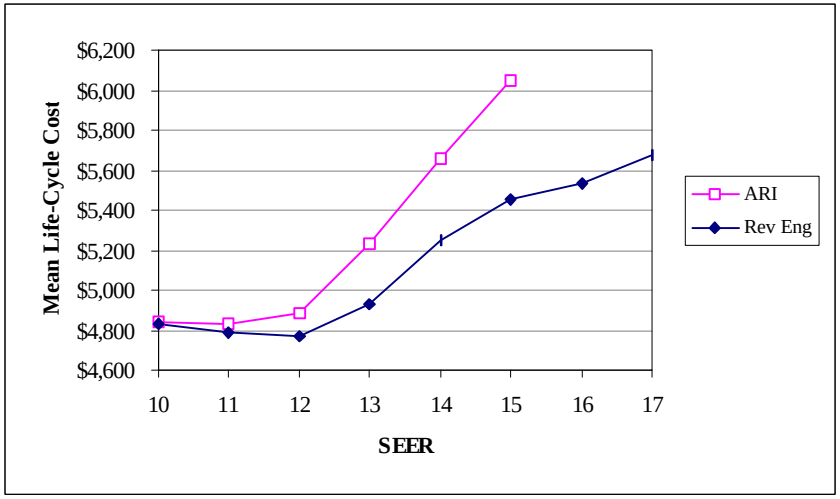

Figure 51 Split A/C: Mean Life-Cycle Cost – ARI vs. Rev Eng

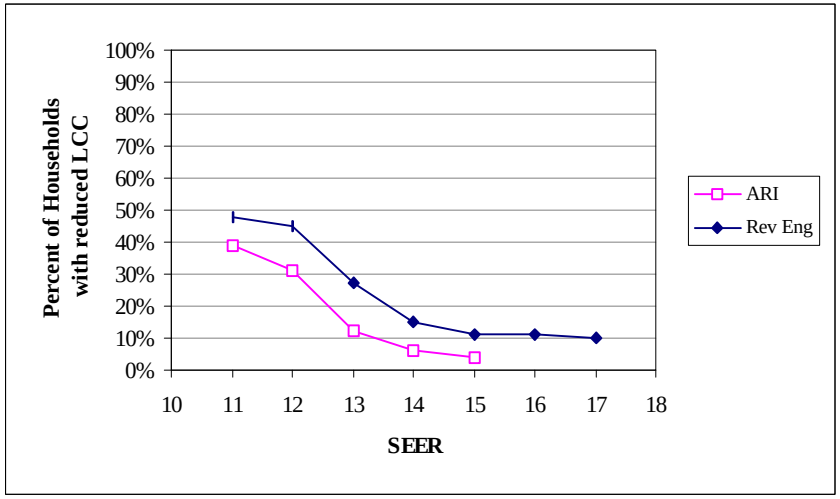

Figure 52 Split A/C: Percent with reduced LCC – ARI vs. Rev Eng

Table 19 Summary of LCC Results for Split Heat Pumps

Efficiency Level (SEER /HSPF)	Change in LCC from Baseline Shown by Percentiles of the Distribution of Results (values in 1998$)												Percent of Households with reduced LCC
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean	
ARI													
11 / 7.1	$-2,824	$-488	$-326	$-231	$-165	$-110	$-64	$-19	$24	$78	$169	$-171	74%
12 / 7.4	$-6,395	$-824	$-523	$-341	$-219	$-114	$-28	$54	$134	$231	$421	$-234	63%
13 / 7.7	$-8,619	$-745	$-338	$-101	$66	$194	$306	$410	$509	$639	$1,083	$33	36%
14 / 8.0	$-9,091	$-768	$-227	$51	$256	$433	$569	$693	$826	$1,001	$1,577	$225	28%
15 / 8.2	$-10,502	$-98	$485	$806	$1,031	$1,213	$1,361	$1,501	$1,644	$1,853	$2,671	$993	11%
Rev Eng													
11 / 7.1	$-3,359	$-616	$-454	$-362	$-301	$-246	$-199	$-156	$-113	$-60	$22	$-306	99%
12 / 7.4	$-6,468	$-1,06	$-738	$-570	$-445	$-347	$-258	$-179	$-94	$5	$166	$-468	90%
13 / 7.7	$-7,247	$-915	$-505	$-281	$-121	$7	$116	$218	$323	$466	$803	$-151	49%
14 / 8.0	$-8,162	$-712	$-204	$79	$282	$435	$571	$694	$827	$1,004	$1,541	$245	27%
15 / 8.2	$-8,663	$-604	$9	$340	$570	$752	$915	$1,064	$1,204	$1,410	$2,114	$633	20%
16 / 8.4	$-9,632	$-555	$110	$470	$722	$915	$1,087	$1,243	$1,418	$1,658	$2,564	$678	18%

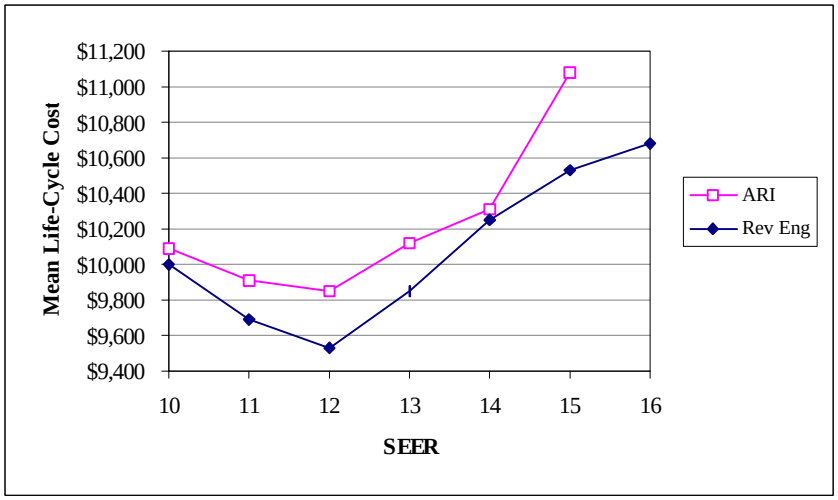

Figure 53 Split HP: Mean Life-Cycle Costs – ARI vs. Rev Eng

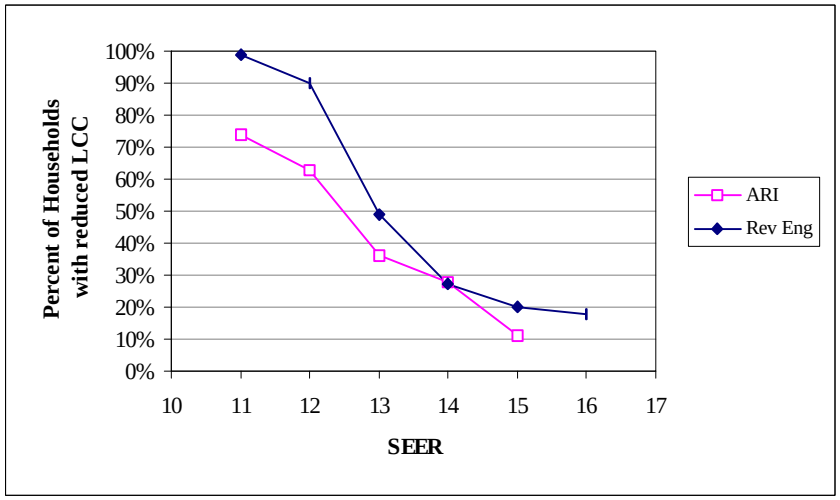

Figure 54 Split HP: Percent with reduced LCC – ARI vs. Rev Eng

Table 20 Summary of LCC Results for Single Package Air Conditioners

Efficiency Level (SEER)	Change in LCC from Baseline Shown by Percentiles of the Distribution of Results (values in 1998$)												Percent of Households with reduced LCC
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean	
ARI													
11	$-1,525	$-113	$-4	$57	$102	$138	$166	$188	$210	$231	$292	$88	20%
12	$-3,528	$-277	$-78	$34	$119	$183	$233	$279	$320	$359	$453	$92	26%
13	$-5,373	$238	$478	$617	$711	$784	$849	$907	$961	$1,033	$1,374	$690	5%
14	$-5,024	$469	$765	$926	$1,047	$1,136	$1,212	$1,285	$1,362	$1,460	$1,893	$1,021	4%
15	$-6,394	$936	$1,277	$1,461	$1,595	$1,700	$1,792	$1,880	$1,978	$2,102	$2,774	$1,580	2%
Rev Eng													
12	$-3,125	$-485	$-284	$-184	$-106	$-41	$8	$50	$90	$126	$220	$-130	58%
13	$-4,751	$-202	$63	$208	$310	$385	$449	$506	$557	$612	$876	$274	17%

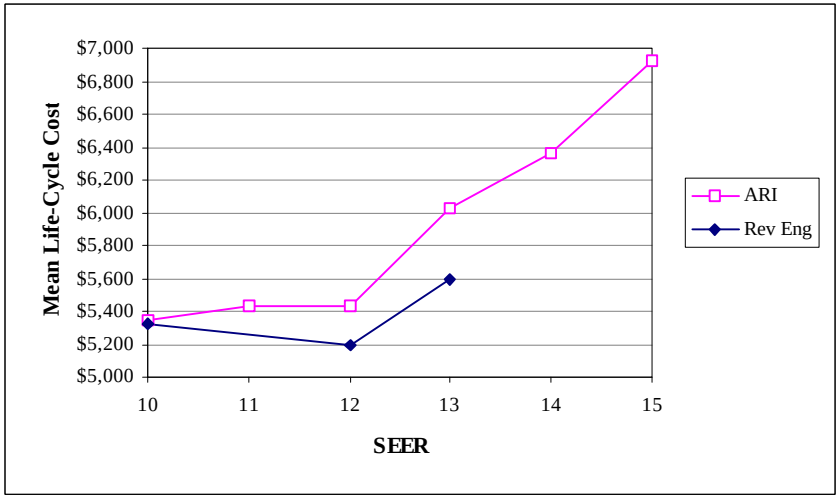

Figure 55 Package A/C: Mean Life-Cycle Costs – ARI vs. Rev Eng

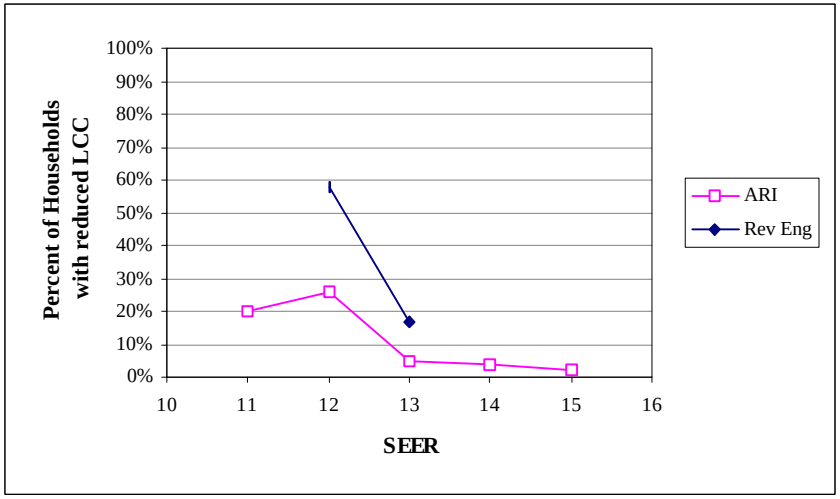

Figure 56 Package A/C: Percent with reduced LCC – ARI vs. Rev Eng

Table 21 Summary of LCC Results for Single Package Heat Pumps

Efficiency Level (SEER)	Change in LCC from Baseline Shown by Percentiles of the Distribution of Results (values in 1998$)												Percent of Households with reduced LCC
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean	
ARI													
11 / 7.1	$-3,343	$-437	$-269	$-175	$-109	$-55	$-6	$35	$79	$133	$222	$-119	61%
12 / 7.4	$-5,706	$-788	$-472	$-300	$-182	$-78	$14	$101	$181	$281	$462	$-190	58%
13 / 7.7	$-9,377	$-468	$-44	$186	$348	$468	$572	$673	$768	$919	$1,387	$317	22%
14 / 8.0	$-7,381	$-549	$-46	$233	$429	$596	$726	$845	$972	$1,145	$1,670	$400	21%
15 / 8.2	$-9,444	$-33	$519	$821	$1,041	$1,210	$1,358	$1,496	$1,644	$1,849	$2,810	$1,006	10%
Rev Eng													
12 / 7.4	$-5,235	$-940	$-636	$-468	$-344	$-246	$-161	$-83	$1	$101	$260	$-361	80%

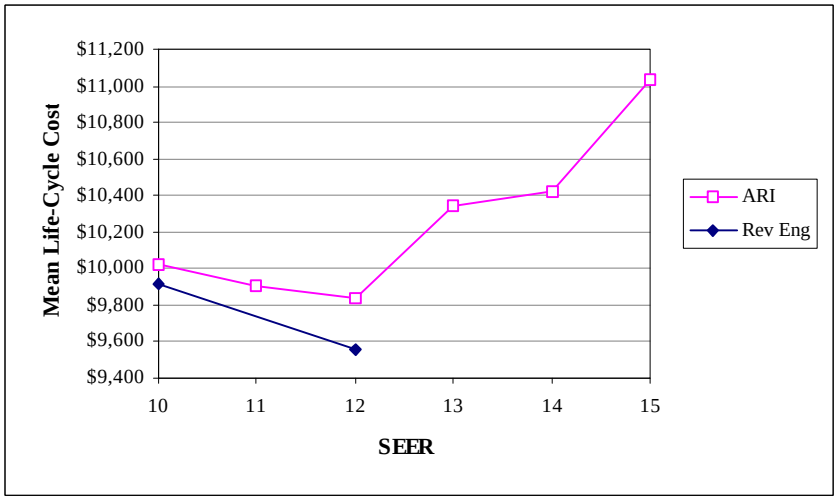

Figure 57 Package HP: Mean Life-Cycle Costs – ARI vs. Rev Eng

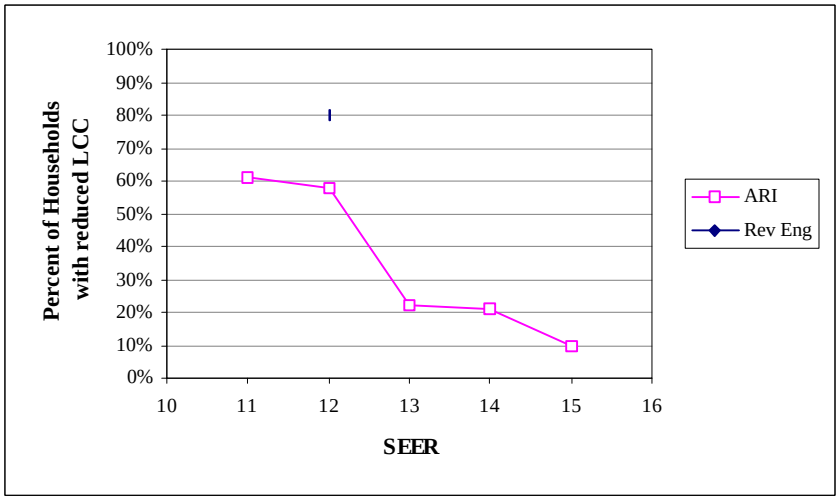

Figure 58 Package HP: Percent with reduced LCC – ARI vs. Rev Eng

Payback Period

Simple payback periods (ratio of increase in purchase price to decrease in annual operating expense) were calculated using the same distributions as for the LCC analysis. The payback is calculated based on the year the standard takes effect, in this case the year 2006. Because this is a simple payback, escalation rates beyond the year 2006 have no affect on the calculation, nor do discount rates.

Tables 25 through 25 show the payback period results for each of the four primary product classes. Results are summarized for the payback period by percentile groupings (i.e., percentile of the distribution of results). The mean payback period for each standard level are also shown.

Figures 59 through 66 graphically compare the ARI and reverse engineering payback period results. In this way, direct comparisons can be made as to how the different sets of cost data impact payback period. The first figure for each product class shows the median (50th percentile) payback periods while the second figure shows the mean payback periods. In must be noted that in the figures, payback periods exceeding 35 years are represented graphically as a 35 year payback.

Table 22 Summary of Payback Period Results for Split Air Conditioners

Efficiency Level (SEER)	Payback Period in Years Shown by Percentiles of the Distribution of Results											
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean
ARI												
11	1	5	7	8	10	13	16	21	28	44	>1000	33
12	2	6	8	10	13	15	20	25	34	52	>1000	28
13	2	10	15	20	27	41	70	182	1000	1000	>1000	440
14	3	14	22	32	48	80	222	1000	1000	1000	>1000	546
15	3	17	28	42	67	137	1000	1000	1000	1000	>1000	1104
Rev Eng												
11	1	4	5	7	8	10	13	17	22	34	>1000	26
12	1	4	6	7	9	11	14	18	25	37	>1000	20
13	1	6	8	11	14	20	29	47	115	1000	>1000	204
14	2	9	13	18	24	35	59	137	1000	1000	>1000	375
15	2	10	15	21	29	43	80	261	1000	1000	>1000	352
16	2	11	15	22	30	46	84	273	1000	1000	>1000	1086
17	2	11	16	23	32	49	95	419	1000	1000	>1000	855

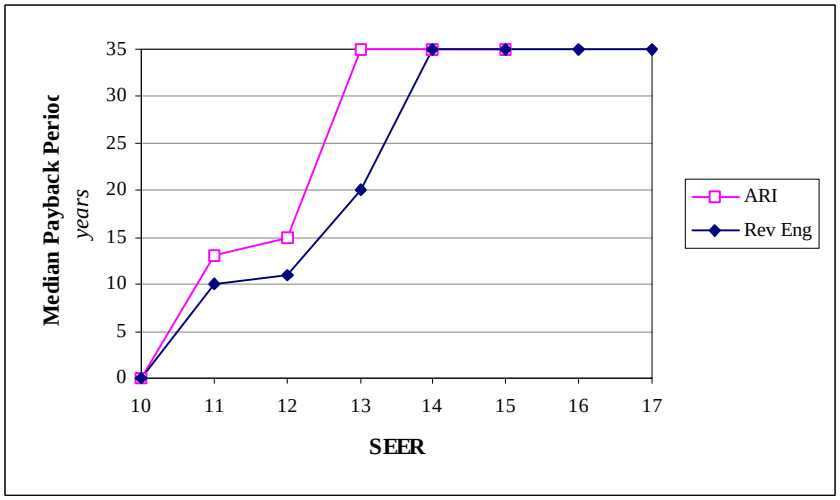

Figure 59 Split A/C: Median Payback Periods – ARI vs. Rev Eng

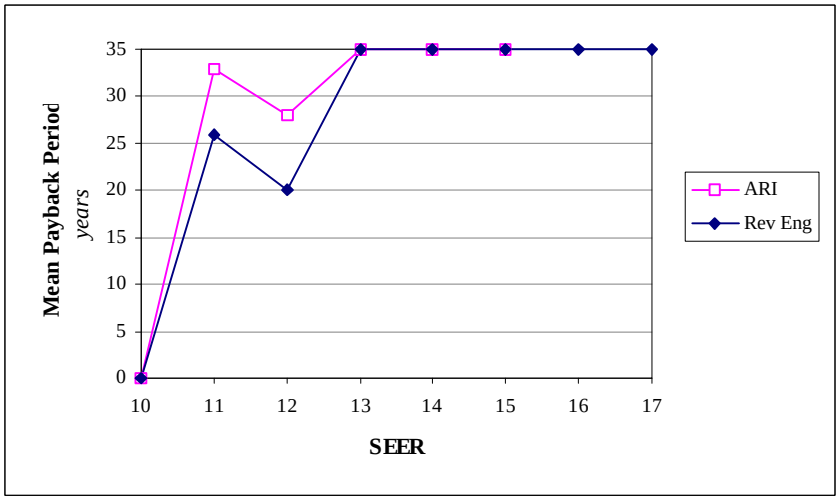

Figure 60 Split A/C: Mean Payback Periods – ARI vs. Rev Eng

Table 23 Summary of Payback Period Results for Split Heat Pumps

Efficiency Level (SEER / HSPF)	Payback Period in Years Shown by Percentiles of the Distribution of Results											
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean
ARI												
11 / 7.1	1	3	4	5	5	6	7	8	10	16	250	10
12 / 7.4	1	4	5	6	7	8	9	11	13	21	326	13
13 / 7.7	1	6	7	9	11	13	17	21	31	85	>1000	129
14 / 8.0	2	7	9	11	14	17	21	28	42	245	>1000	131
15 / 8.2	2	11	14	19	24	31	42	61	122	1000	>1000	219
Rev Eng												
11 / 7.1	0	0	1	1	1	1	1	1	1	2	34	1
12 / 7.4	0	2	2	2	3	3	4	4	5	9	111	5
13 / 7.7	1	4	6	7	8	10	12	15	20	50	>1000	81
14 / 8.0	1	7	9	11	14	17	21	27	41	204	>1000	119
15 / 8.2	2	8	11	14	17	21	27	37	58	841	>1000	142
16 / 8.4	2	8	11	15	18	22	28	38	63	1000	>1000	150

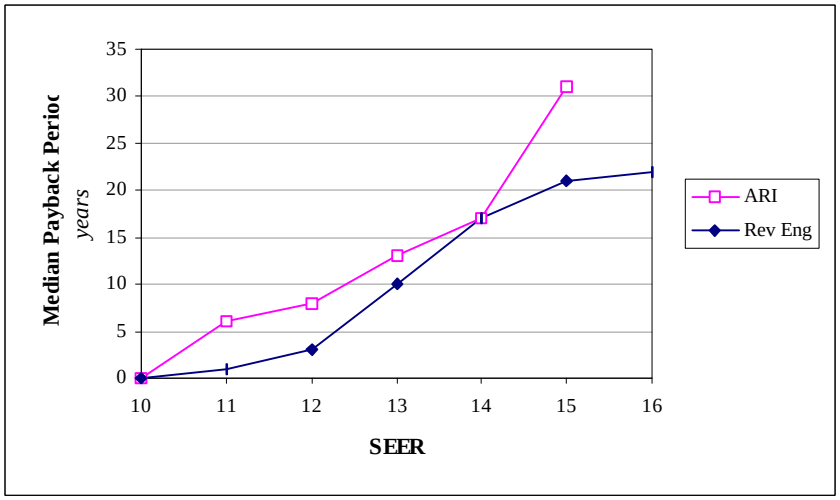

Figure 61 Split HP: Median Payback Periods – ARI vs. Rev Eng

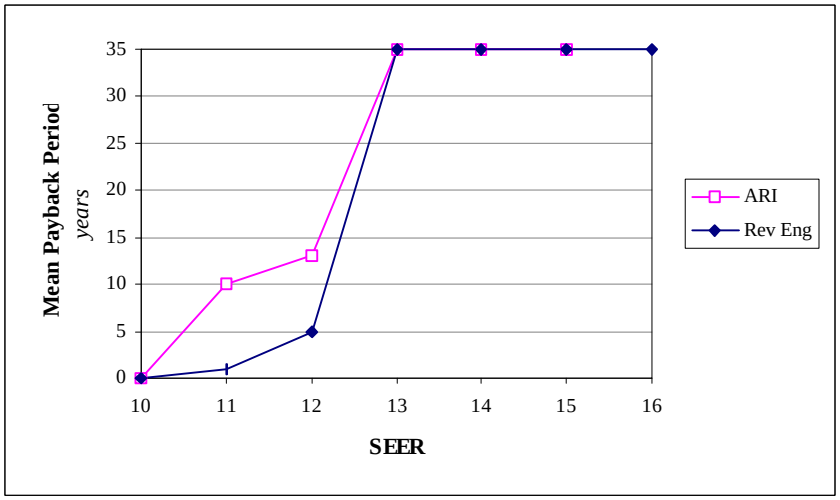

Figure 62 Split HP: Mean Payback Periods – ARI vs. Rev Eng

Table 24 Summary of Payback Period Results for Single Package Air Conditioners

Efficiency Level (SEER)	Payback Period in Years Shown by Percentiles of the Distribution of Results											
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean
ARI												
11	2	8	11	14	17	20	26	34	46	71	>1000	36
12	2	7	9	12	14	17	22	29	39	63	>1000	42
13	2	15	23	33	50	84	267	1000	1000	1000	>1000	486
14	3	17	28	42	67	133	1000	1000	1000	1000	>1000	531
15	4	23	40	66	125	558	1000	1000	1000	1000	>1000	645
Rev Eng												
12	1	3	4	5	7	8	10	13	18	27	>1000	15
13	2	8	12	16	22	30	49	108	1000	1000	>1000	288

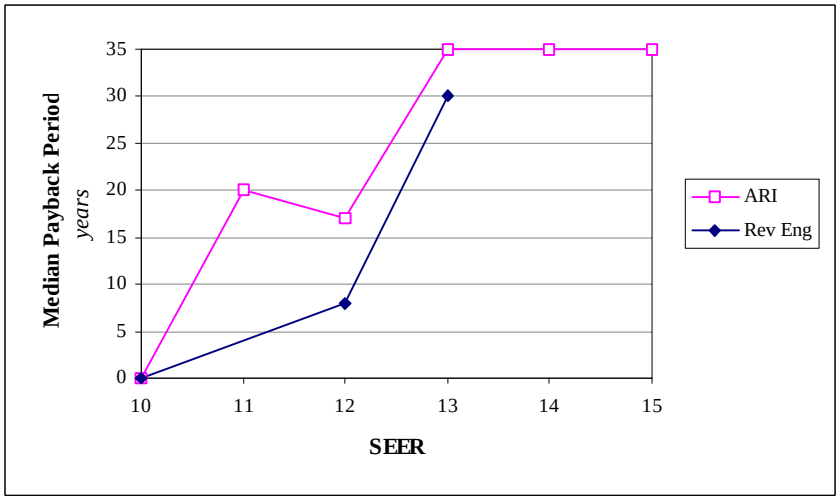

Figure 63 Package A/C: Median Payback Periods – ARI vs. Rev Eng

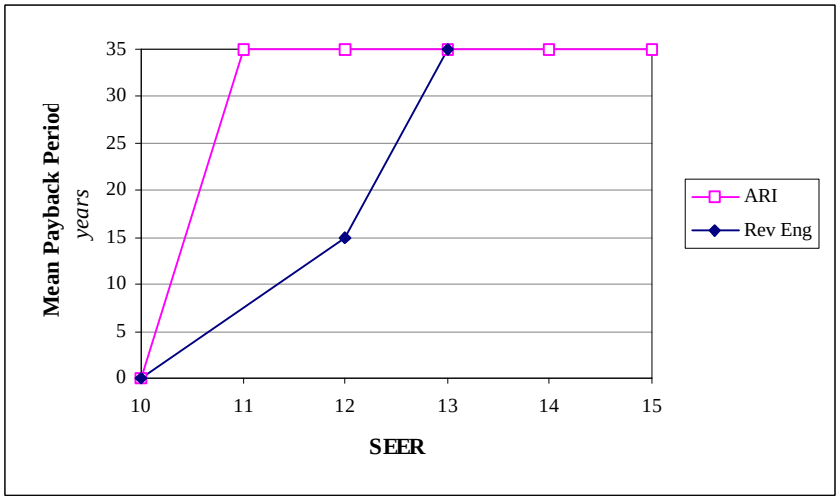

Figure 64 Package A/C: Mean Payback Periods – ARI vs. Rev Eng

Table 25 Summary of Payback Period Results for Single Package Heat Pumps

Efficiency Level (SEER / HSPF)	Payback Period in Years Shown by Percentiles of the Distribution of Results											
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Mean
ARI												
11 / 7.1	1	4	5	6	7	8	9	11	14	21	321	13
12 / 7.4	1	4	5	6	8	9	10	12	15	25	313	14
13 / 7.7	2	8	10	13	16	20	25	34	51	503	>1000	183
14 / 8.0	2	8	10	13	16	20	25	34	51	477	>1000	134
15 / 8.2	2	11	15	19	24	31	42	63	128	1000	>1000	218
Rev Eng												
12 / 7.4	1	3	3	4	5	5	6	7	9	14	181	8

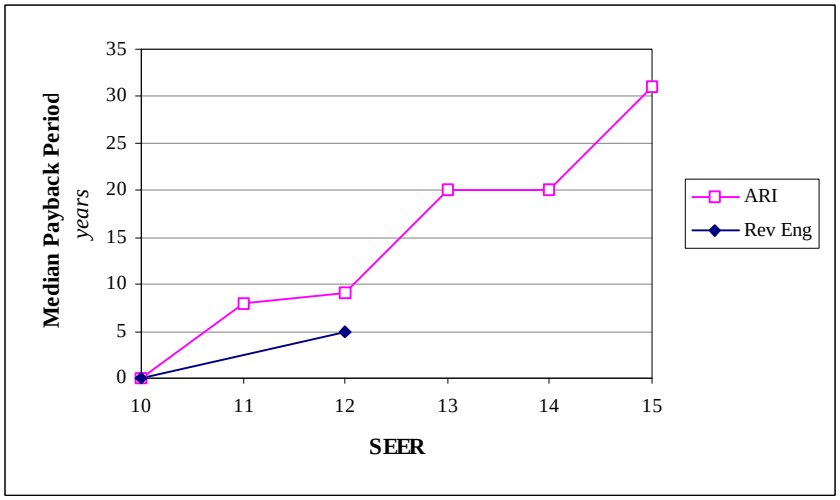

Figure 65 Package HP: Median Payback Periods – ARI vs. Rev Eng

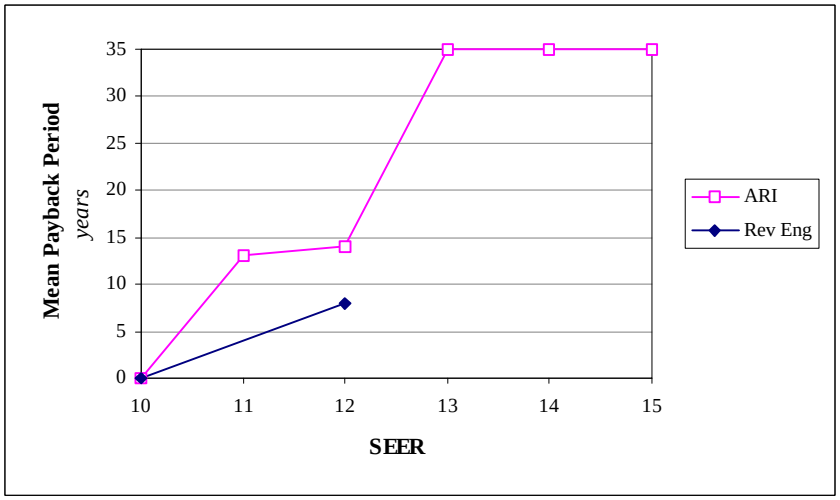

Figure 66 Package HP: Mean Payback Periods – ARI vs. Rev Eng