CHAPTER 5: LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

5.1 INTRODUCTION

This chapter describes the method for analyzing the economic impacts of possible standards on individual consumers. The effect of standards on individual consumers include a change in operating expense (usually decreased) and a change in purchase price (usually increased). This chapter describes three metrics used in the consumer analysis to determine the effect of standards on individual consumers:

- **Life-cycle cost** (LCC) captures the tradeoff between purchase price and operating expenses for appliances.

- **Payback period** (PBP) measures the amount of time it takes consumers to recover the assumed higher purchase expense of more energy-efficient equipment through lower operating costs.

- **Rebuttable Payback Period** is a special case of PBP. Where LCC and PBP are estimated over a range of inputs reflecting actual conditions, Rebuttable Payback Period is based on laboratory conditions, specifically, DOE test procedure inputs.

These are discussed in sections 5.2, 5.3 and 5.4 of this chapter, respectively. Inputs and preliminary results are presented for each metric. Key variables, current assumptions, and calculations are presented for each metric. The calculations discussed here are performed on a series of Microsoft Excel spreadsheets which are accessible over the Internet. Details and instructions for the spreadsheets are discussed in section 5.5. A more complete set of results are presented in Appendix E.

5.1.1 General Approach for LCC and PBP Analysis

In recognition that each building where air conditioners or heat pumps are used is unique, variability and uncertainty is analyzed by performing the LCC and PBP calculations detailed here for a representative sample of individual households and commercial buildings. The analysis takes into account equipment use in commercial buildings based on the assumption that 10% of equipment applications are in commercial buildings. The results are expressed as the number of buildings experiencing economic impacts of different magnitudes. The LCC and PBP model was developed using Microsoft Excel spreadsheets combined with Crystal Ball (a commercially available add-in).

The LCC and PBP analyses explicitly model both the uncertainty and the variability in the model's inputs using Monte Carlo simulation and probability distributions. A detailed explanation of Monte Carlo simulation and the use of probability distributions is contained in Appendix A.

The LCC and PBP results are displayed as distributions of impacts compared to the baseline conditions. Results are presented at the end of this chapter and are based on 10,000 samples per Monte Carlo simulation run. A variety of graphic displays will be created to illustrate the implications of the analysis. Examples would be: 1) a cumulative probability distribution showing the percentage of consumers that would experience a net savings by owning a more energy efficient appliance, and 2) a frequency chart depicting variation in life-cycle cost for each efficiency level considered.

5.1.2 Overview of LCC, PBP, and Rebuttable PBP Inputs

LCC is the total consumer expense over the life of the appliance, including purchase expense and operating costs (including energy expenditures). Future operating costs 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 cost 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 total installed cost, and 2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer cost*: The cost to manufacture equipment meeting existing minimum efficiency standards.

- *Standard-level manufacturer cost multiplier*: The multiplicative factor used for calculating the manufacturer cost associated with each standard-level.

- *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, *dealer markup* – markup for converting the dealer or contractor cost to the price which builder or consumers pay for the equipment, and *builder markup* – markup for converting the builder cost to the price which consumers pay for the equipment (applies only to the new construction market). In addition to the markups, a *sales tax* was developed.

- *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. Thus, the total installed 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 cost 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. For households, the annual energy consumption is based on data from the 1997 Residential Energy Consumption Survey (RECS). For those households surveyed in RECS with either a central air conditioner or heat pump, the estimated annual energy consumption corresponds to the household's stock equipment, specifically its capacity and efficiency. For equipment used in commercial buildings, the annual energy consumption is determined through computer simulations of 77 nationally representative commercial buildings based on assumptions similar to what were used to develop the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' (ASHRAE) Standard 90.1-99.

- *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 are primarily based on data from the 1997 RECS. For equipment used in commercial buildings, all buildings were assumed to have equipment efficiencies equal to existing minimum efficiency standards. To estimate the annual energy consumption associated with a particular standard-level, the ratio of the building's stock efficiency to the standard-level efficiency is multiplied by the buildings'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.

- *Electricity price trends*: The Annual Energy Outlook 2000 (AEO00) was used to forecast electricity prices into the future. For the results presented here, the AEO00 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).

- *Repair costs*: The cost associated with repairing or replacing component failures.

- *Lifetime*: The age at which the central air conditioner or heat pump is retired from service.

- *Discount rate*: The rate at which future expenditures are discounted to establish their present value.

Figure 5.1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC, PBP, and Rebuttable PBP. All of the inputs depicted in Figure 5.1 that are needed for the determination of LCC, PBP, and Rebuttable PBP are discussed in detail in Section 5.2.

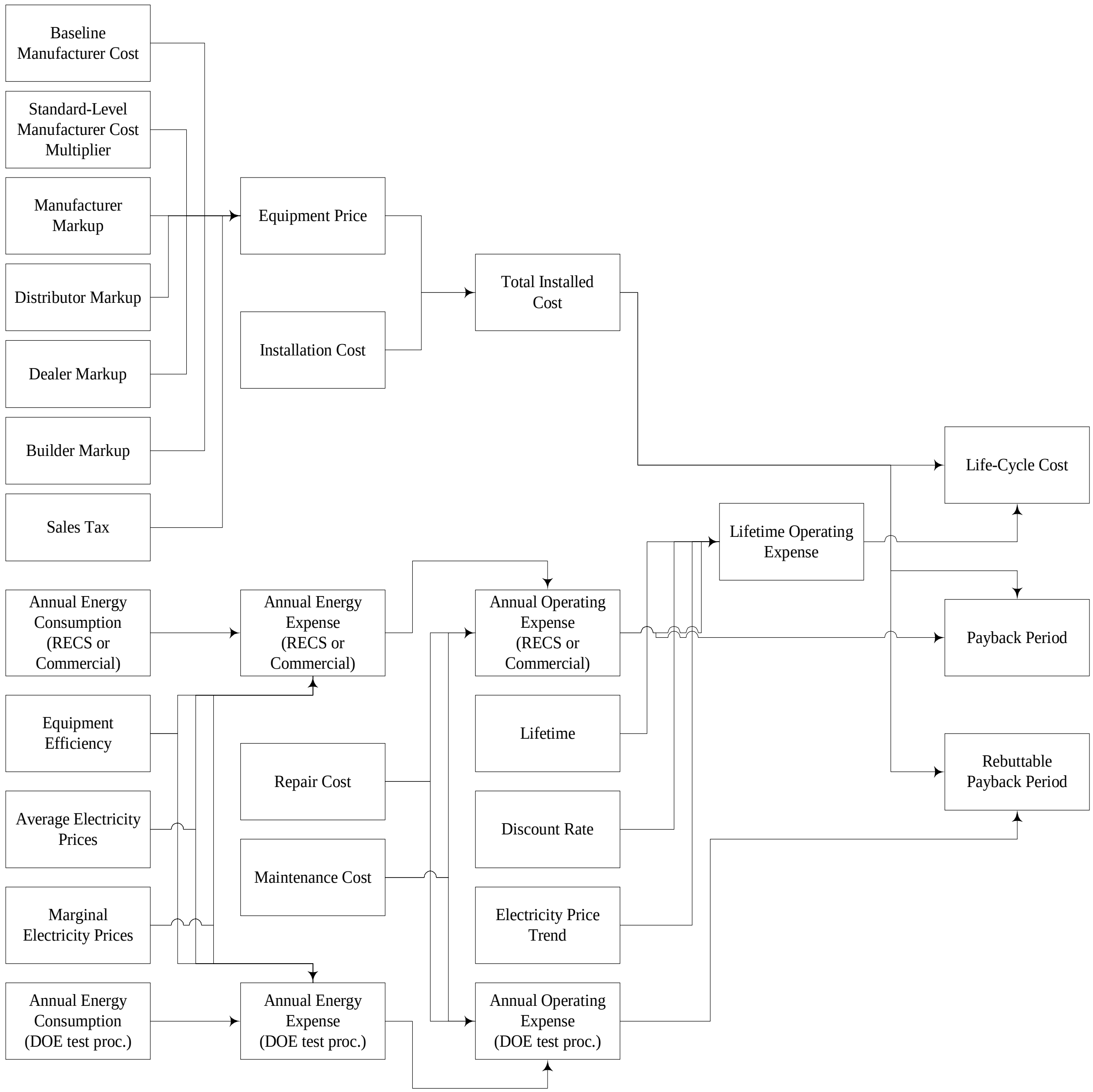

Figure 5.1 Flow Diagram of LCC, PBP, and Rebuttable PBP Inputs

5.1.3 Use of Residential Energy Consumption Survey (RECS) in LCC and PBP Analysis

The LCC and PBP calculations detailed here are for a representative sample of individual households and commercial buildings. Ninety percent of equipment applications are assumed to be in households. For equipment used in households, the 1997 Residential Energy Consumption Survey (RECS)[1] serves as the basis for determining the representative sample. The 1997 RECS is based on a sample of 5,900 households which were surveyed for information on their housing units, energy consumption and expenditures, stock of energy-consuming appliances, and energy-related behavior. The information collected represents all households nationwide – approximately 101 million.

RECS is conducted every three years directly form energy end users. The 1997 RECS is the tenth survey of residential housing units conducted by the U.S Department of Energy's (DOE) Energy Information Administration (EIA). Previous RECS were conducted annually form 1978 to 1982 and triennially since 1984. The RECS consists of three parts:

- Personal interviews with households for information about energy used, how it is used, energy-using appliances, structural features, energy efficiency measures, and demographic characteristics of the household.

- Telephone interviews with rental agents for households that have any of their energy use included in their rent. This information augments information collected from those households that may not be knowledgeable about the fuels used for space heating or water heating.

- Mail questionnaires sent to energy suppliers (after obtaining permission from households) to collect the actual billing data on energy consumption and expenditures.

Of the 5900 households surveyed in the 1997 RECS, 2003 households representing 37.6% of the housing population have a central air conditioner while 579 households representing 11.1% of housing population have an electric heat pump[a]. Using the households in RECS that utilize a central air conditioner or heat pump, LCC and PBP analyses are performed on a household-by-household basis to determine whether an increase in the minimum efficiency standard is economically justified.

Of the inputs necessary for the LCC and PBP analysis, there are four inputs (as depicted in Figure 5.1) which are based on data from the 1997 RECS; 1) space-conditioning annual energy consumption (RECS-based), 2) equipment efficiency, 3) average electricity price, and 4) marginal electricity price. All four of these inputs are used in determining the operating cost. With the exception of the equipment efficiency, each household in RECS with a central air conditioner or heat pump has a unique value for the space-conditioning annual energy consumption, the average electricity price, and the marginal electricity price. In other words, the annual energy consumption, average electricity price, and marginal electricity price associated with a particular RECS household

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[a] The number of households actually used in the central air conditioner and heat pump LCC and PBP analyses were 1218 and 308, 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.

are not uncertain and are, therefore, not expressed with probability distributions. Although the above three input variables are not uncertain, they are extremely variable. Due to the vast number of households considered in the LCC and PBP analysis (over 1200 for central air conditioners and over 300 for heat pumps), the range of annual energy use, average electricity price, and marginal electricity price is quite large (the actual ranges are presented and discussed later in this chapter). Thus, although the above three input variables are not uncertain for any particular household, their variability across all households contributes significantly to the range of LCCs and PBPs calculated for any particular standard-level.

5.1.4 Commercial Building Analysis

Ten percent of residential-type (i.e., single-phase) central air conditioner and heat pump applications are assumed to be in commercial buildings. A representative sample of commercial buildings where this equipment may be applied was developed based on assumptions consistent with the process to update ASHRAE Standard 90.1, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*[2].

In updating ASHRAE 90.1, 77 nationally representative commercial buildings (consisting of seven different commercial building types in eleven different regions of the country) were developed. These same 77 buildings were used for the LCC and PBP allowing for a building-by-building approach to be utilized for determining whether an increase in the standard is economically justified (e.g., similar to the approach described above for households from the 1997 RECS). The weighting given to each building (i.e., the percentage each building represents of the commercial building stock) were based on data from the 1992 and 1995 Commercial Building Energy Consumption Survey (CBECS)[3,4].

As with the analysis of residential buildings, four inputs are necessary (as depicted in Figure 5.1) from the commercial building analysis in order to perform the LCC and PBP calculations: 1) space-conditioning annual energy consumption, 2) equipment efficiency, 3) average electricity price, and 4) marginal electricity price.

The space-conditioning energy consumption associated with each of the 77 buildings were determined through computer modeling performed at Pacific Northwest National Laboratory (PNNL) using the Building Loads and Systems Thermodynamics (BLAST) simulation tool[5]. The procedure for calculating space-conditioning energy consumption relied on the determination of full-load equivalent operating hours (FLEOH) for each of the 77 buildings. The determination of space-cooling and space-heating FLEOHs assumed that a single type of equipment, in our case residential-type space-conditioning equipment, were used to condition the building. Once the FLEOHs were determined, the corresponding annual energy consumption was established using the calculation procedure specified in the Department of Energy's (DOE) test procedure for determining annual energy use. In determining both space-cooling and space-heating annual energy use, the DOE test procedure requires equipment efficiencies as well as cooling and heating capacities. For purposes of developing LCCs and PBPs, all of the 77 nationally representative buildings are assumed to have equipment efficiencies equal to the standard-level being analyzed. Equipment capacities for both cooling and heating are assumed to be 36,000 Btu/hr.

The average and marginal electricity prices were developed through a procedure of matching building peak demand characteristics for each of the 77 nationally representative buildings (determined from the computer modeling analysis for establishing FLEOHs) to actual modeled commercial tariffs and then calculating customer bills. The methodology for matching commercial building peak demands to modeled tariffs is explained in a 1999 DOE report on marginal energy prices[6]. Energy bills are calculated for a baseline case (10 SEER) and a standards cases. Average electricity prices are determined by taking the bill for the baseline case and dividing it by the amount of energy consumed. Marginal electricity prices are determined by taking the bill difference between the baseline and standard cases (in dollars) and dividing it by the usage difference (in kWh) to give a "marginal" rate of $/kWh for that increment. For purposes of simplifying the analysis, a standard-level increase of 20% was only considered. Thus, the marginal rate developed for a 20% increase in the standard was assumed to be applicable for all standards cases. Since several tariffs were applied to each building, both the average and marginal rates calculated from each tariff were weighted by the number of customers covered by the tariff to come up with a *weighted-average* marginal and average rate for each building. The above procedure was used to develop space-cooling average and marginal rates. Since detailed building loads and demands were not available for space-heating, average rather than marginal electricity prices were used to determine the energy costs associated with the operation of heat pumps during the space-heating season.

As with the residential buildings from the RECS sample, the annual energy consumption, average electricity price, and marginal electricity price associated with each of the 77 commercial buildings are not uncertain and are, therefore, not expressed with probability distributions. Although the above three input variables are not uncertain, they are variable. Due to the number of buildings considered in the LCC and PBP analysis, the range of annual energy use, average electricity price, and marginal electricity price is large (the actual ranges are presented and discussed later in this chapter). Thus, although the above three input variables are not uncertain for any particular building, their variability across all buildings contributes significantly to the range of LCCs and PBPs calculated for any particular standard-level.

5.2 LIFE-CYCLE COST (LCC)

5.2.1 Definition

Life-cycle cost is the total consumer expense over the life of an appliance, including purchase expense and operating costs (including energy expenditures). Future operating costs are discounted to the time of purchase, and summed over the lifetime of the appliance. Life-cycle cost is defined by the following equation:

$$LCC = IC + \frac{OC_t}{(1+r)^t} \qquad \textbf{(5.1)}$$

Where,

LCC = life-cycle cost,
IC = total installed cost ($),
$\sum$ = sum over the lifetime, from year 1 to year N, where N = lifetime of appliance (years),
OC = operating cost ($),
r = discount rate, and
t = year for which operating cost is being determined.

We treat total installed cost, operating cost, lifetime, and discount rate in turn in the following sections.

5.2.2 Total Installed Cost Inputs

The total installed cost to the consumer is defined by the following equation:

$$IC = EQP + INST \qquad \textbf{(5.2)}$$

Where,

EQP = equipment price (i.e., consumer price for only the equipment) ($) and
$INST$ = consumer price to install equipment (i.e., the cost for labor and materials) ($).

The equipment price is defined by the following equation:

$$EQP = (MFG \cdot MM_{STD} \cdot MU_{MFG} \cdot MU_{DISTR} \cdot MU_{DEAL} \cdot MU_{BUILD} \cdot ST) \qquad \textbf{(5.3)}$$

Where,

MFG = manufacturing cost of baseline (10 SEER) equipment ($),
MM_{STD} = standard-level manufacturer cost multiplier,
MU_{MFG} = manufacturer markup,
MU_{DISTR} = distributer or wholesaler markup,
MU_{DEAL} = dealer or contractor markup,
MU_{BUILD} = builder markup, and
ST = sales tax.

The remainder of this section provides information about the variables and assumptions used to calculate the total installed cost for central air conditioners and heat pumps. For each variable, the discussion includes:

- definition;
- approach; and
- current assumptions.

Inputs for the determination of total installed cost are shown in Table 5.1.

Table 5.1 Inputs for Total Installed Costs

Baseline manufacturer cost ($)
Standard-level manufacturer cost multipliers
Manufacturer markup
Distributor or wholesaler markup
Dealer or contractor markup
Sales tax
Installation cost ($)

5.2.2.1 Baseline Manufacturer Cost

Definition

The cost to the manufacturer of producing baseline or minimum efficiency equipment.

Approach

Baseline manufacturer costs were developed by Arthur D. Little (ADL) through a reverse engineering approach. Refer to Chapter 4, Section 4.2, *Manufacturing Costs,* for details on how the costs were developed.

Assumptions

The manufacturer costs for minimum efficiency (i.e., 10 SEER) split air conditioners, split heat pumps, package air conditioners, and package heat pumps are summarized in Table 5.2.

Table 5.2 Baseline Manufacturer Costs

	Baseline Manufacturer Cost	
System Type	**Without Air Handler**	**With Air Handler**
Split Air Conditioner	$367	$449
Split Heat Pump	-	$572
Package Air Conditioner	-	$511
Package Heat Pump	-	$593

Since the life-cycle cost analysis is performed on a building-by-building basis using housing data from the 1997 RECS and a nationally representative set of commercial buildings, the determination of what manufacturer cost to use for split air conditioners is based on whether a warm-air central furnace is present in the household. If the building has a fuel-fired (gas-, oil-, or LPG-fired) furnace, the "without air handler"split air conditioner manufacturer cost is used. Otherwise, the "with air handler" cost is used.

5.2.2.2 Standard-Level Manufacturer Cost Multipliers

Definition

The multiplicative factor used for calculating the manufacturer cost associated with each standard-level. The factor is multiplied by the baseline manufacturer cost to arrive at the standard-level manufacturer cost. For example, if the average manufacturer cost multiplier for 11 SEER split system heat pumps is 1.10, its associated average manufacturer cost would equal the baseline manufacturer cost of $572 multiplied by the average multiplier (1.10) or $629.

Approach

Data submittals from the Air Conditioning & Refrigeration Institute (ARI) were used for developing the standard-level manufacturer cost multipliers. ARI collected data from its member manufacturers and provided minimum, maximum, and *weighted-mean* values for each standard-level and each product class. Please refer to Chapter 4, Section 4.2, *Manufacturing Costs*, for more details on the ARI data submittal.

Assumptions

ARI provided minimum, maximum, and shipment *weighted-mean* values for each standard-level. Because it was unknown as to how the ARI cost data were distributed, only the shipment *weighted-mean* values were used in the LCC analysis. Table 5.3 provides the minimum, maximum, and shipment *weighted-mean* values for only the standard-levels analyzed (11 through 13 SEER and 18 SEER (max tech)) for each product class. Of important note, since cost data were not provided for the maximum technologically feasible standard-level (18 SEER), cost multipliers associated with the highest efficiency level which data were provided (i.e., 15 SEER) were used as a proxy.

Table 5.3 ARI Standard-Level Manufacturer Cost Multipliers

	Split A/C			Split HP			Package A/C			Package HP		
SEER	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
10	-	1.00	-	-	1.00	-	-	1.00	-	-	1.00	-
11	1.03	1.16	1.30	1.05	1.10	1.15	1.03	1.19	1.27	1.06	1.14	1.25
12	1.09	1.36	1.55	1.11	1.24	1.35	1.15	1.30	1.40	1.06	1.28	1.50
13	1.30	1.63	1.90	1.17	1.44	1.66	1.40	1.63	1.75	1.45	1.60	1.90
18[a]	1.81	2.40	3.50	1.75	2.09	2.52	1.89	2.23	2.92	1.93	2.13	2.47

[a] Cost multipliers for 18 SEER are based on data for 15 SEER.

5.2.2.3 Manufacturer Markup

Definition

The markup for converting the manufacturer cost to the cost which distributors or wholesalers pay for space-conditioning equipment.

Approach

Manufacturer markups were developed by ADL. Please refer to Chapter 4, Section 4.3.2, *Determination of the Manufacturer Markup,* for more details.

Assumptions

The manufacturer markups used in the LCC analysis were based on values of 1.18 and 1.41 which were assumed to be representative of 80% and 20% of the industry, respectively. A discrete distribution consisting of the above two values was used in the analysis. Figure 5.2 shows the distribution for the manufacturer markup. The *weighted-average* markup equals 1.23 (80% · 1.18 + 20% · 1.41).

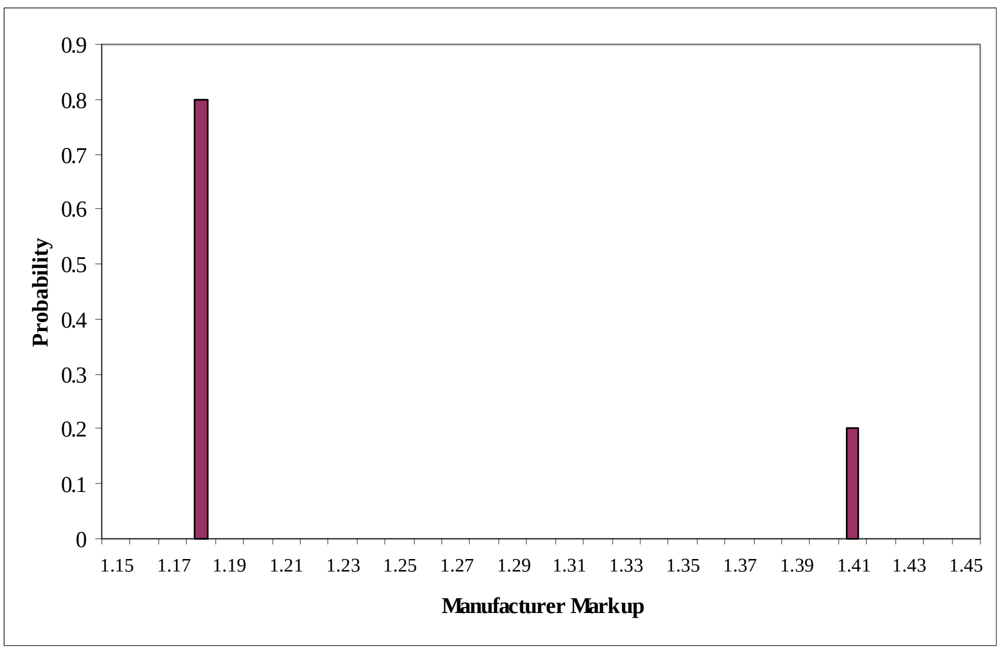

Figure 5.2 Distribution of Manufacturer Markups

The manufacturer markup was assumed to remain constant with increasing efficiency and it was assumed to be applicable to all product classes. In addition, variations in the markup based on market destination (i.e, whether the equipment would eventually be sold to the new construction or replacement/retrofit market) were assumed to be negligible. In other words, the markup for the new construction and replacement/retrofit markets were assumed to be identical.

5.2.2.4 Distributor Markup

Definition

The markup for converting the distributor or wholesaler cost to the cost which contractors or dealers pay for space-conditioning equipment.

Approach

Distributor markups were developed through an analysis of financial data for an average air-conditioning wholesale business from data in the Air-conditioning & Refrigeration Wholesalers' (ARW) *1998 Wholesaler Profit Survey Report*. The results of the financial analysis were validated with a econometric analysis of 1997 U.S. Census Bureau economic data of revenues and costs for warm air heating and air conditioning equipment wholesalers. Please refer to Appendix D for more details.

Assumptions

The analysis of distributor cost data revealed a measurable difference between the *average* aggregate markup on the entire set of direct business costs and the *incremental* markup on only direct equipment costs. In other words, for an incremental increase in the cost of the equipment, the markup required to cover the incremental cost increase is distinctly different than the average markup required to cover all business costs. From the financial analysis, the *average* aggregate distributor markup was determined to be 1.36 and is assumed to cover the direct business costs that are present at the current baseline (i.e., 10 SEER) level. The *incremental* distributor markup was determined to be 1.11 and is assumed to cover incremental equipment cost increases, such as those associated with increases in equipment efficiency.

Because the econometric analysis provided a distribution of markup values rather than the single-point values from the financial analysis, results from the econometric analysis were used to represent the distributor markup. The econometric analysis yielded mean values for the *average* and *incremental* markups which were only slightly different from the financial analysis (*average* and *incremental* values of 1.37 and 1.09, respectively, as opposed to 1.36 and 1.11). The distribution of *incremental* markups ranged from a minimum of 1.027 to a maximum of 1.155. Table 5.4 shows the cumulative probabilities of the values pertaining to the *incremental* distributor markup.

Table 5.4 Cumulative Probability Distribution of Distributor/Wholesaler Markups

Distributor Markup	Cumulative Probability
1.027	1%
1.056	10%
1.069	20%
1.077	30%
1.084	40%
1.091	50%
1.098	60%
1.105	70%
1.114	80%
1.126	90%
1.155	99%

Both the *average* and *incremental* distributor markups were assumed to apply to all product classes. In addition, variations in the markup based on market destination (i.e, whether the equipment would eventually be sold to the new construction or replacement/retrofit market) were assumed to be negligible. In other words, the markup for the new construction and replacement/retrofit markets were assumed to be identical.

5.2.2.5 Dealer Markup

Definition

The markup for converting the dealer or contractor cost to the price that either builders (for equipment destined for the new construction market) or consumers (for equipment destined for the replacement/retrofit market) pay for the space-conditioning equipment.

Approach

Dealer markups were developed through an an analysis of financial data for an average residential air-conditioning contractor from data in the Air Conditioning Contractor Association's (ACCA) *Financial Analysis for the HVACR Contracting Industry*, 1995 edition. The results of the financial analysis were validated with an econometric analysis of 1997 U.S. Census Bureau economic data of revenues and costs for the Heating, Ventilating, Air-Conditioning (HVAC) contractor industry. Please refer to Appendix D for more details.

Assumptions

The financial analysis of contractor cost data revealed a significant difference between the markup required for covering labor and equipment expenses and the markup required for covering only equipment expenses. The markup covering all business expenses was determined to be 1.53 while the markup for only equipment expenses was determined to have a mean value of 1.28. Because the LCC analysis breaks out the contractor's installation cost (i.e., the cost to install the equipment) from the cost which is charged for the equipment, only the markup value of 1.28 is applicable for marking up the equipment. As with the distributor markup, a contractor markup associated only with an *incremental* increase in equipment cost was also determined. Since the *incremental* markup was shown to be close to the *average* value of 1.27, only the *average* markup value was used in the analysis.

Because the econometric analysis provided a distribution of markup values rather than the single-point values from the financial analysis, results from the econometric analysis were used to represent the dealer markup. The econometric analysis yielded a mean value for the equipment markup which was only slightly different from the financial analysis (1.27 as opposed to 1.28). As with the distributor markup, a dealer markup associated only with an *incremental* increase in equipment cost was also determined from the econometric analysis. Since the *incremental* markup was shown to be close to the *average* value of 1.27, only the *average* markup value was used in the analysis. The *average* dealer markups ranged from a minimum of 1.027 to a maximum of 1.155. Table 5.5 shows the cumulative probabilities of the values pertaining to the *incremental* distributor markup.

Table 5.5 Cumulative Probability Distribution of Dealer/Contractor Markups

Distributor Markup	Cumulative Probability
1.050	1%
1.150	10%
1.190	20%
1.219	30%
1.244	40%
1.267	50%
1.290	60%
1.314	70%
1.343	80%
1.384	90%
1.483	99%

The contractor markup of 1.27 was assumed to apply to all product classes. In addition, variations in the markup based on market destination (i.e, whether the equipment would eventually be sold to the new construction or replacement/retrofit market) were assumed to be negligible. In other words, the markup for the new construction and replacement/retrofit markets were assumed to be identical.

5.2.2.6 Builder Markup

Definition

The markup for converting the builder cost to the price that consumers pay for the space-conditioning equipment as part of their new home purchase.

Approach

Buidler markups were developed by ADL. Please refer to Chapter 4, Section 4.3.4, *Determination of Builder Markup*, for more details.

Assumptions

The builder markups range uniformly from a minimum of 1.20 to a maximum of 1.32. Thus, the *weighted-average* markup is equal to the average value of 1.26. The builder markup was assumed to remain constant with increasing efficiency and applicable to all product classes.

Builder markups do not pertain to the replacement/retrofit market as they are only applicable for the new construction market. Based on data from the Air-Conditioning, Heating, and Refrigeration News[7], 34% of equipment shipped are sold to the new construction market while the remaining 66% are sold for the replacement/retrofit market. Thus, the *weighted-average* builder markup for the entire air-conditioning and heat pump market is 1.088 (34% · 1.26 + 66% · 1.00).

5.2.2.7 Sales Tax

Definition

State and local sales taxes. Used as a multiplicative factor to increase equipment price.

Approach

Sales taxes were developed by ADL. Please refer to Chapter 4, Section 4.3.5, *Determination of Sales Tax*, for more details.

Assumptions

The sales tax rates essentially range from a minimum of 5% to a maximum of 8% with a mean value of 6.7% and apply only to the replacement/retrofit market. The sales tax was assumed to remain constant with increasing efficiency. In addition, the sales tax was assumed to be applicable to all product classes. Figure 5.3 shows the distribution for the sales tax.

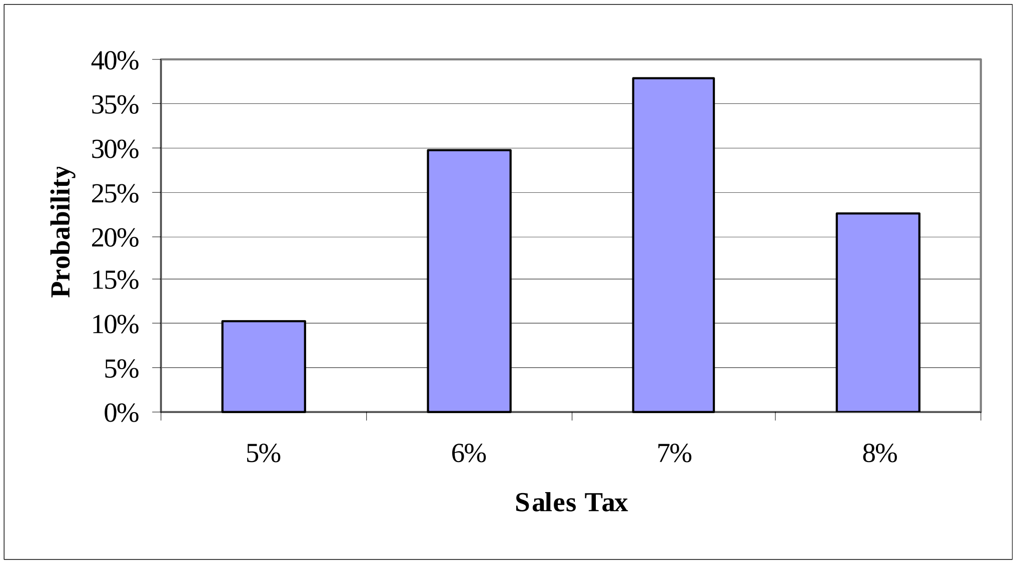

Figure 5.3 Sales Tax Distribution for the Replacement/Retrofit Market

No sales taxes were assumed for equipment bought for the new construction market as consumers do not purchase the equipment directly. As stated earlier, 34% of equipment shipped are sold to the new construction market while the remaining 66% are sold to the replacement/retrofit market. Thus, the *weighted-average* sales tax for the entire air-conditioning and heat pump market is 1.044 (34% · 1.00 + 66% · 1.067).

5.2.2.8 Installation Cost

Definition

The cost to the consumer of labor and materials (other than the actual equipment) needed to install a central air conditioner or heat pump.

Approach

Installation costs were based on typical figures for total installed costs that were collected from public sources and phone calls to HVAC contractors. The installation price was determined by subtracting the derived equipment price from the typical total installed cost.

Assumptions

The installation cost to install a minimum efficiency (i.e., 10 SEER) split air conditioner, split heat pump, package air conditioner, and package heat pump are provided below. The costs vary by product class and were based on data on total installed costs collected by Lawrence Berkeley National Laboratory (LBNL) from public[8,9] and private[10] sources.

Table 5.6 Baseline Installation Costs

Split AC	Split HP	Package AC	Package HP
$1,279	$2,280	$1,367	$2,160

Due to the large variability in installation costs, the representative cost for each product class was assumed to vary by ±20%. A triangular distribution was created for each product class assuming low and high values that were -20% less and +20% greater, respectively, than the representative installation cost. Probabilities of 0% were assigned for the low and high installation cost values. For example, the Figure 5.4 shows the distribution of values that were used for split air conditioners. The low and high values ($1023 and $1535) are -20% less and +20% greater than the typical cost.

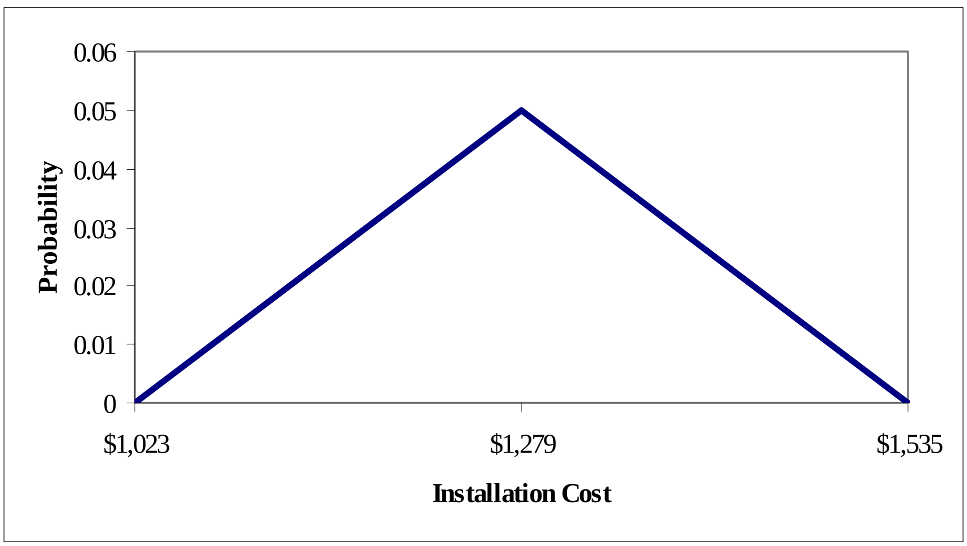

Figure 5.4 Probability Distribution of Split A/C Installation Cost

For all product classes, the installation cost is assumed to stay constant as efficiency increases.

5.2.2.9 Weighted-Average Total Installed Costs

As presented in Eqn. 5.2 and 5.3, the total installed cost is the summation of the equipment price and the installation cost. The equipment price is derived by multiplying the baseline manufacturer cost by the appropriate manufacturer cost multiplier and the appropriate markups and sales tax. Because several of the markups, the sales tax, and the installation cost are represented by probability distributions, the resulting total installed cost for a particular standard-level will not be a single-point value, but rather, a distribution of values. With this said, the *weighted-average* total installed costs are presented for each standard-level and product class to provide an indication of the increase in the total installed cost due to an efficiency increase.

The derivation of the total installed cost is relatively straight forward. The baseline manufacturer cost is the starting point for determining the total installed cost, and for split system heat pumps, single package air conditioners, and single package heat pumps, this value is taken directly from Table 5.2. But for split system air conditioners, the *weighted-average* baseline manufacturer cost is dependent on whether an air handler is required. Data from the 1997 RECS is used to determine the percentage of households requiring an air handler. For the households in the 1997 RECS utilizing a central air conditioner, additional information is provided indicating the presence of a gas-fired forced-air furnace. If a forced-air furnace is present, it is assumed that an air handler is not required. For the households with air conditioners analyzed in the LCC analysis (1218 households), 74.3% (by population weight) had a forced-air furnace while 25.7% did not. Thus, the residential split system air conditioner *weighted-average* baseline manufacturer cost is:

$$\begin{aligned} MFG_{SAC-Res} &= MFG_{SAC-w/o\,AH} \cdot PERC_{SAC-w/o\,AH} + MFG_{SAC-w/\,AH} \cdot PERC_{SAC-w/\,AH} \\ &= \$367 \cdot 74.3\% + \$449 \cdot 25.7\% \\ &= \$388 \end{aligned}$$

Since the LCC analysis takes into account equipment use in commercial buildings based on the assumption that 10% of equipment applications are in commercial buildings, the *weighted-average* baseline manufacture cost must reflect split system air conditioner use in commercial buildings. It is assumed that split air conditioners used in commercial buildings will always require an air handler. Thus, the representative baseline manufacturer cost for commercial applications is $449. Based on the assumption that 10% of equipment applications are in commercial buildings, the split system air conditioner *weighted-average* baseline manufacturer cost is:

$$\begin{aligned} MFG_{SAC} &= MFG_{SAC-Res} \cdot 90\% + MFG_{SAC-Comm} \cdot 10\% \\ &= \$388 \cdot 90\% + \$449 \cdot 10\% \\ &= \$394 \end{aligned}$$

With the issue of the *weighted-average* baseline manufacturer cost resolved for split system air conditioners, both baseline and standard-level *weighted-average* total installed costs can now be presented. Table 5.7 summarizes all of the *weighted-average* costs and markups necessary for determining the *weighted-average* baseline and standard-level total installed costs.

Table 5.7 Costs and Markups for Determination of Weighted-Average Total Installed Costs

Variable	**Weighted-Average Value**
Baseline Manufacturer Cost	Split A/C = $394; Split HP = $572; Package A/C = $511; Package HP = $593
Manufacturer Cost Multiplier	Refer to Mean Values in Table 5.3 for each product class
Manufacturer Markup	1.23
Distributor Markup	1.37 for all direct business costs; 1.09 for incremental equipment cost increases
Dealer Markup	1.27
Builder Markup	1.088
Sales Tax	1.044
Installation Cost	Split A/C = $1279; Split HP = $2280; Package A/C = $1367; Package HP = $2160

To illustrate the derivation of the *weighted-average* total installed cost, the calculation is presented below for baseline (i.e., 10 SEER) and 11 SEER split system air conditioners. For baseline split system air conditioners, the calculation of the total installed cost ($IC_{SAC\text{-}Baseline}$) is as follows:

$$\begin{aligned} IC_{SAC-Baseline} &= \$394 \cdot 1.23 \cdot 1.37 \cdot 1.27 \cdot 1.088 \cdot 1.044 + \$1279 \\ &= \$957 + \$1279 \\ &= \$2236 \end{aligned}$$

The calculation of the 11 SEER split system air conditioner total installed cost includes the use of a manufacturer cost multiplier. In addition, since a separate distributor markup was derived based on incremental equipment cost changes, the derivation of the 11 SEER total installed cost is based on determining the change in equipment price over the baseline cost. The calculation of the 11 SEER total installed cost ($IC_{SAC\text{-}11\,SEER}$) is as follows:

$$\begin{aligned} IC_{SAC-11SEER} &= EQP_{SAC-Baseline} + \Delta EQP_{SAC-Base\,to\,11SEER} + INST_{SAC} \\ &= \$957 + (\$394 \cdot 1.16 - \$394) \cdot 1.23 \cdot 1.09 \cdot 1.27 \cdot 1.088 \cdot 1.044 + \$1279 \\ &= \$957 + \$121 + \$1279 \\ &= \$2357 \end{aligned}$$

Table 5.8 presents the *weighted-average* total installed costs for each of the four product class at each standard-level.

Table 5.8 Weighted-Average Total Installed Costs for Central Air Conditioners and Heat Pumps

SEER	Split A/C *1998$*	Package A/C *1998$*	Split HP *1998$*	Package HP *1998$*
10	$2,236	$2,607	$3,668	$3,599
11	$2,357	$2,795	$3,779	$3,760
12	$2,510	$2,903	$3,933	$3,920
13	$2,715	$3,229	$4,155	$4,287
18	$3,302	$3,822	$4,873	$4,894

5.2.3 Operating Cost Inputs

The operating cost is determined for households using data from the 1997 Residential Energy Consumption Survey (RECS)[11]. The operating cost for commercial buildings is based on computer modeling of 77 nationally representative commercial buildings based on assumptions similar to what were used to develop ASHRAE Standard 90.1-99[12]. For the LCC analysis of central air conditioners (either split or package systems), the LCC of an increased efficiency level is calculated for those residential and commercial buildings that are determined to have a central air conditioner. For heat pumps (either split or package systems), the LCC of an increased efficiency level is calculated for those buildings that are determined to have a central heat pump. After the LCC analysis is performed, a distribution of LCC differences (i.e., the LCC difference between the baseline equipment and equipment with a higher efficiency level) is generated to determine the mean LCC difference, as well as the percentage of buildings analyzed that have positive LCC savings associated with the more-efficient equipment.

The operating cost is defined by the following equation:

$$OC = EC + RC + MC \tag{5.4}$$

Where,

EC =	energy expenditure associated with operating the equipment,
RC =	the repair cost associated with component failure, and
MC =	the service cost for maintaining equipment operation.

Of the above inputs to the operating cost, the energy cost or energy expense is the most complicated to determine. As discussed at the beginning of this chapter in sections 5.1.3 and 5.1.4, the determination of the energy cost is dependent on several input variables from either RECS (for the analysis of households) or the commercial building analysis. The figures below show the relationship between the input variables drawn from RECS or the commercial building analysis and the determination of the energy cost for a particular standard-level. There are two sets of figures: one set for the determination of the standard-level annual space-cooling and space-heating energy expense for households while the other set is for commercial buildings. In Figures 5.5 and 5.6 for households, the boxes labeled with "RECS" designate those input variables being drawn from RECS. One box in Figures 5.5 and 5.6 (Shipments disaggregated by efficiency) is labeled as "ARI" designating that the source of this data is from the Air-Conditioning and Refrigeration Institute (ARI). In Figures 5.7 and 5.8 for commercial buildings, the boxes labeled with "Commercial" designate those input variables being drawn from the computer modeling of the 77 nationally representative buildings. Figures 5.5 and 5.7 show the flow diagram for the determination of the annual space-cooling energy cost associated with a particular central air conditioner or heat pump SEER standard-level while Figures 5.6 and 5.8 show the flow diagram for the determination of the annual space-heating energy cost associated with a particular heat pump HSPF standard-level.

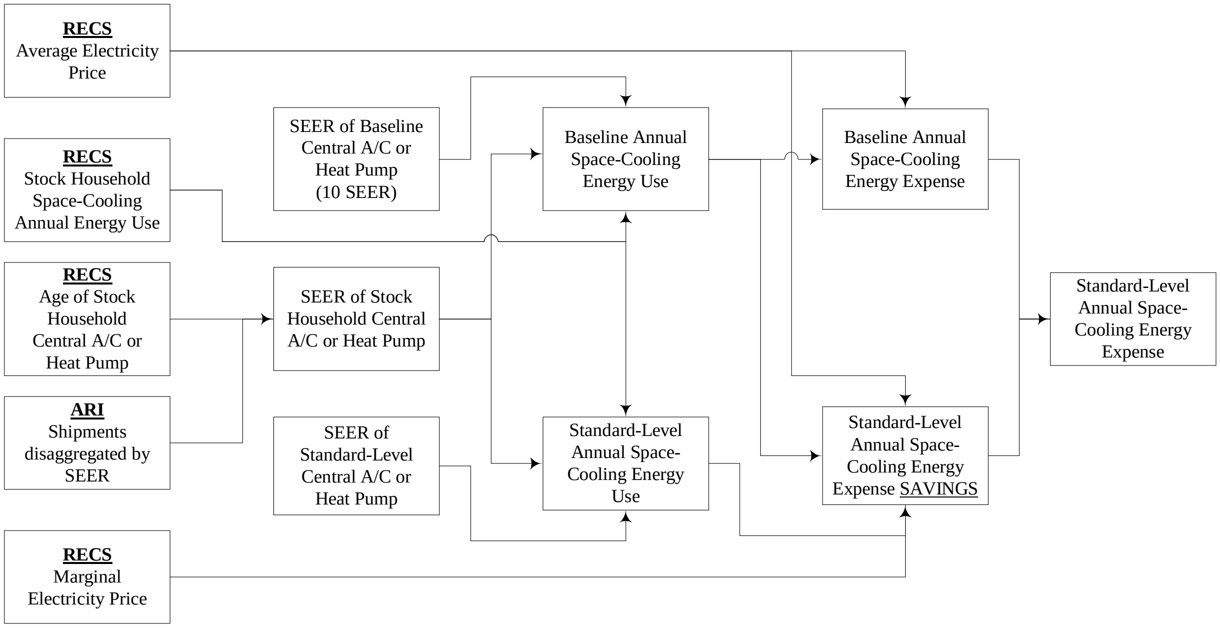

Figure 5.5 Flow Diagram for the Determination of the Standard-Level Annual Space-Cooling Energy Cost for Households

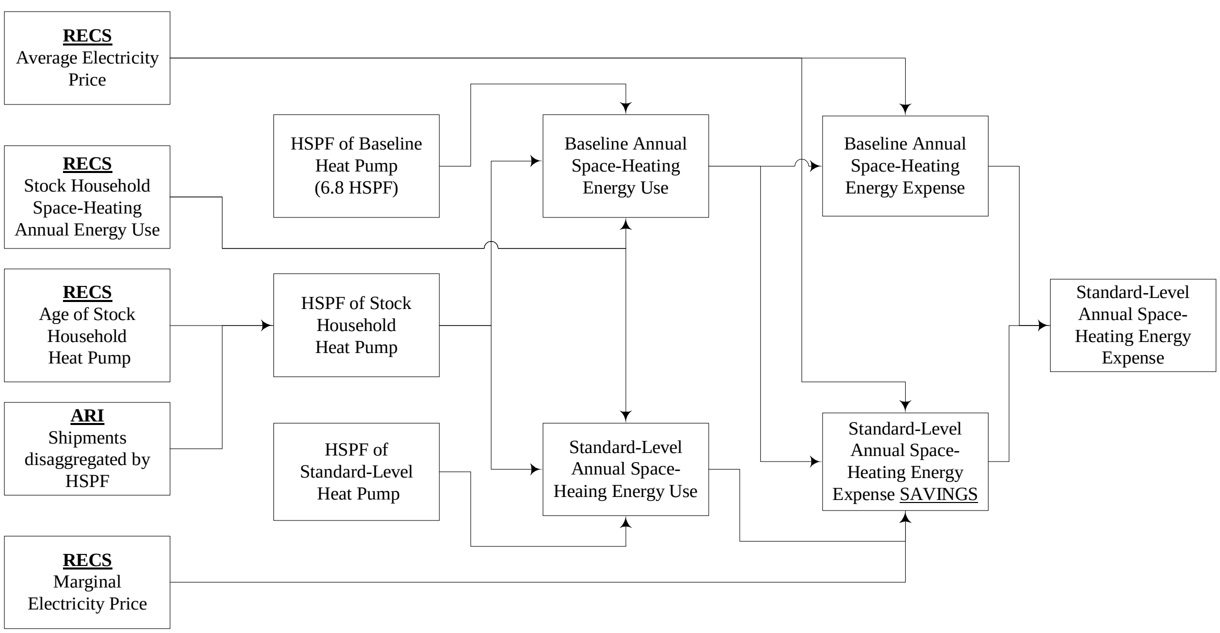

Figure 5.6 Flow Diagram for the Determination of the Standard-Level Annual Space-Heating Energy Cost for Households

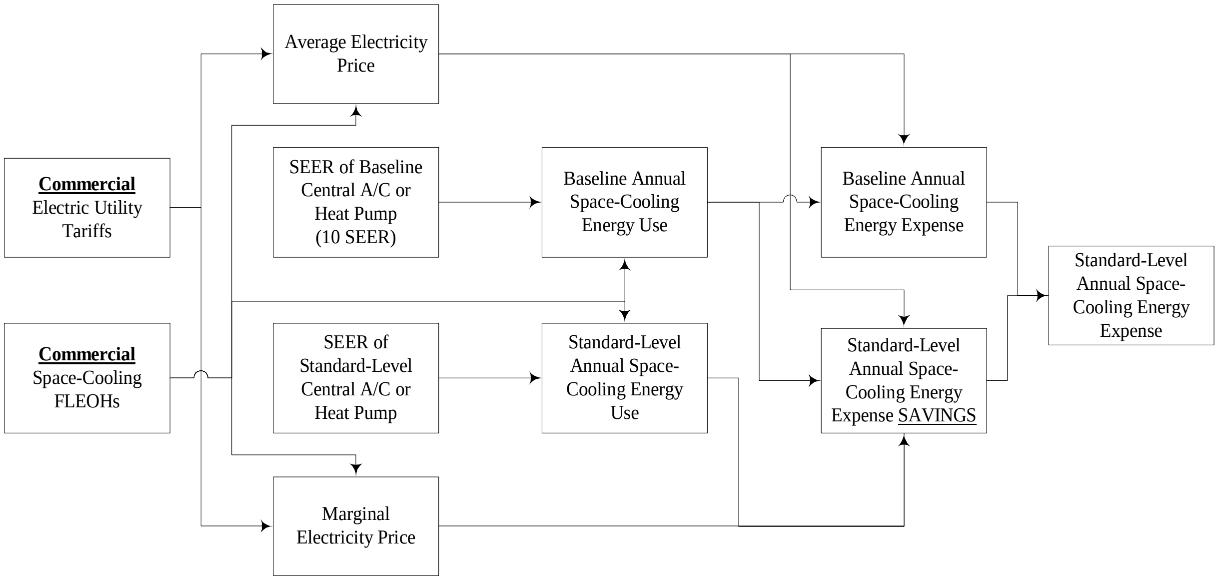

Figure 5.7 Flow Diagram for the Determination of the Standard-Level Annual Space-Cooling Energy Cost for Commercial Buildings

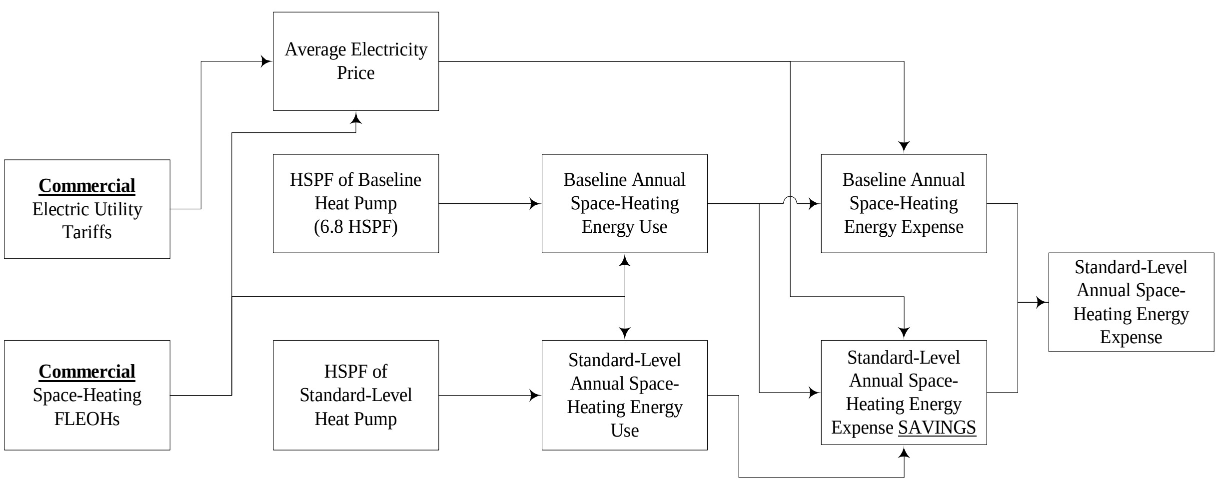

Figure 5.8 Flow Diagram for the Determination of the Standard-Level Annual Space-Heating Energy Cost for Commercial Buildings

With the above figures clarifying the relationship between RECS input variables and the energy cost, the following equation is now presented for the energy cost:

$$EC = EC_{cool} + EC_{heat} \quad \textbf{(5.5)}$$

Where,

EC_{cool} = energy expenditure associated with operating central air conditioners and heat pumps during the cooling season, and
EC_{heat} = energy expenditure associated with operating heat pumps during the heating season.

The energy cost for space-cooling is defined by the following equation:

$$EC_{cool} = UEC_{base\_c} \cdot EL_{avg} - (UEC_{base\_c} - UEC_{std\_c}) \cdot EL_{marg} \quad \textbf{(5.6)}$$

Where,

UEC_{base_c} = annual space-cooling energy use associated with the baseline efficiency level (i.e., 10 SEER),
UEC_{std_c} = annual space-cooling energy use associated with an increased efficiency level,
$ELEC_{avg}$ = average electricity price, and
$ELEC_{mrg}$ = marginal electricity price.

For the case where the energy cost is being determined only for the baseline unit, the second expression within Eqn. 5.6, $(UEC_{base\_c} - UEC_{std\_c}) \cdot EL_{marg}$, is ignored. It is also worth noting that the annual energy savings associated with an increased efficiency level is multiplied by the marginal electricity price rather than the household's average electricity price. An in-depth discussion of the marginal electricity price and its determination is presented later.

The expression for determining the energy cost for space-heating is identical to that for space-cooling and is defined by the following equation:

$$EC_{heat} = UEC_{base\_h} \cdot EL_{avg} - (UEC_{base\_h} - UEC_{std\_h}) \cdot EL_{marg} \quad \textbf{(5.7)}$$

Where,

UEC_{base_h} = annual space-heating energy use associated with the baseline efficiency level (i.e., 10 SEER),
UEC_{std_h} = annual space-heating energy use associated with an increased efficiency level,

As with the determination of the space-cooling energy cost, for the case where the space-heating energy cost is being determined only for the baseline unit, the second expression within Eqn. 5.7, $(UEC_{base\_h} - UEC_{std\_h}) \cdot EL_{marg}$, is ignored.

The remainder of this section provides information about the variables and assumptions used to calculate the operating cost for central air conditioners and heat pumps. For each variable, the discussion includes:

- definition;
- approach; and
- assumptions.

Inputs for the determination of operating cost are shown in Table 5.9. Note that although the lifetime, discount rate, and effective date of the standard are not needed for determining the operating cost, they are required for establishing the operating cost's present value. The base case and standard case designs define the efficiency levels of the design of interest (standard case design) and what design (base case design) it is being judged against.

Table 5.9 Inputs for Operating Costs

Baseline annual space-cooling energy use
Standard-level annual space-cooling energy use
Baseline annual space-heating energy use
Standard-level annual space-heating energy use
Average electricity price ($)
Marginal electricity price ($)
Electricity price trend
Repair cost ($)
Maintenance cost ($)
Lifetime
Discount rate
Effective date of standard
Base case design
Standard case design

5.2.3.1 Baseline Annual Space-Cooling Energy Use

Definition

The annual space-cooling energy use associated with baseline (i.e., 10 SEER) air conditioning or heat pump equipment. For households, the baseline annual energy use is directly proportional to the energy use associated with the stock air-conditioning or heat pump equipment in the specific RECS household being analyzed. For commercial buildings, it is calculated using the DOE test procedure's annual energy use equation for central air conditioners based on the number of full-load equivalent operating hours (FLEOH) the equipment is assumed to operate.

Approach

Residential

For household air conditioners and the cooling-performance of heat pumps, the baseline annual space-cooling energy use ($UEC_{res\_base\_c}$) is defined by the following equation:

$$UEC_{res\_base\_c} = UEC_{res\_stock\_c} \cdot \frac{SEER_{res\_stock}}{SEER_{base}} \qquad \textbf{(5.8)}$$

Where,

$UEC_{res\_stock\_c}$ = annual space-cooling energy use associated with the stock equipment in the RECS household,

$SEER_{res\_stock}$ = the SEER associated with the stock equipment in the RECS household, and

$SEER_{base}$ = the SEER associated with the baseline equipment (i.e., 10 SEER).

Thus, the approach for determining the annual baseline space-cooling energy use for households requires that the UEC_{stock_c} and $SEER_{stock}$ first be determined.

Commercial

For commercial building air conditioners and the cooling-performance heat pumps, the baseline annual space-cooling energy use ($UEC_{comm\_base\_c}$) is defined by the following equation taken from the DOE test procedure:

$$UEC_{comm\_base\_c} = \frac{CAP_{cool}}{SEER_{base}} \cdot FLEOH_{cool} \qquad \textbf{(5.9)}$$

Where,

CAP_{cool} = cooling capacity of equipment (assumed to be 36,000 Btu/hr),

$SEER_{base}$ = the SEER associated with the baseline equipment (i.e., 10 SEER), and

$FLEOH_{cool}$ = the full-load equivelent operating hours for space-cooling.

In order to be consistent with the cost data provided by manufacturers, the cooling capacity of the equipment is assumed to be 36,000 Btu/hr (3-ton). All manufacturer cost data provided by ARI are based on a system with a 3-ton cooling capacity.

Assumptions

Residential

The following discusses the assumptions for determining the residential stock annual space-cooling energy use and the residential stock space-cooling efficiency. Both are needed for calculating the residential baseline annual space-cooling energy use.

Stock Annual Space-Cooling Energy Use ($UEC_{res\_stock\_c}$)

The stock annual space-cooling energy consumption is based on data from the 1997 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.

In order to mitigate the effect of annual weather fluctuations on the annual energy consumption values in the 1997 RECS, the household stock annual energy use values are adjusted based on 30-year average cooling degree day (CDD) data[13]. In the 1997 RECS, although the 30-year (1961-1990) average CDD data are not provided for each household, the household's location is specified at the Census Division level. In addition, its state-level location is specified if it resides in either one of the following large states: California, Florida, New York, and Texas. Thus, with 30-year average CDD values for each Census Division and each of the large states, the household annual energy use values can at least be adjusted on a regional basis. The calculation to adjust the household energy use value is straight forward and is represented by the following equation:

$$UEC_{res\_stock\_c} = UEC_{res\_stock\_c\_non-adj} \cdot \frac{CDD_{30\,yr\,avg}}{CDD_{res\_stock}} \quad \textbf{(5.10)}$$

Where,

$UEC_{res\_stock\_c}$ = weather-adjusted annual space-cooling energy use associated with the stock equipment in the RECS household,

$UEC_{res\_stock\_c\_non-adj}$ = annual space-cooling energy use associated with the stock equipment in the RECS household,

CDD_{res_stock} = the CDD associated with the stock equipment in the RECS household, and

$CDD_{30\,yr\,avg}$ = the 30-year average CDD for the specific Census Division or state location of the RECS household.

Table 5.10 shows the 30-year average CDD values for each of the nine Census Divisions and the four large states. For those Census Divisions encompassing a large state, the calculation of the average CDD excludes the state. Each CDD value was determined through a shipment/population weighting (i.e., taking into where air-conditioning equipment is shipped and the population of the areas where the equipment is being shipped to). Appendix E provides a detailed description of this weighting procedure.

Table 5.10 Census Division and Four Large State 30-year Average CDD

Census Division	States	30-year average CDD
New England	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut	587
Middle Atlantic	Pennsylvania, New Jersey	1035
East North Central	Michigan, Wisconsin, Illinois, Indiana, Ohio	733
West North Central	Minnesota, Iowa, Missouri, Kansas, North Dakota, South Dakota, Nebraska	1156
South Atlantic	West Virginia, Virginia, Georgia, South Carolina, North Carolina, District of Columbia	1563
East South Central	Kentucky, Tennessee, Alabama, Mississippi	1788
West South Central	Oklahoma, Arkansas, Louisiana	2209
Mountain	Montana, Idaho, Wyoming, Nevada, Utah, Arizona, New Mexico, Colorado	2595
Pacific	Washington, Oregon, Alaska, Hawaii	324
-	New York	842
-	Florida	3179
-	Texas	2664
-	California	1287

Figure 5.9 depicts the weighted distribution of the weather-adjusted stock annual space-cooling energy use for those RECS households with a central air conditioner. Of the 5900 households surveyed in RECS, 1218 were determined to have a central air conditioner. The range of the space-cooling energy is quite wide. The minimum value is 57 kWh/yr while the maximum value is 16,286 kWh/yr. The *weighted-average* value is 2132 kWh/yr.

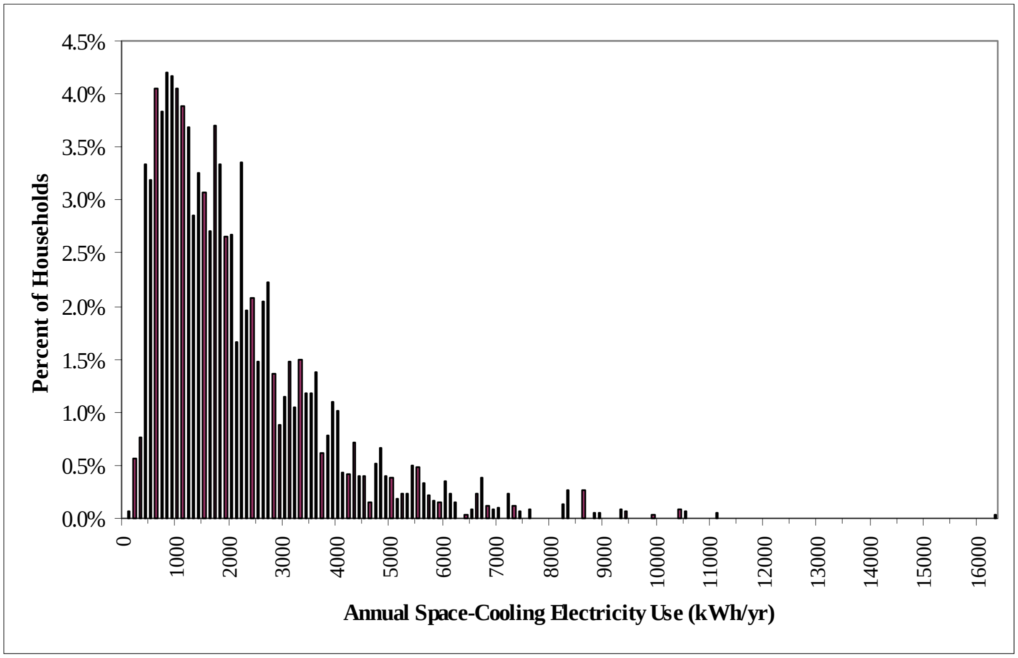

Figure 5.9 Percent of Households with Central A/C by Weather-Adjusted Annual Space-Cooling Energy Consumption (Source: U.S. DOE-EIA, 1997 RECS)

Figure 5.10 depicts the weighted distribution of the weather-adjusted stock annual space-cooling energy use for those RECS households with a heat pump. Of the 5900 households surveyed in RECS, 308 were to determined to have heat pumps. Similar to central air conditioners, the range of the space-cooling energy use is quite wide. The minimum value is 0 kWh/yr while the maximum value is 11,756 kWh/yr. The *weighted-average* value is 2585 kWh/yr. As indicated in the figure below, the weighted percentage of households without space cooling energy consumption (over 5%) is quite high. This situation arises from the fact that several of the RECS households with heat pumps were determined not to use their equipment for space-cooling purposes.

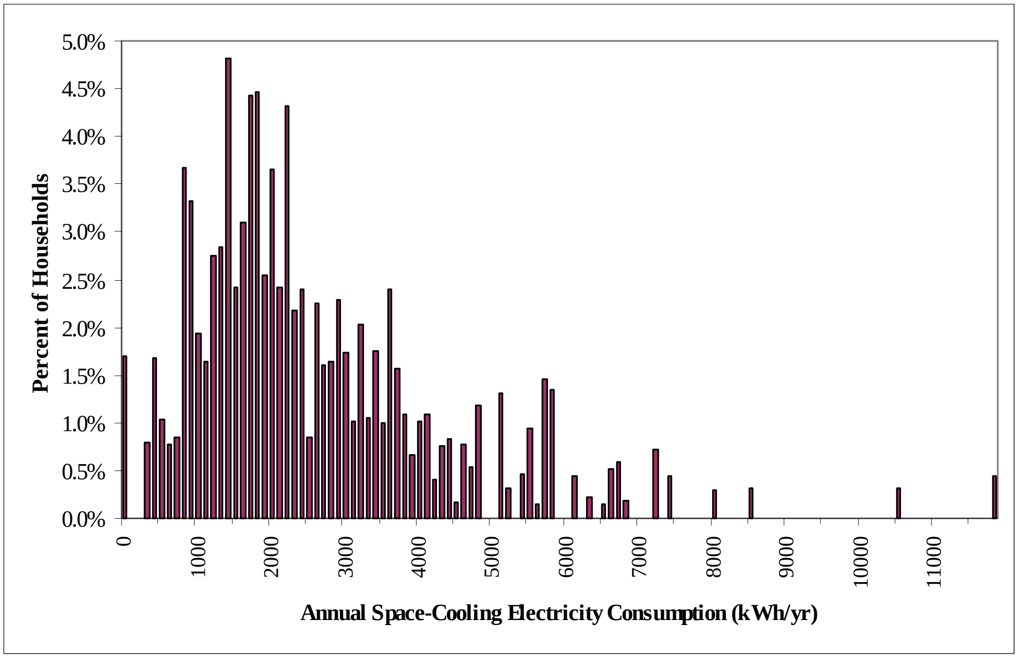

Figure 5.10 Percent of Households with Heat Pumps by Weather-Adjusted Annual Space-Cooling Energy Consumption (Source: U.S. DOE-EIA, 1997 RECS)

Stock Space-Cooling Efficiency ($SEER_{res\_stock}$)

As indicated in the baseline annual space-cooling energy use equation (Eqn. 5.8), the SEER of the stock equipment is necessary for determining the annual space-cooling energy use associated with minimum (10 SEER) efficiency equipment.

In order to establish the SEER of the stock equipment, the age of the equipment as indicated by the 1997 RECS is first established. For each household surveyed with an air conditioner or heat pump, RECS provides an age index for the space-conditioning equipment. Each index value corresponds to a range of equipment ages. Figures 5.11 and 5.12 show the distribution of age indices for central air conditioners and heat pumps in RECS, respectively. A table is imbedded within each figure showing the corresponding range of ages for each index. Each value in the range of ages that correspond to a particular age index is assumed to have an equal probability of occurring.

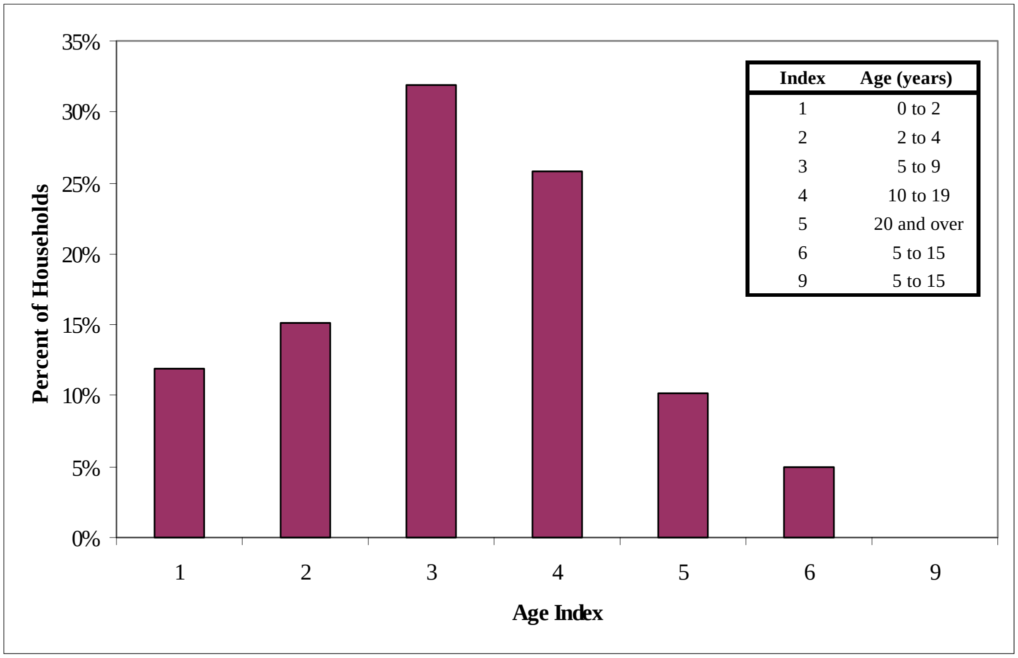

Figure 5.11 Distribution of Age Indices for RECS households with a Central A/C (Source: U.S. DOE-EIA, 1997 RECS)

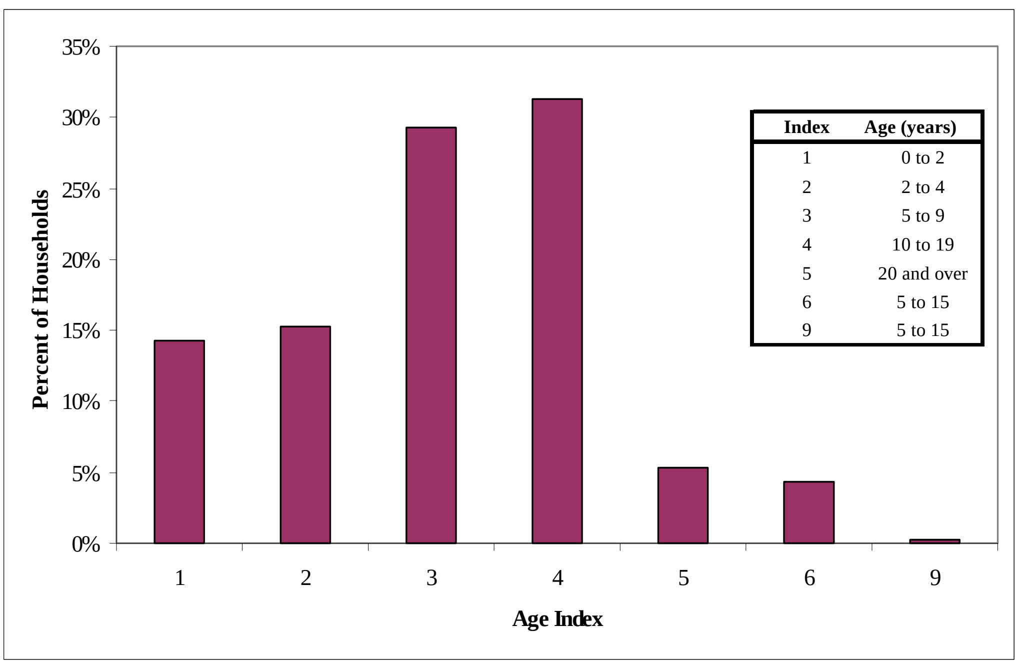

Figure 5.12 Distribution of Age Indices for RECS households with a Heat Pump (Source: U.S. DOE-EIA, 1997 RECS)

Once the age of the equipment is established, disaggregated shipments data provided by ARI are used to determine the efficiency of the equipment. For the years 1976 through 1997, ARI provided data that disaggregates unitary air conditioner and heat pump shipments by efficiency, thus, providing an efficiency distribution for each year. The shipment *weighted-average* efficiencies by year for both central air conditioners and heat pumps are provided below[14]. It should be noted that due to the year in which RECS was conducted (1997), only efficiencies up to 1997 are utilized in the LCC analysis.

Table 5.11 Shipment Weighted SEERs of Unitary Air Conditioners and Heat Pumps

Year [a]	Unitary Air Conditioners	Unitary Heat Pumps
1976	7.03	6.87
1977	7.13	6.89
1978	7.34	7.24
1979	7.47	7.34
1980	7.55	7.51
1981	7.78	7.70
1982	8.31	7.79
1983	8.43	8.23
1984	8.66	8.45
1985	8.82	8.56
1986	8.87	8.70
1987	8.97	8.93
1988	9.11	9.13
1989	9.25	9.26
1990	9.31	9.46
1991	9.49	9.77
1992	10.46	10.60
1993	10.56	10.86
1994	10.61	10.94
1995	10.68	10.97
1996	10.68	11.00
1997	10.66	10.97

[a] For the years 1976 to 1980, values are shipment weighted EERs.

For all the households in RECS with either a central air conditioner or heat pump, the methodology for establishing the stock space-cooling efficiency of space-conditioning equipment yields a *weighted-average* stock efficiency of 9.13 SEER for central air conditioners and a *weighted-average* stock efficiency of 9.32 SEER for heat pumps.

Baseline Annual Space-Cooling Energy Use ($UEC_{res\_base\_c}$)

A baseline annual space-cooling energy use is determined for each RECS household with a central air conditioner and heat pump based on the household's stock energy use and equipment efficiency. The resulting baseline energy use values for these RECS households have a large range. To provide an indication of the magnitude of the baseline energy use for central air conditioners and heat pumps, weighted-average values are calculated and provided below.

Based on the use of the RECS *weighted-average* stock space-cooling energy use and *weighted-average* efficiency for central air conditioners, the *weighted-average* baseline space-cooling annual energy use for central air conditioners for households is:

$$UEC_{CAC_{wght-avg}\_base\_c} = UEC_{CAC_{wght-avg}\_stock\_c} \cdot \frac{SEER_{CAC_{wght-avg}\_stock}}{SEER_{base}} = 2132 \cdot \frac{9.13}{10.00} = 1947 \; kWh/yr$$

Based on the use of the RECS *weighted-average* stock space-cooling energy use and *weighted-average* efficiency for heat pumps, the *weighted-average* baseline space-cooling annual energy use for heat pumps is:

$$UEC_{HP_{wght-avg}\_base\_c} = UEC_{HP_{wght-avg}\_stock\_c} \cdot \frac{SEER_{HP_{wght-avg}\_stock}}{SEER_{base}} = 2585 \cdot \frac{9.32}{10.00} = 2409 \; kWh/yr$$

<u>Commercial</u>

The following discusses the assumptions for determining the space-cooling FLEOHs and, in turn, how they are used for calculating the commercial baseline annual space-cooling energy use.

Full-Load Equivalent Operating Hours (FLEOH)

The space-cooling FLEOH is effectively the number of hours that a system would have to run at full capacity to serve a total load equal to the annual load on the equipment. FLEOH is calculated as:

$$FLEOH_{cool} = \frac{Load_{cool}}{CAP_{cool}} \tag{5.11}$$

Where,

$Load_{cool}$ = annual equipment load for space-cooling.

FLEOH is strictly defined as being related to the equipment capacity, not the peak load of the system. Because FLEOH is used to generate annual cooling loads irrespective of equipment size, it is assumed that the equipment is sized based on the design-day peak equipment load with no explicit oversizing. Thus equation 5.10 becomes:

$$FLEOH_{cool} = \frac{Load_{cool}}{Peak\ Load_{cool}} \qquad \textbf{(5.12)}$$

Where,

$Peak\ Load_{cool}$ = design-day peak cooling load.

The FLEOH for a piece of equipment is a function of the relative annual load to the peak building load. In general, this ratio will vary depending on building construction, building internal loads, building schedules, and orientation an exposure of the zone that the equipment serves. It was assumed that for any given building type, the internal-load characteristics and building schedules are constant across the building.

FLEOHs were determined for a set of 77 nationally representative commercial buildings. The 77 buildings are comprised of seven different types of commercial buildings located in eleven different geographic regions of the U.S. consistent with assumptions used to develop ASHRAE 90.1-1999. In conducting the computer modeling of the buildings, it was assumed that a single type of equipment, in our case residential-type space-conditioning equipment, were used to condition the building. Additionally, it was assumed that the equipment did not use economizers but did operate with setback theromstats. Table 5.12 presents the FLEOHs for each of the 77 commercial building which were modeled.

Table 5.12 Space-Cooling FLEOHs for Commercial Buildings utilizing Residential-Size Space-Cooling Equipment (hours)

Census Division / Region	Building Type						
	Assembly	Education	Food Service	Lodging	Office	Retail	Warehouse
New England	1059	773	1524	1210	1118	1239	1015
Mid-Atlantic	1059	773	1524	1210	1118	1239	1015
East N. Central	984	676	1422	1106	1041	1147	927
West N. Central	1020	709	1443	1136	1057	1127	971
South Atlantic	2278	1519	2921	2496	2083	2360	1794
East S. Central	1906	1281	2532	2104	1811	2066	1581
West S. Central	2237	1494	2873	2471	2054	2341	1739
Mountain-North	1193	829	1765	1434	1347	1419	1296
Mountain-South	2850	2001	3492	3238	2602	2903	2539
Oregon-Wash	843	574	1494	985	1093	1274	1194
California	1720	1176	2801	2051	1937	2340	1392

Baseline Annual Space-Cooling Energy Use ($UEC_{comm\_base\_c}$)

Using Eqn. 5.9, baseline annual space-cooling energy use values can be calculated for each of the 77 nationally representative commercial buildings by using the space-cooling FLEOHs in Table 5.12. The baseline space-cooling energy use values pertain to commercial building equipped with either central air conditioners or heat pumps. Table 5.13 shows the calculated energy use values.

Table 5.13 Baseline Annual Space-Cooling Energy Use for Commercial Buildings utilizing Residential-Size Space-Cooling Equipment (kWh/year)

Census Division / Region	Building Type						
	Assembly	Education	Food	Lodging	Office	Retail	Warehouse
New England	3814	2782	5488	4356	4026	4461	3653
Mid-Atlantic	3814	2782	5488	4356	4026	4461	3653
East N. Central	3541	2435	5119	3982	3747	4129	3336
West N. Central	3673	2552	5196	4091	3805	4058	3497
South Atlantic	8202	5470	10514	8984	7499	8497	6458
East S. Central	6862	4610	9116	7575	6521	7437	5690
West S. Central	8054	5379	10343	8896	7395	8426	6262
Mountain-North	4294	2985	6355	5163	4850	5107	4665
Mountain-South	10262	7203	12571	11656	9368	10452	9140
Oregon-Wash	3035	2067	5379	3545	3934	4586	4297
California	6192	4233	10083	7384	6973	8426	5010

Proper allocation of the shipments is necessary in order to obtain the proper representation or weighting for each of the building types. The allocation of the number of shipments to each of the 77 nationally representative commercial buildings is based on data from the 1992 and 1995 CBECS using a methodology developed by PNNL. Table 5.14 presents the percentage of shipments allocated to each of the 77 building types.

Table 5.14 Fraction of Building Stock utilizing Residential-Size Space-Cooling Equipment

Census Division / Region	Building Type						
	Assembly	Education	Food	Lodging	Office	Retail	Warehouse
New England	0.371%	0.790%	0.071%	0.333%	1.024%	1.502%	0.497%
Mid-Atlantic	1.005%	1.790%	0.230%	0.278%	2.993%	3.660%	1.844%
East N. Central	1.340%	2.014%	0.862%	0.960%	3.050%	3.847%	2.919%
West N. Central	0.771%	1.071%	0.124%	0.387%	1.515%	2.272%	0.635%
South Atlantic	1.640%	2.367%	0.578%	1.401%	4.532%	5.487%	2.501%
East S. Central	1.059%	0.799%	0.302%	0.659%	1.206%	3.121%	1.528%
West S. Central	1.268%	2.325%	0.490%	0.515%	2.200%	3.480%	1.275%
Mountain-North	0.677%	0.245%	0.147%	0.340%	1.601%	0.920%	0.239%
Mountain-South	0.775%	0.436%	0.068%	0.267%	0.825%	0.574%	0.536%
Oregon-Wash	0.208%	0.101%	0.118%	0.111%	0.820%	0.630%	0.120%
California	1.936%	1.457%	0.442%	0.710%	3.432%	3.191%	2.187%

Figure 5.13 depicts for the 77 nationally represented commercial buildings, the weighted distribution of the stock baseline annual space-cooling energy use. As with the residential building stock, the range of the space-cooling energy is quite wide. The minimum value is 2067 kWh/yr while the maximum value is 12,571 kWh/yr. The *weighted-average* value is 5824 kWh/yr.

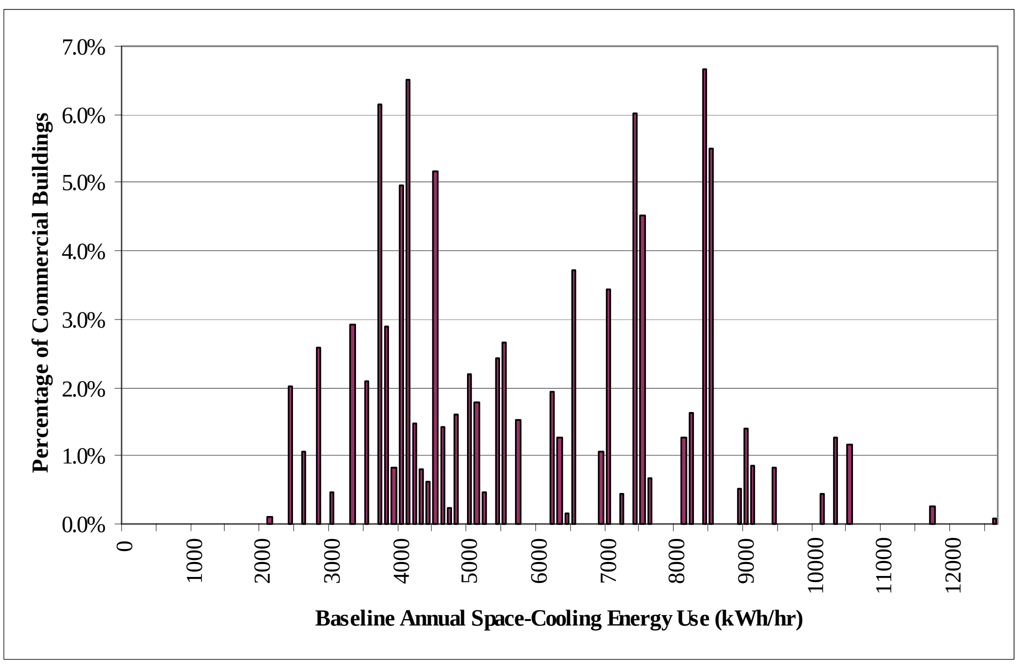

Figure 5.13 Percent of Commercial Buildings by Baseline Annual Space-Cooling Energy Consumption

5.2.3.2 Standard-Level Annual Space-Cooling Energy Use

Definition

The annual space-cooling energy use associated with air conditioning or heat pump equipment at a specific standard-level. For both residential and commercial buildings, the approach for calculating the standard-level energy use is identical to that for the baseline annual energy use. For households, the standard-level annual energy use is directly proportional to the energy use associated with the stock air-conditioning or heat pump equipment in the specific RECS household being analyzed. For commercial buildings, it is calculated using the DOE test procedure's annual energy use equation for central air conditioners based on the number of full-load equivalent operating hours (FLEOH) the equipment is assumed to operate.

Approach

Residential

For household air conditioners and the cooling-performance of heat pumps, the standard-level annual space-cooling energy use ($UEC_{res\_std\_c}$) is defined by the following equation:

$$UEC_{res\_std\_c} = UEC_{res\_stock\_c} \cdot \frac{SEER_{res\_stock}}{SEER_{std}} \quad \textbf{(5.13)}$$

Where,

$UEC_{res\_stock\_c}$ = annual space cooling energy use associated with the stock equipment in the RECS household,
$SEER_{res\_stock}$ = the SEER associated with the stock equipment in the RECS household, and
$SEER_{std}$ = the SEER associated with the increased efficiency level or standard.

The above equation for determining the standard-level annual space-cooling energy use is identical to that for the baseline annual space-cooling energy use, with the exception that the SEER associated with the increased standard is used in place of the baseline efficiency (i.e., 10 SEER). Thus, the determination of the standard-level annual space-cooling energy use is based upon the same information as used for the baseline energy use, namely, the stock annual space-cooling energy use and efficiency.

Commercial

For commercial building air conditioners and the cooling-performance of heat pumps, the standard-level annual space-cooling energy use ($UEC_{comm\_std\_c}$) is defined by the following equation taken from the DOE test procedure:

$$UEC_{comm\_std\_c} = \frac{CAP_{cool}}{SEER_{std}} \cdot FLEOH_{cool} \quad \textbf{(5.14)}$$

Where,

CAP_{cool} = cooling capacity of equipment (assumed to be 36,000 Btu/hr),
$SEER_{std}$ = the SEER associated with the increased efficiency level or standard, and
$FLEOH_{cool}$ = the full-load equivelent operating hours for space-cooling.

In order to be consistent with the cost data provided by manufacturers, the cooling capacity of the equipment is assumed to be 36,000 Btu/hr (3-ton). All manufacturer cost data provided by ARI are based on a system with a 3-ton cooling capacity.

The above equation for determining the standard-level annual space-cooling energy use is identical to that for the baseline annual space-cooling energy use, with the exception that the SEER associated with the increased standard is used in place of the baseline efficiency (i.e., 10 SEER). Thus, the determination of the standard-level annual space-cooling energy use is based upon the same information as used for the baseline energy use, namely, the FLEOHs.

Assumptions

Residential

The assumptions for determining the residential stock annual space-cooling energy use and the stock space-cooling efficiency have been discussed in the previous section (Section 5.2.3.1). For central air conditioners, the *weighted-average* stock annual space-cooling energy use and the *weighted-average* stock efficiency are 2132 kWh/yr and 9.13 SEER, respectively. For heat pumps, the *weighted-average* stock annual space-cooling energy use and the *weighted-average* stock efficiency are 2585 kWh/yr and 9.32 SEER, respectively.

Based on the above *weighted-average* values and the use of Eqn 5.13, *weighted-average* standard-level annual space-cooling energy use values can be determined. Table 5.15 shows the *weighted-average* annual space-cooling energy use values for standard-levels of 11 through 13 SEER and 18 SEER for both central air conditioners and heat pumps. It is worth reiterating that the values shown in Table 5.15 are the *weighted-average* values associated with each standard-level. In the course of conducting the LCC analysis with Crystal Ball, the energy use due to a particular standard-level is determined for each household in RECS based on the unique age and space-cooling energy use associated with that household. As a point of reference, the *weighted-average* stock annual space-cooling energy use and the *weighted-average* stock efficiency are included in Table 5.15. Also provided are the *weighted-average* baseline space-cooling energy use and efficiency values.

Table 5.15 Residential Central Air Conditioner and Heat Pump Annual Space-Cooling Energy Use scaled to SEER

	Standard-Level *SEER (Btu/W·hr)*	Central Air Conditioners *kWh/yr*	Heat Pumps *kWh/yr*
survey	9.13[a] (CAC), 9.32[a] (HP)	2132[a]	2585[a]
scaled	10	1947	2409
	11	1770	2190
	12	1622	2008
	13	1497	1853
	18	1081	1338

[a] RECS-based *weighted-average* values for household equipment in use in 1997.

<u>*Commercial*</u>

The assumptions for determining the space-cooling FLEOHs necessary for determining the commercial baseline annual space-cooling energy use have been discussed in the previous section (Section 5.2.3.1). The both central air conditioners and the cooling-performance of heat pumps, the weighted-average baseline annual space-cooling energy use is 5824 kWh/yr.

Rather than using Eqn. 5.14, *weighted-average* standard-level space-cooling energy use values can be determined by simply by multiplying the baseline energy use by the ratio of the baseline efficiency (i.e., 10 SEER) to the standard-level efficiency. Table 5.16 shows the *weighted-average* annual space-cooling energy use values for standard-levels of 11 through 13 SEER and 18 SEER It is worth reiterating that the values shown in Table 5.16 are only the *weighted-average* values associated with each standard-level. In the course of conducting the LCC analysis with Crystal Ball, the energy use due to a particular standard-level is determined for each commercial building.

Table 5.16 Commercial Building Central Air Conditioner and Heat Pump Annual Space-Cooling Energy Use scaled to SEER

	Standard-Level *SEER (Btu/W·hr)*	Space-Cooling Energy Use *kWh/yr*
Baseline	10	5824
Scaled	11	5295
	12	4853
	13	4480
	18	3236

Weighted-average annual space-cooling energy use values for the entire building stock are based on the same scaling method used for determining the *weighted-average* residential and commercial energy use values. For coming up with the overall energy use values, the overall stock space-cooling energy use values and efficiencies for central air conditioners and heat pumps are first determined. Based on the assumption that 90% of the central air-conditioning and heat pump stock reside in households (with the remaining 10% residing in commercial buildings), the overall energy use and efficiency values are determined by multiplying the residential and commercial values by 90% and 10%, respectively, and then summing the result. In lieu of having stock energy use values and efficiencies for commercial equipment, the baseline (i.e., 10 SEER) energy use and efficiency are used. Thus, the resulting overall *weighted-average* stock space-cooling energy use values are 2501 kWh/yr for central air conditioners and 2950 kWh/yr for heat pumps. The resulting overall *weighted-average* stock efficiencies are 9.22 SEER for central air conditioners and 9.39 for heat pumps. Table 5.17 summarizes the overall *weighted-average* annual space-cooling energy use values for each standard-level. Again, it is must be emphasized that the values shown in Table 5.17 are only the *weighted-average* values associated with each standard-level. In the course of conducting the LCC analysis with Crystal Ball, the energy use due to a particular standard-level is determined for each residential and commercial building.

Table 5.17 Overall Central Air Conditioner and Heat Pump Annual Space-Cooling Energy Use scaled to SEER

	Standard-Level *SEER (Btu/W·hr)*	**Central Air Conditioners** *kWh/yr*	**Heat Pumps** *kWh/yr*
stock	9.22 (CAC), 9.39 (HP)	2501	2950
scaled	10	2305	2769
	11	2096	2517
	12	1921	2307
	13	1773	2130
	18	1281	1538

5.2.3.3 Baseline Annual Space-Heating Energy Use

Definition

The annual space-heating energy use associated with baseline (i.e., 6.8 HSPF) heat pump equipment. For households, the baseline annual energy use is directly proportional to the energy use associated with the stock heat pump equipment in the specific RECS household being analyzed. For commercial buildings, it is calculated using the DOE test procedure's annual energy use equation for heat pumps based on the number of full-load equivalent operating hours (FLEOH) the equipment is assumed to operate.

Approach

<u>Residential</u>

For the household heating-performance of heat pumps, the baseline annual space-heating energy use ($UEC_{res\_base\_h}$) is defined by the following equation:

$$UEC_{res\_base\_h} = UEC_{res\_stock\_h} \cdot \frac{HSPF_{res\_stock}}{HSPF_{base}} \qquad \textbf{(5.15)}$$

Where,

$UEC_{res\_stock\_h}$ = annual space-heating energy use associated with the stock equipment in the RECS household,
$HSPF_{res\_stock}$ = the HSPF associated with the stock equipment in the RECS household, and
$HSPF_{base}$ = the HSPF associated with the baseline equipment (i.e., 6.8 HSPF).

Thus, the approach for determining the annual baseline space-heating energy use requires that the UEC_{stock_h} and $HSPF_{stock}$ first be determined.

<u>Commercial</u>

For the commercial building heating-performance of heat pumps, the baseline annual space-heating energy use ($UEC_{comm\_base\_h}$) is defined by the following equation taken from the DOE test procedure:

$$UEC_{comm\_base\_h} = \frac{DHR}{HSPF_{base}} \cdot FLEOH_{heat} \cdot 0.77 \qquad \textbf{(5.16)}$$

Where,

DHR = standardized design heating requirement nearest to the heating capacity of the system,
$HSPF_{base}$ = the HSPF associated with the baseline equipment (i.e., 6.8 HSPF),
$FLEOH_{heat}$ = the full-load equivelent operating hours for space-heating, and
0.77 = factor to adjust the calculated design heating requirement and heat load hours to the actual load experienced by a heating system.

In order to be consistent with the cost data provided by manufacturers, the heating capacity of the equipment is assumed to be 36,000 Btu/hr resulting in the DHR being set to 36,000 Btu/hr. All manufacturer cost data provided by ARI are based on a system with a 3-ton cooling capacity with a corresponding heating capacity of 36,000 Btu/hr.

Assumptions

<u>Residential</u>

The following discusses the assumptions for determining the stock annual space-heating energy use and the stock space-heating efficiency. Both are needed for calculating the residential baseline annual space-heating energy use.

Stock Annual Space-Heating Energy Use ($UEC_{res\_stock\_h}$)

The stock annual space-heating energy consumption is based on data from the 1997 RECS. For each household with a 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.

In order to mitigate the effect of annual weather fluctuations on the annual energy consumption values in the 1997 RECS, the household stock annual energy use values are adjusted based on 30-year average heating degree day (HDD) data[15]. In the 1997 RECS, although the 30-year (1961-1990) average HDD data are not provided for each household, the household's location is specified at the Census Division level. In addition, its state-level location is specified if it resides in either one of the following large states: California, Florida, New York, and Texas. Thus, with 30-year average HDD values for each Census Division and each of the large states, the household annual energy use values can at least be adjusted on a regional basis. The calculation to adjust the household energy use value is straight forward and is represented by the following equation:

$$UEC_{res\_stock\_h} = UEC_{res\_stock\_h\_non-adj} \cdot \frac{HDD_{30\,yr\,avg}}{HDD_{res\_stock}} \qquad \textbf{(5.17)}$$

Where,

$UEC_{res\_stock\_h}$ = weather-adjusted annual space-heating energy use associated with the stock equipment in the RECS household,

$UEC_{res\_stock\_c\_non-adj}$ = annual space-heating energy use associated with the stock equipment in the RECS household,

HDD_{res_stock} = the HDD associated with the stock equipment in the RECS household, and

$HDD_{30\,yr\,avg}$ = the 30-year average HDD for the specific Census Division or state location of the RECS household.

Table 5.18 shows the 30-year average HDD values for each of the nine Census Divisions and the four large states. For those Census Divisions encompassing a large state, the calculation of the average HDD excludes the state. Each HDD value was determined through a shipment/population weighting (i.e., taking into where air-conditioning equipment is shipped and the population of the areas where the equipment is being shipped to). Appendix E provides a detailed description of this weighting procedure.

Table 5.18 Census Division and Four Large State 30-year Average HDD

Census Division	States	30-year average CDD
New England	Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut	6187
Middle Atlantic	Pennsylvania, New Jersey	5676
East North Central	Michigan, Wisconsin, Illinois, Indiana, Ohio	6371
West North Central	Minnesota, Iowa, Missouri, Kansas, North Dakota, South Dakota, Nebraska	6009
South Atlantic	West Virginia, Virginia, Georgia, South Carolina, North Carolina, District of Columbia	3432
East South Central	Kentucky, Tennessee, Alabama, Mississippi	3314
West South Central	Oklahoma, Arkansas, Louisiana	2756
Mountain	Montana, Idaho, Wyoming, Nevada, Utah, Arizona, New Mexico, Colorado	3248
Pacific	Washington, Oregon, Alaska, Hawaii	4801
-	New York	4116
-	Florida	961
-	Texas	2045
-	California	2020

Figure 5.14 depicts the weighted distribution of the weather-adjusted stock annual space-heating energy use for those RECS households with a heat pump. As discussed earlier, of the5900 households surveyed in RECS, 308 were to determined to have heat pumps. The space heating energy use ranges from a minimum value of 174 kWh/yr to a maximum value of 17,272 kWh/yr. The *weighted-average* value is 3921 kWh/yr.

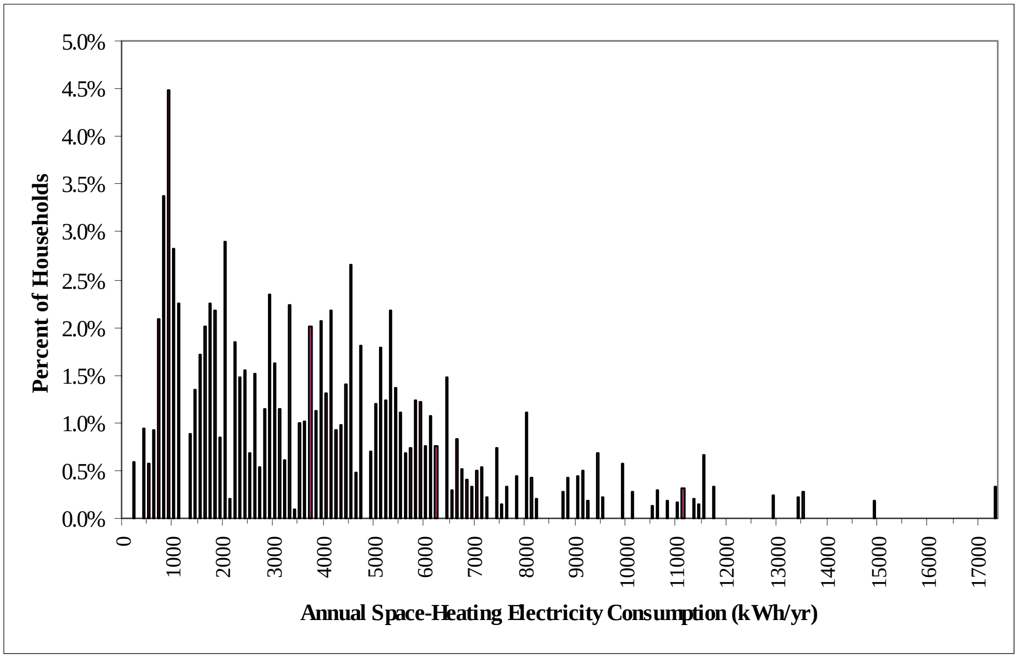

Figure 5.14 Percent of Households with Heat Pumps by Weather-Adjusted Annual Space-Heating Energy Consumption (Source: U.S. DOE-EIA, 1997 RECS)

Stock Space-Heating Efficiency ($HSPF_{res\_stock}$)

As indicated in the baseline annual space-heating energy use equation (Eqn. 5.15), the HSPF of the stock equipment is necessary for determining the annual space-heating energy use associated with minimum (6.8 HSPF) efficiency heat pump equipment.

In order to establish the HSPF of the stock equipment, the age of the equipment as indicated by the 1997 RECS is first established. For each household surveyed with a heat pump, RECS provides an age index for the equipment. Each index value corresponds to a range of equipment ages. The distribution of age indices for the heat pumps in RECS was shown previously in the discussion of stock space-cooling efficiency (Figure 5.12). That figure is repeated below as Figure 5.15. A table is imbedded in the figure showing the corresponding range of ages for each index. Each age in the range of values that correspond to a particular age index is assumed to have an equal probability of occurring.

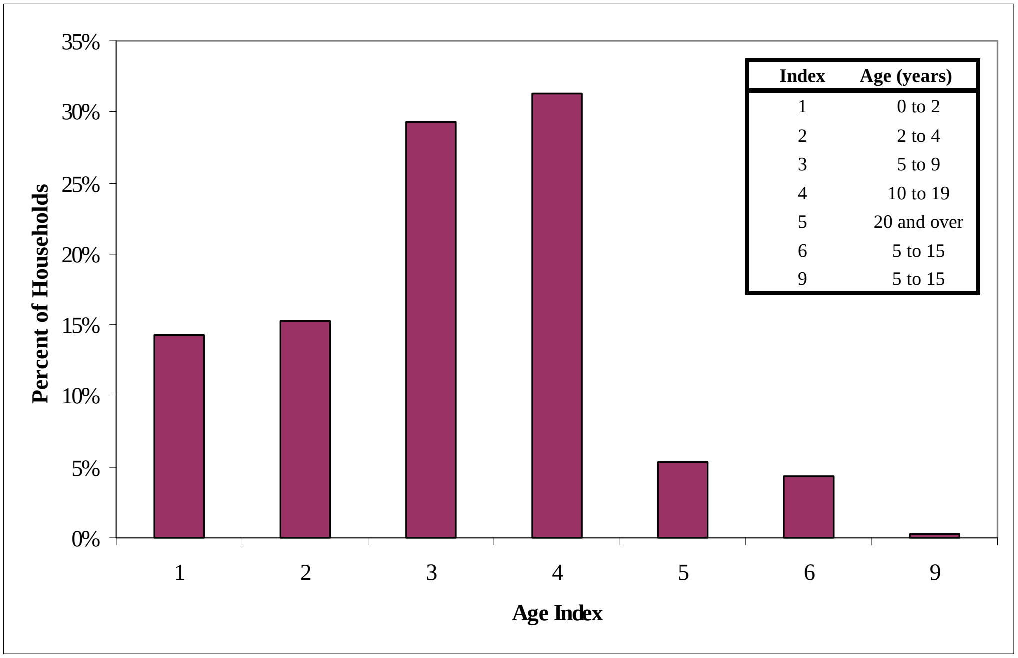

Figure 5.15 Distribution of Age Indices for RECS households with a Heat Pump (Source: U.S. DOE-EIA, 1997 RECS)

Once the age of the equipment is established, disaggregated shipments data provided by ARI are used to determine the efficiency of the equipment. Unlike the data provided by ARI for the SEER, shipments data disaggregated by HSPF are available only for a limited number of years (1987 through 1990). With this data, an efficiency distribution for each year from 1987 to 1990 can be created. The shipment *weighted-average* efficiencies by year are shown in the table below (Table 5.19). For years preceding 1987 and extending past 1990 to 1993, an efficiency increase rate of 1.5% per year is used to establish the shipment weighted HSPF (the resulting values are presented in Table 5.19). This rate of increase is the average rate of increase exhibited by the shipment weighted HSPF from 1987 to 1990. For the years 1994 through 1997, the efficiency is assumed to remain constant. Efficiency distributions for those years in which data were not provided were assumed to have the same distributional shape as the years (1987 through 1990) in which data were provided.

Table 5.19 Shipment Weighted HSPFs of Unitary Heat Pumps

Year	Unitary Heat Pumps [a]
1976	5.66
1977	5.74
1978	5.83
1979	5.91
1980	6.00
1981	6.09
1982	6.18
1983	6.28
1984	6.37
1985	6.47
1986	6.56
1987	6.66
1988	6.81
1989	6.87
1990	6.98
1991	7.08
1992	7.19
1993	7.30
1994	7.30
1995	7.30
1996	7.30
1997	7.30

[a] 1987-1990: HSPFs are actual shipment weighted values from ARI shipments data. Years prior to 1987 and from 1991-1993: HSPFs based on efficiency rate increase of 1.5%. 1994-1997: Efficiency frozen at 1993 HSPF.

For all the households in RECS with a heat pump, the methodology for establishing the stock space-heating efficiency yields a *weighted-average* stock efficiency of 6.77 HSPF.

Baseline Annual Space-Heating Energy Use ($UEC_{res\_base\_h}$)

A baseline annual space-heating energy use is determined for each RECS household with a heat pump based on the household's stock energy use and equipment efficiency. The resulting baseline energy use values for these RECS households have a large range. To provide an indication of the magnitude of the baseline energy use for heat pumps, *weighted-average* values are calculated and provided below.

Based on the use of the RECS *weighted-average* stock space-heating energy use and *weighted-average* efficiency for heat pumps, the *weighted-average* baseline space-heating annual energy use is:

$$UEC_{HP_{wght-avg}\_base\_h} = UEC_{HP_{wght-avg}\_stock\_h} \cdot \frac{HSPF_{HP_{wght-avg}\_stock}}{HSPF_{base}} = 3921 \cdot \frac{6.77}{6.80} = 3904 \ kWh/yr$$

Commercial

The following discusses the assumptions for determining the space-heating FLEOHs and, in turn, how they are used for calculating the commercial baseline annual space-heating energy use.

Full-Load Equivalent Operating Hours (FLEOH)

The space-heating FLEOH is effectively the number of hours that a system would have to run at full capacity to serve a total load equal to the annual load on the equipment. FLEOH is calculated as:

$$FLEOH_{heat} = \frac{Load_{heat}}{CAP_{heat}} \qquad \textbf{(5.18)}$$

Where,

$Load_{heat}$ = annual equipment load for space-heating.

FLEOH is strictly defined as being related to the equipment capacity, not the peak load of the system. Because FLEOH is used to generate annual heating loads irrespective of equipment size, it is assumed that the equipment is sized based on the design-day peak equipment load with no explicit oversizing. Thus equation 5.10 becomes:

$$FLEOH_{heat} = \frac{Load_{heat}}{Peak\ Load_{heat}} \qquad \textbf{(5.19)}$$

Where,

$Peak\ Load_{heat}$ = design-day peak heating load.

The FLEOH for a piece of equipment is a function of the relative annual load to the peak building load. In general, this ratio will vary depending on building construction, building internal loads, building schedules, and orientation an exposure of the zone that the equipment serves. It was assumed that for any given building type, the internal-load characteristics and building schedules are constant across the building.

FLEOHs were determined for a set of 77 nationally representative commercial buildings. The 77 buildings are comprised of seven different types of commercial buildings located in eleven different geographic regions of the U.S. consistent with assumptions used to develop ASHRAE 90.1-1999. In conducting the computer modeling of the buildings, it was assumed that a single type of equipment, in our case residential-type space-heating equipment, were used to condition the building. Additionally, it was assumed that the equipment did not use economizers but did operate with setback theromstats. Table 5.20 presents the FLEOHs for each of the 77 commercial building which were modeled.

Table 5.20 Space-Heating FLEOHs for Commercial Buildings utilizing Residential-Size Space-Heating Equipment (hours)

Census Division / Region	Building Type						
	Assembly	**Education**	**Food Service**	**Lodging**	**Office**	**Retail**	**Warehouse**
New England	1898	816	1388	1523	597	493	889
Mid-Atlantic	1907	849	1388	1523	674	598	887
East N. Central	2044	964	1575	1683	780	655	1056
West N. Central	2014	926	1507	1690	851	759	1157
South Atlantic	1144	493	817	666	289	171	512
East S. Central	1352	582	949	839	341	276	308
West S. Central	1103	448	810	596	242	129	166
Mountain-North	1837	815	1282	1336	485	489	604
Mountain-South	965	322	722	349	178	34	32
Oregon-Wash	2363	1070	1589	1732	624	617	928
California	1317	528	781	521	214	94	18

Baseline Annual Space-Heating Energy Use ($UEC_{comm\_base\_h}$)

Baseline annual space-heating energy use values can be calculated for each of the 77 nationally representative commercial buildings by using the space-heating FLEOHs in Table 5.20. The baseline space-heating energy use values pertain to commercial building equipped with heat pumps. Table 5.21 shows the calculated energy use values.

Table 5.21 Baseline Annual Space-Heating Energy Use for Commercial Buildings utilizing Residential-Size Space-Heating Equipment (kWh/year)

Census Division / Region	Building Type						
	Assembly	Education	Food Service	Lodging	Office	Retail	Warehouse
New England	7735	3325	5658	6208	2434	2008	3625
Mid-Atlantic	7775	3462	5658	6208	2748	2439	3618
East N. Central	8333	3930	6419	6862	3182	2668	4304
West N. Central	8210	3776	6145	6888	3467	3094	4715
South Atlantic	4662	2012	3331	2716	1178	699	2088
East S. Central	5512	2371	3870	3419	1390	1125	1257
West S. Central	4498	1827	3300	2428	985	526	676
Mountain-North	7488	3323	5225	5445	1977	1994	2461
Mountain-South	3934	1311	2943	1421	724	140	131
Oregon-Wash	9633	4360	6476	7060	2543	2516	3782
California	5368	2154	3184	2125	872	381	75

Proper allocation of the shipments is necessary in order to obtain the proper representation or weighting for each of the building types. The allocation of the number of shipments to each of the 77 nationally representative commercial buildings is based on data from the 1992 and 1995 CBECS using a methodology developed by PNNL. Table 5.22 presents the percentage of shipments allocated to each of the 77 building types. The allocation is identical to that used for the space-cooling FLEOHs.

Table 5.22 Fraction of Building Stock utilizing Residential-Size Space-Cooling Equipment

Census Division / Region	Building Type						
	Assembly	Education	Food	Lodging	Office	Retail	Warehouse
New England	0.371%	0.790%	0.071%	0.333%	1.024%	1.502%	0.497%
Mid-Atlantic	1.005%	1.790%	0.230%	0.278%	2.993%	3.660%	1.844%
East N. Central	1.340%	2.014%	0.862%	0.960%	3.050%	3.847%	2.919%
West N. Central	0.771%	1.071%	0.124%	0.387%	1.515%	2.272%	0.635%
South Atlantic	1.640%	2.367%	0.578%	1.401%	4.532%	5.487%	2.501%
East S. Central	1.059%	0.799%	0.302%	0.659%	1.206%	3.121%	1.528%
West S. Central	1.268%	2.325%	0.490%	0.515%	2.200%	3.480%	1.275%
Mountain-North	0.677%	0.245%	0.147%	0.340%	1.601%	0.920%	0.239%
Mountain-South	0.775%	0.436%	0.068%	0.267%	0.825%	0.574%	0.536%
Oregon-Wash	0.208%	0.101%	0.118%	0.111%	0.820%	0.630%	0.120%
California	1.936%	1.457%	0.442%	0.710%	3.432%	3.191%	2.187%

Figure 5.16 depicts for the 77 nationally represented commercial buildings, the weighted distribution of the stock baseline annual space-heating energy use. As with the residential building stock, the range of the space-heating energy use is quite wide. The minimum value is 75 kWh/yr while the maximum value is 9633 kWh/yr. The *weighted-average* value is 2654 kWh/yr.

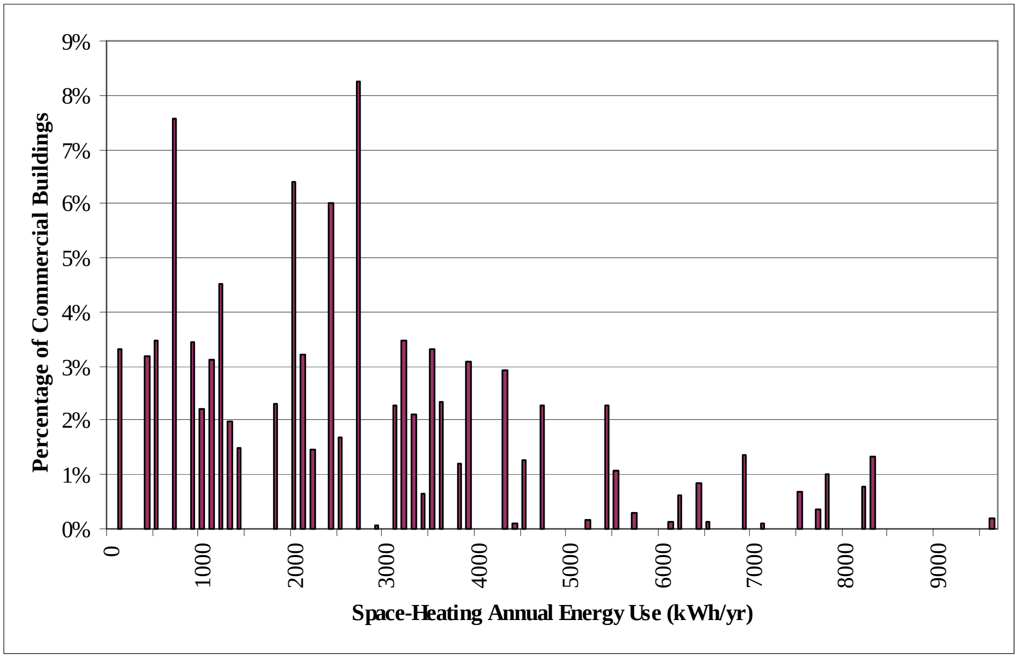

Figure 5.16 Percent of Commercial Buildings by Baseline Annual Space-Heating Energy Consumption

5.2.3.4 Standard-Level Annual Space-Heating Energy Use

Definition

The annual space-heating energy use associated with heat pump equipment at a specific standard-level. For both residential and commercial buildings, the approach for calculating the standard-level energy use is identical to that for the baseline annual energy use. For households, the standard-level annual energy use is directly proportional to the energy use associated with the stock heat pump equipment in the specific RECS household being analyzed. For commercial buildings, it is calculated using the DOE test procedure's annual energy use equation for heat pumps based on the number of full-load equivalent operating hours (FLEOH) the equipment is assumed to operate.

Approach

<u>*Residential*</u>

For the household heating-performance of heat pumps, the standard-level annual space-heating energy use ($UEC_{res\_std\_h}$) is defined by the following equation:

$$UEC_{res\_std\_h} = UEC_{res\_stock\_h} \cdot \frac{HSPF_{res\_stock}}{HSPF_{std}} \quad \textbf{(5.20)}$$

Where,

$UEC_{res\_stock\_h}$ = annual space-heating energy use associated with the stock equipment in the RECS household,
$HSPF_{res\_stock}$ = the HSPF associated with the stock equipment in the RECS household, and
$HSPF_{std}$ = the HSPF associated with the increased efficiency level or standard.

The above equation for determining the standard-level annual space-heating energy use is identical to that for the baseline annual space-heating energy use, with the exception that the HSPF associated with the increased standard is used in place of the baseline efficiency (e.g., 6.8 SEER). Thus, the determination of the standard-level annual space-heating energy use is based upon the same information as used for the baseline energy use, namely, the stock annual space-heating energy use and efficiency.

<u>Commercial</u>

For the commercial building heating-performance of heat pumps, the standard-level annual space-heating energy use ($UEC_{comm\_std\_h}$) is defined by the following equation taken from the DOE test procedure:

$$UEC_{comm\_std\_h} = \frac{DHR}{HSPF_{std}} \cdot FLEOH_{heat} \cdot 0.77 \quad \textbf{(5.21)}$$

Where,

DHR = standardized design heating requirement nearest to the heating capacity of the system,
$HSPF_{std}$ = the HSPF associated with the increased efficiency level or standard,
$FLEOH_{heat}$ = the full-load equivelent operating hours for space-heating, and
0.77 = factor to adjust the calculated design heating requirement and heat load hours to the actual load experienced by a heating system.

In order to be consistent with the cost data provided by manufacturers, the heating capacity of the equipment is assumed to be 36,000 Btu/hr resulting in the DHR being set to 36,000 Btu/hr. All manufacturer cost data provided by ARI are based on a system with a 3-ton cooling capacity with a corresponding heating capacity of 36,000 Btu/hr.

The above equation for determining the standard-level annual space-heating energy use is identical to that for the baseline annual space-heating energy use, with the exception that the HSPF associated with the increased standard is used in place of the baseline efficiency (i.e., 6.8 HSPF). Thus, the determination of the standard-level annual space-heating energy use is based upon the same information as used for the baseline energy use, namely, the FLEOHs.

Assumptions

<u>*Residential*</u>

The assumptions for determining the stock annual space-heating energy use and the stock space-heating efficiency have been discussed in the previous section (Section 5.2.3.3). The *weighted-average* stock annual space-heating energy use and *weighted-average* stock efficiency are 3921 kWh/yr and 6.77 HSPF, respectively.

Based on the above *weighted-average* values and the use of Eqn 5.19, *weighted-average* standard-level annual space-heating energy use values can be determined. Table 5.23 shows the *weighted-average* annual space-heating energy use values for standard-levels of 7.1 through 7.7 HSPF and 8.8 HSPF. It is worth reiterating that the values shown in Table 5.23 are the *weighted-average* values associated with each standard-level. In the course of conducting the LCC analysis with Crystal Ball, the energy use due to a particular standard-level is determined for each household in RECS based on the unique age and space-heating energy use associated with that household.

Table 5.23 Residential Heat Pump Weighted-Average Annual Space-Heating Energy Use scaled to HSPF

	Standard-Level	**Heat Pumps**
	HSPF (Btu/W·hr)	*kWh/yr*
survey	6.77[a]	3921[a]
scaled	6.8	3904
	7.1	3739
	7.4	3603
	7.7	3447
	8.8	3016

[a] RECS-based *weighted-average* values for household equipment in use in 1997.

<u>*Commercial*</u>

The assumptions for determining the FLEOHs necessary for determining the commercial baseline annual space-cooling energy use have been discussed in the previous section (Section 5.2.3.3). The weighted-average baseline annual space-heating energy use is 2654 kWh/yr.

Rather than using Eqn. 5.19, *weighted-average* standard-level space-heating energy use values can be determined by simply by multiplying the baseline energy use by the ratio of the baseline efficiency (i.e., 6.8 HSPF) to the standard-level efficiency. Table 5.24 shows the *weighted-average* annual space-cooling energy use values for standard-levels of 7.1 through 7.7 HSPF and 8.8 HSPF. It is worth reiterating that the values shown in Table 5.24 are only the *weighted-average* values associated with each standard-level. In the course of conducting the LCC analysis with Crystal Ball, the energy use due to a particular standard-level is determined for each commercial building.

Table 5.24 Commercial Building Heat Pump Weighted-Average Annual Space-Heating Energy Use scaled to HSPF

	Standard-Level *HSPF (Btu/W·hr)*	Space-Heating Energy Use *kWh/yr*
Baseline	6.8	2654
Scaled	7.1	2542
	7.4	2439
	7.7	2344
	8.8	2051

Weighted-average annual space-heating energy use values for the entire building stock are based on the same scaling method used for determining the *weighted-average* residential and commercial energy use values. For coming up with the overall energy use values, the overall stock space-heating energy use values and efficiencies for heat pumps are first determined. Based on the assumption that 90% of the heat pump stock reside in households (with the remaining 10% residing in commercial buildings), the overall energy use and efficiency values are determined by multiplying the residential and commercial values by 90% and 10%, respectively, and then summing the result. In lieu of having stock energy use values and efficiencies for commercial equipment, the baseline (i.e., 6.8 HSPF) energy use and efficiency are used. Thus, the resulting overall *weighted-average* stock space-heating energy use value is 3794 kWh/yr. The resulting overall *weighted-average* stock efficiency is 6.78 HSPF for heat pumps. Table 5.25 summarizes the overall *weighted-average* annual space-heating energy use values for each standard-level. Again, it is must be emphasized that the values shown in Table 5.25 are only the *weighted-average* values associated with each standard-level. In the course of conducting the LCC analysis with Crystal Ball, the energy use due to a particular standard-level is determined for each residential and commercial building.

Table 5.25 Overall Heat Pump Weighted-Average Annual Space-Heating Energy Use scaled to HSPF

	Standard-Level *HSPF (Btu/W·hr)*	Heat Pumps *kWh/yr*
stock	6.78	3794
scaled	6.8	3780
	7.1	3621
	7.4	3474
	7.7	3339
	8.8	2921

5.2.3.5 Average Electricity Price

Definition

Average electricity price is the mean price paid for all electricity. For households, it is the price paid by the 1997 RECS households examined. For commercial buildings, it is the price paid by each of the 77 nationally representative buildings modeled.

Approach

Residential

Distributions of average electricity prices were prepared for groups of 1997 RECS households with central air conditioners and with heat pumps. Because the average electricity price reported in RECS is the average price for the local utility and not the household's own average price, average electricity prices were calculated directly from household billing data.

Commercial

The procedure for developing average electricity prices for the 77 nationally representative commercial buildings matches each building's space-conditioning load and demand (determined from the computer modeling analysis for establishing FLEOHs) to actual modeled commercial tariffs. Customer energy bills are then calculated for the building on a monthly basis. The monthly bill (in 1998$) is divided by the monthly energy consumption (in kWh) to come up with an average monthly electricity price (in $/kWh). An annual average electricity price is determined by averaging the twelve monthly average electricity rates.

Since several tariffs were applied to each building, the average electricity price calculated from each tariff was weighted by the number of customers covered by the tariff to come up with an *weighted-average* average electricity rate for each building.

Assumptions

Residential

Figures 5.17 and 5.18 show the distributions of average electricity prices that were used in the LCC analysis for those 1997 RECS households with central air conditioners and heat pumps, respectively. The *weighted-average* average electricity price for central air conditioners is 8.90 ¢/kWh while for heat pumps it is 7.39 ¢/kWh. Both electricity prices are for the year 1998 in 1998$.

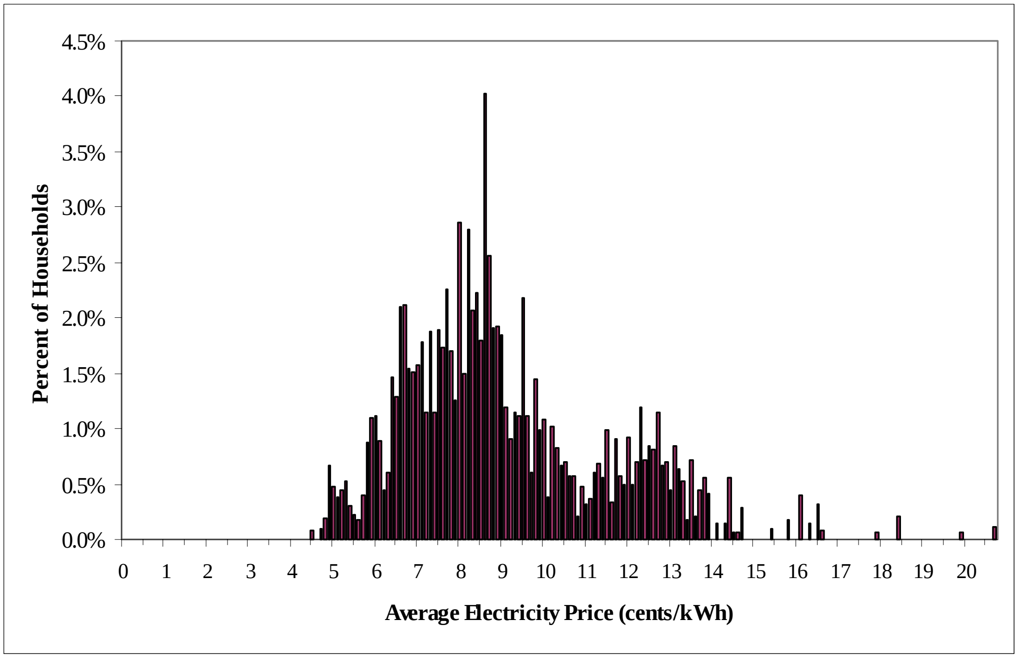

Figure 5.17 Percent of Households with Central Air Conditioners by Average Electricity Prices (Source: U.S. DOE-EIA, 1997 RECS)

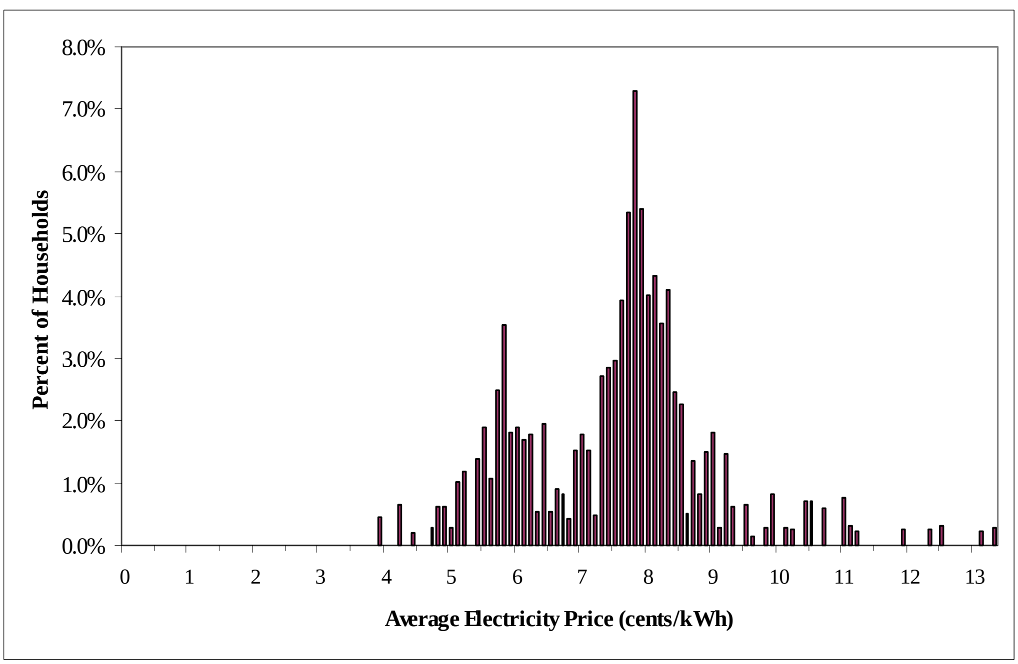

Figure 5.18 Percent of Households with Heat Pumps by Average Electricity Prices (Source: U.S. DOE-EIA, 1997 RECS)

Commercial

Tariffs for the year 1997 were collected from 30 electric utilities through out the U.S. for purposes of developing commercial building average electricity rates. Although most of the utilities were investment owned utilities (IOU), six of the companies were municipal utilities and two were rural cooperatives. Each utility has several tariffs which can be applied to their customers. The customer's peak power demand dictates which tariff is applicable. Thus, for the 77 nationally representative buildings analyzed, only those utility tariffs which matched the building's modeled peak demand characteristics were applied to calculate an energy bill. The methodology for matching building peak characteristics to tariffs is documented in a DOE report on marginal energy prices[16]. As it turns out, only one tariff from each utility was applicable to a building's modeled peak demand. Thus, for each of the 77 commercial buildings, a total of 30 tariffs (one from each utility) were applied.

Table 5.26 summarizes the 30 electric utilities for which tariffs were collected. In Table 5.26 the number of customers covered by the tariffs which were modeled and applied to the 77 commercial buildings are provided. As can be seen from Table 5.26, 21.1% of the U.S. commercial customer base are represented with the tariffs which were modeled and applied to the 77 buildings. For each of the 77 buildings, the average electricity prices calculated from each tariff are weighted by the number of customers represented by the tariff to come up with a customer *weighted-average* average electricity price.

Figure 5.19 show the distribution of average electricity prices for commercial buildings using either central air conditioners or heat pumps. The *weighted-average* average electricity price is 7.95 ¢/kWh. The electricity price is for the year 1998 in 1998$.

Table 5.26 Characterization and Summary of Commercial Electric Utility Sample

Utility	State	Type	Number of Customers Covered by Modeled Tariffs
Alabama Power	AL	IOU	76,417
Appalachian Power Company	VA	IOU	78,554
Arizona Public Service	AZ	IOU	73,663
Benton Public Utility Dept	WA	Muni	4,174
Boston Edison	MA	IOU	80,255
Central Power and Light	TX	IOU	74,107
City of Chattanooga	TN	Muni	19,563
City of Gillette	WY	Muni	4,239
City of Oxford	MS	Muni	854
Cleveland Electric Illuminatin	OH	IOU	63,161
Cleveland Utilities	OH	Muni	3,484
Commonwealth Edison Co	IL	IOU	291,143
Detroit Edison	MI	IOU	166,003
Douglas	WA	Co-op	1,115
Jersey Central Power & Light C	NJ	IOU	104,922
LADWP	CA	Muni	165,630
Madison G&E	WI	IOU	14,815
Niagara Mohawk Power Corp	NY	IOU	143,590
NSP (MN)	MN	IOU	110,807
NSP (WI)	WI	IOU	27,449
Ohio Power Company	OH	IOU	6,442
Pacific Gas and Electric	CA	IOU	352,776
Pennsylvania Power & Light Co	PA	IOU	143,849
PEPCO	MD	IOU	53,620
Poudre Valley	CO	Co-op	2,101
Seattle City Light	WA	IOU	40,794
SoCal Edison	CA	IOU	419,163
Union Electric Co.	MO	IOU	114,262
Virginia Power Company	VA	IOU	137,813
Wisconsin Electric Power Co	WI	IOU	85,735
Total Customers in Selected Tariffs			2,860,500
Total U.S. Commercial Customers			13,540,374
Percent Coverage with Selected Tariffs			21.1%

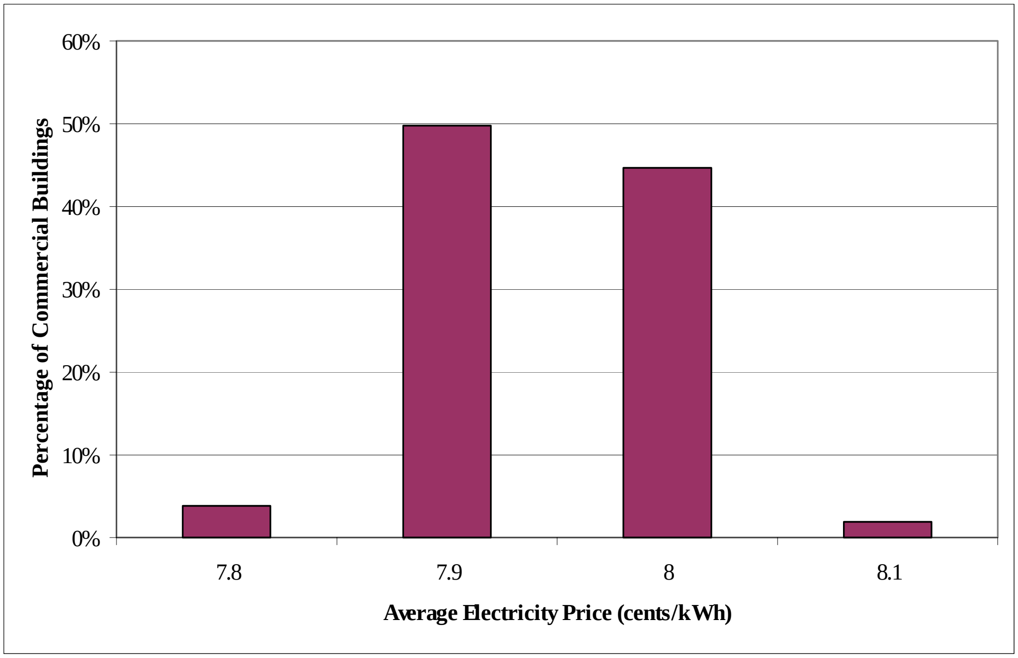

Figure 5.19 Percent of Commercial Buildings with Space-Conditioning Equipment by Average Electricity Prices

5.2.3.6 Marginal Electricity Price

Definition

Marginal electricity prices are the prices faced by households or commercial buildings for the last kWh of electricity purchased. A household's or commercial building's marginal price can be higher or lower than its average price, depending on the relationship between the block rate price structure facing the building and the size of customer charges and/or other charges included in the buildings's electricity bill.

Approach

Residential

Marginal electricity prices were estimated directly from RECS household data by calculating the slopes of regression lines that relate customer bills and customer usage. The slopes of the regressions for four "summer" months (June to September) and, separately, for the remaining ("winter") months were calculated[17].

For purposes of conducting the LCC analysis, an annual marginal electricity price was derived from the "summer" and "winter" marginal prices. The following expression was used for the derivation:

$$EL_{marg} = a \cdot EL_{marg\_sum} + b \cdot EL_{marg\_win} \quad \textbf{(5.22)}$$

Where,

a = seasonal weighting factor for the "summer" marginal electricity price,
EL_{marg_sum} = "summer" marginal electricity price,
b = seasonal weighting factor for the "winter" marginal electricity price, and
EL_{marg_win} = "winter" marginal electricity price.

Because central air conditioners and heat pumps are seasonal household appliances that use energy during specific times of the year, the "summer" and "winter" prices must be weighted appropriately in order to reflect their seasonal energy use. Simulated household cooling and heating loads based on the DOE-2 modeling of residential buildings were used to establish the appropriate seasonal weighing factors[18].

<u>Commercial</u>

As presented in the discussion of average electricity prices, the procedure for developing average electricity prices for the 77 nationally representative commercial buildings matches each building's space-conditioning load and demand (determined from the computer modeling analysis for establishing FLEOHs) to actual modeled commercial tariffs. Customer energy bills are then calculated for the building. The energy bill (in 1998$) is divided by the energy consumption (in kWh) to come up with an average electricity price (in $/kWh).

In the case of developing marginal electricity prices for space-cooling, energy bills for space-cooling are calculated for both the baseline case (i.e., 10 SEER) and a standards case. The difference in the space-cooling energy bills (in dollars) is divided by the usage difference (in kWh) to give a "marginal" rate of $/kWh for the increment of space-cooling energy saved. For purposes of simplifying the analysis, only a standard-level increase of 20% (i.e., 12 SEER) was considered. Thus, the space-cooling marginal rate developed for a 20% increase in the standard was assumed to be applicable for all standard-level cases.

Since detailed building loads and demands were not available for space-heating, marginal electricity prices for space-heating could not be developed. Thus, average electricity prices were used to determine the energy costs associated with the operation of heat pumps during the space-heating season.

Since several tariffs were applied to each building, the marginal electricity price calculated from each tariff was weighted by the number of customers covered by the tariff to come up with an *weighted-average* marginal electricity rate for each building.

Assumptions

<u>Residential</u>

The DOE-2 modeling of U.S. residential buildings was conducted on a regional basis taking into account the vintage of the housing stock. Prototypical homes were constructed by region and vintage based on data from U.S. Census Bureau reports, the National Association of Home Builders

(NAHB), and the F.W. Dodge Corporation[19]. Table 5.27 shows the housing characteristics of the prototypical households with their location and vintage along with a breakdown of their cooling and heating loads during the "summer" and "winter" seasons. The "summer" and "winter" seasons are equivalent to the "summer" and "winter" months defined above. With regard to the breakdown of building loads, the percentage signifies that portion of the building load which occurs during each season. The percentage breakdowns under the "Cooling Only" columns specify that portion of the cooling load which occurs during the "winter" and "summer" seasons. The breakdowns under the "Heating Only" columns specify that portion of the heating load which occurs during each season. And finally, the percentage breakdowns under the "Cooling and Heating" columns specify that portion of the total space-conditioning load (heating and cooling) which occurs during the "summer" and "winter" seasons.

Based on the assumption that the seasonal building loads can be used as a proxy for actual space-conditioning energy consumption, the percentage breakdowns provided in Table 5.27 become the seasonal weighting factors which are used to calculate the annual marginal electricity price from the "summer" and "winter" marginal prices. For those RECS households with central air conditioners, the seasonal weighting factors are based upon the percentage breakdowns listed under the "Cooling Only" columns while those RECS households with heat pumps use the percentage breakdowns listed under the "Cooling and Heating" columns. The "Heating Only" columns in Table 5.27 are provided for informational purposes only.

In order to map the appropriate seasonal weighting factors from Table 5.27 to a RECS household, the general geographic location of the household plus its age are required. For the households surveyed, RECS specifies the household's geographic location by Census Division or large state age and the building's age.

Table 5.27 Prototypical Household Characteristics and Building Load Seasonal Breakdowns

Housing Characteristics									Building Load Seasonal Breakdown					
									Cooling Only		Heating Only		Cooling and Heating	
Census Division	**Base City**	**Prototype**	**Year Built**	**No. of Stories**	**Floor Area**	**Window Area**	**Wall Type**	**Foundation Type**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
New England	Boston	A	pre 1940s	2	1440	280	Wood	Basement	7%	93%	97%	3%	88%	12%
		B	1950-1970	2	2220	430	Wood	Basement	7%	93%	98%	2%	89%	11%
		C	1980s	2	2090	261	Wood	Basement	6%	94%	98%	2%	89%	11%
		D	1990s	2	2280	285	Wood	Basement	6%	94%	98%	2%	87%	13%
Mid-Atlantic	New York	A	pre 1940s	2	1400	277	Wood	Basement	8%	92%	99%	1%	85%	15%
		B	1950-1970	2	1960	385	Wood	Basement	8%	92%	99%	1%	86%	14%
		C	1980s	2	2090	243	Wood	Basement	5%	95%	99%	1%	83%	17%
		D	1990s	2	2280	265	Wood	Basement	4%	96%	99%	1%	84%	16%
East North Central	Chicago	A	pre 1940s	2	1580	300	Wood	Basement	9%	91%	98%	2%	86%	14%
		B	1950-1970	1	1380	264	Brick	Basement	9%	91%	99%	1%	89%	11%
		C	1980s	2	2220	275	Alum	Basement	9%	91%	99%	1%	87%	13%
		D	1990s	2	2420	300	Alum	Basement	10%	90%	99%	1%	84%	16%
West North Central	Kansas City	A	pre 1940s	1	1580	310	Wood	Basement	15%	85%	98%	2%	73%	27%
		B	1950-1970	1	1100	216	Wood	Basement	14%	86%	99%	1%	74%	26%
		C	1980s	2	2220	282	Wood	Basement	12%	88%	99%	1%	72%	28%
		D	1990s	2	2420	307	Wood	Basement	12%	88%	99%	1%	67%	33%
South Atlantic	Washington	A	pre 1940s	1	1165	207	Wood	Crawl	16%	84%	99%	1%	78%	22%
		B	1950-1970	1	1415	249	Brick	Crawl	16%	84%	99%	1%	79%	21%
		C	1980s	2	2180	288	Alum	Basement	12%	88%	99%	1%	73%	27%
		D	1990s	2	2390	316	Alum	Basement	11%	89%	99%	1%	75%	25%
East South Central	Atlanta	A	pre 1940s	1	1165	207	Wood	Crawl	21%	79%	99%	1%	72%	28%
		B	1950-1970	1	1415	249	Brick	Crawl	17%	83%	100%	0%	74%	26%
		C	1980s	2	2180	264	Wood	Basement	17%	83%	100%	0%	62%	38%
		D	1990s	2	2390	289	Wood	Basement	16%	84%	100%	0%	62%	38%
Florida	Miami	A	pre 1940s	1	1165	207	Wood	Crawl	46%	54%	100%	0%	50%	50%
		B	1950-1970	1	1415	249	Brick	Crawl	44%	56%	100%	0%	47%	53%
		C	1980s	1	1620	214	Stucco	Slab	44%	56%	100%	0%	45%	55%
		D	1990s	1	1830	242	Stucco	Slab	44%	56%	100%	0%	45%	55%

Table 5.27 Prototypical Household Characteristics and Building Load Seasonal Breakdowns (cont.)

Housing Characteristics									Building Load Seasonal Breakdown					
									Cooling Only		Heating Only		Cooling and Heating	
Census Division	Base City	Prototype	Year Built	No. of Stories	Floor Area	Window Area	Wall Type	Foundation Type	Winter	Summer	Winter	Summer	Winter	Summer
Texas	Fort Worth	A	pre 1940s	1	1055	216	Wood	Slab	18%	82%	100%	0%	56%	44%
		B	1950-1970	1	1390	286	Brick	Slab	15%	85%	100%	0%	54%	46%
		C	1980s	1	1620	214	Wood	Slab	14%	86%	100%	0%	50%	50%
		D	1990s	1	1830	242	Wood	Slab	13%	87%	100%	0%	52%	48%
West South Central	New Orleans	A	pre 1940s	1	1055	216	Wood	Slab	32%	68%	99%	1%	55%	45%
		B	1950-1970	1	1390	286	Brick	Slab	29%	71%	99%	1%	52%	48%
		C	1980s	1	1620	214	Brick	Slab	26%	74%	99%	1%	47%	53%
		D	1990s	1	1830	242	Brick	Slab	25%	75%	99%	1%	48%	52%
Mountain	Phoenix	A	pre 1940s	1	975	177	Wood	Basement	29%	71%	100%	0%	45%	55%
		B	1950-1970	1	1080	196	Brick	Slab	23%	77%	100%	0%	36%	64%
		C	1980s	1	1660	179	Stucco	Slab	20%	80%	100%	0%	32%	68%
		D	1990s	1	1880	203	Stucco	Slab	20%	80%	100%	0%	32%	68%
Pacific	Seattle	A	pre 1940s	1	1400	244	Wood	Crawl	2%	98%	90%	10%	87%	13%
		B	1950-1970	1	1390	242	Wood	Crawl	2%	98%	91%	9%	89%	11%
		C	1980s	2	2070	383	Wood	Crawl	2%	98%	93%	7%	88%	12%
		D	1990s	2	2290	424	Wood	Crawl	1%	99%	93%	7%	89%	11%
California	Los Angeles	A	pre 1940s	1	1400	244	Wood	Crawl	29%	71%	93%	7%	80%	20%
		B	1950-1970	1	1390	242	Stucco	Crawl	34%	66%	93%	7%	84%	16%
		C	1980s	2	2070	325	Stucco	Slab	42%	58%	92%	8%	81%	19%
		D	1990s	2	2290	360	Stucco	Slab	44%	56%	92%	8%	82%	18%

Figures 5.20 and 5.21 show the distributions of annual marginal electricity prices that were calculated for those RECS households with central air conditioners and heat pumps, respectively. The *weighted-average* annual marginal electricity price for central air conditioners is 8.62 ¢/kWh while the price for heat pumps is 6.86 ¢/kWh. Both electricity prices are for the year 1998 in 1998$. The *weighted-average* marginal electricity prices for central air conditioners and heat pumps are lower than their corresponding *weighted-average* average electricity prices of 8.90 ¢/kWh and 7.39 ¢/kWh for central air conditioners and heat pumps, respectively. It is interesting to note that the range of marginal electricity prices as depicted in Figures 5.20 and 5.21 are greater than those for the average electricity prices (Figures 5.17 and 5.18).

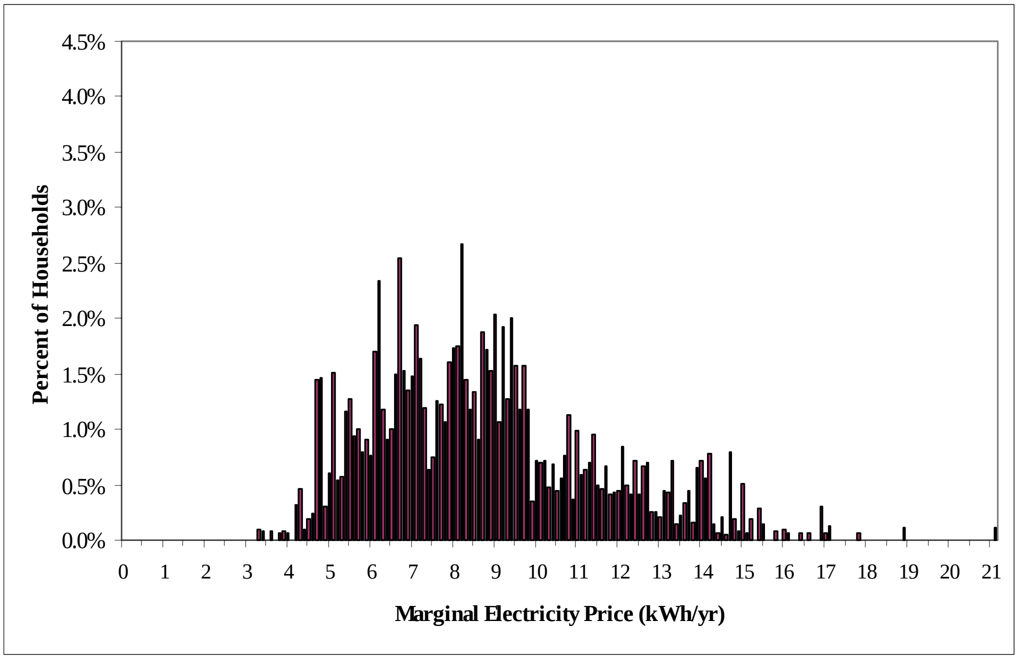

Figure 5.20 Percent of Households with Central Air Conditioners by Marginal Electricity Prices

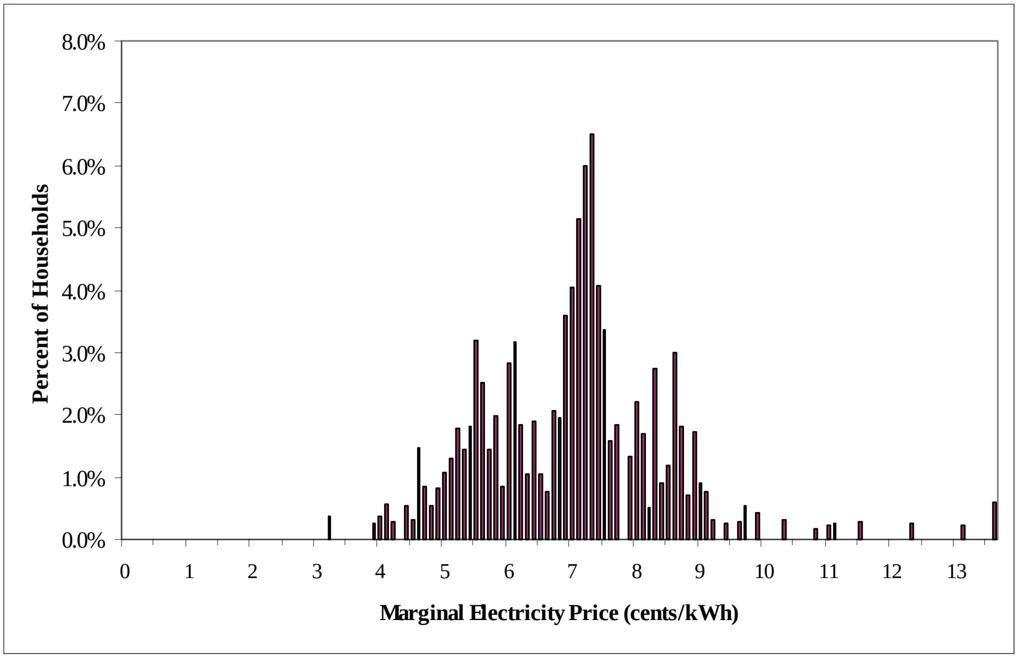

Figure 5.21 Percent of Households with Heat Pumps by Marginal Electricity Prices

Commercial

As was discussed earlier for average electricity prices, tariffs for the year 1997 were collected from 24 electric utilities through out the U.S. for purposes of developing commercial building marginal electricity rates. Figure 5.22 show the distribution of marginal electricity prices for commercial buildings using central air conditioners or heat pumps in the cooling-mode. The *weighted-average* marginal electricity price is 8.08 ¢/kWh. The electricity price is for the year 1998 in 1998$. As noted earlier, marginal electricity prices for heat pumps during the heating season were not developed and average electricity prices were used as a proxy.

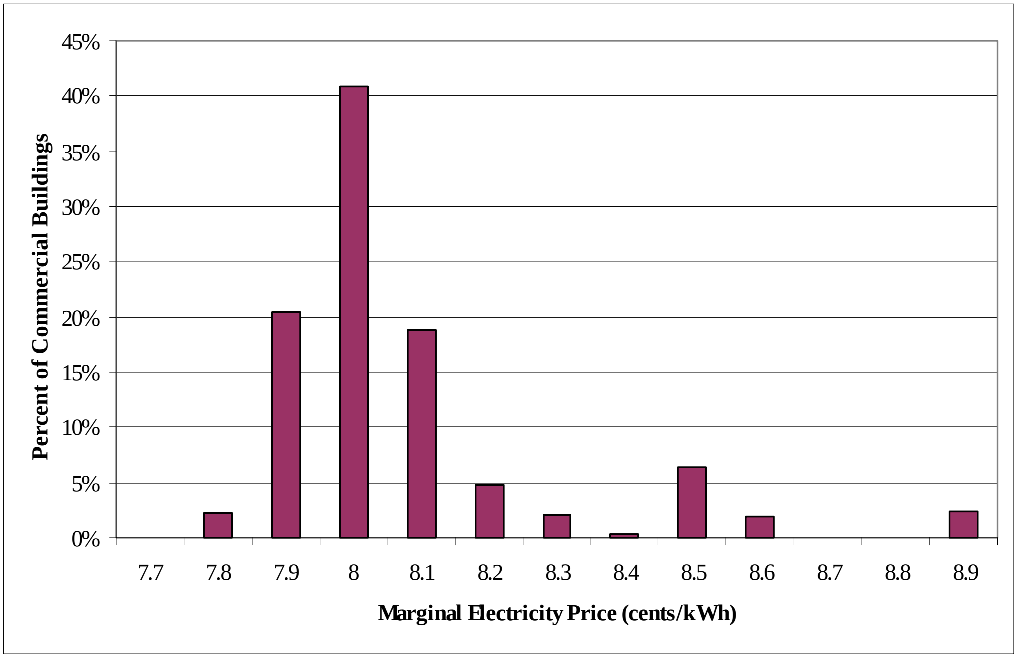

Figure 5.22 Percent of Commercial Buildings with Space-Cooling Equipment by Marginal Electricity Prices

5.2.3.7 Electricity Price Trend

Definition

The relative change in electricity prices for future years out to the year 2030.

Approach

Estimating future electricity rates is very difficult. In some states, the electricity supply industry is undergoing restructuring. Previously, each household or commercial building customer was assigned to a particular utility company, and the rates offered by that utility could be obtained from surveys. In the future, with restructuring, households and commercial building customers will be able to purchase electricity from a large set of suppliers.

A projected trend in national average electricity prices is applied to each household's and commercial building's energy prices, after accounting for "value of savings" (described above). In the life-cycle cost (LCC) spreadsheets, the user can select from the following scenarios:

1) Constant energy prices at 1999 values
2) Energy Information Administration Annual Energy Outlook 2000, High Economic Growth[20]
3) Energy Information Administration Annual Energy Outlook 2000, Reference Case[21]
4) Energy Information Administration Annual Energy Outlook 2000, Low Economic

Growth[22]

5) Gas Research Institute 1998 Baseline Projection[23]

Figure 5.23 shows the trends for the last four of those projections. The values in later years (i.e. after 2015 for GRI and after 2020 for all others) are interpolated from their relative sources. Interpolation is needed because the sources used do not forecast beyond 2020 (or 2015 in the case of the GRI forecast). To arrive at values for these later years electricity prices were held constant at 2020 levels on the assumption that the transition to a restructured utility industry will have been completed..

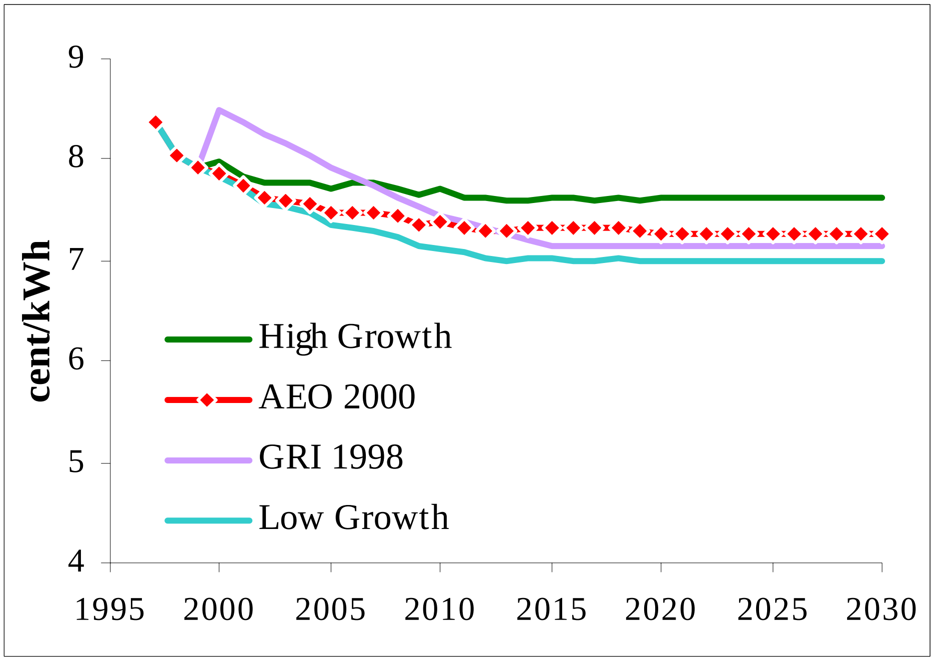

Figure 5.23 Electricity Price Trends

Assumptions

The current LCC analysis assumes the trend from the *AEO2000* Reference Case. The LCC spreadsheets have the capability to use the *AEO2000* High and Low Growth price trends, the 1998 Gas Research Institute Baseline Projection, and constant energy prices.

5.2.3.8 Repair Cost

Definition

The repair cost is the cost to the consumer for replacing or repairing components which have failed in the space-conditioning equipment.

Approach

The assumed annualized repair cost for baseline efficiency central air-conditioning and heat pump equipment (i.e., the cost the consumer pays annually for repairing the equipment) and equipment with efficiencies of 13 SEER and greater are based on the following expression:

$$RC = \frac{0.5 \cdot EQP}{LIFE} \qquad \textbf{(5.23)}$$

Where,

EQP = equipment price (consumer price for only the equipment), and
LIFE = the average lifetime of the equipment (18.4 years).

Equipment with efficiencies of 11 through 13 SEER were assumed to incur a 1% increase in repair cost over the minimum efficiency level (10 SEER).

Assumptions

The rationale for assuming essentially flat repair costs through efficiencies up to and including 13 SEER pertains to the level of technology being used at these system efficiency levels. Through 13 SEER, system technology generally does not incorporate sophisticated electronic components which are believed to incur higher repair costs. Increases in SEER are generally achieved through more efficient single-speed compressors or more efficient and/or larger heat exchanger coils. Systems with efficiencies beyond 13 SEER start to incorporate modulating blowers or compressors which are generally believed to be more susceptible to failure.

Table 5.28 shows the average repair costs by standard-level for split and single package central air conditioners and heat pumps. Since equipment prices are a function of variables which are represented by distributions rather than single point-values (e.g., manufacturer, distributor, dealer, and builder markups, installation costs, and sales tax), repair costs are actually represented by a distribution of values rather than just the average values shown in Table 5.28.

Table 5.28 Central Air Conditioner and Heat Pump Average Repair Costs

SEER	**Split System A/C**	**Single Package A/C**	**Split System HP**	**Single Package HP**
Btu/W·hr	ARI	ARI	ARI	ARI
10	\$26	\$34	\$38	\$39
11	\$26	\$34	\$38	\$39
12	\$27	\$34	\$38	\$40
13	\$27	\$35	\$39	\$40
18	\$55	\$67	\$70	\$74

5.2.3.9 Maintenance Cost

Definition

The maintenance cost is the cost to the consumer of maintaining equipment operation. The maintenance cost is not the cost associated with the replacement or repair of components which have failed. Rather, the maintenance cost is associated with general maintenance (e.g., checking and maintaining refrigerant charge levels and cleaning heat exchanger coils).

Approach

Data from Service Experts[24], an HVAC service company, were used to establish service costs.

Assumptions

Figure 5.24 shows the distribution of maintenance costs which are assumed in the LCC analysis. As the figure shows, 73% of consumers are assumed to incur no service cost while 27% of consumers are assumed to incur an annual service cost of $135. The *weighted-average* maintenance cost from this distribution is $36. The distribution of maintenance costs depicted in Figure 5.24 are assumed to apply to all product types (split or package systems, air conditioners or heat pumps).

The maintenance cost is assumed not to change with increased efficiency. The rationale being that the general maintenance of more efficient products should not be impacted by the more sophisticated components that they contain. In other words, general maintenance such as the checking of refrigerant charge levels and the cleaning of heat exchanger coils should be the same regardless of the sophistication level of the system components.

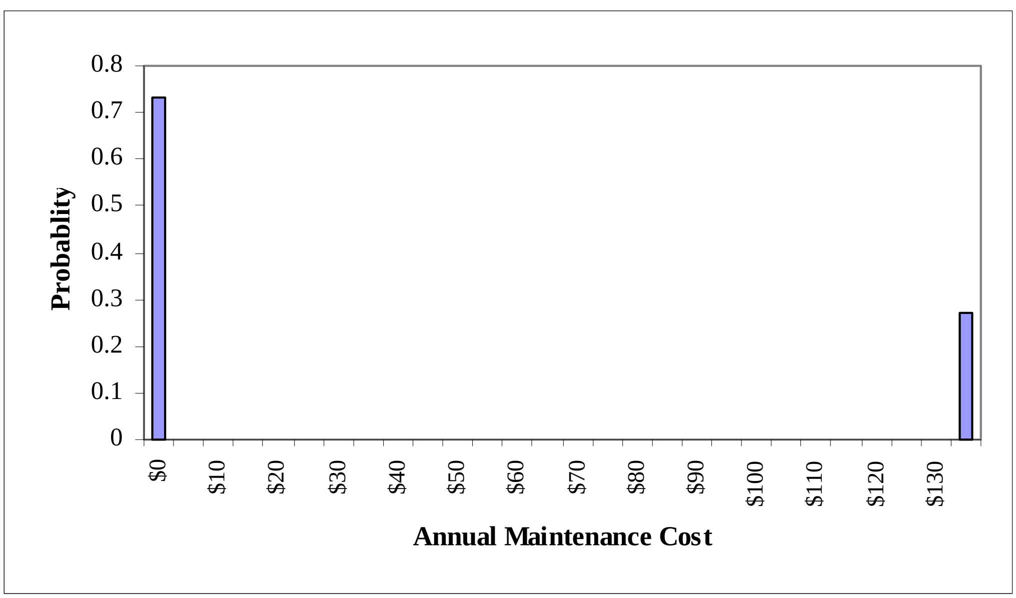

Figure 5.24 Distribution of Annual Maintenance Costs

5.2.3.10 Lifetime and Compressor Replacement Cost

Definition

The lifetime is the age at which the central air conditioner or heat pump is retired from service.

Approach

A literature search was conducted to determine the most relevant and accurate lifetime data for central air conditioners and heat pumps.

Assumptions

In choosing a value for lifetimes of central air conditioners and heat pumps, a variety of sources were reviewed. These studies on air conditioner and heat pump lifetime indicate that there is a wide range of values. Table 5.29 summarizes the sources of lifetime information with their respective mean or median lifetime value.

Table 5.29 Central Air Conditioner and Heat Pump Mean and Median Lifetimes

Source	**Central AC** *years* [a]	**Heat Pump** *years* [a]
Appliance Magazine[b]. The Life Expectancy/Replacement Picture, Sept. 1998 [25]	13	14
National Association of Home Builders. Housing Facts [c], Figures, and Trends, 1998 [26]	15	15
1995 ASHRAE Applications Handbook [d] [27]	15	15
M.E. Bucher et al, American Electric Power Service Corp. 1990. "Heat Pump Life and Compressor Longevity in Diverse Climates" [28]	-	19 [e]
K.A. Pientka, Commonwealth Edison Co. 1987. "Heat Pump Service Life and Compressor Longevity in a Northern Climate" [29]	-	15 to 16 [e]
C.C. Hiller, EPRI and N.C. Lovvorn, Alabama Power Co. 1987. "Heat Pump Compressor Life in Alabama" [30]	-	20 [e]
J.E. Lewis, Easton Consultants. 1987. "Survey of Residential Air-to-Air Heat Pump Service Life and Maintenance Issues" [31]	12.1	10.9
MTSC, Inc.[f] Energy Capital in the U.S. Economy, prepared for the Office of Policy, Planning, and Evaluation, U.S. Department of Energy, Nov. 1980 [32]	12	12

[a] Mean lifetimes except where noted.

[b] Based on first-owner use. Central AC min life = 8, max life = 18. Heat Pump min life = 10, max life = 17.

[c] Sources: Air Conditioning and Refrigeration Institute; Air Conditioning, Heating, and Refrigeration News; Air Movement and Control Association; American Gas Association; American Society of Gas Engineers; ASHRAE

[d] Source for Central A/C: Akalin, M.T. 1978. "Equipment life and maintenance cost survey", ASHRAE Transactions 84(2):94-106. Source for Heat Pump: ASHRAE Technical Committee 1.8, 1986.

[e] Median lifetime.

[f] Based on retirement function.

The above sources report mean and median lifetimes ranging from 10.9 to 20 years. The 1990 ASHRAE technical paper by Bucher, et al, has the most recent and most detailed information on heat pump life available, based on a survey performed for the Electric Power Research Institute of 2,184 heat pump installations in a seven-state region of the United States. The sources that report shorter average lifetimes are based on data of a lesser quality, and are therefore considered less reliable. For example, in the case of *Appliance Magazine*, the reported lifetime values are based on expert opinion rather than empirical data.

Central air conditioners and heat pumps produced at some future date may have different lifetimes than those in the same class produced in the past. The projections of lifetimes and other parameters used in the analysis should be based on observed empirical trends, as well as expert knowledge of likely changes in the industry, since future changes are not always straight-line projections of past trends. While expert judgement is crucial, however, it must have a strong empirical basis. With this in mind, it is felt that the value for lifetimes in the Bucher paper are the most sound, given available evidence of past performance and recent trends.

Figure 5.25 shows the retirement function that was developed from the Bucher paper. It should be noted that the retirement function developed from the survey covered the first 19 years of the product's life. In order to complete the entire retirement function, an extrapolation was used based on estimates performed by others.[33] Although the survey was conducted only on heat pumps, the retirement function was used as the basis for estimating central air conditioner product lifetime in addition to the lifetime of heat pumps. The retirement function depicted in Figure 5.21 yields a *weighted-average* lifetime of 18.4 years.

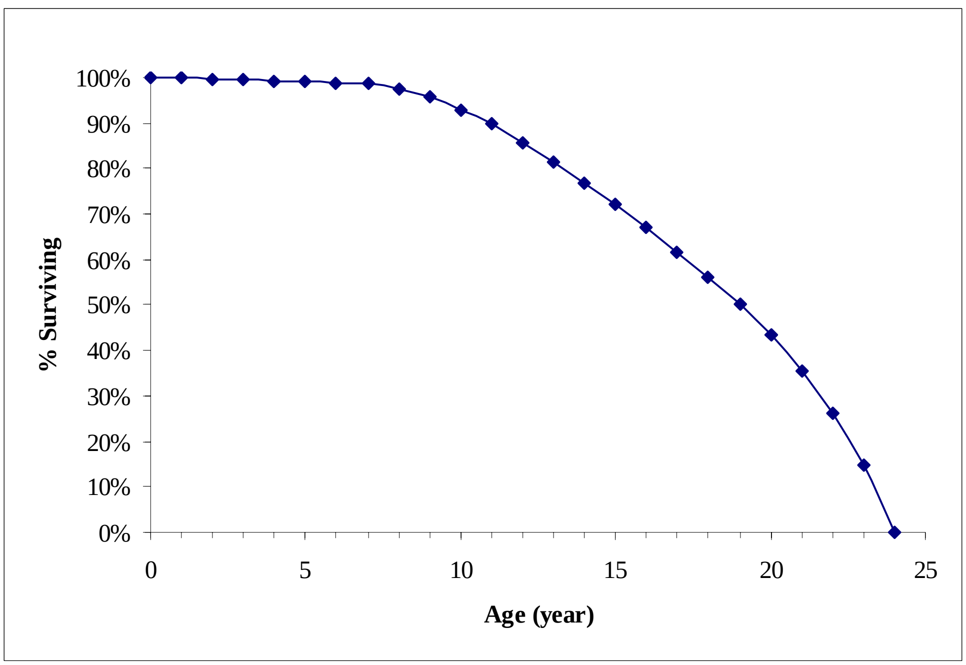

Figure 5.25 Retirement Function for Central Air Conditioners and Heat Pumps

The heat pump survey also indicates that essentially all heat pump owners replace their original compressor once in the lifetime of system. In accordance with the survey data, we have assumed the compressor to be replaced in the 14th year of the system's life. Because more efficient systems tend to use more efficient and, thus, more expensive compressors, the compressor replacement cost is assumed to increase as system efficiency increases. Table 5.30 shows the manufacturer cost, average consumer price, and the present value of the consumer price (discounted based on an average rate of 5.6%). It is important to note that the compressor replacement price is the price for the compressor only. The labor cost associated with the compressor's installation is assumed to remain constant as system efficiency increases.

Table 5.30 Compressor Replacement Costs

Efficiency	**Split System and Single Package A/C**			**Split System and Single Package Heat Pump**		
	Manufacturer Cost	**Consumer Price**		**Manufacturer Cost**	**Consumer Price**	
SEER		In year replaced	Present Value		In year replaced	Present Value
10	$122	$278	$131	$124	$283	$133
11	$152	$332	$156	$153	$335	$157
12	$153	$334	$157	$153	$335	$157
13	$167	$360	$169	$169	$364	$171
18	$221	$458	$215	$279	$564	$265

5.2.3.11 Discount Rate

Definition

The rate at which future expenditures are discounted to establish their present value.

Approach

Past methodologies for establishing discount rates have relied upon defining the share of various finance methods that are used for purchasing an appliance and then determining the associated interest rates for each of the finance methods. This method focuses on establishing the type of financing utilized at the time of purchase. For equipment financed through the purchase of a new home, a second mortgage~~s~~, or a home equity line~~s~~ of credit, this approach is reasonable. But for equipment purchased to replace old or failed equipment where cash or some form of credit is used to finance the acquisition, it is more appropriate to establish how the purchase affects a consumer's overall household financial situation. For example, even though the purchase might be financed through a dealer loan or some other short-term financing vehicle, the more probable effect of the purchase is to either cause the consumer to incur additional credit card debt or forego investment in some type of savings-related asset. Cash that was once available to either pay for household expenses or to invest in an asset like the stock market or a savings account now must be earmarked to pay off the equipment purchase, thus either causing the consumer to incur additional credit card debt or to lose the opportunity to earn income from their assets.

Assumptions

With regard to equipment obtained through the purchase of a new home, data from the Air Conditioning, Heating, and Refrigeration News[34] indicate that 34% of central air conditioner and heat pump shipments went to new homes. Thus, we assumed that 34% of equipment purchases are financed through new home mortgages.

Of the remaining 66% of shipments, a portion were assumed to be financed with second mortgages. We assumed that the remaining shipments were purchased with methods that impacted the homeowner's finances by either increasing their credit card debt or reducing investment. The methodology for determining the specific share captured by each finance method relied upon determining those households in the Federal Reserve Board's *1998 Survey of Consumer Finances* (SCF)[35] with second mortgages, credit card debt, and holdings in various assets (i.e., stocks, mutual funds, bonds, savings bonds, certificate of deposits, and transaction accounts (e.g., savings or checking accounts)). These specific shares or percentages are shown in Table 5.31. Table 5.31 demonstrates how each finance method share was normalized to arrive at the percentages used in the discount rate analysis (it is the last column in Table 5.31 which is used to represent the share captured by each finance method).

Table 5.31 Finance Method Shares

Finance Method	1998 SCF: Percent of Households with Finance Method	Assets Normalized to Total a 91% Share	Finance Methods w/o New Home Normalized to Total 100%	All Finance Methods Normalized to Total 100%
New Home	-	-	-	34%[a]
Second Mortgage	44%	44%	32%	21%
Credit Card	5%	5%	3%	2%
All Assets	91%	91%	65%	43%
Transaction Accounts	91%	50%	36%	24%
CD	15%	9%	6%	4%
Savings Bonds	19%	11%	8%	5%
Bonds	3%	2%	1%	1%
Stocks	19%	11%	8%	5%
Mutual Funds	17%	9%	7%	4%

[a] Based on data from the Air Conditioning, Heating, and Refrigeration News.

After establishing the share captured by each finance method, the range of interest rates due to each method were established. The 1998 SCF was used to establish the range of interest rates for new home mortgages, second mortgages, and credit cards. A variety of sources were used to establish the interest rates for the various assets described above.

Figures 5.26 through 5.28 show the distribution of nominal (non-adjusted) interest rates drawn from the 1998 SCF for new home mortgages, second mortgages, and credit cards, respectively. The range of after-tax rates for new home and second mortgages were derived assuming a tax of 28% and a 1998 inflation rate of 1.56%. Credit card nominal interest rates were adjusted to real interest rates by using the 1998 inflation rate of 1.56%.

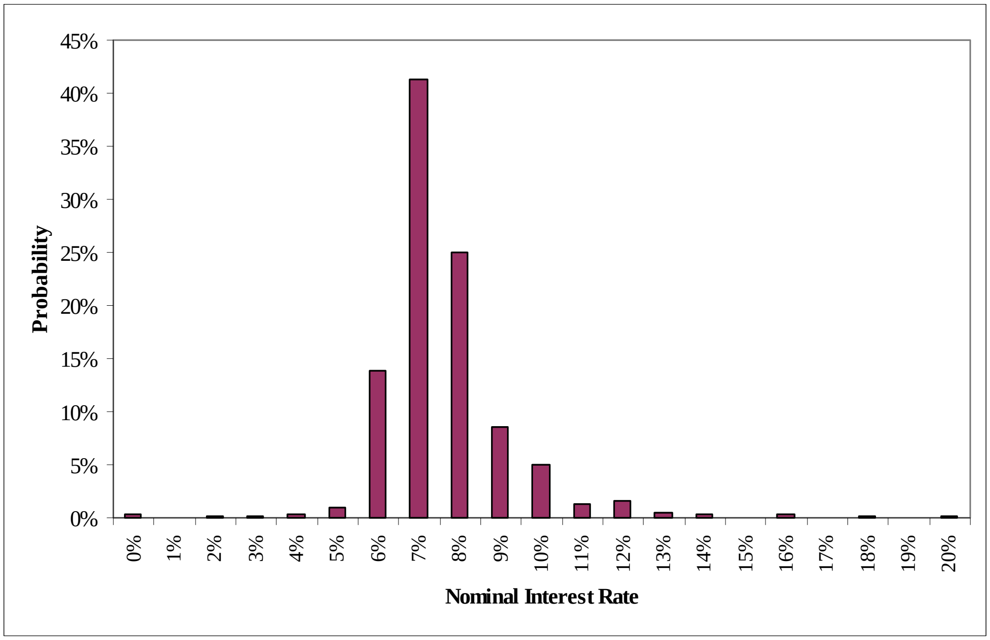

Figure 5.26 Distribution of New Home Mortgage Nominal Interest Rates

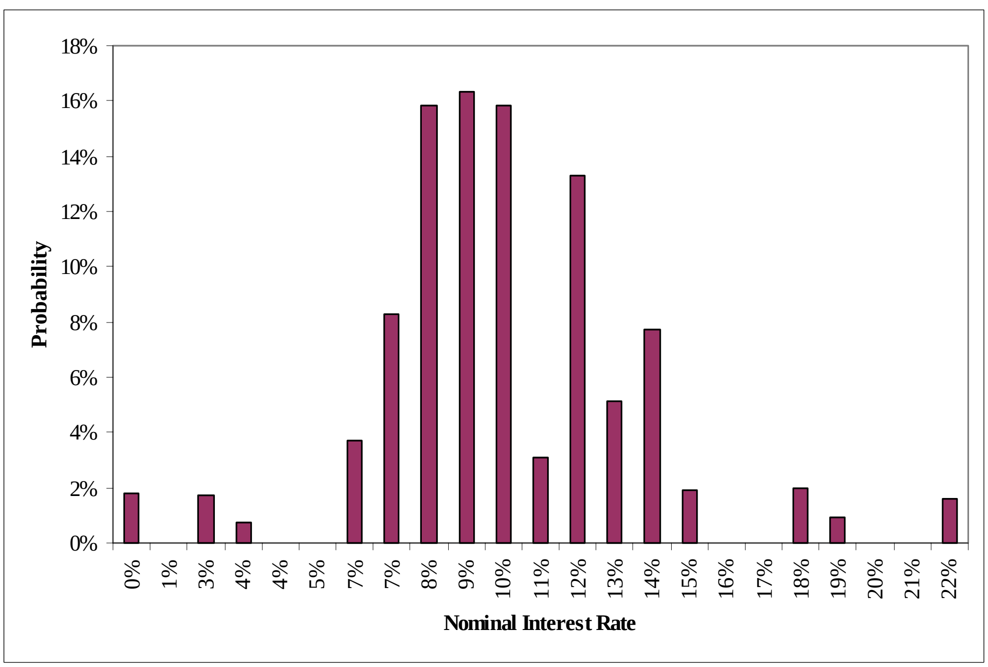

Figure 5.27 Distribution of Second Mortgage Nominal Interest Rates

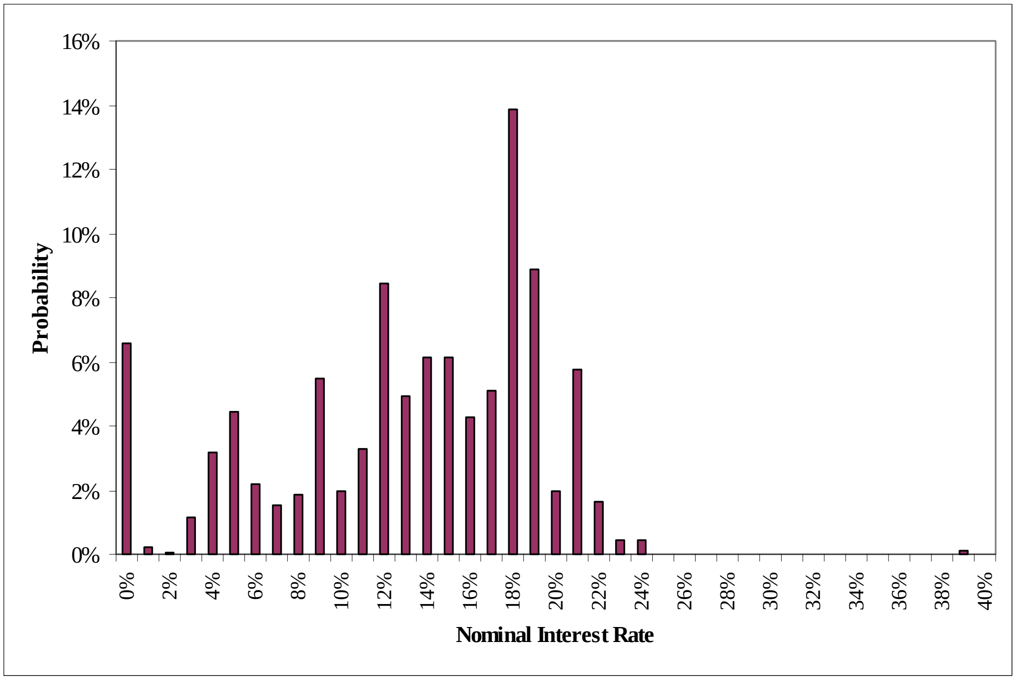

Figure 5.28 Distribution of Credit Card Nominal Interest Rates

Rates of return on certificates of deposit, savings bonds, and bonds were based on historical interest rates associated with six-month, secondary market CDs (1964-1999)[36], one-year Treasury Bills (1959-1999)[37], and Moody's AAA Corporate Bonds (1976-1999)[38], respectively. Historical stock and mutual fund interest rate data were based on historical returns from the Standard & Poor 500 (1950-1999)[39] and the Nasdaq stock market (1985-1999)[40], respectively. For each of the above assets, the historical data provided a distribution of interest rates where each year's corresponding rate of return was weighted equally. Transaction account real interest rates were assumed to range from zero to 4%. Table 5.32 shows the historical annual real interest rates associated for each of the above assets.

Table 5.32 Annual Real Interest Rates for Various Financial Assets

Year	Mutual Funds	Stocks	Bonds	CDs	Savings Bonds
1999	13%	60%	5%	3%	3%
1998	24%	34%	5%	4%	3%
1997	21%	12%	5%	3%	3%
1996	14%	19%	4%	3%	2%
1995	28%	36%	5%	3%	3%
1994	-7%	-9%	5%	2%	2%
1993	3%	9%	4%	0%	0%
1992	4%	6%	5%	1%	1%
1991	17%	37%	5%	2%	1%
1990	-5%	-16%	4%	3%	2%
1989	14%	9%	4%	4%	3%
1988	4%	7%	6%	4%	3%

Table 5.32 Annual Real Interest Rates for Various Financial Assets (cont.)

Year	Mutual Funds	Stocks	Bonds	CDs	Savings Bonds
1987	-14%	-19%	6%	3%	3%
1986	12%	2%	7%	5%	4%
1985	14%	13%	8%	5%	4%
1984	-2%	-	8%	6%	6%
1983	10%	-	9%	6%	6%
1982	11%	-	8%	6%	5%
1981	-16%	-	4%	5%	3%
1980	5%	-	-2%	-1%	-3%
1979	-3%	-	-2%	0%	-2%
1978	0%	-	1%	1%	0%
1977	-13%	-	2%	-1%	-1%
1976	1%	-	3%	0%	0%
1975	8%	-	-	-2%	-3%
1974	-40%	-	-	-1%	-3%
1973	-22%	-	-	3%	1%
1972	10%	-	-	2%	2%
1971	2%	-	-	1%	0%
1970	3%	-	-	2%	1%
1969	-16%	-	-	2%	1%
1968	8%	-	-	2%	1%
1967	8%	-	-	2%	2%
1966	-16%	-	-	3%	2%
1965	4%	-	-	3%	2%
1964	9%	-	-	3%	2%
1963	12%	-	-	-	2%
1962	-9%	-	-	-	2%
1961	15%	-	-	-	2%
1960	3%	-	-	-	2%
1959	7%	-	-	-	4%
1958	30%	-	-	-	-
1957	-14%	-	-	-	-
1956	5%	-	-	-	-
1955	25%	-	-	-	-
1954	37%	-	-	-	-
1953	-7%	-	-	-	-
1952	8%	-	-	-	-
1951	2%	-	-	-	-
1950	18%	-	-	-	-

Table 5.33 summarizes the real interest rates associated with each of the finance methods. Also provided is the weighted-average discount rate of 5.6% that is calculated from the mean interest rates for each finance method. It should also be noted that real interest rates below 0% were not considered. Since negative real interest rates represent approximately 7% of the entire distribution of interest rates, an equal percentage of excessively high interest rates were removed from the distribution. This had the effect of eliminating real interest rates in excess of 18%.

Table 5.33 Real Interest Rates associated with each Finance Method

Finance Method	Share	Real Interest Rates [a] Minimum	Maximum	Mean
New Home Mortgages (after tax)	34%	-1.6%	12.8%	4.2%
Second Mortgages (after tax)	2%	-1.6%	14.3%	5.9%
Credit Card	21%	-1.6%	37.4%	12.0%
Transaction Accounts	24%	0.0%	4.0%	2.0%
Certificates of Deposit	4%	-2.2%	6.4%	2.4%
Savings Bonds	5%	-3.3%	5.6%	1.8%
Bonds	1%	-1.7%	8.8%	4.5%
Stocks	5%	-19.4%	60.2%	13.3%
Mutual Funds	4%	-40.0%	37.2%	4.5%
			Weighted-Average	5.6%

[a] Real interest rates below 0% and exceeding 18% were not considered in the LCC analysis.

5.2.3.12 Effective Date of Standard

Definition

This is the year at which a new standard is expected to become effective.

Approach

The LCC is calculated for all households as if they each purchase a new central air conditioner or heat pumps in the year the standard takes affect. The cost of the equipment are based on this year, however, all dollar values are expressed in 1998 dollars. Annual energy prices are included for the life of the central air conditioner or heat pump.

Assumption

The new energy efficiency standard for central air conditioners and heat pumps is assumed to take effect in the year 2006.

5.2.3.13 Base Case Design

Definition

This is the cost and efficiency of the starting point to which different improvement levels of central air conditioners and heat pumps are compared.

Approach

As detailed earlier, cost data were supplied a baseline (i.e., 10 SEER) and higher efficiency levels. In the LCC spreadsheets, the user can select any standard-level against which to compare higher efficiency levels.

Assumption

The default assumption for the base case design for both central air conditioners and heat pumps is the baseline design option (i.e., 10 SEER).

5.2.3.14 Standard Case Design

Definition

The improved efficiency level for comparison with the base case design.

Approach

The LCC spreadsheet user selects the level for the analysis.

Assumption

Analysis is done for all levels for which data were provided.

5.2.4 LCC Results

This section presents results for LCC for the efficiency improvement levels specified in the Engineering Analysis (Chapter 4). Results presented here are based on the inputs described in sections 5.2.2 and 5.2.3.

As has been detailed in the previous sections, the value of most inputs are uncertain and are represented by a distribution of values rather than a single point-value. Thus, the LCC results will also be a distribution of values. But before proceeding with the presentation of the distributional LCC results, it is worth showing how, on an average basis, the installed consumer costs, annual operating expenses, and, finally, the life-cycle costs vary with efficiency for each of the four product classes.

5.2.4.1 LCC Breakdown based upon Average Input Values

For each product class, Figures 5.29 through 5.40 show how, on an average basis, the installed consumer costs, annual operating expenses, and life-cycle costs vary with efficiency. Figures 5.29 through 5.31 pertain to split system air conditioners, Figures 5.32 through 5.34 pertain to split system heat pumps, Figures 5.35 through 5.37 pertain to single package air conditioners, and Figures 5.38 through 5.40 pertain to single package heat pumps.

The figures for installed cost are segmented into equipment and installation price. The figures for annual operating expense are segmented into annual electricity, repair, maintenance, and compressor replacement 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 Crystal Ball analysis, they serve to demonstrate how the various inputs ultimately impact life-cycle cost.

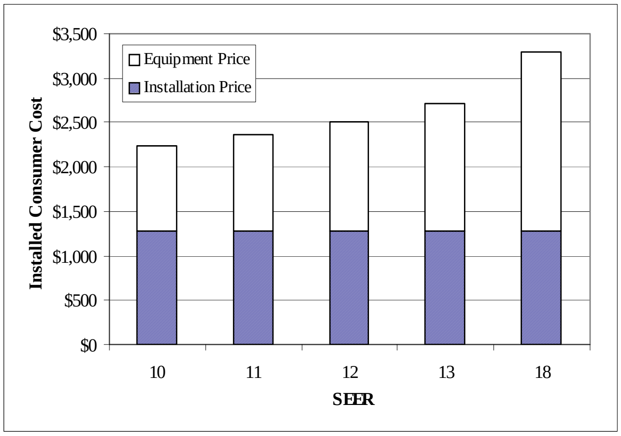

Figure 5.29 Split A/C: Mean Installed Consumer Costs

Figure 5.32 Split HP: Mean Installed Consumer Costs

Figure 5.30 Split A/C: Mean Annual Operating Costs

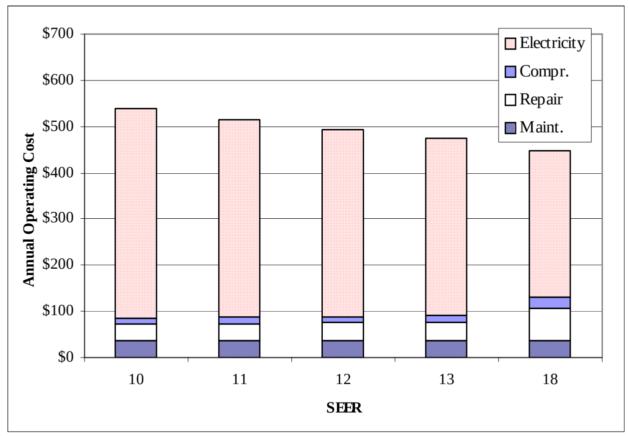

Figure 5.33 Split HP: Mean Annual Operating Costs

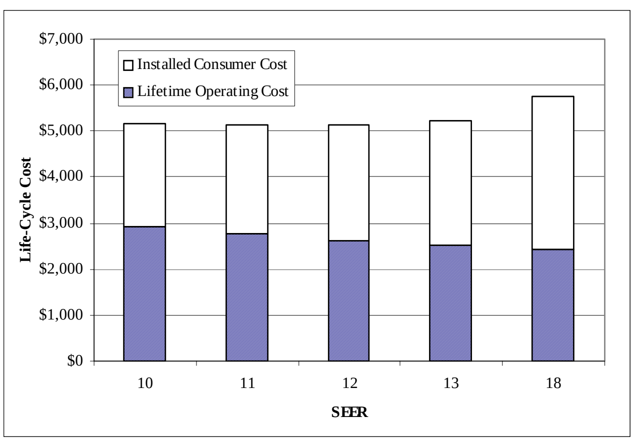

Figure 5.31 Split A/C: Mean Life-Cycle Costs

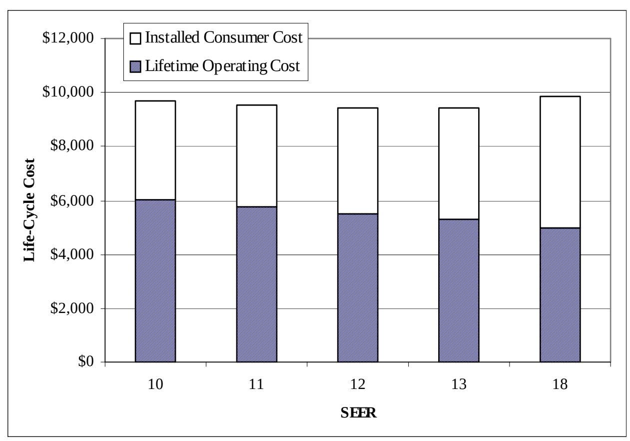

Figure 5.34 Split HP: Mean Life-Cycle Costs

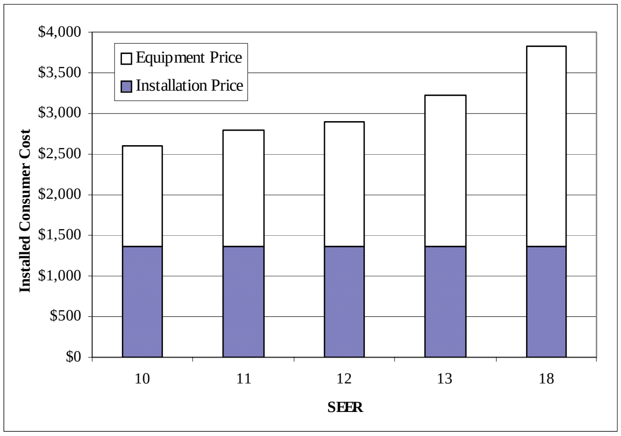

Figure 5.35 Pack A/C: Mean Installed Consumer Costs

Figure 5.36 Pack A/C: Mean Annual Operating Costs

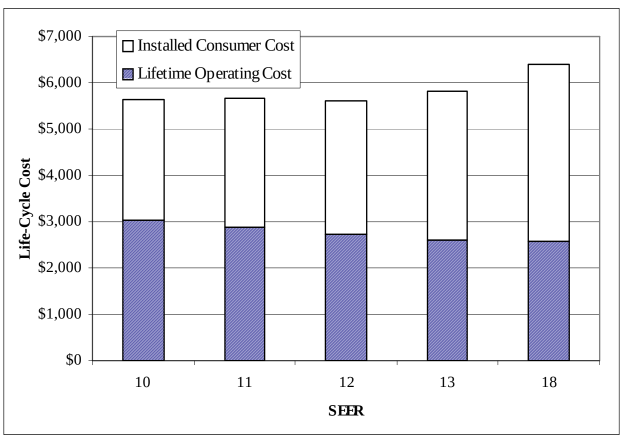

Figure 5.37 Pack A/C: Mean Life-Cycle Costs

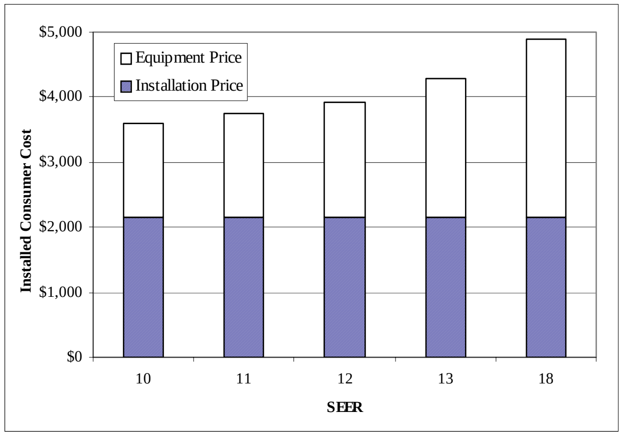

Figure 5.38 Pack HP: Mean Installed Consumer Costs

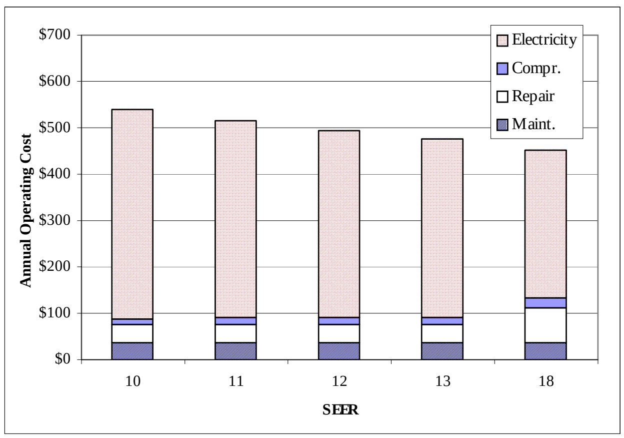

Figure 5.39 Pack HP: Mean Annual Operating Costs

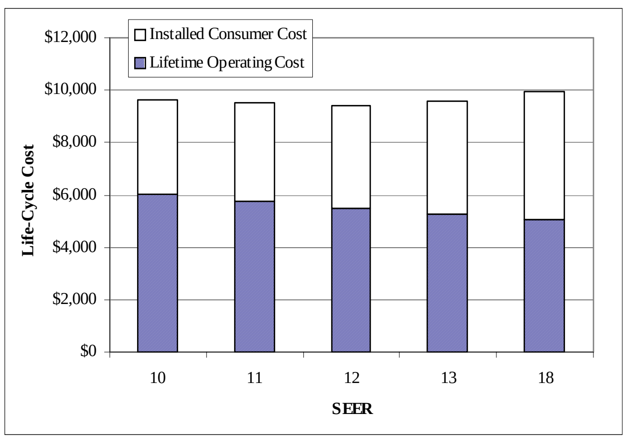

Figure 5.40 Pack HP: Mean Life-Cycle Costs

In reviewing the installed consumer cost results in Figure 5.29 for split system air conditioners, Figure 5.32 for split system heat pumps, Figure 5.35 for single package air conditioners, and Figure 5.38 for single package heat pumps, the largest contributor to increased consumer cost is the equipment price since the installation price remains constant across efficiency.

With regard to annual operating expense, Figure 5.30 for split system air conditioners, Figure 5.33 for split system heat pumps, Figure 5.36 for single package air conditioners, and Figure 5.39 for single package heat pumps show that the largest contributor to the overall operating cost at any efficiency level is the annual electricity cost. Of course, as efficiency increases, the electricity cost decreases. At an efficiency of 18 SEER for all product classes, the jump in repair cost that occurs at this efficiency level negates the reduction in electricity cost that is realized from higher efficiency. This is especially true for split system and single package air conditioners. Note that for air conditioning systems, the repair cost is a larger percentage of the overall operating cost than that for heat pumps. Because the maintenance cost is assumed to remain constant across all efficiency levels, the overall operating cost is not impacted by the maintenance cost as efficiency increases.

The life-cycle cost results in Figure 5.31 for split system air conditioners, Figure 5.34 for split system heat pumps, Figures5.37 for single package air conditioners, and Figure 5.40 for single package heat pumps reveal that as efficiency increases, the installed consumer cost has more of an impact on the life-cycle cost than the lifetime operating cost. Even in the case of split system and single package heat pumps where the lifetime operating cost contributes more to the overall life-cycle cost, as efficiency increases, the increase in the installed consumer cost tends to negate any reduction in life-cycle cost realized from lower lifetime operating costs.

It is worth reiterating that the results shown in Figures 5.29 through 5.40 are based upon average input values and not input distributions. Thus, although observations can be made as to how the various inputs impact life-cycle cost and, in turn, how the resulting life-cycle costs change with efficiency, conclusions should only be drawn from the distribution of life-cycle cost results that are presented later (Section 5.2.4.3).

5.2.4.2 Baseline LCC Distributions

As stated earlier, the Monte Carlo method of analysis relying on Crystal Ball (i.e., random sampling from distributions) was used to conduct the LCC analysis. The following results presented here are based on 10,000 samples per Monte Carlo run.

The first step in developing LCC results is to develop the baseline LCC for each of the four product classes. For this analysis, the baseline LCC is based on *average* electricity prices (Section 5.2.3.5) from each RECS household or modeled commercial building. The change in LCC for various efficiency levels (to be presented later) is based on *marginal* electricity prices (Section 5.2.3.6).

Figures 5.41 through 5.44 show the frequency chart for the baseline LCC for the four product classes. A frequency chart shows the distribution of LCCs with its corresponding probability of occurrence. As discussed earlier, the baseline efficiency level is assumed to equal the existing minimum energy efficiency standards. For split system and single package air conditioners, this means the baseline efficiency level is set to 10 SEER. For split system and single package heat pumps, the baseline efficiency levels are set to 10 SEER for the cooling performance and 6.8 HSPF for the heating performance. Table 5.34 summarizes the baseline distributions depicted in Figures 5.41 through 5.44 by showing the mean, median, minimum, and maximum LCCs.

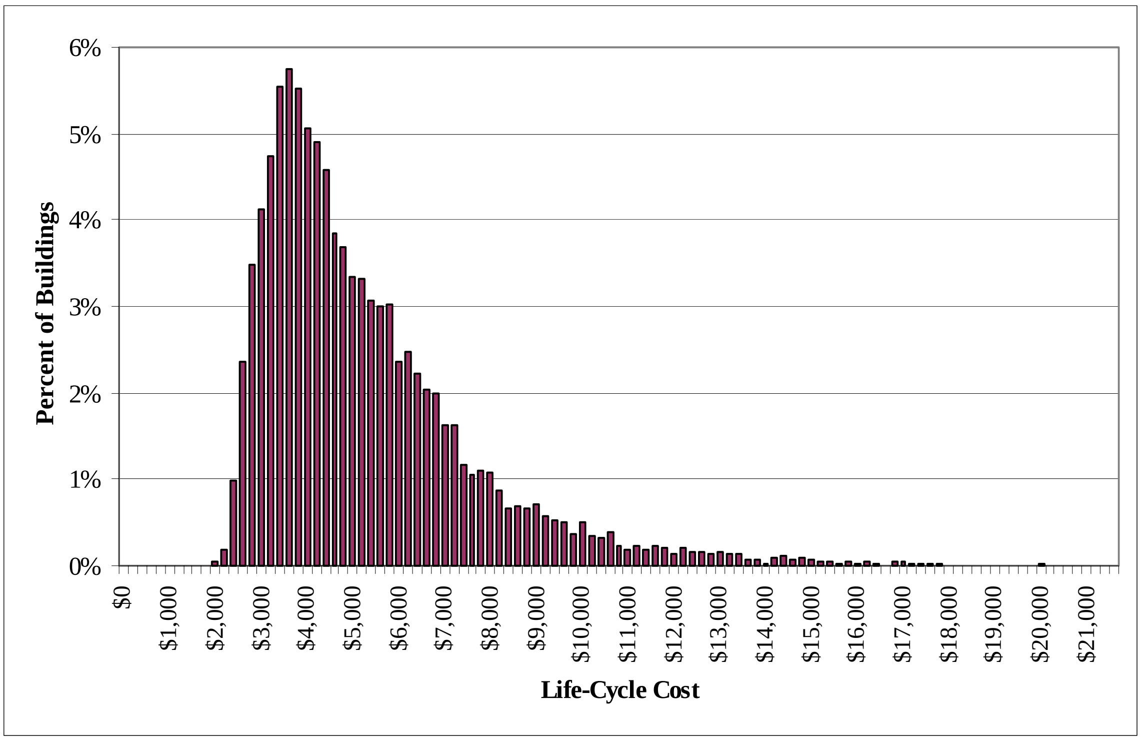

Figure 5.41 Split A/C: Percent of Buildings by Life-Cycle Cost, Baseline

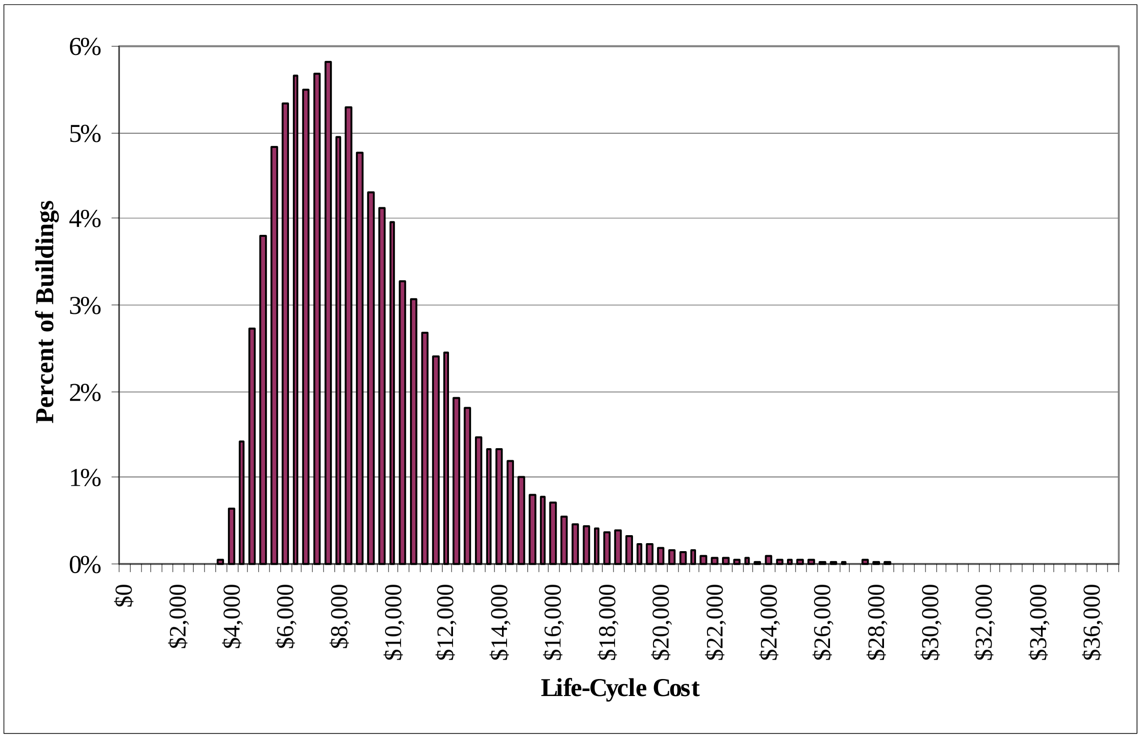

Figure 5.42 Split HP: Percent of Buildings by Life-Cycle Costs, Baseline

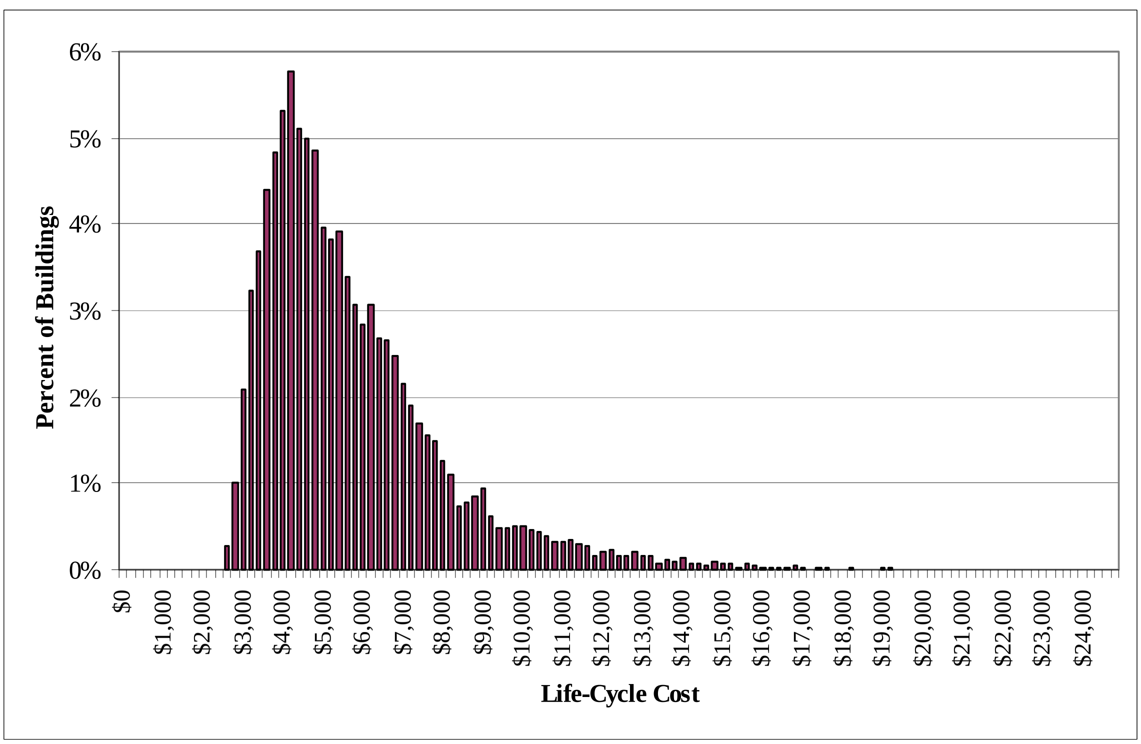

Figure 5.43 Package A/C: Percent of Buildings by Life-Cycle Costs, Baseline

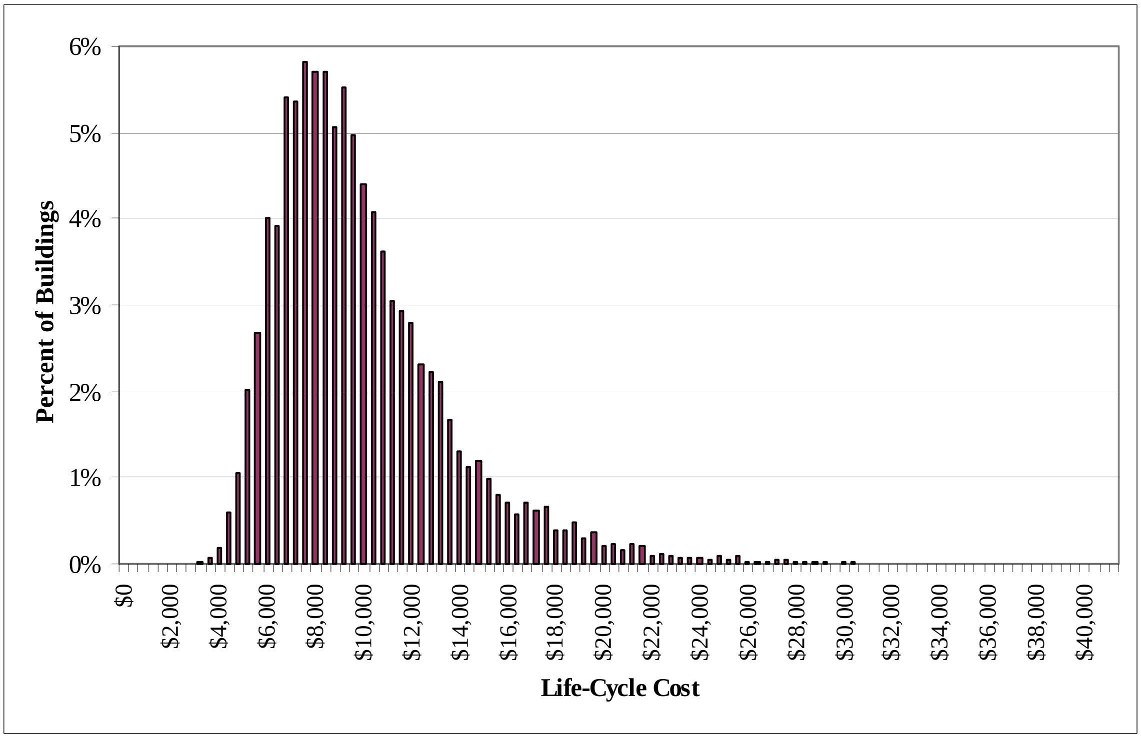

Figure 5.44 Package HP: Percent of Buidlings by Life-Cycle Costs, Baseline

Table 5.34 Baseline LCC: Mean, Median, Minimum, and Maximum Values

Product Class	Minimum	Median	Mean	Maximum
Split A/C	$2,026	$4,637	$5,170	$21,508
Split Heat Pump	$3,521	$8,464	$9,679	$36,901
Package A/C	$2,535	$5,126	$5,629	$24,781
Package Heat Pump	$3,282	$9,164	$9,626	$41,377

5.2.4.3 Change in LCC Results

The change in LCC results are presented as differences in the LCC relative to the baseline central air conditioner or heat pump design. As mentioned previously, the LCC differences are depicted as a distribution of values. The primary results are presented in two types of charts within Crystal Ball: 1) a *frequency chart* showing the distribution of LCC differences with its corresponding probability of occurrence and 2) a *cumulative chart* showing the cumulative distribution of LCC differences along with the corresponding probability of occurrence. In each chart, the mean LCC difference is provided along with the percent of the population for which the LCC will decrease.

In the explanation below, the two charts depicting the case for an 11 SEER efficiency level are used (Figures 5.45 and 5.46). In either chart (frequency or cumulative), the mean change (reduction of $44 in the examples here) is shown in a text box next to a vertical line at that value on the x-axis. The phrase "Certainty is 45.52% from -Infinity to $0" means that 45.52% of households will have reduced LCC with the increased efficiency level compared to the baseline efficiency level (i.e., 10 SEER).

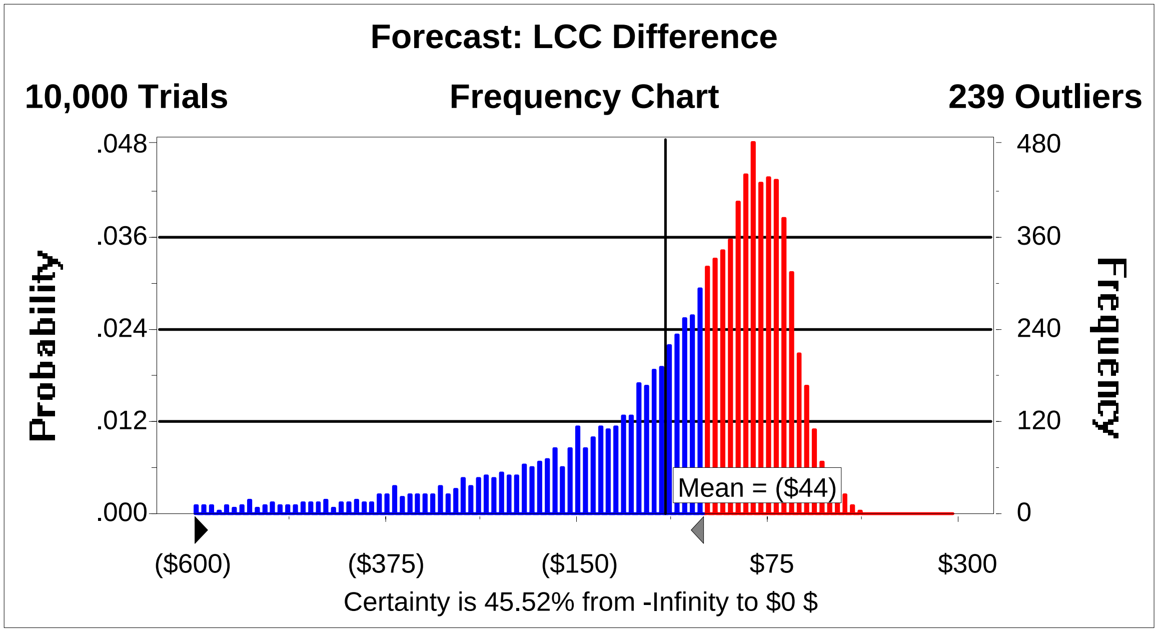

Figure 5.45 Split A/C: Frequency Chart of LCC Differences for 11 SEER Efficiency Level

Figure 5.45 is an example of a *frequency chart*. The y-axes show the number of households ("Frequency" at right y-axis) and percent of all households ("Probability" at left y-axis). In this example, 10,000 households were examined ("10,000 trials") and all the almost all the results are displayed ("182 outliers"). The x-axis is the difference in LCC between a baseline efficiency level and a higher efficiency level (in this example, 11 SEER). The x-axis begins with negative values on the left, which indicate that standards for those households provide savings (reduced LCC). Reduced LCC occurs when reduced operating expenses more than compensate for increased purchase expense. In Figure 5.45, going from the baseline efficiency level (10 SEER) to the 11 SEER efficiency level provides buildings with an average LCC reduction of $44, and range from reductions of $600 (at the left) to increases of $210 (at the right) depending upon the building. (The minimum and maximum values cannot be read with precision from the graph, but rather, the program provides them in a statistical summary. It should be noted that in this example, reductions in LCC extend to $15 but, because they are considered outliers, are not shown.)

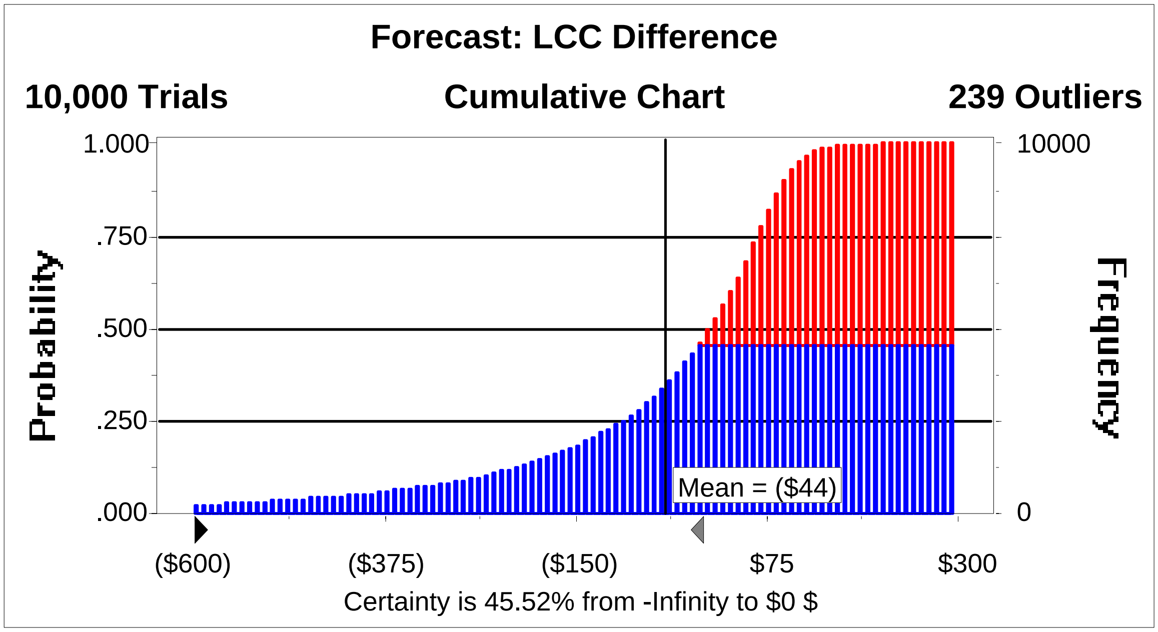

Figure 5.46 Split A/C: Cumulative Chart of LCC Differences for 11 SEER Efficiency Level

The vertical axis in Figure 5.46 is the cumulative probability (left axis) or frequency (right axis) that the LCC difference will be less than the value on the horizontal axis. Starting at the left, there is a 0% probability that a household will have a reduction in LCC larger than $600 in absolute value (excluding outliers). At the right, there is a 100% probability that a household will have either a decrease in LCC or an increase in LCC of less than $210.

Appendix E contains the *frequency* and *cumulative charts* for all the efficiency levels. These charts provide more complete information than summary statistics, but a summary of the change in LCC from the baseline by percentile groupings (i.e., of the distribution of results) are provided below in Tables 5.35 through 5.38 for each of the product classes. The mean and the percent of LCCs that are reduced for each standard-level are also shown.

As an example of how to interpret the information in Tables 5.35 through 5.38, the 11 SEER efficiency level for split system air conditioners based is reviewed. The 11 SEER efficiency level in Table 5.35 (row 1) shows that the maximum (zero percentile column) change in LCC is savings of $1,542. (Negative values are net savings.) For 90% of the cases studied (90th percentile), the change in LCC is a cost of $101 or less. The largest increase in LCC is $210 (100th percentile). The mean change in LCC is a net savings of $44. The last column shows that 45% of the sample have reduced LCC (i.e., change in LCC less than or equal to zero).

Table 5.35 Summary of LCC Results for Split System 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	
11	$-1,542	$-267	$-134	$-60	$-15	$15	$39	$59	$78	$101	$210	$-44	45%
12	$-3,914	$-430	$-194	$-75	$2	$54	$98	$141	$178	$222	$450	$-45	40%
13	$-4,723	$-530	$-198	$-26	$90	$170	$236	$294	$347	$414	$774	$29	32%
18	$-9,815	$-465	$146	$454	$639	$768	$880	$996	$1,129	$1,301	$2,653	$555	17%

Table 5.36 Summary of LCC Results for Split System 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	
11 / 7.1	$-1,691	$-429	$-271	$-192	$-137	$-89	$-50	$-19	$13	$48	$181	$-150	76%
12 / 7.4	$-3,433	$-748	$-480	$-314	$-213	$-127	$-59	$5	$64	$132	$405	$-242	69%
13 / 7.7	$-4,891	$-943	$-537	$-327	$-177	$-57	$38	$128	$216	$311	$659	$-215	56%
18 / 8.8	$-7,037	$-1,068	$-324	$87	$358	$563	$719	$877	$1,033	$1,251	$2,452	$276	27%

Table 5.37 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	
11	$-1,729	$-206	$-75	$-1	$45	$78	$105	$127	$148	$173	$285	$20	31%
12	$-4,096	$-443	$-201	$-64	$20	$80	$129	$171	$209	$250	$415	$-29	37%
13	$-4,798	$-403	$-64	$123	$244	$327	$393	$450	$504	$573	$899	$175	23%
18	$-7,212	$-328	$295	$632	$820	$974	$1,095	$1,214	$1,350	$1,536	$2,377	$741	14%

Table 5.38 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	
11 / 7.1	$-2,030	$-440	$-269	$-178	$-118	$-69	$-30	$6	$40	$84	$244	$-134	68%
12 / 7.4	$-3,567	$-831	$-516	$-344	$-230	$-138	$61	$12	$84	$166	$491	$-254	68%
13 / 7.7	$-4,579	$-921	$-469	$-246	$-78	$45	$152	$252	$359	$486	$1,032	$-112	45%
18 / 8.8	$-9,042	$-1,164	$-395	$57	$348	$573	$770	$954	$1,155	$1,416	$2,580	$296	28%

5.2.4.4 LCC Results based on ±2% Threshold

The results in Tables 5.35 through 5.38 show the percent of households with reduced LCC. But considering that the baseline LCC for each product class is significantly greater than the LCC differences shown in Tables 5.35 through 5.38, it is more useful to demonstrate which consumers experience significant net LCC savings or costs due to a higher standard-level. We define significant as those consumers experiencing net LCC savings or costs which are greater than 2% of the baseline LCC. For central air conditioners, this translates to an LCC increase of approximately $100 or an annual expense of approximately $5 over the lifetime of the system. Table 5.39 summarizes the baseline LCCs for split system and single package central air conditioners and heat pumps and also provides the 2% threshold at which consumers are considered to be significantly impacted by a standard-level.

Table 5.39 Baseline Life-Cycle Costs and Threshold for Significant Impacts

Product Class	Baseline Life-Cycle Cost	Threshold for Adverse Impacts: 2% of Baseline LCC
Split Air Conditioners	$5,170	$103
Split Heat Pumps	$9,679	$194
Single Package Air Conditioners	$5,629	$113
Single Package Heat Pumps	$9,626	$193

Tables 5.40 through 5.43 and Figures 5.47 through 5.54 depict the LCC results for split system and single package central air conditioners and heat pumps based on the above defined 2% threshold. The tables show the average LCC values for the baseline level (10 SEER) and the various standard-levels analyzed. As presented earlier in Tables 5.35 through 5.38, Tables 5.40 through 5.43 also provide for each product class the difference in LCC at each efficiency level relative to the baseline. The differences represent either an LCC savings or an LCC cost increase. In addition, each table shows the subset of consumers (both residential and commercial) at each efficiency level who are impacted in one of three ways: consumers who achieve *significant* net LCC savings (i.e., LCC savings greater than 2% of the baseline LCC), consumers who are impacted in an insignificant manner by having either a small reduction or small increase in LCC (i.e., within ±2% of the baseline LCC), or consumers who achieve a *significant* net LCC increase (i.e., an LCC increase exceeding 2% of the baseline LCC). Accompanying each percentage value is the average LCC savings or increase that corresponds to each subset of consumers. For example, in the case of the 12 SEER efficiency level for split system air conditioners (Table 5.40), the percentage of consumers with significant net savings is 27% and the corresponding average LCC savings for those consumers is $457.

For each product class, two figures are presented; one showing the mean LCC by efficiency level and the other showing the percentage of consumers for each efficiency level that fall within the three consumer subsets (i.e., net savings, no significant impacts, or net costs). For the figure presenting the percentage of consumers with net savings, no significant impacts, and net costs, the corresponding average LCC savings or increase is also presented.

Table 5.40 LCC Results for Split System Central Air Conditioners

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$5,170	-	-		-		-	
11	$5,126	($44)	23%	($304)	68%	($82)	9%	$127
12	$5,125	($45)	27%	($457)	34%	$17	39%	$188
13	$5,199	$29	25%	($602)	17%	$11	58%	$313
18	$5,725	$555	15%	($1,072)	4%	$6	81%	$880

Figure 5.47 Average LCCs for Split System Central Air Conditioners

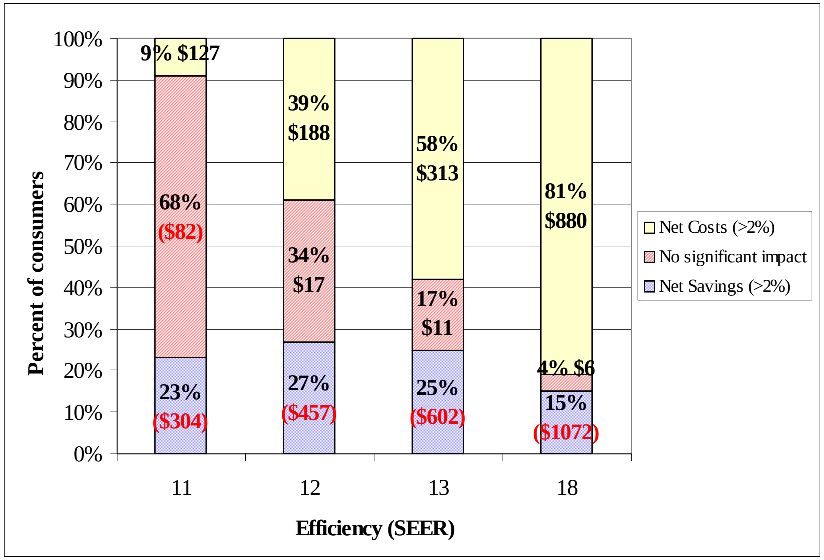

Figure 5.48 Percent of Split System Central A/C Consumers with Net Costs, No Significant Impacts, and Net Savings

Table 5.41 LCC Results for Split System Heat Pumps

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with: Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$9,679	-	-		-		-	
11	$9,529	($150)	30%	($44)	70%	($40)	0%	$0
12	$9,437	($242)	42%	($592)	55%	($2)	3%	$234
13	$9,464	($215)	39%	($748)	39%	$15	22%	$312
18	$9,955	$276	23%	($1,280)	11%	$20	66%	$850

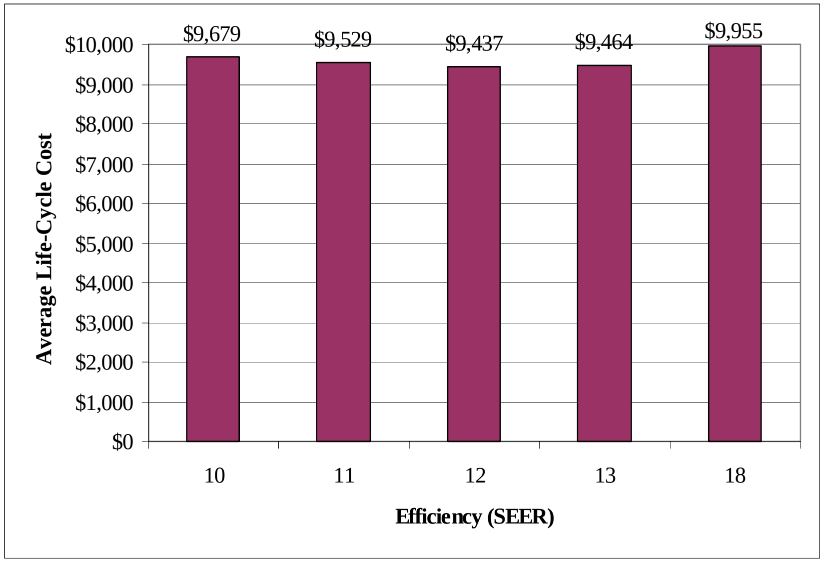

Figure 5.49 Average LCCs for Split System Heat Pumps

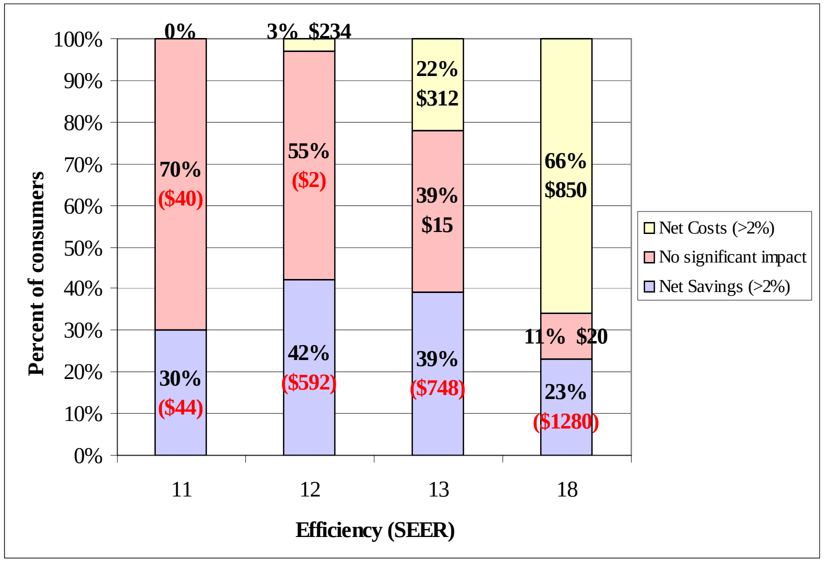

Figure 5.50 Percent of Split System Heat Pump Consumers with Net Costs, No Significant Impacts, and Net Savings

Table 5.42 LCC Results for Single Package Central Air Conditioners

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$5,629	-	-		-		-	
11	$5,649	$20	16%	($318)	47%	$31	37%	$157
12	$5,600	($29)	26%	($482)	30%	$18	44%	$206
13	$5,804	$175	18%	($660)	11%	$10	71%	$413
18	$6,370	$741	12%	($1,147)	4%	$10	84%	$1,052

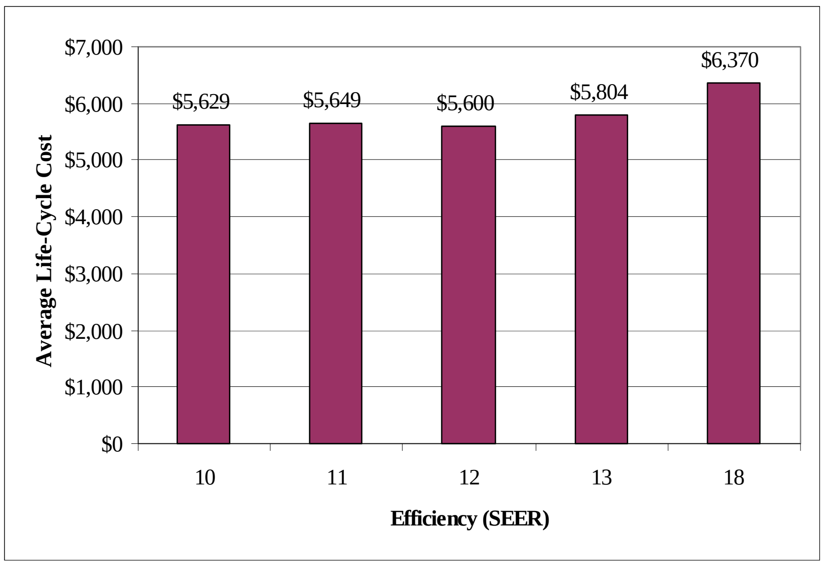

Figure 5.51 Average LCCs for Single Package Central Air Conditioners

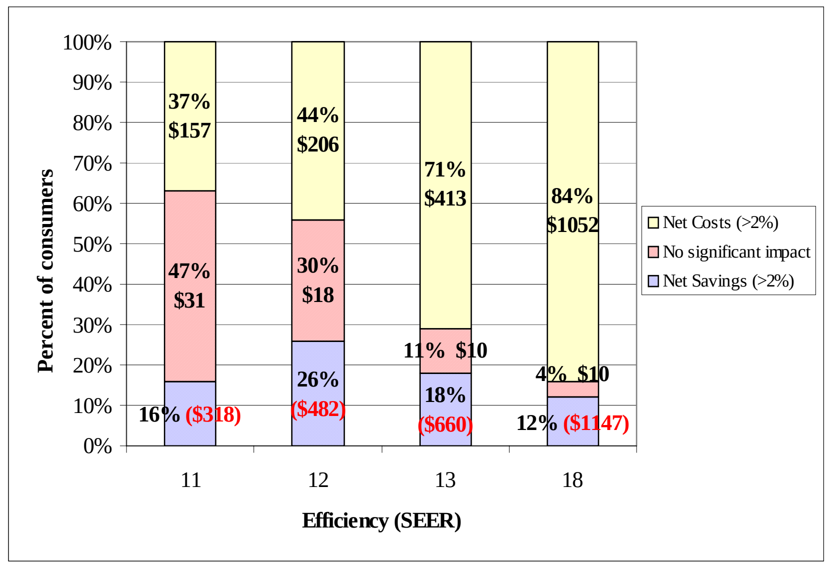

Figure 5.52 Percent of Single Package Central A/C Consumers with Net Costs, No Significant Impacts, and Net Savings

Table 5.43 LCC Results for Single Package Heat Pumps

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with: Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$9,626	-	-		-		-	
11	$9,492	($134)	28%	($431)	72%	($19)	0%	$213
12	$9,372	($254)	44%	($623)	49%	($1)	7%	$256
13	$9,514	($112)	33%	($810)	31%	$19	36%	$407
18	$9,922	$296	24%	($1,342)	10%	$15	66%	$936

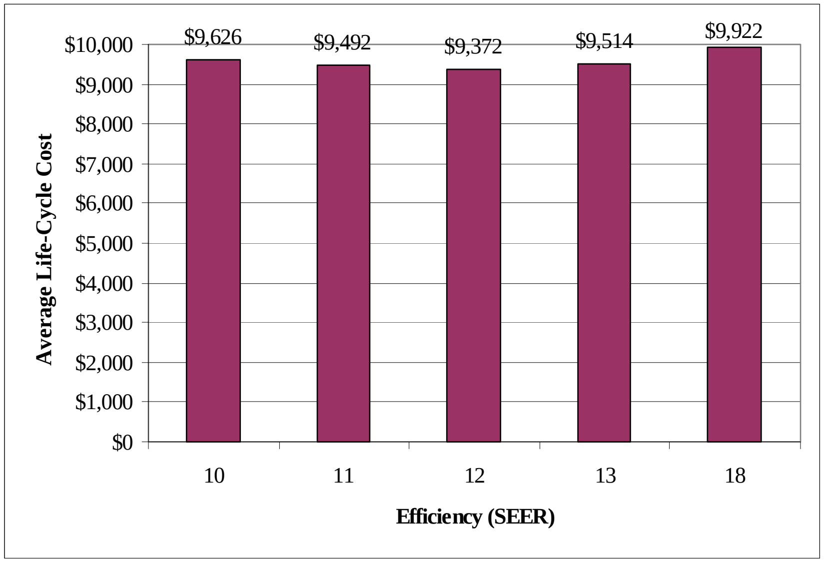

Figure 5.53 Average LCCs for Single Package Heat Pumps

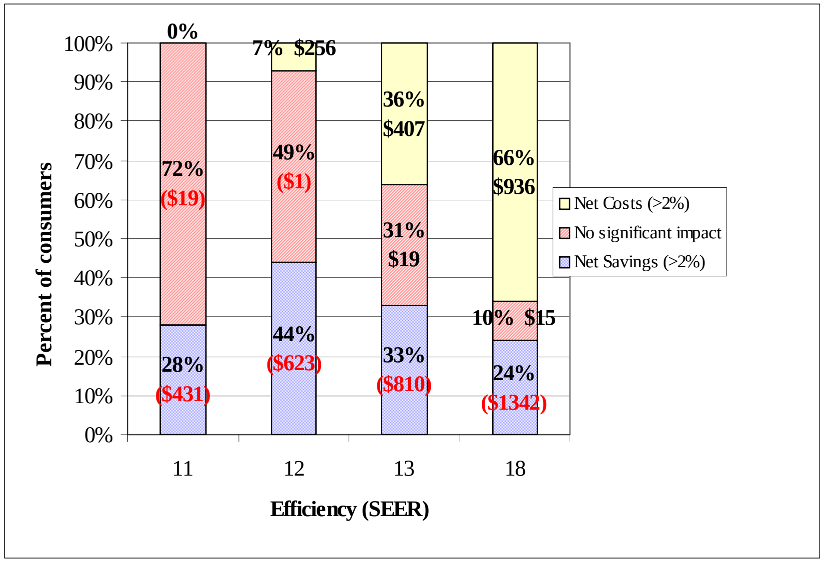

Figure 5.54 Percent of Single Package Heat Pump Consumers with Net Costs, No Significant Impacts, and Net Savings

5.2.4.5 LCC Scenarios

Two of the key assumptions for the LCC analysis pertain to the manufacturer costs and the system lifetime. Two scenarios are investigated where lower estimates of the manufacturer costs and system lifetime are analyzed.

Manufacturer Cost Scenario

An LCC scenario in which manufacturer cost estimates based on the reverse engineering analysis (Chapter 4) are substituted for the estimates provided by ARI. Table 5.44 compares the ARI shipment-weighted mean and reverse engineering mean manufacturer cost multipliers.

Table 5.44 ARI Shipment-Weighted Mean and Revised Reverse Engineering Mean Manufacturer Cost Multipliers

	Product Class							
Efficiency Level	**Split A/C**		**Split Heat Pump**		**Package A/C**		**Package Heat Pump**	
SEER	ARI	Rev Eng	ARI	Rev Eng	ARI	Rev Eng	ARI	Rev Eng
11	1.16	1.12	1.10	1.05	1.19	1.09	1.14	1.08
12	1.36	1.28	1.24	1.13	1.30	1.16	1.28	1.13
13	1.63	1.44	1.44	1.30	1.63	1.43	1.60	1.38
18[a]	2.40	1.99	2.09	1.94	2.23	1.87	2.13	1.86

[a] Cost Multipliers for 18 SEER based on data for 15 SEER.

Tables 5.45 through 5.48 and Figures 5.55 through 5.62 show the LCC results for each of the product classes under the scenario of replacing the ARI manufacturer cost estimates with those from the reverse engineering analysis. The following results are presented in the same manner as the previous LCC results where average LCC savings or costs and the percentage of consumers with net savings, insignificant impacts, and net costs are presented for each efficiency level. Note that since manufacturer cost multipliers were not available for the 18 SEER efficiency levels, 15 SEER cost multipliers were used for all 18 SEER calculations resulting in 18 SEER LCC results which underestimate their true cost level.

Table 5.45 LCC Results for Split System A/C – LCC Scenario with Reverse Engineering Manufacturer Costs

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$5,170	-	-		-		-	
11	$5,095	($75)	28%	($305)	70%	($10)	2%	$118
12	$5,057	($113)	35%	($453)	40%	$18	25%	$158
13	$5,057	($113)	34%	($589)	27%	$11	39%	$217
18	$5,307	$137	25%	($1,045)	7%	$5	68%	$584

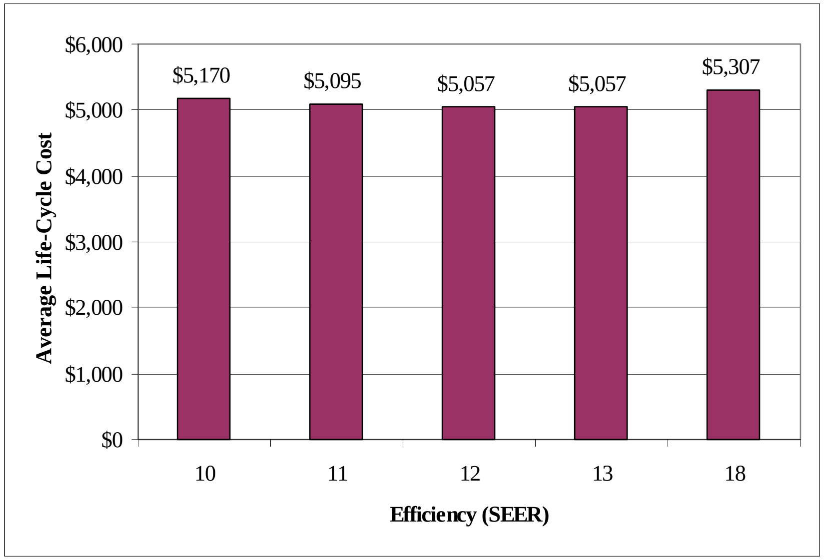

Figure 5.55 Average LCCs for Split A/C – LCC Scenario with Rev Eng Manufacturer Costs

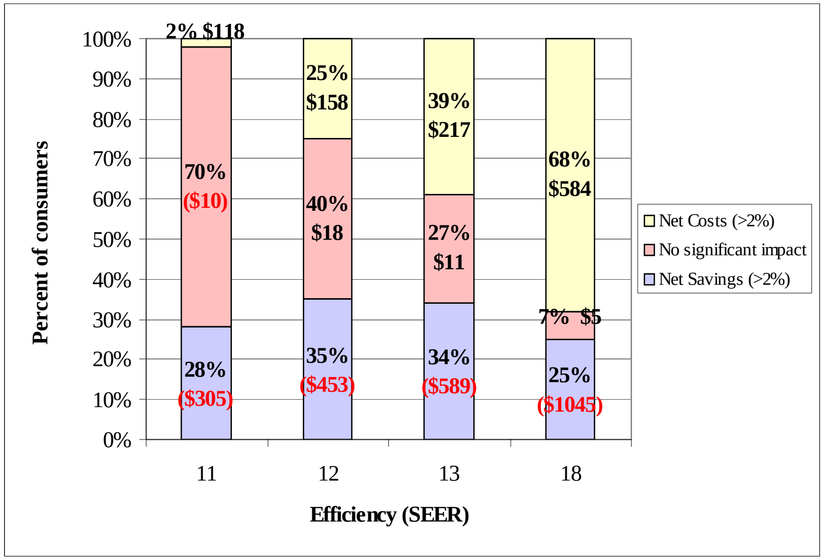

Figure 5.56 Percent of Split A/C Consumers with Net Costs, No Significant Impacts, and Net Savings – LCC Scenario with Rev Eng Manufacturer Costs

Table 5.46 LCC Results Split System Heat Pump – LCC Scenario with Reverse Engineering Manufacturer Costs

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$9,679	-	-		-		-	
11	$9,470	($209)	40%	($409)	60%	($77)	0%	$0
12	$9,314	($365)	58%	($591)	42%	($58)	0%	$216
13	$9,307	($372)	52%	($742)	42%	($2)	6%	$259
18	$9,720	$41	28%	($1,295)	15%	$11	57%	$712

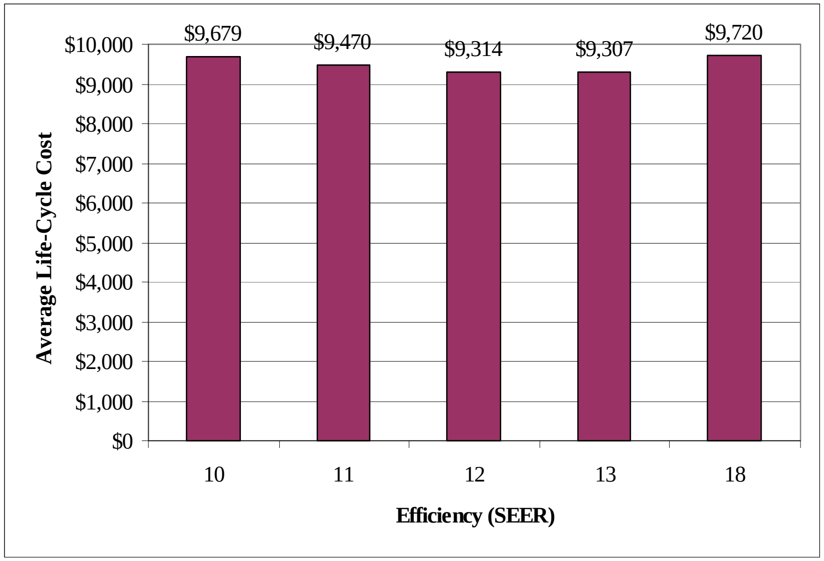

Figure 5.57 Average LCCs for Split HP – LCC Scenario with Rev Eng Manufacturer Costs

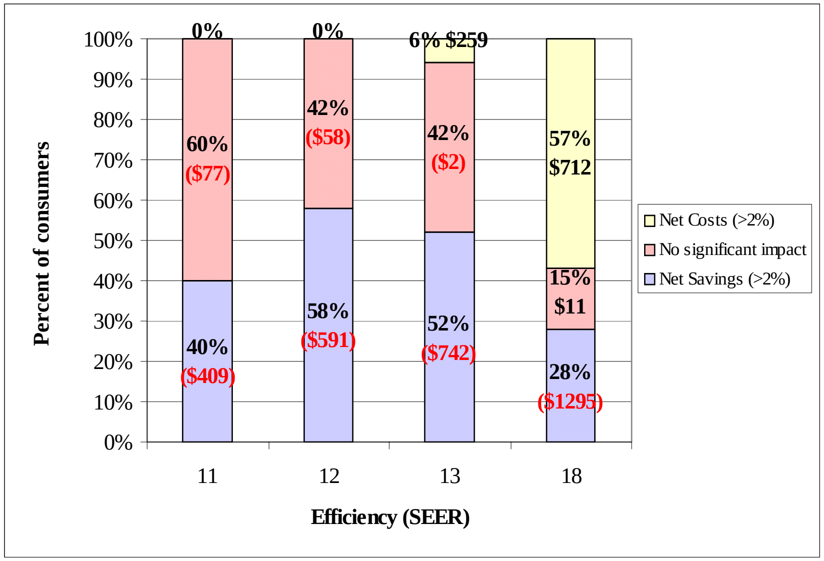

Figure 5.58 Percent of Split HP Consumers with Net Costs, No Significant Impacts, and Net Savings – LCC Scenario with Rev Eng Manufacturer Costs

Table 5.47 LCC Results for Single Package A/C – LCC Scenario with Reverse Engineering Manufacturer Costs

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$5,629	-	-		-		-	
11	$5,551	($78)	27%	($313)	72%	$9	1%	$120
12	$5,466	($163)	40%	($460)	51%	$13	9%	$140
13	$5,600	($29)	28%	($632)	20%	$16	52%	$275
18	$5,905	$276	21%	($1,101)	6%	$8	73%	$690

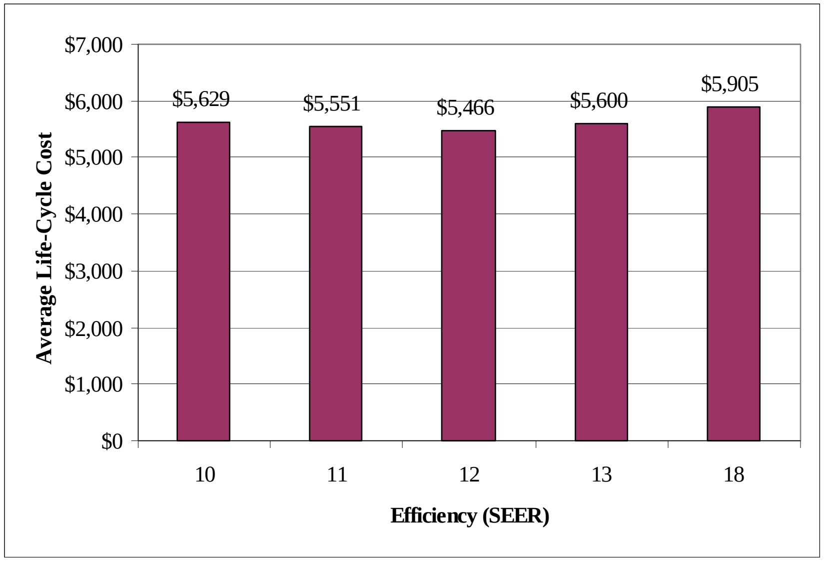

Figure 5.59 Average LCCs for Single Pakcage A/C – LCC Scenario with Rev Eng Manufacturer Costs

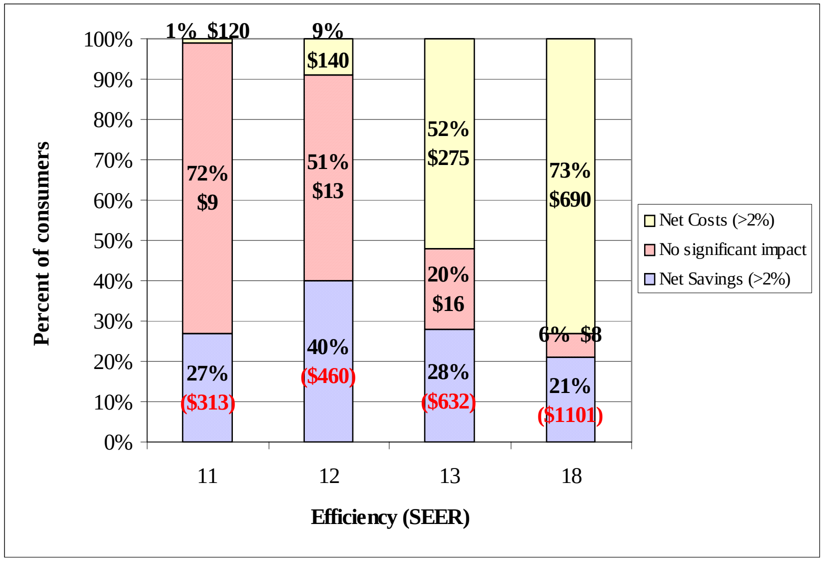

Figure 5.60 Percent of Single Package A/C Consumers with Net Costs, No Significant Impacts, and Net Savings – LCC Scenario with Rev Eng Manufacturer Costs

Table 5.48 LCC Results for Single Package HP – LCC Scenario with Reverse Engineering Manufacturer Costs

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$9,626	-	-		-		-	
11	$9,419	($207)	39%	($426)	61%	($65)	0%	$0
12	$9,205	($421)	66%	($606)	34%	($62)	0%	$214
13	$9,273	($353)	50%	($775)	38%	($1)	12%	$299
18	$9,460	($166)	37%	($1,344)	15%	$13	48%	$683

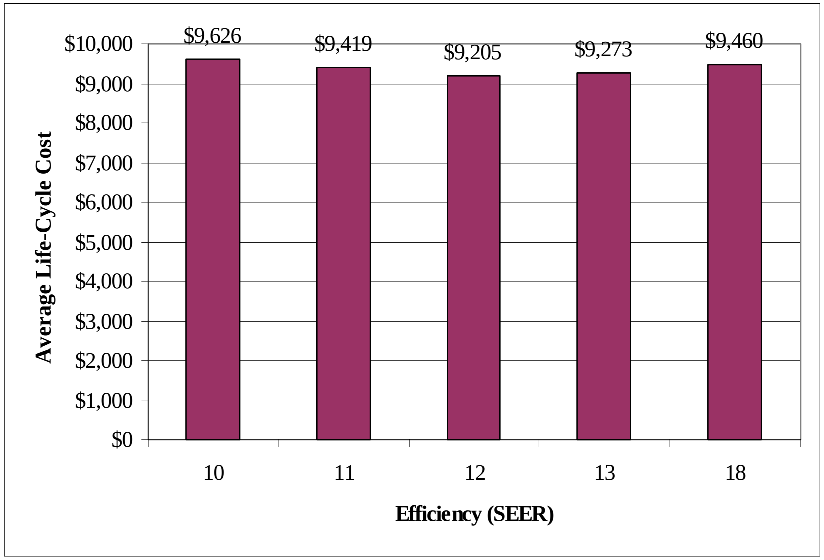

Figure 5.61 Average LCCs for Single Package HP – LCC Scenario with Rev Eng Manufacturer Costs

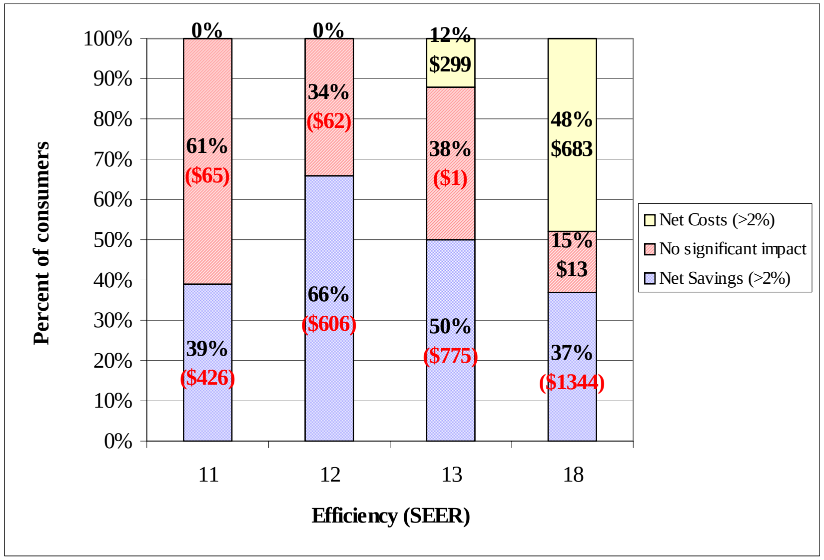

Figure 5.62 Percent of Single Package HP Consumers with Net Costs, No Significant Impacts, and Net Savings – LCC Scenario with Rev Eng Manufacturer Costs

Lifetime Scenario

A lifetime scenario is considered based on a retirement function yielding an average lifetime of 14 years in which no compressor replacement occurs. The shorter lifetime is based on the assumption that most, if not all, consumers when faced with replacing a failed compressor would choose to replace the entire system rather than replace the compressor in a relatively old system.

Tables 5.49 through 5.52 and Figures 5.63 through 5.70 show the LCC results for each of the product classes under the 14 year lifetime, no compressor replacement scenario. The following results are presented in the same manner as the previous LCC results where average LCC savings or costs and the percentage of consumers with net savings, insignificant impacts, and net costs are presented for each efficiency level.

Table 5.49 LCC Results for Split System A/C – LCC Scenario with 14 year average Lifetime

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$4,682	-	-		-		-	
11	$4,650	($32)	22%	($252)	69%	$20	9%	$113
12	$4,672	($10)	24%	($392)	31%	$16	45%	$178
13	$4,769	$87	21%	($498)	15%	$14	64%	$296
18	$5,336	$654	12%	($928)	3%	$11	85%	$893

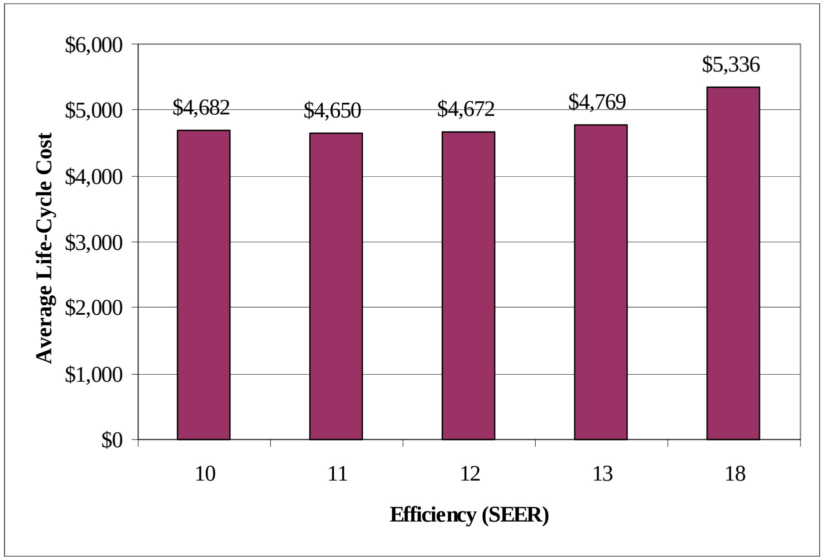

Figure 5.63 Average LCCs for Split A/C – LCC Scenario with 14 year average Lifetime

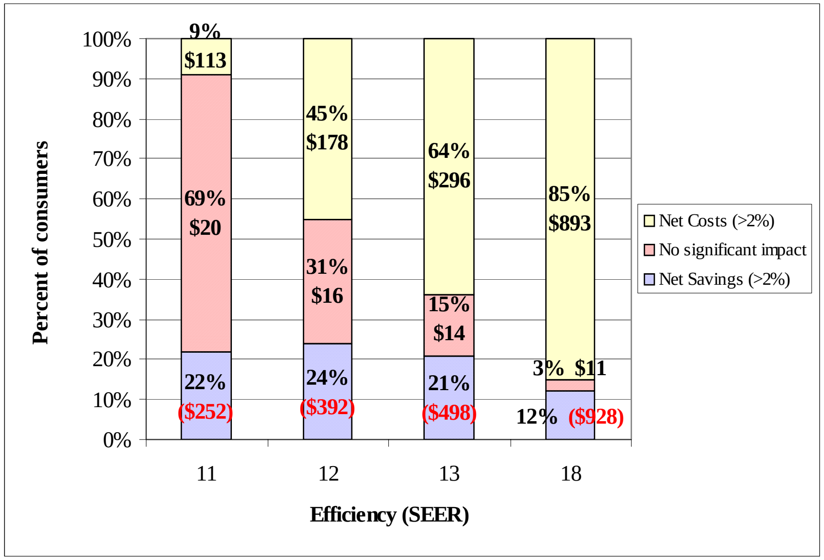

Figure 5.64 Percent of Split A/C Consumers with Net Costs, No Significant Impact, and Net Savings – LCC Scenario with 14 year average Lifetime

Table 5.50 LCC Results for Split System Heat Pump – LCC Scenario with 14 year avearge Lifetime

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$8,747	-	-		-		-	
11	$8,623	($124)	27%	($362)	73%	($33)	0%	$0
12	$8,587	($160)	35%	($505)	58%	$9	7%	$214
13	$8,630	($117)	33%	($645)	37%	$16	30%	$300
18	$9,184	$437	18%	($1,079)	9%	$11	73%	$862

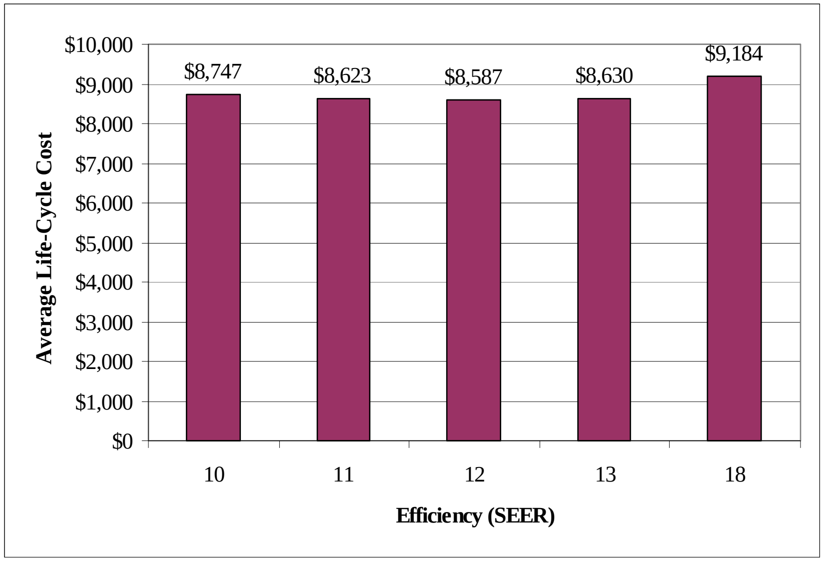

Figure 5.65 Average LCCs for Split HP – LCC Scenario with 14 year average Lifetime

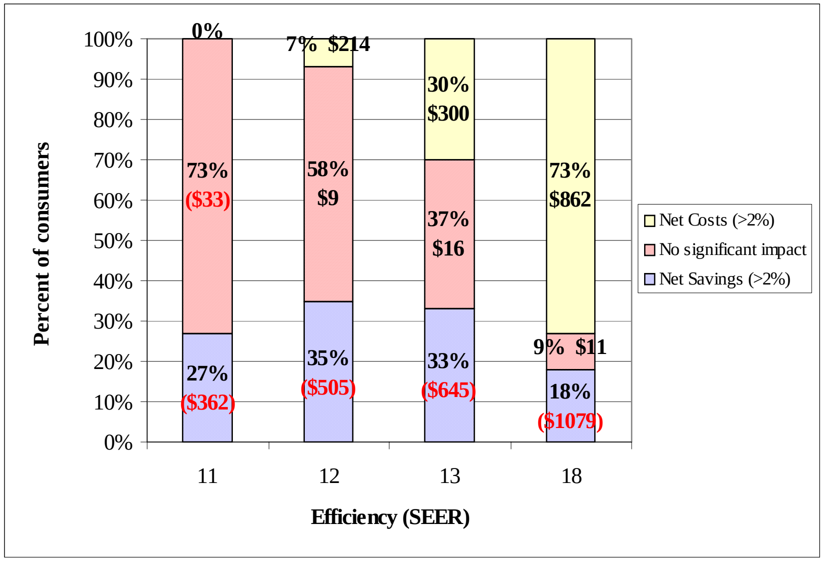

Figure 5.66 Percent of Split HP Consumers with Net Costs, No Significant Impacts, and Net Savings – LCC Scenario with 14 year average Lifetime

Table 5.51 LCC Results for Single Package A/C – LCC Scenario with 14 year average Lifetime

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$5,150	-	-		-		-	
11	$5,182	$32	14%	($286)	46%	$31	40%	$144
12	$5,157	$7	22%	($428)	29%	$18	49%	$199
13	$5,378	$228	14%	($564)	10%	$12	76%	$406
18	$6,011	$861	9%	($953)	3%	($4)	88%	$1,082

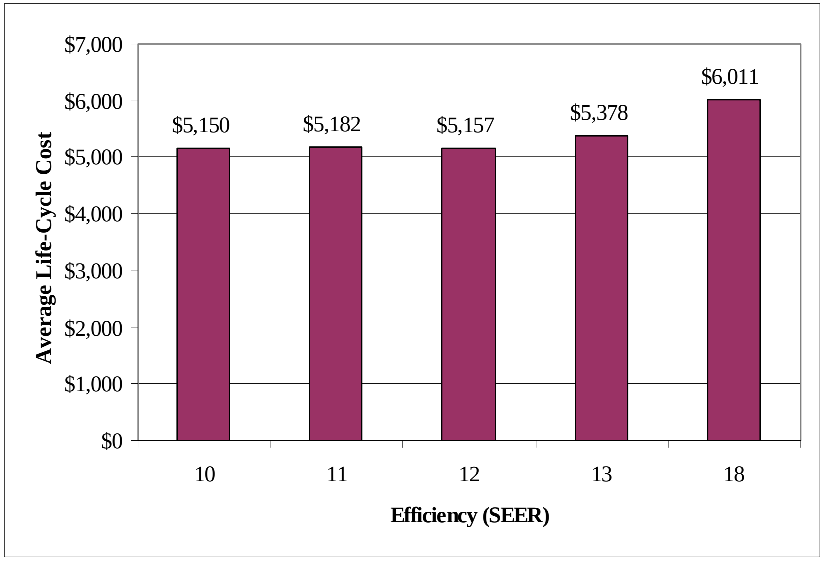

Figure 5.67 Average LCCs for Single Package A/C – LCC Scenario with 14 year average Lifetime

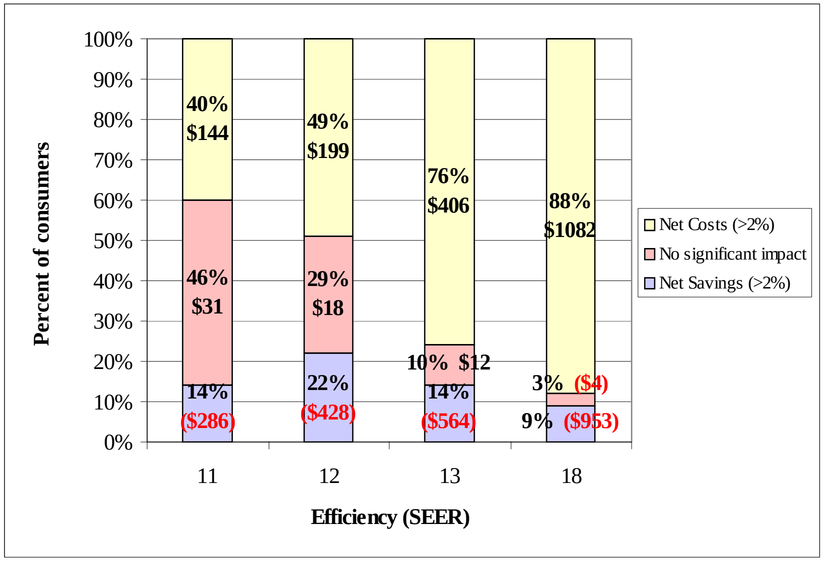

Figure 5.68 Percent of Single Package A/C Consumers with Net Costs, No Significant Impact, and Net Savings – LCC Scenario with 14 year average Lifetime

Table 5.52 LCC Results for Single Package Heat Pump – LCC Scenario with 14 year aveage Lifetime

SEER	Average LCC	Average LCC (Savings) Costs	Percent of consumers with					
			Net Savings (>2%)	Avg LCC (Save) Cost	No significant impact	Avg LCC (Save) Cost	Net Costs (>2%)	Avg LCC (Save) Cost
10	$8,695	-	-		-		-	
11	$8,597	($98)	25%	($369)	75%	($11)	0%	$185
12	$8,528	($167)	37%	($533)	51%	$8	12%	$236
13	$8,707	$12	26%	($687)	27%	$18	47%	$399
18	$9,179	$484	18%	($1,146)	8%	$14	74%	$933

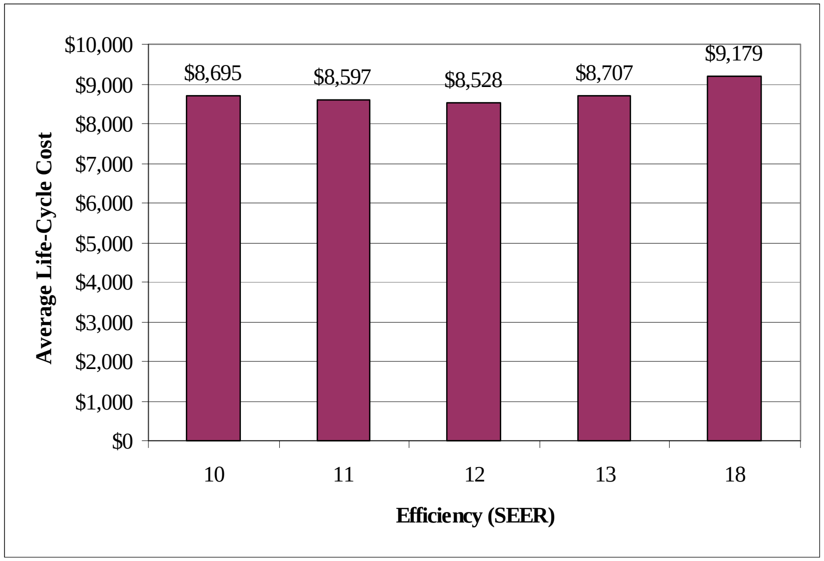

Figure 5.69 Average LCCs for Single Package HP – LCC Scenario with 14 year average Lifetime

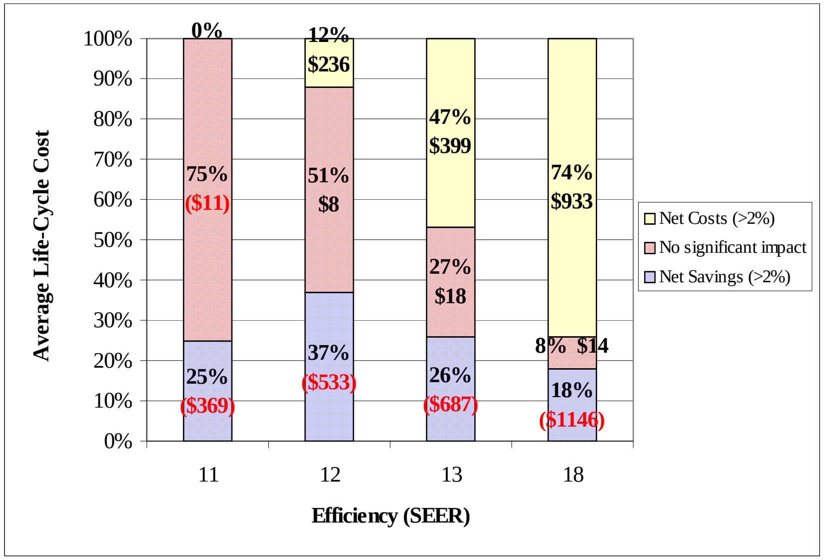

Figure 5.70 Percent of Single Package HP Consumers with Net Costs, No Significant Impacts, and Net Savings – LCC Scenario with 14 year average Lifetime

5.3 DISTRIBUTION PAYBACK PERIOD

5.3.1 Metric

The payback period (PBP) measures the amount of time it takes the consumer to recover the assumed higher purchase expense of more energy-efficient equipment through lower operating costs. Numerically, the PBP is the ratio of the increase in purchase expense (i.e., from a less efficient design to a more efficient design) to the decrease in annual operating expenditures. This type of calculation is known as a "simple" payback period, because is does not take into account changes in operating expense over time or the time value of money, that is, the calculation is done at an effective discount rate of 0%.

PBP is found by solving the equation:
for *PAY*, where ΔP = difference in purchase expense between the more efficient and the less efficient

$$PAY = \frac{\Delta P}{\Delta O} \tag{5.24}$$

design options, and ΔO = difference in annual operating expenses. PBPs are expressed in years. PBPs greater than the life of the product mean that the increased purchase expense is not recovered in reduced operating expenses.

5.3.2 Inputs

The data inputs to PBP are the purchase expense (otherwise known as the total installed consumer cost) for each design option and the annual (first year) operating expenditures for each design option. The inputs to the purchase expense are the equipment price and the installation price. The inputs to the operating costs are the annual energy savings, the energy price, the annual repair cost savings, and the annual maintenance cost savings. The Distribution PBP uses the same inputs as the LCC analysis described in section 5.2 except for a few exceptions described below.

Since this is a "simple" payback the electricity rate used is only for the year the standard takes effect, assumed here to be the year 2006. The price of electricity is that projected for that year. Discount rates are not used for the payback calculation.

5.3.3 Payback Period Results

Figure 5.71 is an example of a chart showing the distribution of payback periods for the 11 SEER efficiency level for split system air conditioners. The chart is the result of 10,000 Monte Carlo runs or in other words, 10,000 samples from each of the distribution inputs.

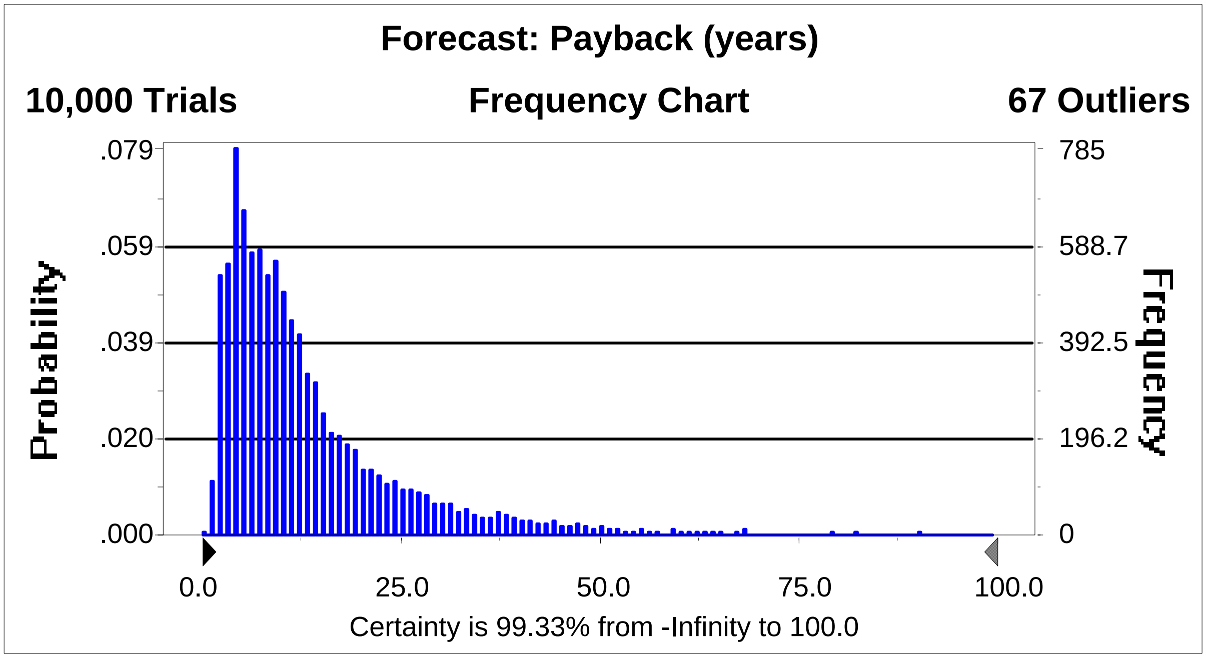

Figure 5.71 Frequency Chart of Payback Periods for 11 SEER Efficiency Level for Split Air Conditioners

Tables 5.53 through 5.56 summarize 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 5.72 through 5.75 graphically display the payback period results. 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 5.53 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
11	1	4	5	7	9	11	13	16	21	31	681	16
12	1	5	6	8	10	13	15	19	26	39	622	19
13	1	6	8	10	13	16	20	24	33	50	>1000	24
18	2	8	12	18	25	36	55	106	1000	1000	>1000	451

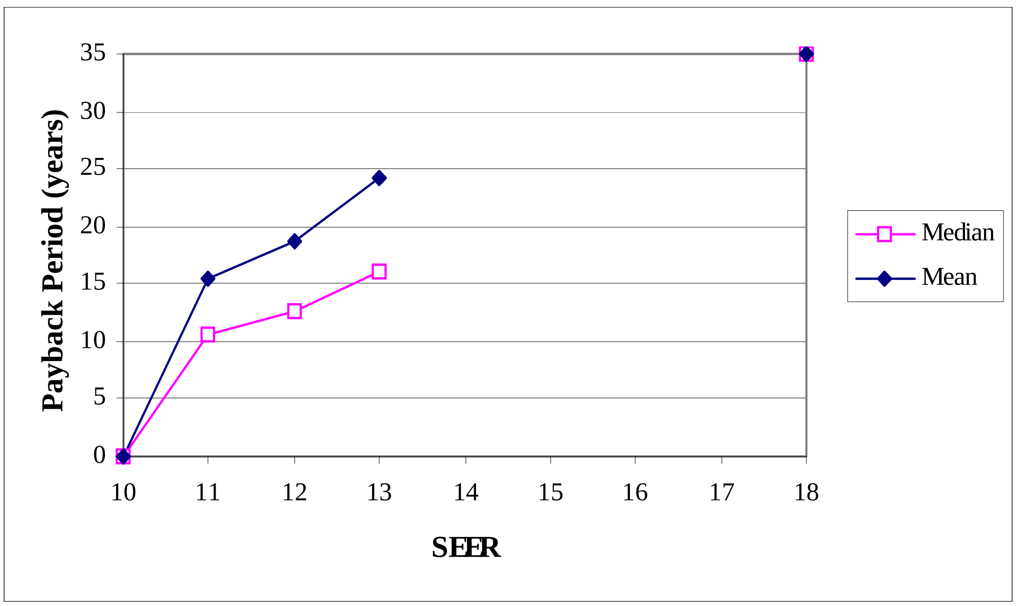

Figure 5.72 Split A/C: Median and Mean Payback Periods

Table 5.54 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
11 / 7.1	1	2	3	4	5	6	7	8	10	13	>1000	9
12 / 7.4	1	3	4	5	6	7	8	10	12	17	1000	10
13 / 7.7	1	4	6	7	8	9	11	13	16	22	1000	13
18 / 8.8	2	6	9	11	14	17	22	29	44	102	>1000	135

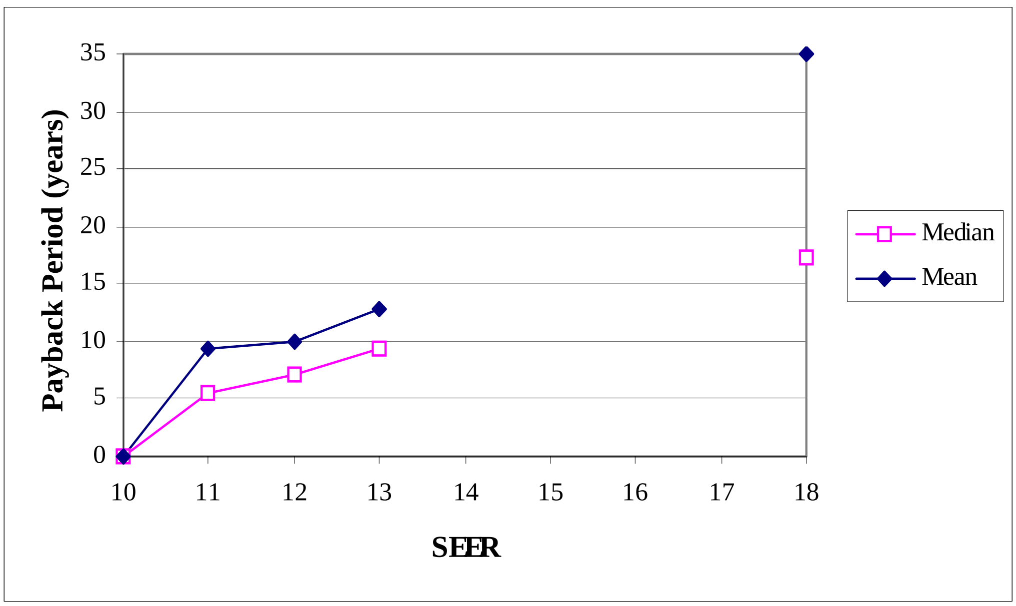

Figure 5.73 Split HP: Median and Mean Payback Periods

Table 5.55 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
11	1	5	8	10	13	16	20	25	34	52	596	24
12	1	5	7	9	11	14	17	22	30	45	927	22
13	2	7	10	14	18	22	26	33	46	69	>1000	33
18	2	9	14	21	32	49	84	237	1000	1000	>1000	378

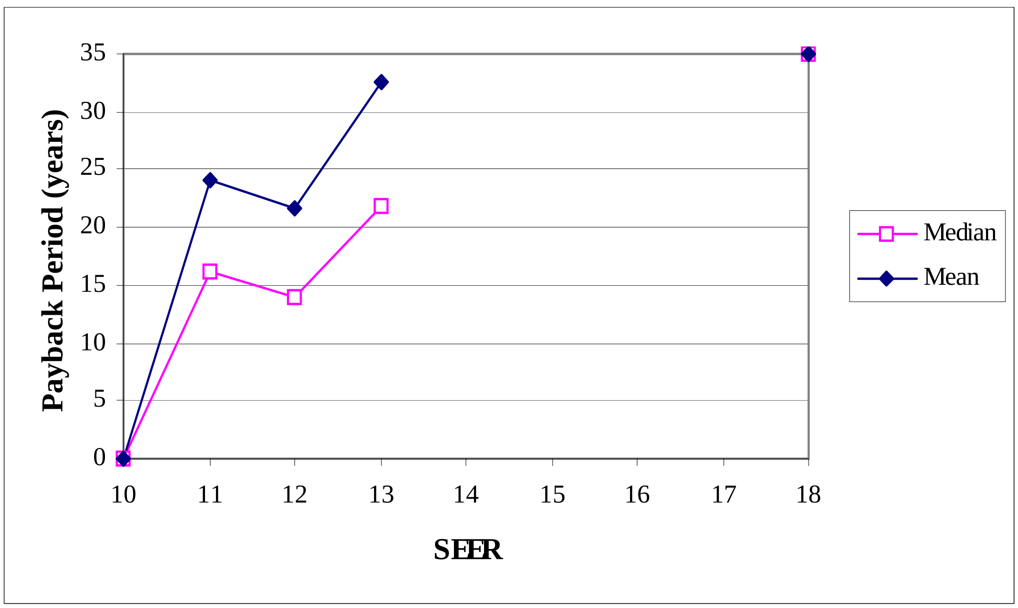

Figure 5.74 Package A/C: Median and Mean Payback Periods

Table 5.56 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**
11 / 7.1	1	4	5	6	7	8	9	11	14	19	1000	11
12 / 7.4	1	4	5	6	7	9	10	12	15	21	1000	13
13 / 7.7	2	6	8	10	11	13	16	18	23	32	>1000	19
18 / 8.8	2	7	10	12	16	19	25	34	53	160	>1000	114

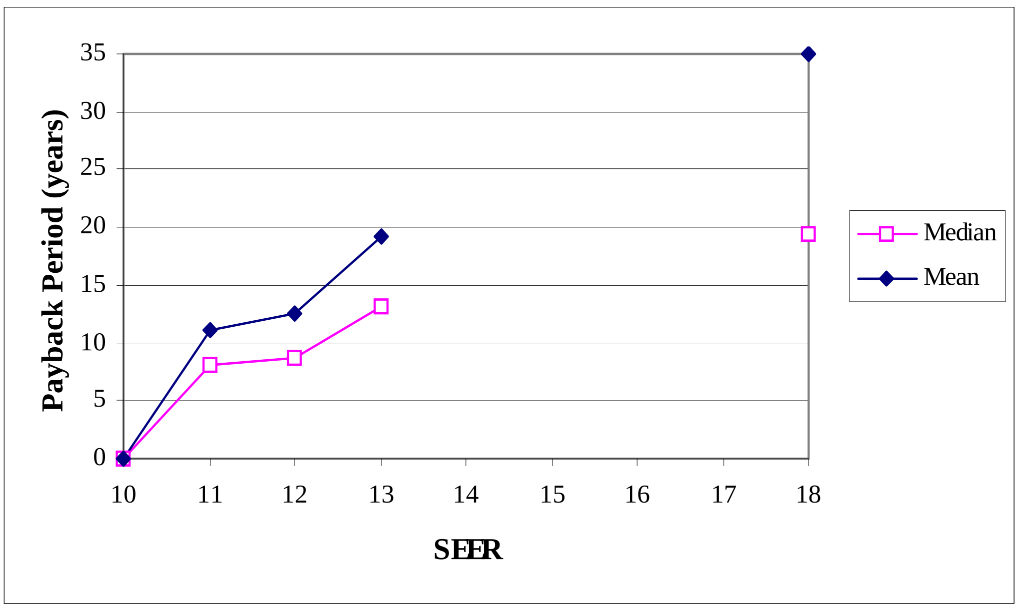

Figure 5.75 Package HP: Median and Mean Payback Periods

5.4 REBUTTABLE PAYBACK PERIOD

Rebuttable PBP's are presented in order to provide the legally established rebuttable presumption that a energy efficiency standard is economically justified if the additional product costs attributed to the standard are less than three times the value of the first year energy cost savings (42 U.S.C. §6295 (o)(2)(B)(iii)).

5.4.1 Metric

The basic equation for Rebuttable PBP is the same as that shown in section 5.3 (Eqn. 5.24). Unlike the analyses in sections 5.2 and section 5.3, the Rebuttable PBP is not based on distributions and does not utilize the Crystal Ball option in the spreadsheet model. Rather than using distributions, the Rebuttable PBP is based on discrete single-pont values. For example, where a probability distribution of electricity prices are used in the distributional Payback Analysis, only the *weighted-average* value from the probability distribution of electricity prices is used for the determination of the Rebuttable PBP.

Other than the use of single point-values, the most notable difference between the Distribution PBP and the Rebuttable PBP is the latter's reliance on the DOE test procedure to determine a central air conditioner's or heat pump's annual energy consumption[41]. In the case of central air conditioners and the cooling seasonal performance of heat pumps, the DOE test procedure uses the following expression to calculate the annual space-cooling energy consumption:

$$UEC_{cool\ Reb\ PBP} = \frac{CAP_{cool}}{SEER} \cdot Hours \qquad \textbf{(5.25)}$$

Where,

- $UEC_{cool\ Reb\ PBP}$ = annual space-cooling energy use based on the DOE test procedure,
- CAP_{cool} = the cooling capacity of the equipment at 95°F, and
- $SEER$ = the SEER of the equipment, and
- $Hours$ = 1000, the assumed annual operational hours.

For the heating seasonal performance of heat pumps, the DOE test procedure uses the following expression to calculate the annual space-heating energy consumption:

$$UEC_{heatReb\ PBP} = \frac{DHR}{HSPF} \cdot 0.77 \cdot Hours \qquad \textbf{(5.26)}$$

Where,

- $UEC_{heat\ Reb\ PBP}$ = annual space-heating energy use based on the DOE test procedure,
- DHR = the design heat requirement (which for 3-ton cooling capacity heat pumps is typically 35,000 Btu/hr),

HSPF = the HSPF of the equipment, and
Hours = 2080, the assumed annual operational hours.

As will be shown later (Section 5.4.3), based on the use of the DOE test procedure equations, the calculated annual space-cooling and heating energy consumption are on the order of 50% greater than the *weighted-average* values from the 1997 RECS. This means that for any standard-level being analyzed, the Rebuttable PBP value will be significantly lower than the average payback value from the distributional analysis.

5.4.2 Inputs

Inputs differ from the Distribution PBP in that discrete values are used rather than distributions for inputs. The following describe the single point-values which were used in the determination of the Rebuttable PBP. All dollar values are in 1998$.

- Manufacturer costs are based on mean values as presented in Table 5.3 for the ARI cost data.

- All markups and sales taxes are based on mean values.

- Installation prices are based on mean values for split and single package air conditioners and for split and single package heat pumps.

- Annual energy consumption is based on the DOE test procedure as presented in Eqns. 5.25 and 5.26. In determining the annual space-cooling energy use, the assumed cooling capacity is 3-tons (36,000 Btu/hr). In determining the annual space-heating energy use for heat pumps, the assumed design heating requirement is 35,000 Btu/hr.

- Electricity rates for both average and marginal prices are based on *weighted-average* values for the year the standard takes effect, i.e., AEO projections for the year 2006.

- An average discount rate or lifetime is not required in this calculation.

- Effective data of standard is assumed to be 2006.

5.4.3 Rebuttable Payback Period Results

Rebuttable payback periods are calculated between the new standard-level being analyzed and each central air conditioner or heat pump efficiency being sold in the year 2006. Based on the most recently available shipments data from ARI (from 1994), Table 5.57 depicts the markets shares by efficiency level for each of the four product classes.

Table 5.57 Efficiency Level Market Shares for 1994

SEER	Split A/C	Split HP	Single Package A/C	Single Package HP
10	78.7%	59.3%	82.3%	64.2%
11	5.4%	15.0%	9.7%	13.6%
12	12.0%	19.7%	6.8%	22.2%
13	3.6%	4.5%	1.2%	0.0%
14	0.1%	1.0%	0.0%	0.0%
15	0.2%	0.5%	0.0%	0.0%

Because the shipment weighted efficiencies of unitary air conditioners and heat pumps have remained essentially flat over the four year period from 1994 to 1997, the above market shares in Table 5.57 for 1994 are assumed to be representative of those in the year new standards are assumed to become effective (2006).

After the payback periods are determined against each efficiency level sold in the year 2006, they are weighted and averaged according to the percentage of each equipment efficiency sold before a new standard is enacted. As described earlier, rather than being based on probability distributions, single point-values are used for the input variables. Annual energy use values are defined by inputs (e.g., operating hours) and expressions found in the DOE test procedure. The result is a single-value of payback and not a probability distribution. The payback is calculated for the expected effective year of the standard (e.g., 2006).

Tables 5.58 through 5.61 show the Rebuttable PBPs for the four primary product classes. Two tables are presented for each product class; one based on the ARI manufacturer cost data and other based on the reverse engineering cost data. In each table the primary inputs used in the determination of Rebuttable PBP are presented. Of special note are the two columns of data that show the *weighted-average* installed consumer cost and *weighted-average* annual operating expense. For each standard-level, the *weighted-average* consumer cost and *weighted-average* operating expense are the *baseline* values which the standard-level is referenced against. Both of these values are based upon the normalized percentage of each equipment efficiency sold that precedes the particular efficiency level of interest. This approach of calculating Rebuttable PBP is equivalent to weighting and averaging the payback against each efficiency level.

To illustrate the *weighted-average* concept of calculating Rebuttable PBP, the *weighted-average* installed cost and operating expense values are calculated here for the 12 SEER efficiency level for split system air conditioners (Table 5.58). For the 12 SEER efficiency level, the *weighted-average* installed consumer cost is calculated with the following expression:

$$IC_{12\,SEER\,wt\,avg} = \$2236 \cdot \left(78.7\% / (78.7\% + 5.4\%) \right) + \$2357 \cdot \left(5.4\% / (78.7\% + 5.4\%) \right) = \$2243$$

The *weighted-average* operating expense is calculated with the following expression:

$$OC_{12\,SEER\,wt\,avg} = \$357 \cdot \left(78.7\% / (78.7\% + 5.4\%) \right) + \$331 \cdot \left(5.4\% / (78.7\% + 5.4\%) \right) = \$355$$

Finally, the Rebuttable PBP is calculated as follows:

$$PBP_{\mathrm{Re}butt} = \frac{(\$2510 - \$2236)}{(\$355 - \$310)} = 5.8\,years$$

Table 5.58 Summary of Rebuttable PBPs and Inputs for Split System Air Conditioners

Effc'y Level	Installed Consumer Cost	Annual Energy Use	Annual Repair Cost	Annual Maint. Cost	Annual Operating Expense	Assumed 2006 Effc'y Distr.	Weighted-Avg of Units Sold below Effc'y: Installed Consumer Cost	Weighted-Avg of Units Sold below Effc'y: Annual Operating Expense	Rebutt. Payback Period
SEER	*1998$*	*kWh/yr*	*1998$*	*1998$*	*1998$*		*1998$*	*1998$*	*years*
10	$2,236	3,600	$26	$36	$357	78.7%	-	-	-
11	$2,357	3,273	$26	$36	$331	5.4%	$2,236	$357	4.7
12	$2,510	3,000	$27	$36	$310	12.0%	$2,243	$355	5.8
13	$2,715	2,769	$27	$36	$292	3.6%	$2,277	$350	7.6
18	$3,302	2,000	$55	$36	$259	0.2%	$2,294	$347	11.3

Table 5.59 Summary of Rebuttable PBPs and Inputs for Split System Heat Pumps

Effc'y Level *SEER/HSPF*	Installed Consumer Cost *1998$*	Annual Energy Use *kWh/yr*	Annual Repair Cost *1998$*	Annual Maint. Cost *1998$*	Annual Operating Expense *1998$*	Assumed 2006 Effc'y Distr.	Weighted-Avg of Units Sold below Effc'y: Installed Consumer Cost *1998$*	Weighted-Avg of Units Sold below Effc'y: Annual Operating Expense *1998$*	Rebutt. Payback Period *years*
10 /6.8	$3,668	11,844	$38	$36	$894	59.3%	-	-	-
11 / 7.1	$3,779	11,168	$38	$36	$850	15.0%	$3,668	$894	2.5
12 / 7.4	$3,933	10,575	$38	$36	$812	19.7%	$3,691	$885	3.3
13 / 7.7	$4,155	10,049	$39	$36	$778	4.5%	$3,741	$870	4.5
18 / 8.8	$4,873	8,370	$70	$36	$701	0.5%	$3,772	$864	6.8

Table 5.60 Summary of Rebuttable PBPs and Inputs for Single Package Air Conditioners

Effc'y Level *SEER*	Installed Consumer Cost *1998$*	Annual Energy Use *kWh/yr*	Annual Repair Cost *1998$*	Annual Maint. Cost *1998$*	Annual Operating Expense *1998$*	Assumed 2006 Effc'y Distr.	Weighted-Avg of Units Sold below Effc'y: Installed Consumer Cost *1998$*	Weighted-Avg of Units Sold below Effc'y: Annual Operating Expense *1998$*	Rebutt. Payback Period *years*
10	$2,607	3,600	$34	$36	$365	82.3%	-	-	-
11	$2,795	3,273	$34	$36	$339	9.7%	$2,607	$365	7.3
12	$2,903	3,000	$34	$36	$318	6.8%	$2,627	$362	6.2
13	$3,229	2,769	$35	$36	$300	1.2%	$2,646	$359	9.8
18	$3,822	2,000	$67	$36	$270	0.0%	$2,653	$358	13.3

Table 5.61 Summary of Rebuttable PBPs and Inputs for Single Package Heat Pumps

Effc'y Level *SEER/HSPF*	Installed Consumer Cost *1998$*	Annual Energy Use *kWh/yr*	Annual Repair Cost *1998$*	Annual Maint. Cost *1998$*	Annual Operating Expense *1998$*	Assumed 2006 Effc'y Distr.	Weighted-Avg of Units Sold below Effc'y: Installed Consumer Cost *1998$*	Weighted-Avg of Units Sold below Effc'y: Annual Operating Expense *1998$*	Rebutt. Payback Period *years*
10 / 6.8	$3,599	11,844	$39	$36	$895	64.2%	-	-	-
11 / 7.1	$3,759	11,168	$39	$36	$852	13.6%	$3,599	$895	3.7
12 / 7.4	$3,920	10,575	$40	$36	$814	22.2%	$3,627	$888	4.0
13 / 7.7	$4,286	10,049	$40	$36	$780	0.0%	$3,692	$871	6.5
18 / 8.8	$4,893	8,370	$74	$36	$705	0.0%	$3,692	$871	7.2

5.5 USER INSTRUCTIONS FOR SPREADSHEETS

It is possible to examine and reproduce the detailed results obtained in this part of the analysis using a Microsoft Excel spreadsheet available on the U.S. Department of Energy Office of Codes and Standards website at: http://www.eren.doe.gov/buildings/codes_standards/.

There are currently two LCC spreadsheets; one for central air conditioners (**lcc_cac.xls**) and another for heat pumps (**lcc_hp.xls**). Each spreadsheet allows the user to perform LCC analyses of either split or single package systems. To execute the spreadsheets fully requires both Mircosoft Excel and Crystal Ball software. Both applications are commercially available. Crystal ball is available at http://www.decisioneering.com.

The spreadsheets posted on the DOE website represent the latest versions of the applicable models, and have been tested with Excel 2000 and earlier versions of Excel. Each LCC spreadsheet or workbook consists of the following worksheets:

Instructions	contains the instructions for using the spreadsheet.
LCC (Sample Calc)	contains the input selections and a summary table of energy use, operating costs, LCC and Payback.
LCC (Simulations)	contains the input selections as in the LCC (Sample Calc) sheet. If Crystal Ball is running, the energy, cost, LCC, and payback data are from the current sample. If Crystal Ball has finished running, the data are from the final sample.
Engineering	contains the manufacturer costs submitted by ARI for split systems and single package systems at each efficiency level. Also included are the manufacturer, distributor, and dealer markups, the sales tax, the installation price, and the repair and maintenance costs.
RECS HH Data	for each sample household from the 1997 RECS, contains average and marginal electricity prices, annual space-cooling energy consumption (and space-heating energy consumption for heat pumps), the station (i.e., geographic) location, the year the household was built, and the equipment's age index.
COMM Data	for each sample building, for each sample building, contains average and marginal electricity prices, and annual space-cooling energy consumption (and space-heating energy consumption for heat pumps).
Energy Price	contains projections of future energy prices from various sources.

SEER Dist — contains historical shipment weighted efficiency data by year; this is used for determining the probable SEER of existing space-conditioning equipment based on age.

HSPF Dist — contains historical shipment weighted efficiency data by year; this is used for determining the probable HSPF of existing heat pump based on age. (This worksheet is included only in the LCC spreadsheet for heat pumps (**lcc_hp.xls**)).

Seasonal Allocation Factors — contains seasonal (i.e., summer and non-summer) allocation factors of annual cooling (or heating) energy which indicate the fraction used by season. The seasonal allocation factors are based on the age and the geographic location of the household. The factors are used for determining the annual marginal electricity rate. Summer and non-summer allocation factors are multiplied by summer and non-summer marginal rates, respectively, and then summed to arrive at the annual marginal rate.

drate dist — contains data from which an average discount rate and a distribution of discount rates are determined.

Lifetime — contains the survival function for central air conditioners and heat pumps and the average central air conditioner and heat pump lifetime in years.

Setup — this is used as an interface between user inputs and the rest of the worksheets -- do not modify this sheet.

The following provides basic instructions for operating the LCC spreadsheets:

1. Once the LCC spreadsheets have been downloaded from the website, open either file using Microsoft Excel. At the bottom, click on the tab for either the worksheet **LCC (Sample Calc)** or **LCC (Simulations)**.

2. Use Microsoft Excel's commands at the top **View/Zoom** to change the size of the display to make it fit your monitor.

3. The user interacts with the spreadsheet by clicking choices or entering data using the graphical interface that comes with the spreadsheet. Choices can be selected from the box labeled **List Inputs** on either of the two worksheets **LCC (Sample Calc)** or **LCC (Simulations)**. A change in either worksheet also changes the other. In the box titled **List Inputs** select choices from the selection boxes for (1) energy price

projection, (2) start year, (3) base case design, and (4) standard case design. Also included are options for selecting different markups and manufacturer cost multipliers. Outside the upper right hand corner of the **List Inputs** box is an option for selecting the system type (split or single package). A new discount rate or lifetime can also be entered if a value other than the default value or default distribution is wanted, however, this would change the code and we do not recommend saving the spreadsheet after the code is changed.

4. To change assumptions on **List Inputs** click on the assumption you wish to change, and click on the new assumption from the menu.

5. This spreadsheet gives the user two methods of running the spreadsheet.

    a. If the **LCC (Sample Calc)** sheet is chosen, then all calculations are performed for single input values, usually an average. The new results are shown on the same sheet as soon as the new values are entered.

    b. Alternately, if the **LCC (Simulations)** sheet is used, the spreadsheet generates results that are distributions. Some of the inputs are also distributions. The results from the LCC distribution are shown as single values and refer only to the results from the last Monte Carlo sample and are therefore not meaningful. To run the distribution version of the spreadsheet the Microsoft Excel add-in software called Crystal Ball must be enabled.

To produce sensitivity results using Crystal Ball, simply select ***Run*** from the **Run** menu (on the menu bar). To make basic changes in the run sequence, including altering the number of trials, select ***Run Preferences*** from the **Run** menu. After each simulation run, the user needs to select ***Reset*** (also from the **Run** menu) before ***Run*** can be selected again. Once Crystal Ball has completed its run sequence it will produce a series of distributions. Using the menu bars on the distribution results it is possible to obtain further statistical information. The time taken to complete a run sequence can be reduced by minimizing the Crystal Ball window in Microsoft Excel. A step by step summary of the procedure for running a distribution analysis is outlined below:

1. Find the Crystal Ball toolbar (at top of screen)

2. Click on **Run** from the menu bar
3. Select ***Run Preferences*** and choose from the following choices:
    a. Monte Carlo[b]
    b. Latin Hypercube (recommended)
    c. Initial seed choices and whether you want it to be constant between runs

[b] Because of the nature of the program, there is some variation in results due to random sampling when Monte Carlo or Latin Hypercube sampling is used.

d. Select number of Monte Carlo Trials (we suggest 10,000).

4. To run the simulation, follow the following sequence (on the Crystal Ball toolbar)
Run
Reset
Run

5. Now wait until the program informs you that the simulation is completed.

The following instructions are provided to view the output generated by Crystal Ball.

6. After the simulation has finished, to see the distribution charts generated, click on the Windows tab bar that is labeled Crystal Ball.

7. The life-cycle cost savings and payback periods are defined as ***Forecast*** cells. The *frequency* charts display the results of the simulations, or trials, performed by Crystal Ball. Click on any chart to bring it into view. The charts show the low and high endpoints of the forecasts. The ***View*** selection on the Crystal Ball toolbar can be used to specify whether you want cumulative or frequency plots shown.

8. To calculate the probability of that LCC savings will occur, either type 0 in the box by the right arrow, or move the arrow key with the cursor to 0 on the scale. The value in the ***Certainty*** box shows the likelihood that the LCC savings will occur. To calculate the certainty of payback period being below a certain number of years, choose that value as the high endpoint.

9. To generate a printout report, select ***Create Report*** from the **Run** menu. The toolbar choice of ***Forecast Windows*** allows you to select the charts and statistics you are interested in. For further information on Crystal Ball outputs, please refer to *Understanding the Forecast Chart* in the Crystal Ball manual.

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