CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

The effect of amended standards on individual customers usually includes a reduction in operating cost and an increase in purchase cost. This chapter describes two metrics used in the analysis to determine the economic impact of standards on individual residential consumers and commercial customers.

- Life-cycle cost (LCC) is the total customer cost over the life of an appliance or product, including purchase costs and operating costs (which in turn include maintenance, repair, and energy costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance or product.
- Payback period (PBP) measures the amount of time it takes customers to recover the assumed higher purchase price of more energy-efficient products through reduced operating costs.

The U.S. Department of Energy (DOE) conducted the LCC and PBP analysis using a spreadsheet model developed in Microsoft Excel. When combined with Crystal Ball (a commercially available software program), the LCC and PBP model generates a Monte Carlo simulation to perform the analysis by incorporating uncertainty and variability considerations in certain of the key parameters as discussed below.

Inputs to the LCC and PBP analyses of central air conditioning (CAC), heat pump (HP), and furnace products are discussed in sections 8.2 and 8.3 respectively. Results for each metric are presented in section 8.4. Key variables and calculations are presented for each metric. The calculations discussed here were performed with a series of Microsoft Excel spreadsheets which are accessible over the Internet (http://www1.eere.energy.gov/buildings/appliance_standards/residential/central_ac_hp.html).

Details of, and instructions for, using the spreadsheets are discussed in appendices 8-A and 8-E.

8.1.1 General Approach for Life-Cycle Cost and Payback Period Analyses

In recognition that each building where air conditioners (A/C), heat pumps (HP), or furnaces 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. Although the vast majority of the products are used in residential buildings, the analysis takes into account product use in commercial buildings based on the assumption that 7% of air conditioner and heat pump product 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. 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.

The LCC analysis used the estimated energy use for each CAC, HP, and furnace unit as described in the energy use characterization analysis in chapter 7 of the TSD. Energy use of CACs, HPs, and furnaces is sensitive to climate, so it varies by location within the United States. An important feature of the LCC and PBP analysis is that it has been conducted at both the regional and national level. Aside from energy use, other important factors influencing the LCC and PBP analyses include energy prices, installation costs, product distribution markups, and sales taxes. At both the national and the regional level, the LCC spreadsheets explicitly modeled both the uncertainty and the variability in the model's inputs, using probability distributions based on the shipment of products to different regions of the country.

As mentioned above, DOE generated LCC and PBP results as probability distributions using a simulation based on Monte Carlo analysis methods, in which certain key inputs to the analysis consist of probability distributions rather than single-point values. Therefore, the outcomes of the Monte Carlo analysis can also be expressed as probability distributions. As a result, the Monte Carlo analysis produces a range of LCC and PBP results. A distinct advantage of this type of approach is that DOE can identify the percentage of customers achieving LCC savings or attaining certain PBP values due to an increased efficiency level, in addition to the average LCC savings or average PBP for that efficiency level.

The LCC and PBP results are displayed as distributions of impacts compared to a market baseline. As described in chapter 7, the market baseline efficiency level is for 2016 and is defined as a mix of CAC, HP, or furnace efficiency levels reflecting the current distribution of efficiency levels purchased by product class. Results are presented at the end of this chapter. A variety of graphic displays can be created to illustrate the implications of the analysis. Examples of graphic displays are (1) a cumulative probability distribution showing the percentage of CAC, HP, or furnace product in U.S. residential and commercial buildings that would experience a net LCC savings, and (2) a cumulative frequency chart depicting variation in PBP for each central air conditioner or furnace efficiency level considered.

For CACs and HPs, all analyses were performed under the assumption that the current R-22 refrigerant would have been displaced by an alternative refrigerant in 2010 due to provisions in the Clean Air Act. The analysis methodology and results presented in this chapter assume that all CAC and HP products manufactured after 2010 will use R-410A.

8.1.2 Overview of Life-Cycle Cost and Payback Period Analyses Inputs

The LCC is the total customer cost over the life of the product, including purchase price (including retail markups, sales taxes, and installation costs), and operating cost (including repair costs, maintenance costs, and energy cost). Future operating costs are discounted to the time of purchase and summed over the lifetime of the product. The PBP is the increase in purchase cost of a higher efficiency product divided by the change in annual operating cost (as a result of lower energy consumption) of the product. It represents the number of years that it will take the

customer to recover the increased purchase cost through decreased operating costs. In the calculation of PBP, future costs are not discounted.

Inputs to the LCC and PBP analyses are categorized as follows: (1) inputs for establishing the purchase cost, otherwise known as the total installed cost; and (2) inputs for calculating the operating cost (*i.e.*, energy, maintenance, and repair costs).

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer selling price*: The baseline manufacturer selling price (MSP) is the price charged by the manufacturer to either a wholesaler or customer for product meeting existing minimum efficiency (or baseline) standards. The MSP includes a markup that converts the cost of production (*i.e.*, the manufacturer cost) to a MSP.
- *Standard-level manufacturer selling price increase*: The standard-level MSP is the incremental change in MSP associated with producing product at each of the higher standard levels.
- *Markups and sales tax*: Markups and sales tax are the wholesaler and contractor margins and state and local retail sales taxes associated with converting the MSP to a customer price. The markups and sales tax are described in detail in chapter 6, Markups for Product Price Determination.
- *Installation cost*: Installation cost is the cost to the customer of installing the product. The installation cost represents all costs required to install the product but does not include the marked-up customer product price. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the customer product price plus the installation price.

The primary inputs for calculating the operating cost are:

- *Product energy consumption*: The product energy consumption is the site energy use associated with the use of the CAC, HP, or furnace units to provide space-conditioning to the building. Chapter 7, Building Energy Use Characterization, provides complete details on CAC, HP, and furnace energy use simulations and their results.
- *Energy Prices*: Electricity prices used in the analysis are the price per kilowatt-hour in cents or dollars ($/kWh) paid by each customer for electricity. For CACs and HPs,

electricity prices are determined using marginal residential and commercial prices[a] calculated from electrical tariff information on individual service areas, as determined from utility data on 90 utilities, in 2008$ (but expressed in the analysis in 2009 dollars).[1, 2] For furnaces, electricity, natural gas, liquid petroleum gas (LPG), and fuel oil prices are determined using average monthly energy prices, in 2009$.

- *Electricity, natural gas, and fuel oil price trends*: The Energy Information Administration's (EIA's) *Annual Energy Outlook 2010* (*AEO 2010*) is used to forecast electricity prices into the future.[3] For the results presented in this chapter, DOE used the *AEO 2010* reference case to forecast future electricity prices.
- *Maintenance costs*: The labor and material costs associated with maintaining the operation of the product (*e.g.*, cleaning heat exchanger coils and drain pans, changing air filters).
- *Repair costs*: The labor and material costs associated with repairing or replacing components that have failed.
- *Lifetime*: The age at which the central air conditioner and furnace product is retired from service.
- *Discount rate*: The rate at which future costs are discounted to establish their present value. Figure 8.1.1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP.

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a. DOE developed residential marginal electricity prices from tariffs collected in 2008 from a representative sample of electric utilities throughout the United States. DOE collected over 150 residential tariffs from a sample of about 90 electric utilities. DOE also developed commercial marginal electricity prices from tariffs for those commercial building applications that use residential CAC and CHP equipment. DOE used 260 commercial tariffs collected in 2004 and adjusted the values to a 2008 basis using data in Edison Electric Institute, *EEI Typical Bills and Average Rates Report,* <www.eei.org/products_and_services/descriptions_and_access/typ_bills_report.htm>, and in Regulatory Research Associates, Inc., *Average Regulated Retail Price of Electricity, 2007 & Comparative Historical Data*, 2008, Jersey City, NJ.

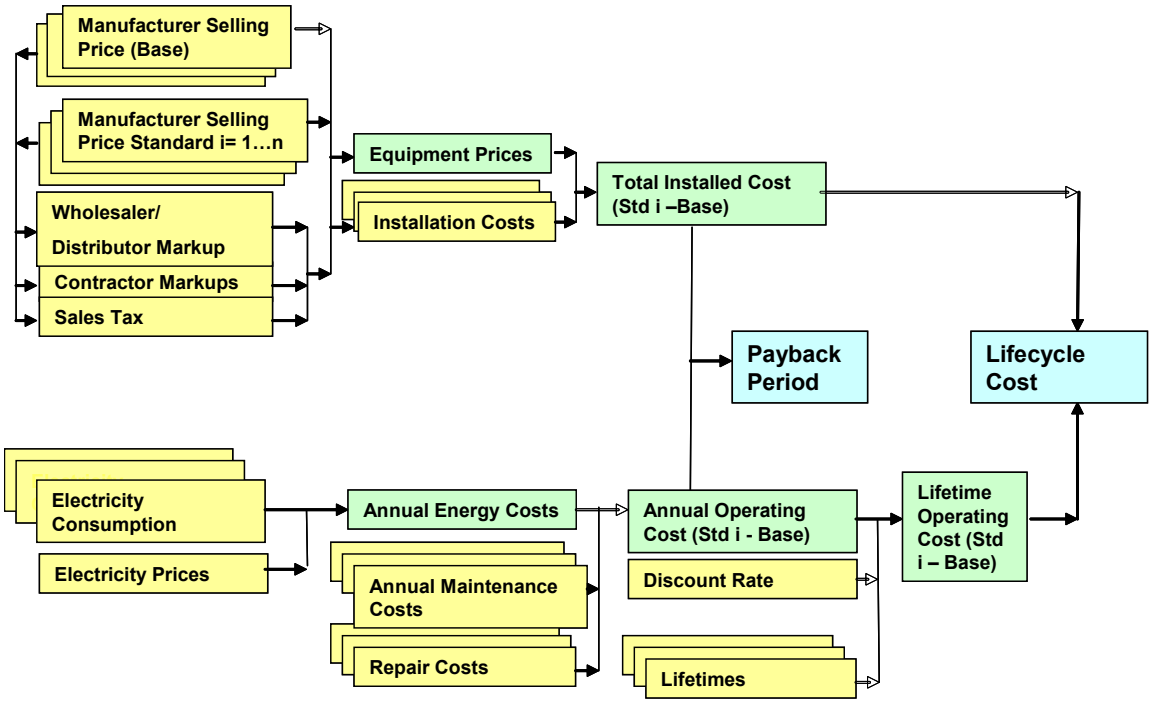

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.1 provides descriptions of the various inputs to the calculation of the LCC and PBP. As noted earlier, most of the inputs are characterized by probability distributions that capture variability in the input variables.

Table 8.1.1 Summary of Inputs and Key Assumptions Used in the LCC and PBP Analyses

Inputs	Description
Affecting Installed Costs	
Product Price	Derived MSP for 2-, 3-, and 5-ton capacity units CAC and HP and for different input capacities for furnaces (from the engineering analysis) and multiplied by wholesaler markups and contractor markups plus sales tax (from markups analysis). Used the probability distribution for the different markups to describe their variability.
Installation Cost	Includes installation labor derived from *RS Means CostWorks 2010* and *RS Means Residential Cost Data 2010*. Overhead and materials costs and profits are assumed to be included in the contractor's markup. Thus, the total installed cost equals the consumer product price (manufacturer cost multiplied by the various markups plus sales tax) plus the installation cost.
Transportation Cost	Shipping cost of units based on volume of the unit and costs per cubic foot, based on a typical 53-foot straight-frame trailer with a storage volume of 4,240 cubic feet.
Affecting Operating Costs	
Annual Energy Use	For CAC and HP, 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 heat pumps, the annual energy consumption is the annual site energy use associated with providing space heating. For households, the annual energy consumption is based on data from the EIA *2005 Residential Energy Consumption Survey* (RECS*)*. For those households surveyed in RECS with a central air conditioner, heat pump, or furnace, the estimated annual energy consumption corresponds to the household's equipment characteristics, specifically its capacity and efficiency. For products used in commercial buildings, the annual energy consumption is determined through computer simulations of a representative small commercial building based on DOE's commercial small-office benchmark building, developed for use as a baseline benchmark for DOE's Net Zero Commercial Building Initiative.[4]
Energy 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). The annual fuel utilization efficiency (AFUE) is the efficiency descriptor for furnaces. Central air conditioner, heat pump, and furnace efficiencies in existing households are primarily based on data from the 2005 RECS. For products used in commercial buildings, all buildings were assumed to have product efficiencies equal to existing minimum efficiency standards (SEER 13). For central air conditioners and heat pumps, 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 building's annual energy consumption. For furnaces, test procedure equations are used to determine the annual energy consumption associated with a particular standard level.
Energy Prices	For residential CAC and HP customers, energy costs were calculated for RECS 2005 households from marginal and average electricity prices in each utility service area in each region, as determined from utility tariff data for 2008. For commercial CAC and HP customers, the analysis used commercial marginal and average electricity price in each utility service area in each region, as determined for 2004, escalated to 2008 prices using data from Edison Electric Institute and Regulatory Research Associates. For residential furnace customers, costs were calculated for RECS 2005 households from monthly average electricity and natural gas, LPG, or fuel oil prices in each census division or four large states. Both residential and commercial prices were escalated by the *AEO 2010* forecasts to estimate the future electricity prices. Escalation was performed separately for residential and commercial heating and cooling at the census division level and aggregated to the larger regions used in the study.
Maintenance Cost	The cost associated with maintaining the operation of the product (*e.g.*, cleaning heat exchanger coils, checking refrigerant charge levels). Costs were chosen from an array of services from a variety of published sources. Annual maintenance cost does not change as a function of MSP, with the exception of oil-fired furnaces at the highest efficiency level.

Repair Cost	Estimated the annualized repair cost for baseline efficiency CAC, HP, or furnace product, based on costs of major repair (compressor or heat exchanger replacement), from a variety of published sources. It is assumed that repair costs would vary in direct proportion with the MSP at higher efficiency levels, because it generally costs more to replace components that are more efficient.
Affecting Present Value of Annual Operating Cost Savings	
Product Lifetime	Used the probability distribution of lifetimes, with mean lifetime for each of four product classes assumed to be 19 years for air conditioning units, 16.3 years for heat pumps, 23.7 years for non-weatherized gas furnaces, 18.8 years for manufactured home furnaces, and 26.6 years for oil-fired furnaces. Based on literature reviews and consultation with industry experts.
Discount Rate	Mean real discount rates ranging from 0 percent to 10.7 percent for various classes of residential customers based on Federal Reserve Board's *Survey of Consumer Finances*. Commercial sector customers are expected to have a mean real discount rate of 6.9% based on a sample of 1,815 companies on the Damodaran Online website. Probability distributions are assumed for the discount rates of both groups of customers.
Date Standards Become Effective	June 30, 2016 (5 years after the publication of the final rule)
Analyzed Efficiency Levels	
Analyzed Efficiency Levels	For CACs and HPs, baseline efficiency levels will follow the estimated market distribution of efficiency levels in 2016 based on a minimum SEER of 13 for new units and from 3 to 15 higher efficiency levels available in four principal product classes and one niche class. For furnaces, the minimum AFUE is 80 for new non-weatherized gas and manufactured home furnaces and 82 for new oil-fired furnaces and from 3 to 4 higher efficiency levels for each product class.

All of the inputs depicted in Figure 8.1.1 and summarized in Table 8.1.1 are discussed in sections 8.2 and 8.3.

8.1.3 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. For CAC and HP, 93% of product applications are assumed to be in residential buildings (households),[5] while all furnace equipment is assumed to be for residential buildings.

For products used in households, the 2005 RECS[6] serves as the basis for determining the representative sample. The 2005 RECS is based on a sample of 4,382 households that were surveyed for information on their housing units, energy consumption and expenditures, stock of energy-consuming appliances, and energy-related behavior. Information was also collected on certain demographic and economic characteristics of household members.

The information collected represents all households nationwide—approximately 111 million. RECS is conducted every 3 years with data collected directly from energy end users. The 2005 RECS is the twelfth survey of residential housing units conducted by the DOE's EIA.

Previous RECS were conducted annually from 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 4,382 households surveyed in the 2005 RECS, 1,854 households representing 25.1% of the housing population have a central air conditioner, 339 households representing 7.7% of the housing population have an electric heat pump,[b] 1,726 households representing 41.0% of the housing population have a gas furnace (non-weatherized or weatherized), 109 representing 2.3% of the housing population have a manufactured home gas furnace, and 150 representing 2.5% of the housing population have an oil-fired furnace. Using the households in RECS that utilize a central air conditioner, heat pump, or furnace, 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. Each RECS household is identified to be within one of the three geographic regions discussed previously in chapter 7 and has an associated household weight representing the number of similar households in the nation.

Of the inputs necessary for the LCC and PBP analysis, there are four inputs (as depicted in Figure 8.1.1) that are based on data from the 2005 RECS: (1) space-conditioning annual energy consumption (RECS-based), (2) product 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 product efficiency, each household in RECS with a central air conditioner, heat pump, or furnace 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 are not uncertain and are, therefore, not expressed with probability distributions. Although those three input variables are not uncertain, they are extremely variable. Due to the large number of households considered in the LCC and PBP analysis (more than 1,850 for central air conditioners, more than 300 for heat pumps, and almost 2,000 for furnaces), the range of annual energy use, average electricity price, and marginal electricity price is quite

[b] The number of households actually used in the central air conditioner and heat pump LCC and PBP analyses were 1,854 and 339, respectively. A small number of 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.

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.

8.1.4 Commercial Building Analysis

Seven percent of residential-type (*i.e.*, single-phase) central air conditioner and heat pump applications are assumed to be in commercial buildings. A small commercial office building was simulated at 237 different locations around the country (corresponding to the Typical Meteorological Year-2 (TMY2) weather stations)[7] to represent commercial applications for CAC and HP units. The results from these simulations were used for the LCC and PBP analysis of commercial buildings, 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 2005 RECS). DOE used population-weighting factors to represent the importance of each climate in each state and in each of the three regions. These weighting factors, in conjunction with the relative weighting between commercial and residential shipments, were used to incorporate the commercial building energy consumption into the overall energy consumption for CAC and HP equipment at each efficiency level. Seventeen locations in Alaska, representing less than 0.2 percent of the national population, were eventually removed from the LCC analysis due to lack of data for electrical pricing and uncertainty about commercial use in these climates.

As with the analysis of residential buildings, four inputs are necessary (as depicted in Figure 8.1.1) from the commercial building analysis in order to perform the LCC and PBP calculations: (1) space-conditioning annual energy consumption, (2) product efficiency, (3) average electricity price, and (4) marginal electricity price. The space-conditioning energy consumption associated with the commercial building in each of the full set of 237 locations simulated were determined through computer modeling performed at Pacific Northwest National Laboratory (PNNL) using the EnergyPlus simulation tool. The procedure for calculating space-conditioning energy consumption relied on the determination of hourly operating loads for each of the 237 buildings.

DOE performed an analysis in which DOE used the EnergyPlus building energy simulation software to simulate the energy consumption of CAC and HP equipment used to satisfy the cooling, supply fan, and, in the case of HP equipment, the electrical heating energy required in a small office building. DOE used an existing small office building model developed for DOE's energy benchmarking task for this analysis. The determination of space-cooling and space-heating loads assumed that a single type of product—in this case a residential-type space-conditioning product—was used to condition the building. DOE simulated the same building as served either by CAC or HP equipment and, for each equipment type, simulated the equipment using four different efficiency levels. These levels were a 13 SEER, 14 SEER, 16 SEER, and a max-tech level for either CAC (SEER 22, based on blower-coil ratings, or SEER 16.5, based on coil-only ratings) or HP (SEER 19.5). Equipment parameters used in the simulation were adjusted to reflect engineering designs corresponding to each efficiency level. The simulated building utilized five individual CAC or HP units. DOE extracted the annual energy

consumption for cooling and fan energy use and HP heating from each unit as well as the equipment capacity from each unit from each simulation run and aggregated these to the whole building level. Using this whole building data, DOE normalized the CAC and HP energy consumption for each location and efficiency level to reflect that of an average 3-ton central air conditioner or central heat pump unit for use in the LCC analysis. To estimate the energy consumption for intermediate efficiency levels between those simulated, DOE linearly interpolated the energy use estimates based on the results for the four simulated efficiencies. A complete description of the commercial energy use calculations is found in chapter 7.

The baseline commercial CAC and HP use developed for the 237 TMY locations (many of which represent climates in portions of more than one state) were associated with relative weighting factors for each TMY location much as the residential analysis uses the representative RECS weights. DOE used population-based weighting factors developed for each TMY climate based on data from the U.S. Geological Survey to represent the importance of each TMY2 climate in each state. The development and documentation of these weighting factors is discussed in chapter 7. Because certain TMY locations represent climates that cover more than one state DOE originally developed weighting factors for a total of 543 TMY-State combinations. Removal of the seventeen Alaskan locations discussed previously resulted in 526 TMY-State combinations, with associated population weights, which then formed the basis of the commercial energy use sample.

The average and marginal electricity prices were developed through a procedure of matching building hourly loads for each of the 526 represented buildings to actual modeled commercial tariffs (including any time-of-use rates) and then calculating customer bills. The methodology for matching commercial building peak demands to modeled tariffs is explained in appendix 8-F. Energy bills are calculated for a market baseline case and standards cases. Average electricity prices are determined by taking the bill for the market baseline case and dividing it by the amount of energy consumed. Marginal electricity prices are determined by taking the bill difference between the market baseline and standard cases (in dollars) and dividing it by the usage difference (in kilowatt-hours) to give a "marginal" rate of $/kWh for that increment.

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 in each region. The above procedure was used to develop space-cooling and space-heating 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 526 commercial buildings observations 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.

8.2 LIFE-CYCLE COST ANALYSIS INPUTS

8.2.1 Definition

Life-cycle cost is the total customer cost over the life of a product, including purchase cost and operating costs (which are composed of energy costs, maintenance costs, and repair costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the product. Life-cycle cost is defined by the following equation:

$$LCC = IC + \sum_{t=1}^{N} OC_t / (1+r)^t \qquad \textbf{Eq. 8.2.1}$$

Where:

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

Although DOE gathered most of its data for the LCC analysis in 2010, DOE expresses all the costs in 2009$. By convention, DOE reports its costs in the years' dollars preceding the year of the analysis. Total installed cost, operating cost, lifetime, and discount rate are discussed in the following sections. In the LCC analysis, the year of product purchase is assumed to be 2016, the effective date of the amended energy conservation standards for central air conditioners and furnaces.

8.2.2 Total Installed Cost Inputs

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

$$IC = EQP + INST \qquad \textbf{Eq. 8.2.2}$$

Where:

EQP =	product price ($) (*i.e.*, customer price for the product only), and
$INST$ =	installation cost or the customer price to install product ($) (*i.e.*, the cost for labor and materials).

The product price is based on the distribution channel through which the customer purchases the product. As discussed in chapter 6, Markups for Product Price Determination, DOE defined one major distribution channel for new units to describe how the product passes from the manufacturer to the customer: the manufacturer sells the product to a wholesaler or distributor, who sells to a mechanical contractor hired by a general contractor. The general contractor purchases and installs the product on behalf of the customer and adds its markup to the mechanical contractor's price. Replacement products follow the same distribution channel, except that there is no general contractor. Instead, the mechanical contractor takes on the general contractor's function.

The remainder of this section provides information about the variables DOE used to calculate the total installed cost for central air conditioner and furnace products. Inputs to determine total installed cost are shown below:

- Baseline manufacturer selling prices ($) (section 8.2.2.2)
- Standard-level manufacturer selling price increases ($) (section 8.2.2.3)
- Transportation costs ($) (section 8.2.2.4)
- Overall markups (section 8.2.2.5)
- Installation costs ($) (section 8.2.2.6)
- Weighted-average total installed costs ($) (section 8.2.2.7)

8.2.2.1 Forecasting Future Product Prices

Examination of historical price data for certain appliances and equipment that have been subject to energy conservation standards indicates that the assumption of constant real prices and costs may, in many cases, overestimate long-term trends in appliance and equipment prices. Economic literature and historical data suggest that the real costs of these products may in fact trend downward over time according to "learning" or "experience" curves. A draft paper, "Using the Experience Curve Approach for Appliance Price Forecasting," posted on the DOE web site at http://www.eere.energy.gov/buildings/appliance_standards, summarizes the data and literature currently available to DOE that is relevant to price forecasts for selected appliances and equipment.

In light of these data and DOE's aim to improve the accuracy and robustness of its analyses, DOE has decided to assess future costs by incorporating learning over time, consistent with the analysis in the available literature. DOE is using this approach to forecast future prices of central air conditioners, heat pumps, and furnaces at the considered efficiency levels.

An extensive literature discusses the "learning" or "experience" curve phenomenon, typically based on observations in the manufacturing sector.[c] In the experience curve method, the real cost of production is related to the cumulative production or "experience" with a product. To explain the empirical relationship, the theory of technology learning is used to substantiate a decline in the cost of producing a given product as firms accumulate experience with the technology. A common functional relationship used to model the evolution of production costs is:

$$Y = aX^{b}$$

Where:

a = an initial price (or cost),
b = a positive constant known as the learning rate parameter,
X = cumulative production, and
Y = the price as a function of cumulative production.

Thus, as experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is known as the learning rate (*LR*), and is given by:

$$LR = 1 - 2^{-b}$$

In typical learning curve formulations, the learning rate parameter is derived using two historical data series: price (or cost) and cumulative production, which is a function of shipments during a long time span.

DOE's derivation of learning rates for central air conditioners, heat pumps, and furnaces, and their application in the LCC and PBP analysis, are described in appendix 8-J.

8.2.2.2 Baseline Manufacturer Selling Price

The baseline MSP is the price charged by manufacturers to either a wholesaler or very large customer for product meeting existing minimum efficiency (or baseline) standards. The MSP includes a markup that converts the cost to manufacture (*i.e.*, the manufacturing cost) to a MSP. DOE developed the baseline MSP through an efficiency level analysis supplemented by certain design-option considerations. Refer to chapter 5, Engineering Analysis, for details. DOE developed MSP for product classes identified in the market and technology assessment analysis, chapter 3 of the TSD.

[c] In addition to the draft paper mentioned above, see Weiss, M., Junginger, H.M., Patel, M.K., and Blok, K. 2010. A Review of Experience Curve Analyses for Energy Demand Technologies. *Technological Forecasting & Social Change*. 77:411-428.

Air Conditioners and Heat Pumps

The LCC and PBP were calculated based on the same set of representative products as given in Table 8.2.1. For this analysis, split-system air conditioners and heat pumps were evaluated at 3 representative capacities: 2-ton (24,000 Btu/hr), 3-ton (36,000 Btu/hr), and 5-ton (60,000 Btu/hr). Single-package systems and small-volume high-velocity systems were evaluated at 3-ton capacities only.

Table 8.2.1 Representative CAC and HP Products Evaluated for the Life-Cycle Cost and Payback Analyses

Product Class	Representative Product Capacities	Description
Split-System AC (Coil-Only)	SS-AC (Coil-Only): 2-, 3- , and 5-Ton	Split-system air conditioners, inside evaporator coil-only (no blower unit purchased)
Split-System AC (Blower-Coil)	SS-AC (Blower-Coil): 2-, 3-, and 5-Ton	Split-system air conditioners, including blower unit (evaporator coil and air handler purchased)
Split-System HP	SS-HP: 2-, 3- ,and 5-Ton	Split-system heat pumps
Single Package AC	SP-AC:3-Ton	Single-package air conditioners
Single Package HP	SP-HP: 3-Ton	Single-package heat pumps
Small-Diameter High-Velocity	SDHV: 3-Ton	Small-diameter duct, high-velocity (SDHV) systems

DOE determined the market baseline with a minimum requirement of 13 SEER[8] as the baseline cooling efficiency levels for CACs and HPs. The minimum efficiency levels specified are detailed in chapter 5, Engineering Analysis. In the case of split-system air conditioners, DOE analyzed options with and without a complete air handler unit, because it is not clear whether a furnace or other fan unit would be purchased at the same time as the inside evaporator coil and outside condensing unit. DOE developed the MSP for the baseline efficiency products as a part of the engineering analysis (see chapter 5 of the TSD); these are shown in Table 8.2.2. Transportation (shipping cost) is also discussed in section 8.2.2.4.

Table 8.2.2 Baseline Manufacturer Selling Price per Unit (CACs and HPs)

Representative Product	Representative Capacity *tons*	SEER (Baseline Efficiency)	Baseline Manufacturer Selling Price*, Excluding Transportation *2009$*	Baseline Manufacturer Selling Price, Including Transportation *2009$*
Split-System A/C (Coil-Only)	2	13.0	662	678
	3	13.0	741	762
	5	13.0	1,033	1,061
Split-System A/C (Blower-Coil)	2	13.0	851	871
	3	13.0	951	976
	5	13.0	1,269	1,305
Split-System -HP	2	13.0	966	992
	3	13.0	1,136	1,165
	5	13.0	1,445	1,482
Single Package A/C	3	13.0	1,093	1,123
Single Package HP	3	13.0	1,347	1,378
SDHV	3	13.0	1,554	1,582

* Baseline MSP is based upon the CAC products using R-410A refrigerant. Shipping not included.

Because air conditioners and heat pumps are commonly sold in situations in which heating and cooling equipment are being considered together, there is some uncertainty in the determination of what assumption should be made concerning any cost and efficiency benefit for a fuel-fired (gas-, oil-, or LPG-fired) furnace. To account for this, the MSP for split-system air conditioners is handled in one of two ways.

In a replacement scenario in which only the outdoor unit and evaporator coil need to be replaced and the coil-only purchase is at SEER values of 14.5 SEER or less, the air-conditioning unit is assumed to be installed in a situation in which an appropriate furnace fan is available to circulate air. For 15-SEER replacements in which the furnace or air handler is not replaced, DOE assumed that half of the units replaced will require an add-on fan kit to supply the multi-speed fan capability required to reach 15 SEER. For 15.5-SEER replacements in which the furnace or air handler is not replaced, DOE assumed that an add-on fan kit always will be required.

In a replacement scenario in which the furnace or air handler is being replaced, DOE assumed that a portion of the cost of furnace replacement is attributable to the air-conditioning requirements of the system. Rather than conduct a complex analysis of the combined furnace and air-conditioning system, DOE assumed that the air-conditioning component of the combined system was equivalent to the cost of an air handler without heating capability. In this case, the cost includes an air handler with a blower and evaporative coil and is called a blower-coil system. The blower-coil configuration also covers all new installations. Systems using a blower-coil configuration can use improvements on the indoor air handler to achieve higher SEER ratings. Systems rated as "coil-only" systems must use improvements on the indoor coil or outdoor condensing unit to achieve higher SEER ratings.

For simplicity, split-system heat pumps always were assumed to be sold with an air handler, due to the need to closely match condensing, evaporative, and air handling capabilities to gain efficiency in a heat pump system. Single-package heat pumps, single-package air conditioners, and SDHVs are sold as complete packages, including condensing unit, evaporator unit, and blower.

Furnaces

DOE developed the baseline manufacturer costs for furnaces as described in chapter 5, Engineering Analysis. The baseline manufacturer costs are shown in Table 8.2.3. The cost of adding two-stage controls is $32 for non-weatherized gas furnaces.

Table 8.2.3 Baseline Manufacturer Production Cost per Unit (Furnaces)

Product Class	Input Capacity *kBtu/h*	AFUE	Motor Type	Manufacturer Production Cost *2009$*
Non-Weatherized Gas Furnaces	60	80%	PSC	259
	80			266
	100			282
	120			305
	60		ECM	325
	80			334
	100			365
	120			388
Manufactured Home Gas Furnaces	80	80%	PSC	297
			ECM	365
Oil-Fired Furnaces	105	82%	PSC	809
			ECM	899

kBtu/h = kilo British thermal units per hour
PSC = permanent split capacitor
ECM = electronically commutated motor

8.2.2.3 Standard-Compliant Manufacturer Selling Price Increases

The standard-compliant MSP increase is the change in MSP associated with producing product at higher efficiency levels. DOE developed MSP increases associated with increases in product efficiency levels through a combination of efficiency level and design-option analyses in the engineering analysis (see chapter 5 of the TSD). MSP increases as a function of product efficiency were developed for each of the representative product categories in the engineering analysis as well.

Air Conditioners and Heat Pumps

Table 8.2.4 and Table 8.2.5 summarize the estimated MSP for CAC and HP efficiency levels considered in the LCC and PBP analyses.

Table 8.2.4 SEER Standard-Compliant Manufacturer Selling Prices per Unit, Split-System CAC and HP Products Including Transportation

Efficiency Level *SEER*	MSP for Representative Standard-Compliant Products *2009$*								
	Split-System AC (Coil-Only)			Split-System AC (Blower-Coil)			Split-System HP		
	2T	3T	5T	2T	3T	5T	2T	3T	5T
13.5	713	796	1,108	906	1,017	1,356	1,028	1,219	1,540
14	752	839	1,166	942	1,059	1,409	1,065	1,272	1,600
14.5	792	889	1,234	976	1,100	1,467	1,106	1,327	1,664
15	838	949	1,315	1,010	1,141	1,525	1,146	1,381	1,728
15.5	886	1,018	1,404	1,047	1,185	1,587	1,185	1,432	1,797
16	937	1,097	1,503	1,083	1,230	1,651	1,241	1,507	1,901
16.5	994	1,184	NA	1,119	1,276	1,717	1,282	1,560	1,979
17	1,054	1,282	NA	1,156	1,323	1,786	1,322	1,614	2,057
18	1,184	NA	NA	1,235	1,420	1,934	1,406	1,722	2,236
19	NA	NA	NA	1,313	1,522	NA	1,493	1,830	NA
20	NA	NA	NA	1,393	1,629	NA	1,580	1,956	NA
21	NA	NA	NA	1,477	1,744	NA	1,670	2,079	NA
22	NA	NA	NA	1,562	1,864	NA	1,763	NA	NA
23	NA	NA	NA	1,649	NA	NA	NA	NA	NA
24.5	NA	NA	NA	1,783	NA	NA	NA	NA	NA

Table 8.2.5 SEER Standard-Compliant Manufacturer Selling Prices per Unit, Single-Package and Niche CAC and HP Products, Including Transportation

Efficiency Level *SEER*	MSP for Representative Standard-Compliant Products *2009$*		
	Single Package AC	Single Package HP	Small Diameter High Velocity
	3T	3T	3T
13.5	1,195	1,428	1,667
14	1,250	1,517	1,755
14.5	1,344	1,630	1,848
15	1,437	1,744	NA
15.5	1,542	1,872	NA
16	1,649	2,044	NA
16.5	1,834	2,219	NA
17	NA	NA	NA
18	NA	NA	NA
19	NA	NA	NA
20	NA	NA	NA
21	NA	NA	NA
22	NA	NA	NA
23	NA	NA	NA
24.5	NA	NA	NA

Furnaces

DOE developed manufacturer cost increases associated with increases in product energy efficiency levels as described in chapter 5, Engineering Analysis. Table 8.2.6 through Table 8.2.8 present the standard-level manufacturer cost increases for the three product classes. Transportation costs are not included in these tables and do not increase with increased efficiency. The incremental cost of permanent split capacitor (PSC) blower motors and electronically commutated motors (ECMs) are the same.

Table 8.2.6 Standard-Level Manufacturer Cost Increases (Non-Weatherized Gas Furnace)
Standard-Level Manufacturer Cost Increases (Non-Weatherized Gas Furnace)

Energy Efficiency Level	Manufacturer Cost Increase *2009$*			
	60 kBtu/h	80 kBtu/h	100 kBtu/h	120 kBtu/h
1	108	112	120	130
2	138	145	159	168
3	194	216	245	263
4	323	329	348	381

Table 8.2.7 Standard-Level Manufacturer Cost Increases (Manufactured Home Gas Furnace)

Energy Efficiency Level	Manufacturer Cost Increase *2009$*
	80 kBtu/h
1	116
2	150
3	223

Table 8.2.8 Standard-Level Manufacturer Cost Increases (Oil-Fired Furnace)

Energy Efficiency Level	Manufacturer Cost Increase *2009$*
	105 kBtu/h
1	8
2	16
3	26
4	279

8.2.2.4 Transportation Cost

The MSP of CAC, HP, and furnace products derived above is considered to be a price that includes the cost of shipping the product to the distributor. Based on the physical attributes of the CAC, HP, and furnace products (product dimensions and shipping) and the requirements for maximum weight and dimensions of a standard 53-ft trailer, DOE determined that manufacturers were likely to run out of volume inside the shipping trailer before reaching the maximum weight for a truckload. The additional cost of transporting a CAC, HP, or furnace unit to the local distribution point depends mainly on its volume, which was calculated for each

product class at each efficiency level. Shipping cost was calculated as a function of its volume for both CAC and HP. DOE first calculated the cost per cubic foot of space on a trailer, based on a cost of $2,500 per shipping load and the standard dimensions of a 53-ft trailer. Chapter 5 of the technical support document (TSD) contains additional details about DOE's shipping cost assumptions and DOE's shipping cost estimates.

Air Conditioners and Heat Pumps

Table 8.2.9 and Table 8.2.10 show the estimated transportation costs of standard-compliant equipment.

Table 8.2.9 Transportation Costs of SEER Standard-Compliant Products, Split-System CAC and HP Products

Efficiency Level ***SEER***	**Transportation Costs for Representative Standard-Compliant Products** ***2009$***								
	Split-system AC (Coil-Only)			**Split-System AC (Blower-Coil)**			**Split-System HP**		
	2T	3T	5T	2T	3T	5T	2T	3T	5T
13.5	18.07	22.62	28.97	21.64	26.95	35.89	25.60	29.58	37.60
14	20.30	24.83	29.50	23.66	29.11	36.16	25.45	30.54	38.42
14.5	20.04	24.16	30.06	23.97	29.55	37.93	28.60	33.50	39.74
15	23.30	25.40	33.08	23.50	28.81	38.20	31.12	35.40	39.58
15.5	23.91	26.73	33.38	25.19	29.76	39.44	32.09	34.70	40.14
16	24.52	28.10	33.65	27.00	30.75	40.69	33.07	34.09	40.71
16.5	26.59	28.90	NA	27.38	32.02	40.69	33.97	35.40	41.44
17	28.67	30.74	NA	27.74	33.35	40.69	34.86	36.72	42.17
18	31.41	NA	NA	33.48	35.23	41.82	36.48	39.52	42.90
19	NA	NA	NA	35.70	37.03	NA	40.27	41.64	NA
20	NA	NA	NA	38.51	38.91	NA	41.15	42.19	NA
21	NA	NA	NA	42.09	42.26	NA	41.59	42.91	NA
22	NA	NA	NA	45.01	44.71	NA	41.82	NA	NA
23	NA	NA	NA	46.36	NA	NA	NA	NA	NA
24.5	NA	NA	NA	46.75	NA	NA	NA	NA	NA

Table 8.2.10 Shipping Costs of SEER Standard-Compliant Products, Split-System Products, Single-package, and Niche CAC and HP Products

Efficiency Level *SEER*	Transportation Costs for Representative Standard-Compliant Products *2009$*		
	Single Package AC	Single Package HP	Small Diameter High Velocity AC
	3T	3T	3T
13.5	32.13	33.38	31.76
14	33.89	34.91	33.93
14.5	35.69	36.48	35.81
15	37.55	38.08	NA
15.5	39.47	39.72	NA
16	41.44	41.39	NA
16.5	43.88	42.75	NA
17	NA	NA	NA
18	NA	NA	NA
19	NA	NA	NA
20	NA	NA	NA
21	NA	NA	NA
22	NA	NA	NA
23	NA	NA	NA
24.5	NA	NA	NA

Furnaces

Table 8.2.11 shows the estimated transportation costs of standard-compliant equipment. Shipping costs do not vary by AFUE or motor type.

Table 8.2.11 Shipping Costs for Furnaces

Product Class	Input Capacity *kBtu/h*	Shipping Cost Estimate *2009$*
Non-Weatherized Gas Furnaces	60	10
	80	10
	100	12
	120	14
Manufactured Home Gas Furnaces	80	19
Oil-Fired Furnaces	105	20

8.2.2.5 Overall Markup

For a given distribution channel, the overall markup is the value determined by multiplying all the associated markups and the applicable sales tax together to arrive at a single overall distribution chain markup value. The overall markup is multiplied times the baseline or

standard-compliant MSP (including transportation) to arrive at the price paid by the customer. Because there are baseline and incremental markups associated with the wholesaler and mechanical contractor, the overall markup is also divided into a baseline markup (*i.e.*, a markup used to convert the baseline manufacturer price into a customer price) and an incremental markup (*i.e.*, a markup used to convert a standard-compliant MSP increase due to an efficiency increase into an incremental customer price). Markups can differ depending on whether the product is being purchased for a new construction installation or is being purchased to replace an existing product. DOE developed the overall baseline markups and incremental markups for both new construction and replacement applications as a part of the markups analysis (chapter 6 of the TSD).

Based on the percentages of the market attributed to each distribution channel in chapter 6, Table 8.2.12 and Table 8.2.13 display the weighted-average overall markups and their associated components for the baseline and incremental markups, respectively. DOE used the appropriate baseline markup times the baseline and incremental MSP (including transportation) to obtain estimates of the retail price of the CAC and HP equipment. The calculations are demonstrated in section 8.2.2.6.

Table 8.2.12 Overall National Average Baseline Markup Factors

Factor	New Construction Application	Replacement Application
Wholesale Markup	1.362	1.362
Mechanical Contractor Markup	1.280	1.380
General Contractor Markup	1.480	NA*
Sales Tax	1.073	1.073
Total Markup	2.767	2.016

* General contractors do not appear in the replacements distribution channel

Table 8.2.13 Overall National Average Incremental Markup Factors

Factor	New Construction Application	Replacement Application
Wholesale Markup	1.091	1.091
Mechanical Contractor Markup	1.024	1.104
General Contractor Markup	1.347	NA*
Sales Tax	1.073	1.073
Total Markup	1.614	1.292

* General contractors do not appear in the replacements distribution channel

8.2.2.6 Installation Cost

The installation cost is the price to the consumer of labor and materials (other than the cost of the actual product) needed to install the central air conditioner or furnace product.

Central Air Conditioner and Heat Pump

DOE derived installation cost for CAC and HP product from data in the *RS Means Residential Cost Data 2009*[9] and *RS Means CostWorks 2010.*[10]

RS Means Residential Cost Data provides estimates on the person-hours required to install CAC and HP products, labor rates, and costs associated with the type of crew required to install the products. Generally speaking, installation involves movement into the building, installation or setting of product (including sleeve), connecting to power supply, filling/flushing/cleaning/touchup, startup and running adjustments, training the owner's representative, and warranty and call-back service. DOE calculated the installation cost by building up the labor costs for installing the components of the system types discussed in the engineering analysis, chapter 5, because materials costs, overheads, and profits were assumed to be captured in the contractor markups. Labor rates vary significantly from region to region of the country, and the *RS Means* data provide the necessary information to capture this regional variability. *RS Means CostWorks* provides cost indices that reflect the labor rates for 295 cities in the United States. Cities in all 50 states and the District of Columbia are identified in the *RS Means* data and most states are represented by more than one city. DOE used the city indices to develop population weighted averages for each state and the District of Columbia. DOE incorporated the state indices into the analysis to capture place-to-place variation in installation cost.

Table 8.2.14 summarizes the nationally representative installation costs based on person-hours and labor rates associated with the installation of CAC and HP products as presented in *RS Means*. DOE assumed that these installation costs remain fixed regardless of efficiency level (a "flat" installation cost scenario). DOE's LCC spreadsheet initially allowed for an alternative scenario—that the installation cost increases with higher efficiency levels—and this alternative was implemented in the LCC spreadsheet by providing for an installation price that varies in proportion to increased manufacturer cost above the baseline efficiency level. However, DOE discussed installation costs with a small sample of installers and did not find a basis for installation costs increasing with efficiency or capacity of system components covered in this rulemaking. DOE therefore assumed that installation costs varied by region but not by efficiency level.

Table 8.2.14 Installation Costs for Baseline CAC and HP Products (SEER 13)

MSP for Representative Standard-Compliant Products *2009$*					
Split-System AC (Coil-Only)	**Split-system AC (Blower-Coil)**	**Split-system HP**	**Single Package AC**	**Single Package HP**	**Small-Diameter High Velocity**
508	511	561	528	403	511

Table 8.2.15 summarizes the cost indices for installations in each of the 50 states, plus the District of Columbia, that were used to vary the nationally representative installation costs in Table 8.2.14. To arrive at an average index for each state, DOE weighted the city indices in each

state by their population within each state. Because city-level population estimates were not available for 2009, DOE used estimated city population weights for the year 2008 from the U.S. Census Bureau[11] to calculate a weighted-average index for each state from the *RS Means CostWorks* data for 2010. Weighted averages and estimates at the regional and national level were computed using 2009 state population weights from the U.S. Census Bureau.[12]

Table 8.2.15 Installation Cost Indices (National Average Value = 100.0)

State	Index	State	Index	State	Index
Alabama	59.2	Kentucky	82.6	North Dakota	59.4
Alaska	111.0	Louisiana	61.5	Ohio	98.8
Arizona	77.9	Maine	71.2	Oklahoma	59.3
Arkansas	57.4	Maryland	95.7	Oregon	105.3
California	129.7	Massachusetts	129.5	Pennsylvania	131.2
Colorado	82.6	Michigan	113.2	Rhode Island	121.7
Connecticut	123.1	Minnesota	127.3	South Carolina	41.8
Delaware	126.3	Mississippi	63.6	South Dakota	48.2
Dist. Of Columbia	101.6	Missouri	106.4	Tennessee	77.3
Florida	68.6	Montana	75.1	Texas	65.0
Georgia	75.0	Nebraska	82.2	Utah	74.5
Hawaii	116.8	Nevada	111.0	Vermont	71.5
Idaho	71.0	New Hampshire	93.9	Virginia	75.2
Illinois	142.5	New Jersey	139.6	Washington	107.7
Indiana	89.5	New Mexico	77.2	West Virginia	93.6
Iowa	75.2	New York	170.0	Wisconsin	104.2
Kansas	69.8	North Carolina	42.0	Wyoming	61.5

Furnaces

The installation cost is the cost to the consumer of installing the furnace. The cost of installation covers all labor and material costs associated with the replacement of an existing furnace or the installation of a furnace in a new home, as well as delivery of the new furnace, removal of the existing furnace, and any applicable permit fees. Higher efficiency furnaces may require additional installation costs. DOE's analysis of installation costs accounts for regional differences in labor costs and estimated specific installation costs for each sample household based on building characteristics given in the 2005 RECS.

DOE estimated installation costs at each considered efficiency level using a variety of sources, including *RS Means Residential Cost Data 2010, RS Means CostWorks 2010*, *RS Means Mechanical Cost Data 2010,* manufacturer literature, and information from expert consultants.

DOE gave separate consideration to the cost of installing a condensing gas furnace in replacement cases and in new homes.DOE conducted a detailed analysis of installation costs when a non-condensing gas furnace is replaced with a condensing gas furnace, with particular attention to venting issues in replacement applications. The installation cost depends on the furnace installation location and DOE used information from 2005 RECS to assign the location of the furnace in each of the sample homes.

For non-weatherized gas furnaces, DOE estimated basic installation costs that are applicable to both replacement and new home installations. These costs, which apply to both condensing and non-condensing gas furnaces, include putting in place and setting up the furnace, gas piping, ductwork, electrical hookup for the thermostat, permit, removal or disposal fees, and, where applicable, additional labor hours for an attic installation. Table 8.2.16 shows the average basic installation cost for replacement installations and Table 8.2.17 shows the average basic installation cost for new construction installations.

For *replacement installations*, DOE included a number of additional costs ("adders") for a fraction of the sample households. These adders apply to both non-condensing and condensing non-weatherized gas furnaces. For non-condensing furnaces, these additional costs included updating flue vent connectors, vent resizing, and chimney relining. For condensing furnaces, these additional costs included adding a new flue vent (PVC), combustion air vent for direct vent installations (PVC), concealing vent pipes for indoor installations, addressing an orphaned water heater (by updating flue vent connectors, vent resizing, or chimney relining), and condensate removal. Freeze protection is accounted for in the cost of condensate removal.

Table 8.2.16 shows the fraction of the impacted replacement installations and the average cost for each of the adders. The derivation of the fraction of impacted installations as well as the derivation of the costs are described in appendix 8-B.

Table 8.2.16 Additional Installation Costs for Non-Weatherized Gas Furnaces in Replacement Installations

Installation Cost Adder	Criteria	Installations Impacted *%*	Average Cost *2009$*	Total Cost *2009$*
Non-Condensing Furnaces				
Basic Installation	All Installations	100	690	690
Flue Vent Connectors	75% of natural draft vent systems	4	199	8
Chimney Relining	100% of unlined chimneys	13	681	87
Vent Resizing	10% of natural draft vent systems	1	576	4
			TOTAL	**$789**
Condensing Furnaces				
Basic Installations	100% of installations	100	690	690
New Flue Venting (PVC)	All Installations	100	306	306
Combustion Air Venting (PVC)	62% of installations	62	301	186
Concealing Vent Pipes	50% of indoor horizontal vented	5	302	15
Orphaned Water Heater	Chimney Relining & Resizing	18	501	89
Condensate Removal	100% of installations	100	71	71
			TOTAL	**$1,357**

DOE also included installation adders for *new construction* installations. For non-condensing furnaces, a new flue vent (metal) is the only adder. For condensing gas furnaces, the adders include new flue vent (PVC), combustion air vent for direct vent installations (PVC), accounting for a commonly vented water heater, and condensate removal. Table 8.2.17 shows the estimated fraction of new home installations impacted and the average cost for each of the adders. For details, see appendix 8-B.

Table 8.2.17 Additional Installation Costs for Non-Weatherized Gas Furnaces in New Construction Applications

Installation Cost Adder	Criteria	Installations Impacted *%*	Average Cost *2009$*	Total Cost *2009$*
Non-Condensing Furnaces				
Basic Installation	All Installations	100	509	509
New Flue Vent	All Installations	100	1,036	1036
Common Venting credit	½ common venting cost is credited	48	-405	-195
			TOTAL	**$1,350**
Condensing Furnaces				
Basic Installations	100% of installations	100	509	509
New Flue Venting (PVC)	All Installations	100	247	247
Combustion Air Venting (PVC)	60% of installations	60	239	144
Common Venting Adder	½ of common venting cost is added	48	405	195
Condensate Removal	100% of installations	100	13	13
			TOTAL	**$1,108**

For *manufactured home gas furnaces* DOE included similar basic installation costs as described above for non-weatherized gas furnaces. DOE also included costs for venting and for condensate removal including freeze protection.. In addition, DOE considered the cost of dealing with space constraints that could be encountered when a condensing furnace is installed.

For oil-fired furnaces DOE included similar basic installation costs as for non-weatherized gas furnaces. DOE also included costs for venting (including stainless steel vent for installations at 83%–85% AFUE) and condensate removal. In addition, DOE assumed that condensing oil-fired furnaces require two additional labor hours to tune up the combustion system.

For further details on installation costs for non-weatherized gas furnaces, manufactured home gas furnaces and oil-fired furnaces, see appendix 8-B.

Total installation cost varies by new construction and replacement markets. The fractions of installations at each market for the three product classes are developed as part of the shipments model described in Chapter 9. For the LCC analysis DOE uses the values derived for 2016. Table 8.2.18 shows the fractions of installations for each market as used in the LCC analysis.

Table 8.2.18 Fraction of Shipments in New Construction and Replacement Applications

Heating Product	Share of Replacement Applications *%*	Share of New Construction Applications *%*
Non-Weatherized Gas Furnace	75	25
Manufactured Home Gas Furnace	50	50
Oil-Fired Furnace	90	10

Table 8.2.19 through Table 8.2.21 show the results for the total installation cost for each furnace product class by region for both, the replacement and new construction market.

Table 8.2.19 Installation Costs by Region and Construction Type - Non-Weatherized Gas Furnaces

Region	Energy Efficiency Level, AFUE	Replacement *2009$*		New Construction *2009$*		All *2009$*	
		Average	Incr.	Average	Incr.	Average	Incr.
National	80%, baseline	789		1,350		928	
	90%	1,357	567	1,108	-242	1,295	367
	92%	1,357	567	1,108	-242	1,295	367
	95%	1,357	567	1,108	-242	1,295	367
	98%	1,367	577	1,133	-217	1,309	381
North	80%, baseline	884		1,458		1,022	
	90%	1,457	573	1,227	-231	1,402	379
	92%	1,457	573	1,227	-231	1,402	379
	95%	1,457	573	1,227	-231	1,402	379
	98%	1,467	583	1,254	-204	1,416	394
South	80%, baseline	642		1,198		785	
	90%	1,202	559	940	-258	1,134	349
	92%	1,202	559	940	-258	1,134	349
	95%	1,202	559	940	-258	1,134	349
	98%	1,211	569	962	-235	1,147	361

Table 8.2.20 Installation Costs by Region and Construction Type - Manufactured Home Gas Furnaces

Region	Energy Efficiency Level, AFUE	Replacement *2009$*		New Construction *2009$*		All *2009$*	
		Average	Incr.	Average	Incr.	Average	Incr.
National	80%, baseline	597		678		637	
	90%	1,158	561	881	203	1,019	381
	92%	1,354	758	959	281	1,156	518
	96%	1,559	962	1,041	363	1,299	661
North	80%, baseline	658		737		698	
	90%	1,246	589	946	209	1,094	397
	92%	1,441	783	1,025	289	1,231	533
	96%	1,648	991	1,106	369	1,374	676
South	80%, baseline	540		621		581	
	90%	1,075	535	818	196	947	366
	92%	1,273	733	895	274	1,085	504
	96%	1,476	936	978	356	1,227	647

Table 8.2.21 Installation Costs by Region and Construction Type - Oil-Fired Furnaces

Region	Energy Efficiency Level, AFUE	Replacement *2009$*		New Construction *2009$*		All *2009$*	
		Average	Incr.	Average	Incr.	Average	Incr.
National	82%, baseline	774		1,889		880	
	83%	909	135	2,099	210	1,015	135
	84%	1,166	392	2,056	167	1,240	360
	85%	1,470	695	2,008	119	1,447	567
	97%	2,184	1,409	1,540	(349)	2,211	1,330

8.2.2.7 Weighted-Average Total Installed Cost

As presented in above, the total installed cost is the sum of the product price and the installation cost. DOE derived the consumer product price for any given efficiency level by taking the product of the baseline MSP and the baseline markup index (including the sales tax) and adding to it the product of the incremental MSP and the incremental markup index (including the sales tax). MSPs, markups, and the sales tax all can take on a variety of values, depending on location, so the resulting total installed cost for a particular efficiency level will not be a single-point value, but rather a distribution of values.

Central Air Conditioners and Heat Pumps

The baseline MSP and the standard-compliant MSP increases are the starting points for determining the total installed cost (values are taken directly from Table 8.2.2, Table 8.2.4, and Table 8.2.5). DOE used the baseline and incremental markups and installation costs to convert the MSPs into total installed costs. Both the percentage retail markups and the percentage installation cost may change with the efficiency level. As an example, the weighted average costs for a 3-ton split-system air conditioner product category are presented for the baseline level. Table 8.2.22 summarizes the weighted-average costs and markups necessary for determining the weighted-average baseline and standard-compliant total installed costs for a new split-system air conditioner coil-only unit.

Table 8.2.22 Costs and Markups for Determination of Weighted-Average Total Installed Costs for a New 3-Ton Split-System A/C Blower-Coil Unit (Efficiency Level 5: SEER 15)

Variable	SEER Weighted Average Value			
	National Average	Hot-Humid	Hot-Dry	Rest of Country
Baseline Manufacturer Selling Price, Including Transportation (SEER 13)	$761.60	$761.60	$761.60	$761.60
Standard-compliant Manufacturer selling price Increase (Efficiency Level 5—SEER 15)	$187.61	$187.61	$187.61	$187.61
Average Overall Baseline Markup (Regional)	2.767	2.711	3.897	2.776
Average Overall Incremental Markup (Regional)	1.614	1.581	2.098	1.619
Installation Cost	$508	$508	$508	$508
Installation Cost Factor – Regional	1.000	0.677	1.194	1.185

To illustrate the derivation of the weighted-average total installed cost shown in Table 8.2.22, DOE presents the calculations for the baseline efficiency (Eq. 8.2.3) and a higher efficiency split-system blower-coil 3-ton air conditioner unit at SEER 15 (Level 5) (Eq. 8.2.4). For baseline products, the calculation of the hot-humid regional average total installed cost is as follows:

$$IC_{BASE\ SS\text{-}AC\text{-}3T} = EQP_{BASE\text{-}SS\text{-}AC\text{-}3T} + INST_{BASE\text{-}SS\text{-}AC\text{-}3T} \times INSTNDEX \quad \textbf{Eq. 8.2.3}$$

$$= MSP_{BASE\text{-}SS\text{-}AC\text{-}3T} \times MU_{BASE\text{-}SS\text{-}AC\text{-}3T} + INST_{BASE\text{-}SS\text{-}AC\text{-}3T} \times INSTNDEX$$

$$= \$761.60 \times 2.711 + \$508 \times 0.677$$

$$= \$2{,}064.70 + \$343.92$$

$$= \$2{,}408.62.$$

Where:

IC = total installed cost ($),
EQP = product price ($),
MSP = manufacturer selling price ($),
MU = overall baseline markup,
INST = installation cost or the customer price to install product ($), and
INSTINDEX = location dependent installation cost index, approximately 1.0 at a national average.

In this specific example, *MSP* is the national average baseline MSP for the split-system blower-coil central air conditioner product class and *MU* is the overall baseline markup factor. The calculation of the higher efficiency (efficiency level 5-SEER 15) total installed cost includes the use of a MSP adder. In addition, DOE derived an incremental markup.

Based on incremental product price changes, the derivation of the efficiency level 5 total installed cost is based on determining the change in product price over the baseline product price. The manufacturer price increment for higher efficiency product is multiplied by the incremental markup.

DOE calculated the efficiency level 5 total installed cost ($IC_{SS\text{-}AC\text{-}3T\ Level\ 5}$) as follows:

$$IC_{SS\text{-}AC\text{-}3T\ Level5} = (EQP_{BASE\text{-}SS\text{-}AC\text{-}3T} + \Delta EQP_{SS\text{-}AC\text{-}3T\ Level\ 5}) + INST_{SS\text{-}AC\text{-}3T\ Level\ 5} \times INSTINDEX \quad \textbf{Eq. 8.2.4}$$

$$= (MSP_{BASE\text{-}SS\text{-}AC\text{-}3T} \times MU_{BASE\text{-}SS\text{-}AC\text{-}3T}) + (\Delta MSP_{SS\text{-}AC\text{-}3T\ Level\ 5} \times MU_{SS\text{-}AC\text{-}3T\ Level\ 5}) + INST_{SS\text{-}AC\text{-}3T\ Level\ 5} \times ISTINDEX$$

$$= \$761.60 \times 2.711 + \$187.61 \times 1.581 + \$508 \times 0.677$$

$$= \$2{,}705.22$$

Where:

ΔEQP = increase in product price ($),
ΔMFG = increase in manufacturer price ($), and
MU = markup factor (base or incremental, as shown in Table 8.2.12 and Table 8.2.13, respectively).

Table 8.2.23 presents the shipments-weighted average product price, installation costs, and total installed costs for the representative product split-system air conditioner (Coil-Only) at the baseline level and at each efficiency level examined. Table 8.2.24 through Table 8.2.28 present these data for the other product classes.

Table 8.2.23 Shipments-Weighted Product Price, Installation Cost, and Total Installed Costs for Split-System CAC (Coil-Only)*

Efficiency Level *SEER*	Product Price (Including Markups) *2009$*	Installation Cost *2009$*	Total Installed Cost *2009$*
National Average			
13	1,584	442	2,026
13.5	1,632	442	2,074
14	1,688	442	2,130
14.5	1,751	442	2,193
15	2,243	512	2,755
15.5	2,742	582	3,324
16	2,834	582	3,416
16.5	2,915	582	3,497
17	3,004	582	3,586
18	3,073	582	3,655
Hot-Humid Region			
13	1,501	333	1,834
13.5	1,546	333	1,880
14	1,600	333	1,934

14.5	1,660	333	1,993
15	2,129	386	2,515
15.5	2,605	439	3,044
16	2,691	439	3,130
16.5	2,769	439	3,208
17	2,854	439	3,293
18	2,926	439	3,365
Hot-Dry Region			
13	1,976	607	2,582
13.5	2,036	607	2,642
14	2,106	607	2,713
14.5	2,184	607	2,791
15	2,807	703	3,510
15.5	3,439	799	4,238
16	3,552	799	4,351
16.5	3,656	799	4,455
17	3,771	799	4,570
18	3,874	799	4,673
Rest of Country			
13	1,586	541	2,127
13.5	1,633	541	2,175
14	1,690	541	2,231
14.5	1,753	541	2,295
15	2,237	627	2,864
15.5	2,728	713	3,440
16	2,821	713	3,534
16.5	2,898	713	3,611
17	2,984	713	3,696
18	3,040	713	3,753

* Details may not add to total due to rounding.

Table 8.2.24 Shipments-Weighted Product Price, Installation Cost, and Total Installed Costs for Split-System CAC (Blower-Coil)*

Efficiency Level ***SEER***	**Product Price (Including Markups)** ***2009$***	**Installation Cost** ***2009$***	**Total Installed Cost** ***2009$***
National Average			
13	2,570	445	3,015
13.5	2,633	445	3,078
14	2,698	445	3,142
14.5	2,761	445	3,206
15	2,825	445	3,269
15.5	2,893	445	3,337
16	2,962	445	3,407

16.5	3,032	445	3,477
17	3,104	445	3,549
18	3,256	445	3,701
19	3,379	445	3,824
20	3,508	445	3,953
21	3,645	445	4,089
22	3,787	445	4,231
23	3,838	445	4,283
24.5	3,918	445	4,362
Hot-Humid Region			
13	2,438	335	2,774
13.5	2,498	335	2,833
14	2,559	335	2,894
14.5	2,619	335	2,955
15	2,679	335	3,015
15.5	2,743	335	3,079
16	2,809	335	3,145
16.5	2,875	335	3,211
17	2,943	335	3,279
18	3,087	335	3,422
19	3,206	335	3,541
20	3,330	335	3,666
21	3,462	335	3,797
22	3,598	335	3,933
23	3,651	335	3,986
24.5	3,733	335	4,069
Hot-Dry Region			
13	3,214	610	3,825
13.5	3,293	610	3,903
14	3,374	610	3,984
14.5	3,453	610	4,063
15	3,532	610	4,142
15.5	3,616	610	4,226
16	3,703	610	4,313
16.5	3,789	610	4,399
17	3,878	610	4,488
18	4,067	610	4,677
19	4,227	610	4,837
20	4,394	610	5,004
21	4,571	610	5,182
22	4,755	610	5,365
23	4,831	610	5,442

24.5	4,949	610	5,559
Rest of Country			
13	2,565	545	3,110
13.5	2,627	545	3,172
14	2,692	545	3,236
14.5	2,755	545	3,300
15	2,819	545	3,364
15.5	2,887	545	3,432
16	2,957	545	3,502
16.5	3,028	545	3,572
17	3,100	545	3,645
18	3,254	545	3,798
19	3,370	545	3,915
20	3,493	545	4,038
21	3,622	545	4,167
22	3,757	545	4,302
23	3,800	545	4,344
24.5	3,865	545	4,410

* Details may not add to total due to rounding.

Table 8.2.25 Shipments-Weighted Product Price, Installation Cost, and Total Installed Costs for Split-System HP*

Efficiency Level ***SEER***	**Product Price (Including Markups)** ***2009$***	**Installation Cost** ***2009$***	**Total Installed Cost** ***2009$***
National Average			
13	2,499	435	2,934
13.5	2,564	435	2,999
14	2,630	435	3,065
14.5	2,700	435	3,135
15	2,812	442	3,254
15.5	2,923	449	3,372
16	3,022	449	3,471
16.5	3,097	449	3,546
17	3,172	449	3,621
18	3,321	449	3,770
19	3,426	449	3,874
20	3,540	449	3,988
21	3,653	449	4,102
22	3,701	449	4,149
Hot-Humid Region			
13	2,439	364	2,804

13.5	2,503	364	2,867
14	2,567	364	2,932
14.5	2,635	364	3,000
15	2,744	370	3,114
15.5	2,851	375	3,226
16	2,948	375	3,323
16.5	3,021	375	3,396
17	3,095	375	3,470
18	3,242	375	3,617
19	3,343	375	3,718
20	3,454	375	3,829
21	3,565	375	3,940
22	3,608	375	3,983
Hot-Dry Region			
13	3,145	663	3,808
13.5	3,227	663	3,890
14	3,310	663	3,973
14.5	3,398	663	4,061
15	3,539	673	4,212
15.5	3,679	682	4,361
16	3,801	682	4,483
16.5	3,893	682	4,575
17	3,985	682	4,667
18	4,169	682	4,851
19	4,316	682	4,998
20	4,476	682	5,158
21	4,636	682	5,318
22	4,705	682	5,387
Rest of Country			
13	2,474	592	3,065
13.5	2,537	592	3,129
14	2,601	592	3,193
14.5	2,670	592	3,262
15	2,780	600	3,380
15.5	2,890	609	3,499
16	2,988	609	3,597
16.5	3,061	609	3,670
17	3,136	609	3,744
18	3,280	609	3,889
19	3,381	609	3,990
20	3,490	609	4,099
21	3,599	609	4,208

22	3,654	609	4,262

* Details may not add to total due to rounding.

Table 8.2.26 Shipments-Weighted Product Price, Installation Cost, and Total Installed Costs for Single Package A/C*

Efficiency Level ***SEER***	**Product Price (Including Markups)** ***2009$***	**Installation Cost** ***2009$***	**Total Installed Cost** ***2009$***
National Average			
13	2,587	453	3,040
13.5	2,690	453	3,143
14	2,770	453	3,223
14.5	2,904	453	3,358
15	3,038	453	3,492
15.5	3,190	453	3,643
16	3,345	453	3,798
16.5	3,611	453	4,064
Hot-Humid Region			
13	2,383	346	2,729
13.5	2,478	346	2,825
14	2,552	346	2,898
14.5	2,676	346	3,022
15	2,799	346	3,145
15.5	2,938	346	3,285
16	3,081	346	3,427
16.5	3,327	346	3,673
Hot-Dry Region			
13	3,173	630	3,803
13.5	3,300	630	3,930
14	3,398	630	4,028
14.5	3,563	630	4,192
15	3,727	630	4,357
15.5	3,913	630	4,542
16	4,103	630	4,733
16.5	4,430	630	5,059
Rest of Country			
13	2,439	562	3,001
13.5	2,537	562	3,099
14	2,612	562	3,174
14.5	2,739	562	3,301
15	2,865	562	3,427
15.5	3,008	562	3,570

16	3,154	562	3,716
16.5	3,405	562	3,967

* Details may not add to total due to rounding.

Table 8.2.27 Manufacturer Shipments-Weighted Selling Price (Including Transportation), Product Price, Installation Cost, and Total Installed Costs for Single Package HP*

Efficiency Level ***SEER***	**Product Price (Including Markups)** ***2009$***	**Installation Cost** ***2009$***	**Total Installed Cost** ***2009$***
National Average			
13	3,300	323	3,623
13.5	3,373	323	3,696
14	3,505	323	3,828
14.5	3,673	323	3,996
15	3,840	323	4,163
15.5	4,029	323	4,353
16	4,284	323	4,607
16.5	4,543	323	4,866
Hot-Humid Region			
13	3,046	264	3,311
13.5	3,114	264	3,378
14	3,235	264	3,500
14.5	3,390	264	3,654
15	3,545	264	3,809
15.5	3,720	264	3,984
16	3,955	264	4,219
16.5	4,194	264	4,458
Hot-Dry Region			
13	4,056	481	4,537
13.5	4,146	481	4,627
14	4,308	481	4,788
14.5	4,514	481	4,995
15	4,720	481	5,200
15.5	4,953	481	5,433
16	5,265	481	5,746
16.5	5,584	481	6,064
Rest of Country			
13	3,118	429	3,546
13.5	3,187	429	3,616
14	3,311	429	3,740
14.5	3,470	429	3,898
15	3,627	429	4,056

15.5	3,807	429	4,236
16	4,047	429	4,476
16.5	4,292	429	4,721

* Details may not add to total due to rounding.

Table 8.2.28 Manufacturer Shipments-Weighted Selling Price (Including Transportation), Product Price, Installation Cost, and Total Installed Costs for Small-Diameter High-Velocity CAC*

Efficiency Level ***SEER***	**Product Price (Including Markups)** ***2009$***	**Installation Cost** ***2009$***	**Total Installed Cost** ***2009$***
National Average			
13	4,470	445	4,915
13.5	4,610	445	5,055
14	4,755	445	5,200
14.5	4,908	445	5,353
Hot-Humid Region			
13	4,275	335	4,610
13.5	4,408	335	4,744
14	4,547	335	4,883
14.5	4,693	335	5,029
Hot-Dry Region			
13	5,692	610	6,302
13.5	5,870	610	6,480
14	6,055	610	6,665
14.5	6,249	610	6,859
Rest of Country			
13	4,375	545	4,919
13.5	4,511	545	5,056
14	4,654	545	5,198
14.5	4,803	545	5,347

* Details may not add to total due to rounding.

Furnaces

Table 8.2.29 through Table 8.2.31 present the shipments-weighted average product price, installation costs, and total installed costs for the each furnace product class at the baseline level and at each efficiency level examined.

Table 8.2.29 Total Installed Cost for Non-Weatherized Gas Furnaces by Region

Region	Energy Efficiency Level, AFUE	Equipment Price *2009$*		Installation Cost *2009$*		Total Installed Cost *2009$*	
		Average	Incr.	Average	Incr.	Average	Incr.
National	80%, baseline	858		927		1,786	
	90%	1,064	205	1,293	366	2,475	689
	92%	1,126	268	1,293	366	2,544	758
	95%	1,271	413	1,293	366	2,705	919
	98%	1,523	665	1,307	379	2,996	1,210
North	80%, baseline	876		1,024		1,901	
	90%	1,083	207	1,391	366	2,474	573
	92%	1,145	269	1,391	366	2,536	635
	95%	1,294	418	1,391	366	2,685	784
	98%	1,538	661	1,405	381	2,943	1,042
South	80%, baseline	831		783		1,614	
	90%	1,035	204	1,147	364	2,182	568
	92%	1,097	265	1,147	364	2,244	630
	95%	1,237	406	1,147	364	2,384	770
	98%	1,502	671	1,159	376	2,661	1,047

Table 8.2.30 Total Installed Cost for Manufactured Home Gas Furnaces by Region

Region	Energy Efficiency Level, AFUE	Equipment Price *2009$*		Installation Cost *2009$*		Total Installed Cost *2009$*	
		Average	Incr.	Average	Incr.	Average	Incr.
National	80%, baseline	794		638		1,432	
	90%	1,021	227	1,019	382	2,040	608
	92%	1,091	297	1,157	519	2,248	816
	96%	1,240	446	1,300	662	2,540	1,108
North	80%, baseline	793		695		1,488	
	90%	1,019	226	1,092	398	2,112	624
	92%	1,089	296	1,229	534	2,318	830
	96%	1,238	445	1,373	678	2,611	1,123
South	80%, baseline	795		583		1,379	
	90%	1,023	227	949	366	1,972	593
	92%	1,093	298	1,088	505	2,181	802
	96%	1,243	447	1,230	646	2,472	1,094

Table 8.2.31 Total Installed Cost for Oil-Fired Furnaces

Region	Energy Efficiency Level, AFUE	Equipment Price *2009$*		Installation Cost *2009$*		Total Installed Cost *2009$*	
		Average	Incr.	Average	Incr.	Average	Incr.
National	82%, baseline	2,128		880		3,008	
	83%	2,141	13	1,016	136	3,157	148
	84%	2,154	26	1,239	359	3,394	385
	85%	2,169	41	1,452	572	3,622	613
	97%	2,575	447	2,235	1,355	4,810	1,802

8.2.3 Operating Cost Inputs

The operating cost is determined for households using data from the 2005 RECS and industry sources on repair cost and maintenance cost. The operating cost for commercial buildings is based on computer modeling of a representative commercial building in 237 climates. 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. For furnaces, the LCC of an increased efficiency level is calculated for those buildings that are determined to have a central furnace. The LCC analysis results in a distribution of LCC savings (*i.e.*, the LCC difference between the baseline product and product with a higher efficiency level) for 10,000 individual realizations at each higher efficiency level nationally and in each region. The analysis computes the mean LCC difference at each efficiency level in each region, as well as the percentage of buildings analyzed that have positive LCC savings associated with the more efficient product.

DOE defined the operating cost by the following equation:

$$OC = EC + RC + MC \qquad \textbf{Eq. 8.2.5}$$

Where:

OC = operating cost ($),
EC = energy cost associated with operating the product ($),
RC = repair cost associated with component failure ($), and
MC = annual maintenance cost for maintaining product operation ($).

The remainder of this section provides information about the variables that DOE used to calculate the operating cost for CAC, HP, and furnace products. Product lifetime, discount rate, and effective date of the amended energy conservation standard are required for determining the operating cost and for establishing the operating cost present value. The annual energy costs of the product are computed from energy consumption per unit for the baseline efficiency and standard-compliant cases (efficiency level 2, 3, etc.), combined with the electricity prices. Chapter 7, Building Energy Use Characterization Analysis, provides complete details on the

central air conditioner product energy consumption results for three regions and the nation as a whole. The key inputs for the determination of operating costs are shown below:

- Baseline and standard-compliant annual energy consumption (kWh) (chapter 7);
- Electricity price (cents/kWh) (section 8.2.3.1);
- Electricity price trend (section 8.2.3.2);
- Repair cost ($) (section 8.2.3.3);
- Maintenance cost ($) (section 8.2.3.4);
- Equipment lifetime (years) (section 8.2.3.5);
- Discount rate (percentage) (section 8.2.3.6); and
- Effective date of amended energy conservation standard (section 8.2.3.7).

8.2.3.1 Electricity Price Analysis

Electricity price information is required to calculate the dollar benefits to consumers who purchase and operate a more efficient appliance. The electricity cost savings comprise the benefit side of the cost-benefit analysis used to define the LCC impacts of a proposed standard. In previous rulemakings, DOE has used estimates of marginal electricity prices to calculate these cost savings. The marginal price for a given consumer is the cost of the next increment of electricity use on the consumer's utility bill, and is the correct estimate of the value of savings that a consumer would see in the real world. In some cases, it may be sufficient to use estimates of average electricity prices, which are less accurate but simpler to calculate. However, if there is reason to believe that marginal prices differ significantly from average prices, the approximation is not justified. For a peak-coincident end-use such as air conditioning, there is a general expectation that the actual cost of operating the appliance is higher than the average price of electricity. These increased costs are often reflected in utility tariff structures, through block rates, different types of demand charges, or mandatory time-of-use rates. Accurate estimation of marginal prices requires taking rate structures into account explicitly.

In general, several methods and data sources can be used to calculate electricity prices. After reviewing the strengths and weaknesses of different approaches and the available data, the Department chose to base the analysis on the utility tariffs comprising the TAP (Tariff Analysis Project) database.[13] The TAP database and calculation tools were first developed at Lawrence Berkeley National Laboratory for use in the Commercial Unitary Air Conditioning (CUAC) rulemaking.[14] This approach provides an up-to-date and geographically diverse data set that can accurately capture real prices. Other data sources have various weaknesses that could lead to significant errors in the estimated electricity cost savings, and do not provide sufficient information to allow DOE to respond adequately to stakeholder comments. A more detailed discussion of electricity price data and calculation methods is presented in appendix 8-F, along with a description of the tariff-based approach, the data used, and validation tests. Detailed documentation is also available in published reports.[10, 11, 15]Residential electricity cost savings are calculated based on the default tariffs collected in the TAP database. Currently, for all

utilities the default tariff is not time-of-use. A large number of utilities offer optional time-of-use (TOU) tariffs, but there are currently very few customers enrolled in these optional rate plans. Appendix 8-G provides a quantitative comparison of prices for consumers on TOU or default tariffs for utilities that offer both.

For the analysis conducted for CACs and HPs, electricity prices are required for both residential and commercial consumers. The LCC is based on a consumer sample derived from RECS and EIA's Commercial Building Energy Consumption Survey (CBECS),[16] and both an average annual price and a seasonal marginal price are required for each household or building in the sample. Following the methodology in the LCC, the consumer sample is also segregated according to product type (*i.e.*, CAC or HP). The basic methodology is to estimate the customer's monthly electricity use and to use the tariff data to calculate the corresponding electricity bill. Empirical marginal prices (EMPs) are calculated by taking the difference between the bill for the baseline electricity use and the bill for a candidate standard level and then dividing by the change in energy use. This approach requires estimation of monthly consumer electricity use for the baseline and the energy savings associated with each candidate standard level. As both the rate structures and the required energy data differ significantly for residential and commercial consumers, the details of the approach for these two sectors are discussed separately.

Calculation of Residential Prices (Central Air Conditioners and Heat Pumps)

The calculation methodology provides, for each household in the building sample, an average annual price and a monthly marginal price. To compute these prices, the monthly baseline energy consumption must first be estimated. This is done using the monthly billing data from the RECS 2001 dataset, because the detailed monthly billing data from the RECS 2005 was considered to be proprietary and could not be used; details of the calculation are presented in appendix 8-F. Given the monthly energy use, 12 monthly bills per household are calculated using the tariffs. To increase the effective size of the sample, within a region each household is paired with each utility in its region. DOE refers to the pairing of a household with a utility as an account. The utilities are weighted by the fraction of customers they serve within a region.[17, 18] Taking the weighted sum over accounts provides a single set of prices for each household.

The annual average baseline price is calculated as a simple average over the 12 monthly baseline bills. To calculate monthly marginal prices for each account, the monthly energy use is decremented by 7%, and the bill recalculated. The marginal price in each month is defined as the bill savings divided by the energy savings under this test. This will be the valid price under all candidate standard levels. Monthly variability in the marginal price is due primarily to seasonal rates, as season definitions vary by utility. Within the LCC, the annual cost savings are equal to the monthly marginal price times the monthly energy savings, summed across months. A description of how the monthly energy savings are estimated for each efficiency level is given in appendix 8-G.

To provide an indication of the prices that result from this analysis, Table 8.2.32 shows the annual average price and marginal prices for January and July. The table presents regional averages calculated for the hot-humid, hot-dry, and rest-of-country regions defined for this

rulemaking. The table also shows the total RECS weight associated with the household sample for each product type. Note that these regional averages are for information only; the LCC uses household-level prices.

Table 8.2.32 Regional Averages of the Annual Average Prices and January and July Marginal Prices

Product and Region	RECS Nweight	Residential Electricity Prices *cents/kWh*		
		Annual Average Price	January Marginal Price	July Marginal Price
Central Air				
Hot-Humid	19,045,578	10.04	8.86	9.75
Hot-Dry	6,164,451	16.11	19.79	19.97
Rest of Country	25,769,446	10.73	9.11	10.57
Nation	50,979,476	11.12	10.30	11.40
Heat Pump				
Hot-Humid	5,545,454	10.01	9.50	10.20
Hot-Dry	837,752	14.35	16.22	15.80
Rest of Country	3,608,821	9.68	8.52	9.93
Nation	9,992,026	10.26	9.71	10.57

Calculation of Commercial Prices (Central Air Conditioners and Heat Pumps)

Electricity tariffs for commercial consumers can be very complex, incorporating block rates, seasonal rates, demand charges, time-of-use rates, etc. To calculate commercial electricity bills requires both the monthly consumption and demand; for utilities with mandatory TOU tariffs, consumption and demand data are required for each TOU period. For the central air conditioner and HP analysis, this data is provided from building simulations. The simulation approach is described in more detail in chapter 7. Briefly, in this approach a representative set of small commercial buildings is simulated at several SEER levels across the full set of weather locations defined in the TMY2 dataset.[d] The simulation output for SEER 13 is taken as the baseline. As with the residential data, a set of accounts are created by pairing each building in the simulation set with each utility in its region. For the commercial analysis the regions are defined as census divisions. Once a building is assigned to a utility, the tariff is assigned automatically based on the tariff rules and the annual peak demand or energy consumption, or both. For each account and each SEER level, monthly energy and demand values, by TOU period if necessary, are determined from the hourly simulation output. With this data, monthly bills can be calculated using the tariffs.

Given the monthly bills, the bill savings in dollars for each account at each SEER level are determined relative to the baseline bill. The EMP can be calculated by taking the ratio of the bill savings to the energy savings. Note that, as far as the analysis is concerned, the EMP is a

[d] TMY means typical meteorological year; version 3 of this dataset is the most recent.

derived quantity that is used for information purposes only; the LCC uses the total annual bill savings for each customer directly.

The commercial tariff data were last updated in 2004. To convert to 2008$, two datasets were used: the report, *Average Regulated Retail Price of Electricity for the years 2004 through 2007,*[2] and the *EEI Typical Bill* reports for 2007 to 2008.[19] Based on these data, a weighted-average price escalation factor for each region was calculated using consumer counts as the weights. The consumer counts come from the most recent EIA Form 861 data, which is for 2006.[19, 20] EIA data from 2003 through 2006 were used to determine how much the rate of price escalation differs on average between the publicly and the privately owned utility companies.

To give an indication of the prices obtained with this methodology, Table 8.2.33 shows the regional average values of the EMP at the SEER levels simulated. These regional averages were calculated based on population-weighting of the building simulation sample. The table also shows the scaling factors used to convert from 2004 to 2008 nominal dollars. Investigation of changes in the Consumer Price Index for electricity showed little or no net change from 2008 to 2009, so these prices were assumed to prevail in 2009 as well. Note that the EMP varies by SEER level, and this variation may be non-monotonic. This behavior results from the complex block structures for both demand and energy charges that exist in commercial tariffs.[18]

Table 8.2.33 Effective Marginal Price by Region for the Commercial Building Sample (¢/kWh).

Census Division	Marginal Prices *cents/kWh*						Scaling Factor*
	Central Air Conditioners			Heat Pumps			
	SEER 14	SEER 16	SEER 19	SEER 14	SEER 16	SEER 19	
1	32.7	22.1	25.3	28.5	19.5	21.9	1.44
2	25.0	17.4	19.6	22.6	15.4	17.4	1.15
3	22.2	14.3	16.6	19.0	12.2	14.1	1.25
4	7.4	6.6	6.9	8.0	6.5	6.9	1.07
5	14.6	12.3	13.1	14.6	11.7	12.6	1.36
6	10.7	9.5	10.0	10.3	9.1	9.4	1.28
7	17.5	14.8	16.0	16.3	13.5	14.5	1.34
8	10.9	9.8	10.1	13.2	9.8	10.6	1.18
9	12.7	12.2	12.5	13.6	11.6	11.8	1.09

* The scaling factors used to convert from 2004$ to 2008$.

Calculation of Residential Prices (Furnaces)

Using data from EIA, DOE derived average annual monthly energy prices for 13 geographic areas in the United States—the nine U.S. census divisions, with four large states (New York, Florida, Texas, and California) treated separately. For census divisions containing one of these large states, DOE calculated the regional average values leaving out data for the large state; for example, the Pacific region average does not include California, and the West

South Central does not include Texas. Using these data, DOE assigned an appropriate price to each household in the sample, depending on its location.

To be able to determine monthly prices for use in the furnace analysis, DOE developed monthly energy price factors for each fuel. For a detailed discussion of the development of monthly energy price factors, see appendix 8-I, Monthly Energy Price Factor Calculations.

Residential Electricity Prices. DOE derived 2009 annual electricity prices from EIA Form 861 data.[21] The EIA Form 861 data are published annually and include annual electricity sales, revenues from electricity sales, and number of consumers for the residential, commercial, and industrial sectors at the utility level. DOE calculated annual regional electricity prices by weighting each utility's average price by the number of electricity consumers in each utility's service area. DOE then aggregated the prices by the nine U.S. census divisions and four large states. Table 8.2.34 shows the monthly average results for each geographic area.

Table 8.2.34 Average Electricity Prices in 2009

Geographic Area	Residential *2009$/kWh*
New England	$0.174
Middle Atlantic (excludes NY)	$0.135
East North Central	$0.111
West North Central	$0.092
South Atlantic (excludes FL)	$0.108
East South Central	$0.095
West South Central (excludes TX)	$0.087
Mountain	$0.101
Pacific (excludes CA)	$0.099
New York	$0.178
Florida	$0.150
Texas	$0.127
California	$0.123
U.S.	$0.121

Residential Natural Gas Prices. DOE obtained the data for the natural gas price calculation from EIA's Natural Gas Navigator.[22] This publication includes a compilation of monthly natural gas prices by state for residential, commercial, and industrial customers. DOE weighted the residential natural gas prices for each state by the number of natural gas consumers in each state[23] and transformed the values from units of $/tcf to $/MMBtu. Finally, DOE aggregated and averaged the prices by the nine U.S. census divisions and four large states. Table 8.2.35 displays the 2009 annual natural gas prices.

Table 8.2.35 Average Residential Natural Gas Prices in 2009

Geographic Area	Residential Average Prices *2009$/MMBtu*
New England	$16.37
Middle Atlantic (excludes NY)	$15.24
East North Central	$11.65
West North Central	$11.64
South Atlantic (excludes FL)	$17.17
East South Central	$14.38
West South Central (excludes TX)	$13.74
Mountain	$11.99
Pacific (excludes CA)	$14.69
New York	$15.27
Florida	$9.07
Texas	$12.43
California	$21.01
U.S.	$12.92

Source: EIA *Natural Gas Navigator*.

Residential Liquid Petroleum Gas (LPG) Prices. DOE collected 2008 average LPG prices from EIA's 2008 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[24] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state. DOE weighted the average residential LPG prices for each state by the amount of LPG consumed by each state. Finally, DOE aggregated and averaged the prices by 13 geographic areas (Table 8.2.36).

Table 8.2.36 Average Residential LPG Prices in 2008

Geographic Area	Annual Average *2009$/MMBtu*
CD 1 - New England	$33.96
CD 2 - Middle Atlantic (excludes NY)	$34.19
CD 3 - East North Central	$26.95
CD 4 - West North Central	$24.04
CD 5 - South Atlantic (excludes FL)	$31.74
CD 6 - East South Central	$30.86
CD 7 - West South Central (excludes TX)	$27.78
CD 8 – Mountain	$28.78
CD 9 - Pacific (excludes CA)	$31.43
CD 10 - New York	$33.26
CD 11 – California	$33.78
CD 12 – Texas	$30.79
CD 13 – Florida	$38.72
CD 14 - United States	$29.26

Residential Fuel Oil Prices. DOE collected 2008 average fuel oil prices from EIA's 2008 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[24] SEDS includes annual fuel oil prices for residential, commercial, industrial, and transportation consumers by state. DOE weighted the average residential fuel oil prices for each state by the amount of fuel oil consumed by each state. Finally, DOE aggregated and averaged the prices by 13 geographic areas (Table 8.2.37).

Table 8.2.37 Average Residential Fuel Oil Prices in 2008

Geographic Area	Annual Average *2009$/MMBtu*
CD 1 - New England	$24.17
CD 2 - Middle Atlantic (excludes NY)	$24.78
CD 3 - East North Central	$23.56
CD 4 - West North Central	$23.48
CD 5 - South Atlantic (excludes FL)	$24.13
CD 6 - East South Central	$23.89
CD 7 - West South Central (excludes TX)	$24.09
CD 8 – Mountain	$23.86
CD 9 - Pacific (excludes CA)	$24.79
CD 10 - New York	$24.61
CD 11 – California	$25.62
CD 12 – Texas	$24.60
CD 13 – Florida	$24.24
CD 14 - United States	$24.27

8.2.3.2 Electricity Price Trend

The electricity price trend provides the relative change in electricity prices for future years out to the year 2045. Estimating future electricity prices is difficult, especially considering that there are efforts in many states throughout the country to restructure the electricity supply industry.

Central Air Conditioners and Heat Pumps

DOE uses regional projections of residential and commercial average electricity prices for heating and cooling end-uses calculated in the NEMS-BT model at the census division level to develop estimates of future electricity costs for the regions covered in this rulemaking. DOE applied projected trends in regional average electricity prices separately for heating and cooling to each customer's 2009 electricity prices. Of the following four scenarios, the main LCC analysis uses the *AEO 2010* reference price scenario:

1. Constant energy prices at 2009 values (Constant index at 2009 = 1.0)
2. *AEO 2010*, High Growth ("High Growth" in Figure 8.2.1–Figure 8.2.4)
3. *AEO 2010*, Reference Case ("Reference" in Figure 8.2.1–Figure 8.2.4)

4. *AEO 2010*, Low Growth ("Low Growth" in Figure 8.2.1–Figure 8.2.4)

Figure 8.2.1 shows the trends for the three *AEO 2010* residential cooling price projections in which prices are assumed to change. DOE extrapolated the values in later years (*i.e.*, after 2035) from their relative sources because *AEO 2010* does not forecast beyond 2035. To arrive at values for these later years, DOE used the price trend from 2020 to 2035 of the forecast to establish prices in the years 2035 to 2045.

The default electricity price trend scenario used in the LCC analysis is the trend from the *AEO 2010* Reference Case, which is the middle line in Figure 8.2.1 through Figure 8.2.4. Spreadsheets used in calculating the LCC have the capability to analyze the other electricity price trend scenarios, namely, the *AEO 2010* High Growth and the *AEO 2010* Low Growth price trends and constant energy prices. A similar set of trend scenarios for the residential heating, commercial cooling, and commercial heating sector are shown in Figure 8.2.2 through Figure 8.2.4.

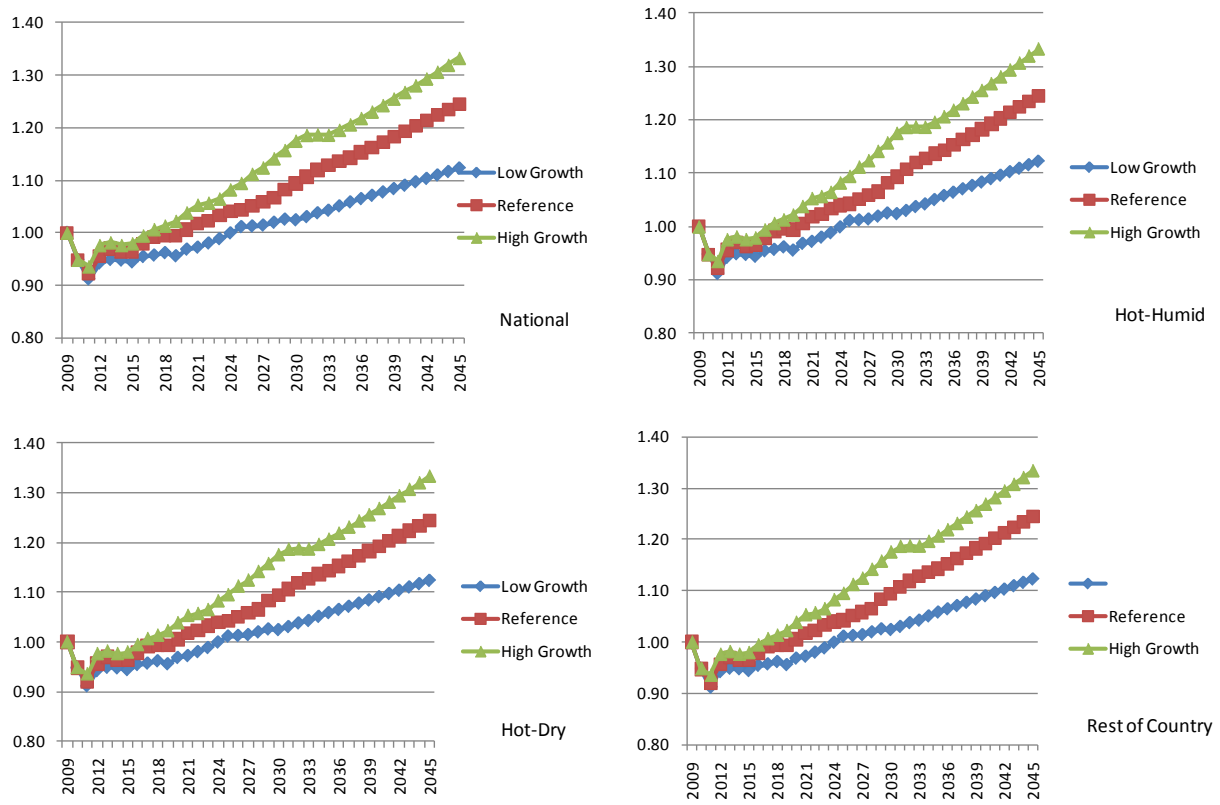

Figure 8.2.1 Electricity Price Trends for Residential Cooling to 2045 (Index: 2009=1.00)

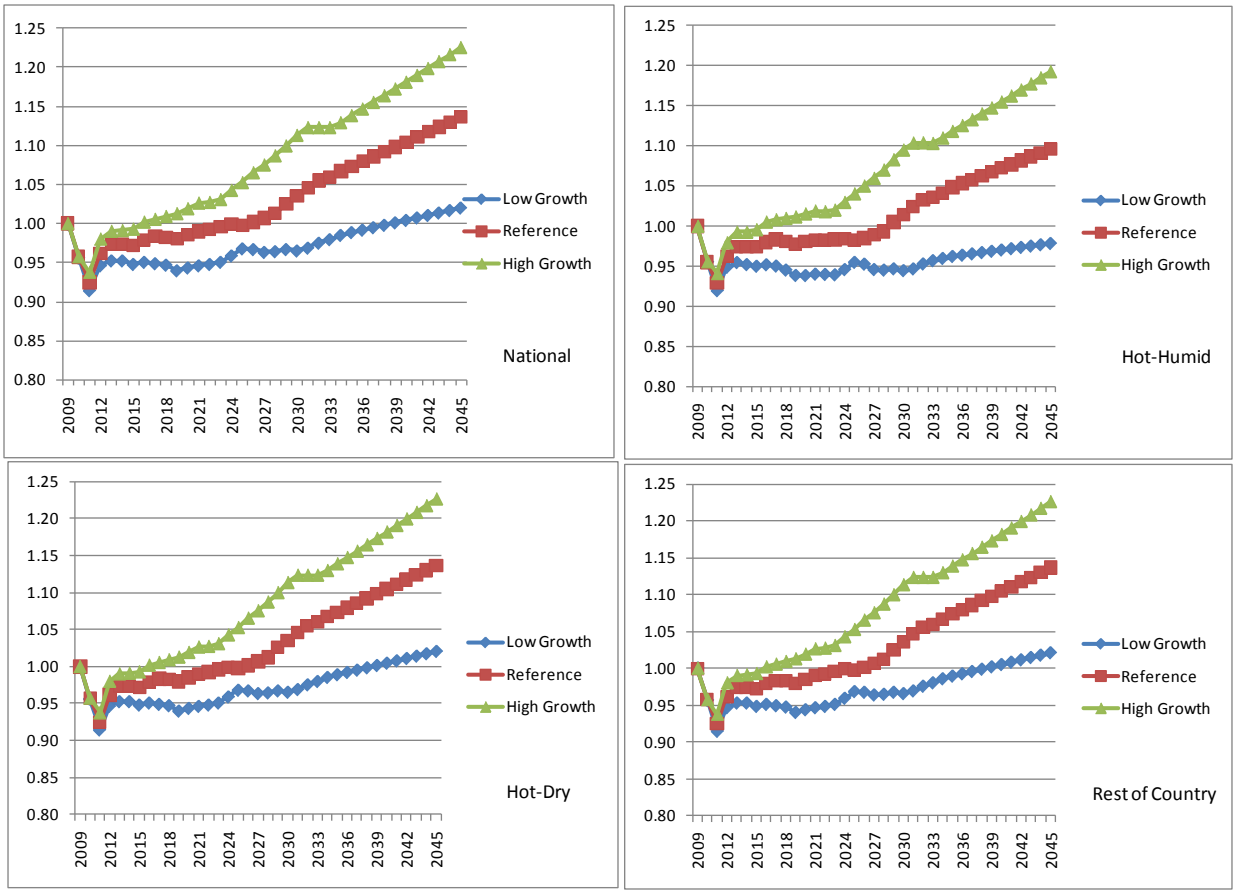

Figure 8.2.2 Electricity Price Trends for Residential Heating to 2045 (Index: 2009=1.00)

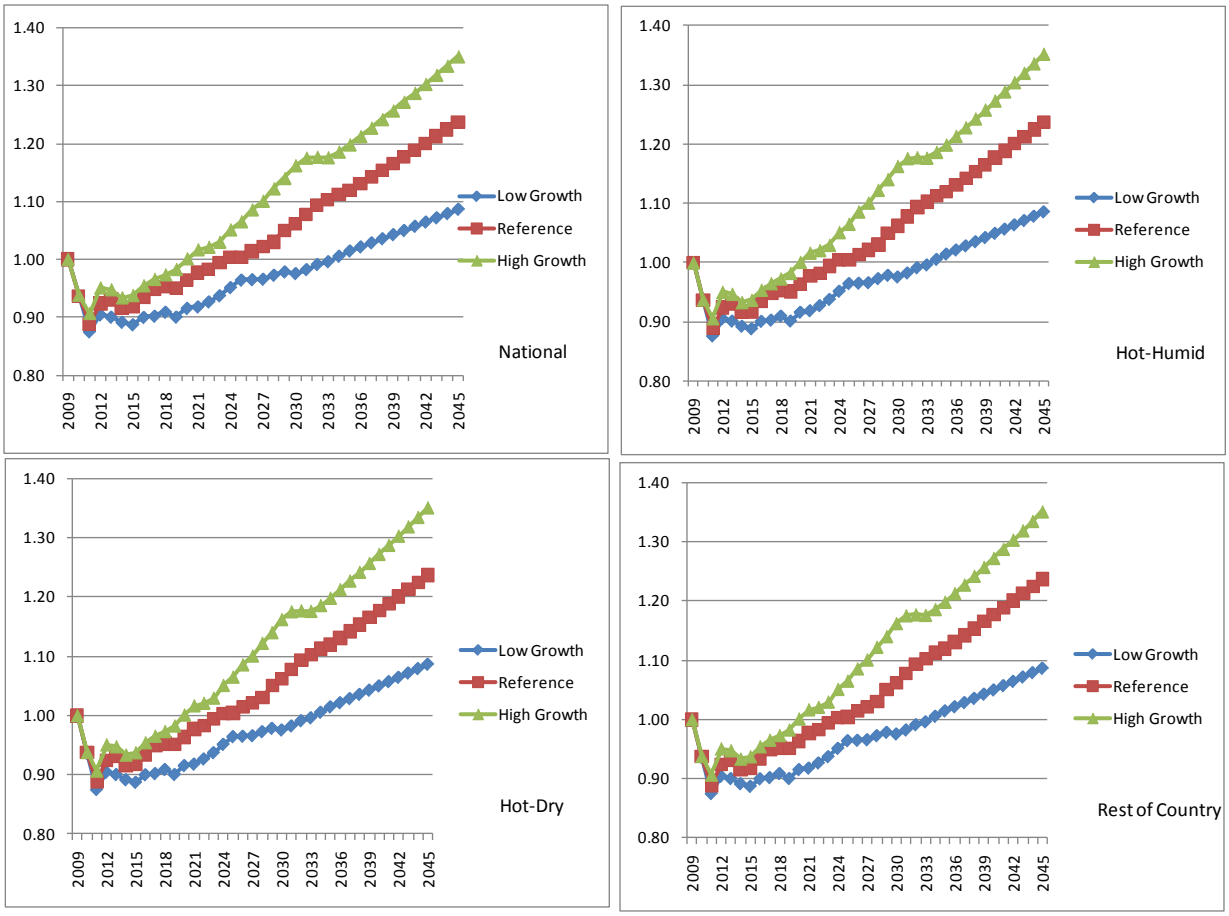

Figure 8.2.3 Electricity Price Trends for Commercial Cooling to 2045 (Index: 2009=1.00)

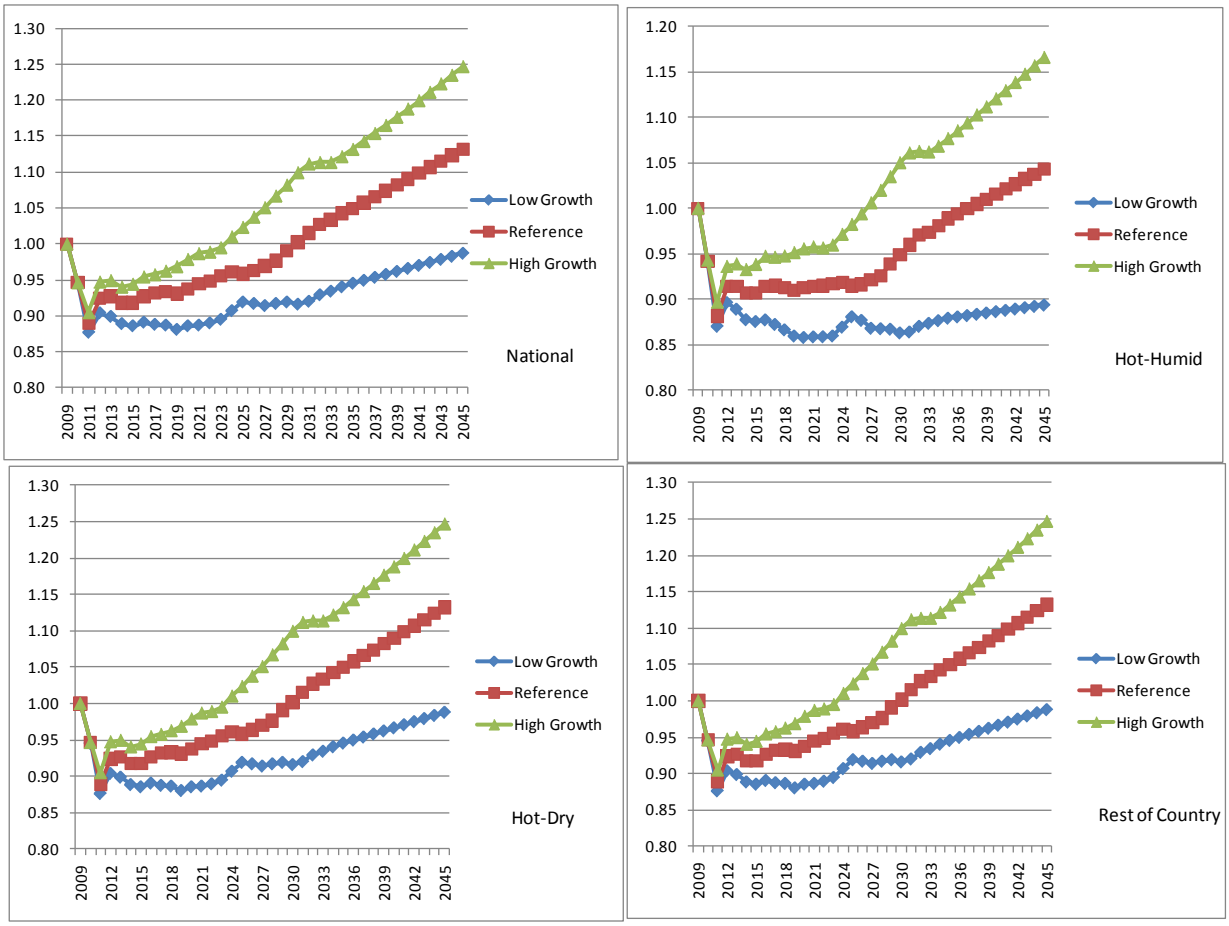

Figure 8.2.4 Electricity Price Trends for Commercial Heating to 2045 (Index: 2009=1.00)

Furnaces

DOE used price forecasts by the EIA to estimate future trends in natural gas and electricity prices. To arrive at prices in future years, it multiplied the average prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2010.* To estimate the trend after 2035, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2020–2035 for electricity, natural gas, and LPG.

DOE calculated LCC and PBP using three separate projections from *AEO 2010*: Reference, Low Economic Growth, and High Economic Growth. The high- and low-growth cases show the projected effects of alternative growth assumptions on energy markets. Figure 8.2.5 through Figure 8.2.8 show the residential and commercial electricity, natural gas, LPG, fuel oil price trends, respectively, based on the three *AEO 2010* projections. For the LCC results, DOE used only the energy price forecasts from the *AEO* Reference Case.

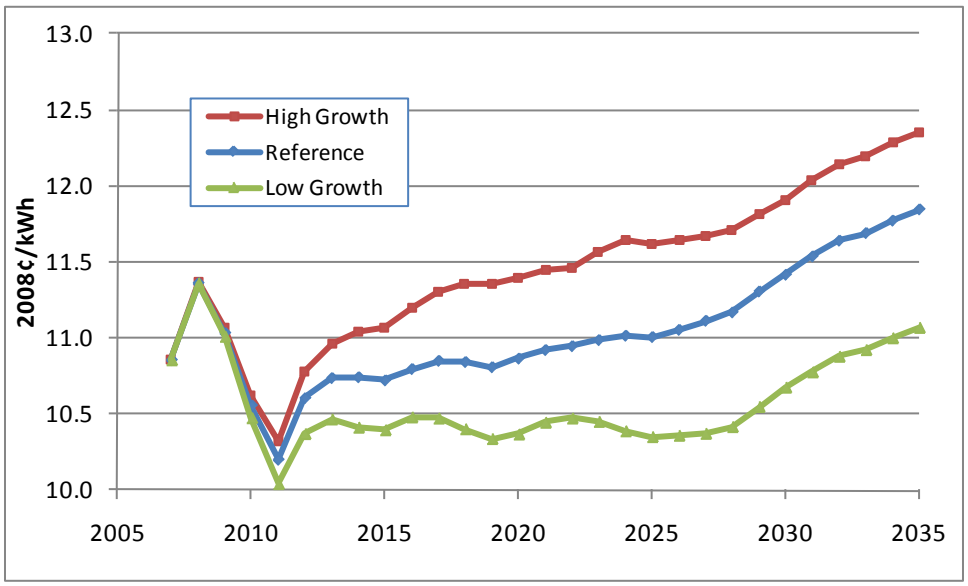

Figure 8.2.5 Residential Electricity Price Trends

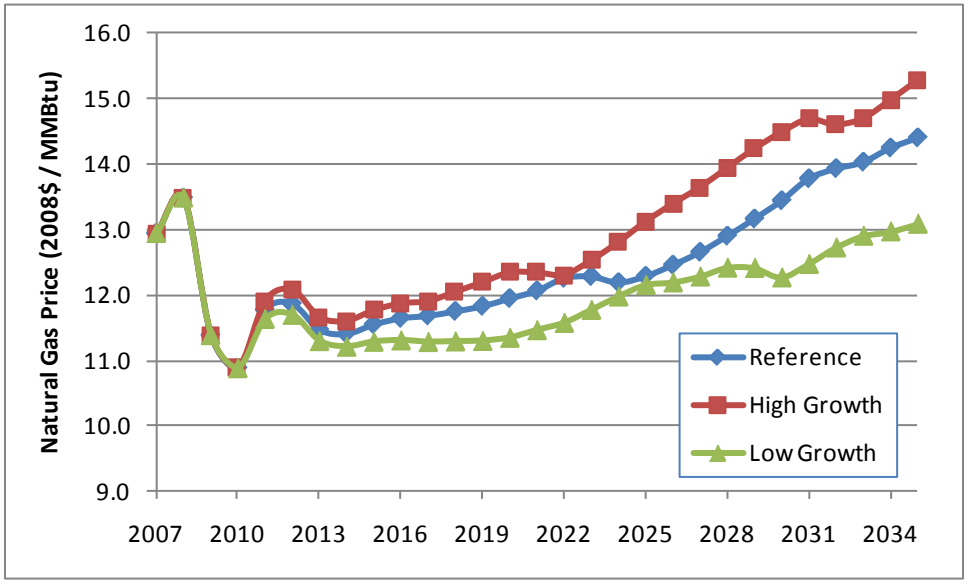

Figure 8.2.6 Residential Natural Gas Price Trend

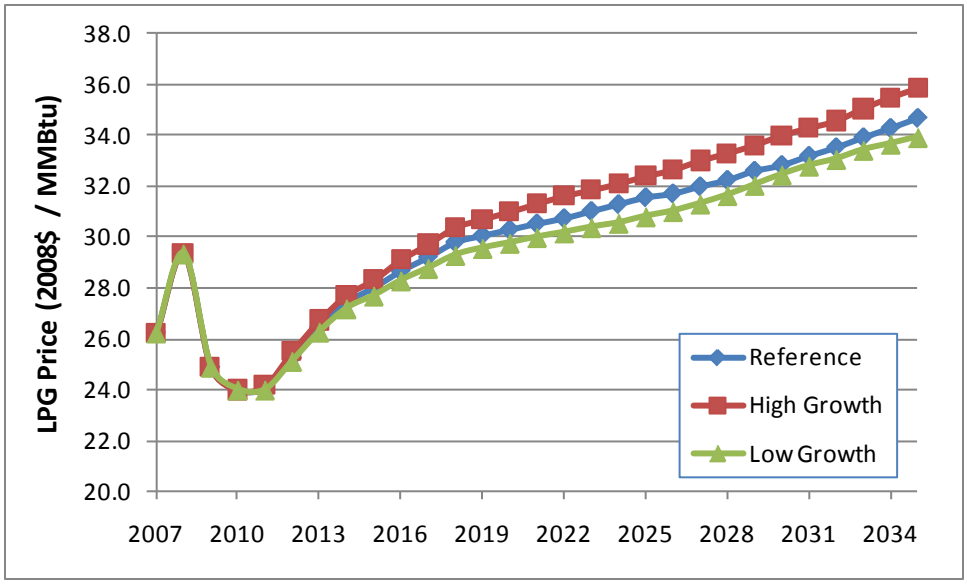

Figure 8.2.7 Residential LPG Price Trend

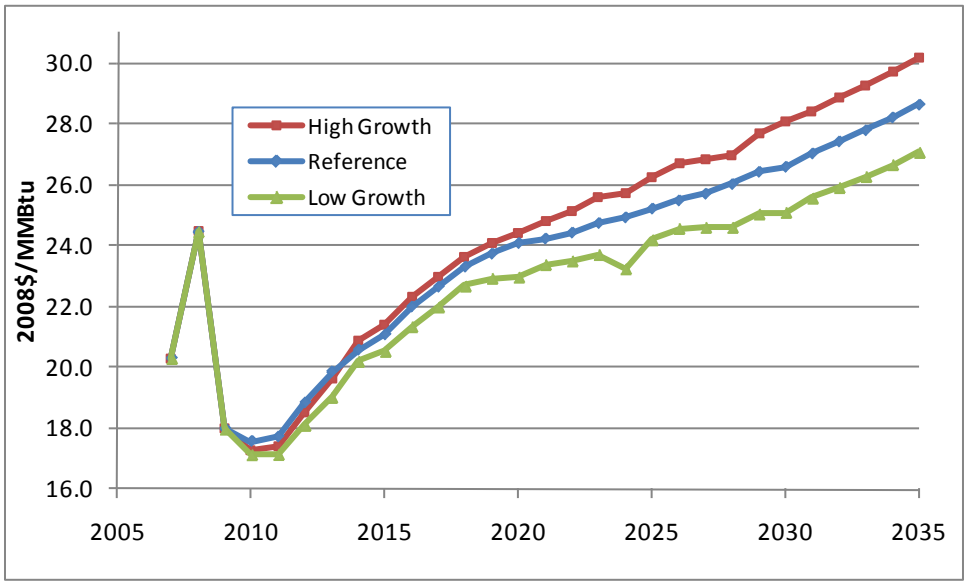

Figure 8.2.8 Residential Fuel Oil Price Trend

8.2.3.3 Repair Cost

The repair cost is the cost to the consumer for replacing or repairing components in the CAC, HP, or furnace equipment that have failed.

Central Air Conditioners and Heat Pumps

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:

$$RC_{STD} = RC_{Base} \bullet \frac{EQP_{STD}}{EQP_{BASE}} \bullet (m_r) \bullet (st_r) \qquad \textbf{Eq. 8.2.6}$$

Where:

RC_{STD} = repair cost at a standard efficiency level (*e.g.*, level 2, 3),
RC_{BASE} = repair cost at the base efficiency level (level 1),
EQP_{STD} = equipment price (consumer price for only the equipment) at a standard level,
EQP_{BASE} = equipment price (consumer price for only the equipment) at the base efficiency level,
m_r = mechanical contractor markup index in region *r*, and
st_r = state and local tax rate index (factor relative to national average).

Data on average repair costs are scarce in published sources. However, based on information in a few consumer advice websites and discussions with service representatives, it appears that the range of values for parts and labor for major repairs, such as replacing a compressor, is between $700 and $1,500.[25, 26, 27, 28, 29, 30, 31] Furthermore, it appears that compressor replacements are rarely needed before about the eighth year and are often covered by warranty, if needed. In addition, if the equipment is older than 15 years, it is usually economically rational to replace the entire system rather than to incur the cost of a major repair for the limited average equipment life remaining. Because this is a range rather than a specific value associated with a particular technology, DOE applied the range to all classes and assumed that the range included average national values for wholesale markups, mechanical contractor markups, and sales taxes.

Through 14 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 or larger heat exchanger coils. Systems with efficiencies beyond 14.5 SEER start to incorporate two-speed and variable-speed fans, as well as larger coils and more complex electronics, all of which are expected to be more susceptible to failure and cost more to repair.

Table 8.2.38 and Table 8.2.39 show the basic average annualized repair costs by standard level for split-system and single-package central air conditioners and heat pumps. The annualized value accounts for the probability of needing a major repair, its uncertain cost, and the time period before such repair might be required (between 8 and 15 years). Since equipment prices are a function of variables that 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 8.2.38 and Table 8.2.39.

Table 8.2.38 Split-System Central Air Conditioner and Heat Pump Basic Average Annualized Repair Costs by Efficiency Level

Efficiency Level *SEER*	Repair Costs for Representative Standard-Compliant Products *2009$*								
	Split-System AC (Coil-Only)			Split-System AC (Blower-Coil)			Split-System HP		
	2 T	3 T	5 T	2 T	3 T	5 T	2 T	3 T	5 T
13	56.54	63.48	88.43	56.67	63.48	84.88	56.67	63.48	84.88
13.5	58.41	65.32	90.96	58.03	65.07	86.85	57.91	65.23	86.85
14	60.47	67.64	94.05	59.40	66.70	88.92	59.16	66.96	88.91
14.5	62.59	70.27	97.70	60.73	68.30	91.13	60.54	68.74	91.07
15	65.09	73.48	102.03	62.04	69.88	93.39	61.91	70.49	93.28
15.5	67.64	77.18	106.77	63.45	71.57	95.78	63.24	72.14	95.61
16	70.37	81.38	112.06	64.88	73.30	98.27	65.15	74.55	99.17
16.5	73.39	86.05	NA	66.26	75.08	100.82	66.53	76.29	101.82
17	76.59	NA	NA	67.67	76.90	103.49	67.91	78.03	104.47
18	83.54	NA	NA	70.73	80.66	109.21	70.73	81.53	110.57
19	NA	NA	NA	73.74	84.60	NA	73.71	85.03	NA
20	NA	NA	NA	76.85	88.75	NA	76.67	89.11	NA
21	NA	NA	NA	80.08	93.18	NA	79.72	93.10	NA
22	NA	NA	NA	83.39	97.82	NA	82.86	NA	NA
23	NA	NA	NA	86.75	NA	NA	NA	NA	NA
24.5	NA	NA	NA	91.93	NA	NA	NA	NA	NA

Table 8.2.39 Single-Package and Niche Central Air Conditioner and Heat Pump Basic Average Annualized Repair Costs by Efficiency Level

Efficiency Level *SEER*	Repair Costs for Representative Standard-Compliant Products *2009$*		
	Single-Package AC	Single-Package HP	Small Diameter High Velocity
	3T	3T	3T
13	63.48	63.48	63.48
13.5	65.89	64.84	65.50
14	67.75	67.27	67.61
14.5	70.89	70.38	69.81
15	74.01	73.48	NA
15.5	77.54	76.99	NA
16	81.15	81.70	NA
16.5	87.37	86.49	NA

Because labor rates and sales taxes vary across the country and repair costs also vary for any given efficiency level for each product type, Table 8.2.40 shows the average annualized repair costs by region of the country and product type.

Table 8.2.40 Table Central Air Conditioner and Heat Pump Shipments-Weighted Average Annualized Repair Costs by Efficiency Level and Region

Efficiency Level *SEER*	Shipments-Weighted Repair Costs *2009$*					
	Split-System AC (Coil-Only)	Split-System AC (Blower-Coil)	Split-System HP	Single Package AC	Single Package HP	Small Diameter High Velocity
	National Average					
13	65	65	64	65	64	64
13.5	67	66	66	67	66	66
14	69	68	68	69	68	68
14.5	72	69	70	73	72	71
15	75	71	72	76	75	NA
15.5	79	73	74	80	79	NA
16	82	75	76	84	84	NA
16.5	86	76	78	90	89	NA
17	89	78	80	NA	NA	NA
18	92	82	84	NA	NA	NA
19	NA	85	87	NA	NA	NA
20	NA	88	89	NA	NA	NA
21	NA	92	92	NA	NA	NA
22	NA	95	93	NA	NA	NA
23	NA	97	NA	NA	NA	NA
24.5	NA	99	NA	NA	NA	NA
	Hot-Humid					
13	63	63	64	63	63	63
13.5	65	64	65	65	64	65
14	67	66	67	67	67	67
14.5	70	68	69	70	70	69
15	73	69	71	74	73	NA
15.5	76	71	73	77	77	NA
16	80	73	75	81	81	NA
16.5	83	74	77	88	86	NA
17	87	76	79	NA	NA	NA
18	90	80	83	NA	NA	NA
19	NA	83	86	NA	NA	NA
20	NA	86	89	NA	NA	NA
21	NA	89	91	NA	NA	NA
22	NA	93	92	NA	NA	NA
23	NA	94	NA	NA	NA	NA
24.5	NA	97	NA	NA	NA	NA
	Hot-Dry					
13	70	69	69	70	70	70
13.5	72	71	70	73	71	72
14	74	73	72	75	74	75
14.5	77	75	74	79	78	77
15	80	76	76	82	81	NA
15.5	84	78	78	86	85	NA
16	88	80	81	91	91	NA
16.5	92	82	83	98	96	NA

17	96	84	85	NA	NA	NA
18	99	88	89	NA	NA	NA
19	NA	91	92	NA	NA	NA
20	NA	95	96	NA	NA	NA
21	NA	99	99	NA	NA	NA
22	NA	103	101	NA	NA	NA
23	NA	104	NA	NA	NA	NA
24.5	NA	107	NA	NA	NA	NA
	Rest of Country					
13	67	66	65	64	64	64
13.5	69	68	67	67	65	66
14	71	69	69	69	68	68
14.5	74	71	70	72	71	71
15	77	73	72	75	75	NA
15.5	80	74	74	79	78	NA
16	84	76	77	83	83	NA
16.5	88	78	79	90	88	NA
17	91	80	81	NA	NA	NA
18	94	84	85	NA	NA	NA
19	NA	87	87	NA	NA	NA
20	NA	90	90	NA	NA	NA
21	NA	93	93	NA	NA	NA
22	NA	97	94	NA	NA	NA
23	NA	98	NA	NA	NA	NA
24.5	NA	100	NA	NA	NA	NA

Furnaces

DOE estimated repair costs at each considered efficiency level using a variety of sources, including *2010 RS Means Facility Repair and Maintenance Data*, manufacturer literature, and information from expert consultants. DOE accounts for regional differences in labor costs.

DOE estimated that about 3% of furnaces are repaired annually based on *Consumer Reports* data on frequency of repair for gas furnaces installed between 2000 and 2006.[32] DOE assumed that an average repair has a parts cost equivalent to one-half of the equipment cost and requires 1.5 hours of labor.

Table 8.2.41 shows the annualized repair cost estimates for each product class.

Table 8.2.41 Annualized Repair Cost for Furnaces

Product Class	Energy Efficiency Level, AFUE	Repair Cost *2009$/year*	
		Average	Incr.
Non-Weatherized Gas Furnaces	0 (80%, baseline)	0.51	
	1 (90%)	0.63	0.12
	2 (92%)	0.67	0.16
	3 (95%)	0.76	0.24
	4 (98%)	0.90	0.39
Manufactured Home Gas Furnaces	0 (80%, baseline)	0.57	
	1 (90%)	0.69	0.12
	2 (92%)	0.72	0.16
	3 (96%)	0.80	0.23
Oil-Fired Furnaces	0 (82%, baseline)	0.89	
	1 (83%)	0.90	0.01
	2 (84%)	0.91	0.01
	3 (85%)	0.91	0.02
	4 (97%)	1.13	0.24

8.2.3.4 Maintenance Cost

The maintenance cost is the routine annual cost to the consumer of maintaining equipment operation. The maintenance cost excludes the cost associated with the replacement or repair of components that have failed (discussed in section 8.2.3.3). It is the cost associated with general maintenance (*e.g.*, checking and maintaining refrigerant charge levels, cleaning heat exchanger coils).

Central Air Conditioner

Virtually no published data are available on annual maintenance cost per unit. DOE estimated the annualized maintenance costs for central air conditioner products based on fragmentary data available on the Internet. The cost of the basic preventative maintenance for an individual central air conditioner unit is specified as a range of values from $20 per year (2009$) for minimal maintenance (homeowner replaces the unit's air filter two times per year) to an advertised full maintenance service at $120 (2009$) per year.[33] The full maintenance service involved the following activities:

For the Indoor Component:

- Inspect refrigerant lines for signs of leakage;
- Check and maintain standard air filters;
- Check operating temperatures;
- Check blower or air handler operation and lubricate as necessary;
- Check blower belt and tension;

- Check condensate drain and maintain as necessary; and
- Check operational controls and thermostat.

For the Outdoor Component:

- Inspect refrigerant lines for signs of leakage;
- Inspect and clean condenser coil as necessary;
- Check condenser fan operation and lubricate as necessary;
- Check operation and condition of the compressor contactor;
- Check system voltage; and
- Check operating temperatures.

Data were not available to indicate how maintenance costs vary with equipment efficiency, but stakeholder comments on the framework document indicated that they likely increase as equipment efficiency increases. However, DOE was not able to identify any components of preventative maintenance costs that increase as equipment efficiency increases. Due to differences in labor costs, maintenance costs were expected to vary regionally with labor costs. Installation costs vary in the same geographic pattern, so average national costs were multiplied times the installation cost index.

$$M_{STD} = M_{Base} \bullet (ic_r) \qquad \textbf{Eq. 8.2.7}$$

Where:

M_{STD} = repair cost at a standard efficiency level (*e.g.*, level 2, 3),
M_{BASE} = repair cost at the base efficiency level (level 1), and
ic_r = installation cost index in region *r* (factor relative to national average).

Because labor rates and sales taxes vary across the country, basic maintenance costs vary by region. However, there appears to be no reason for the costs of basic maintenance activities to vary by product class, by efficiency level, or by capacity within product classes. Table 8.2.42 shows the shipment-weighted average annual maintenance costs by region of the country and product class.

Table 8.2.42 Shipments-Weighted Central Air Conditioner and Heat Pump Basic Average Annual Maintenance Costs

Efficiency Level	Average Maintenance Costs for Representative Standard-Compliant Products *2009$*					
	Split-System AC (Coil-Only)	Split-System AC (Blower-Coil)	Split-system HP	Single Package AC	Single Package HP	Small Diameter High Velocity
National Average	61	61	55	60	56	61
Hot-Humid	46	46	46	46	46	46
Hot-Dry	85	85	85	84	84	85
Rest of Country	74	74	74	74	74	74

Furnaces

DOE estimated repair costs at each considered efficiency level using a variety of sources, including *2010 RS Means Facility Repair and Maintenance Data*, manufacturer literature, and information from expert consultants. DOE accounts for regional differences in labor costs.

DOE estimated costs for annual maintenance using data from a consumer survey[34] on the frequency with which owners of different types of furnaces perform maintenance. For condensing oil furnaces, the high quantity of sulfur in the fuel results in frequent cleaning of the secondary heat exchanger, and DOE accounted for this cost.

Table 8.2.43 shows the annualized maintenance cost estimates for each product class.

Table 8.2.43 Annualized Maintenance Cost for Furnaces

Product Class	Energy Efficiency Level, AFUE	Maintenance Cost *2009$/year*	
		Average	Incr.
Non-Weatherized Gas Furnaces	0 (80%, baseline)	40.78	
	1 (90%)	40.78	40.28
	2 (92%)	40.78	40.28
	3 (95%)	40.78	40.28
	4 (98%)	40.78	40.28
Manufactured Home Gas Furnaces	0 (80%, baseline)	40.78	
	1 (90%)	40.78	40.23
	2 (92%)	40.78	40.23
	3 (96%)	40.78	40.23
Oil-Fired Furnaces	0 (82%, baseline)	60.97	
	1 (83%)	60.97	60.10
	2 (84%)	60.97	60.10
	3 (85%)	60.97	60.10
	4 (97%)	176.85	188.20

8.2.3.5 Lifetime

DOE defined lifetime as the age when a central air conditioner or furnace unit is retired from service. DOE used national survey data, along with manufacturer shipment data, to calculate the distribution of air conditioner and heat pump lifetimes. This analysis concluded that the mean lifetime for central air conditioners is 19.01 years, for heat pumps is 16.24 years, for non-weatherized gas furnaces is 23.68, for manufactured home gas furnaces is 18.80, and for oil-fired furnaces is 26.59.

EIA's RECS[35] surveys occupied primary housing units, noting the presence of a range of appliances and placing the age of each appliance into several-year bins. The U.S. Census's *American Housing Survey* (AHS)[36] surveys all housing, including vacant and second homes. Using the AHS data allowed DOE to adjust the RECS data to reflect some appliance use outside of primary residences. AHS also has a larger sample size, with correspondingly smaller sampling error. By combining these survey results with the known history of appliance shipments (collected from manufacturer trade associations) DOE estimated the fraction of appliances of a given age still in operation. This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an estimate of the average and median appliance lifetime.

The Weibull distribution is a probability distribution function commonly used to measure failure rates.[37] Its form is similar to an exponential distribution, which would model a fixed failure rate, except that it allows for a failure rate which changes over time in a particular fashion. The cumulative distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{ and } P(x) = 1 \text{ for } x \leq \theta, \qquad \textbf{Eq. 8.2.8}$$

Where:

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

When $\beta = 1$, the failure rate is constant over time, and this distribution takes the form of a cumulative exponential distribution. For the case of appliances, β is commonly greater than 1, which results from a rising failure rate as the appliance ages. A plot of a Weibull distribution (DOE's calculated air conditioner survival function) with $\alpha = 20.29$, $\beta = 1.89$, and $\theta = 1.0$ is shown as Figure 8.2.5.

The RECS survey is DOE's primary resource for air conditioner and heat pump ages. For several appliances, including air conditioners, the survey asks respondents to place the appliance's age into one of these bins:

- less than 2 years;
- 2 to 4 years;
- 5 to 9 years;
- 10 to19 years and
- more than 20 years.

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

DOE used RECS appliance age data, AHS total installed stock data, and the history of appliance shipments to generate an estimate of the survival function. For example, DOE summed the total shipments from 5 to 9 years prior to the RECS survey, and compared this number with the number of units of those ages still in use, to calculate one approximation of the surviving appliance fraction within that age bin. The AHS total stock acts as an "all ages" bin. By combining the age bins from five RECS surveys and nine AHS surveys with shipments data,

DOE had enough data to build a fit to a Weibull distribution and find the parameters (α, β, θ) that best approximate the surviving units, using a least-squares method. Because the first two (youngest) RECS bin data tend to have a large scatter relative to the shipments in those years, DOE combined the RECS and shipments data in the first two bins. Generally, appliances do not tend to fail in large numbers during this period, so combining bins does not appreciably lower the accuracy of the shape of the distribution. DOE weighted each bin's contribution to the sum of squares by the inverse of the variance in the survey results, which controls for the changes in sample size between RECS bins, between RECS and AHS, and within each survey over time.[37] RECS and AHS have complicated error models; DOE used only the error due to finite sample size to determine the variance used to weight each data point's contribution. The error due to sampling is less than 1% for AHS survey data and is typically about 5% for RECS age bins. The equation for the sum of squares DOE minimized is therefore:

$$\sum_i \frac{\left(\boldsymbol{RECS}_i - \boldsymbol{Surv}_i\right)^2}{\sigma^2_{i,RECS}} + \sum_j \frac{\left(\boldsymbol{AHS}_j - \boldsymbol{Surv}_j\right)^2}{\sigma^2_{j,AHS}} \qquad \textbf{Eq. 8.2.9}$$

Where:

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

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

- DOE modeled the additional retirement of older appliances and their replacement by new ones that took place in the latter half of the survey year (after a given respondent had been surveyed), using the survival function. This had the effect of moving households from the older RECS age bins to the youngest age bin.
- For appliances installed directly in new construction, such as central air conditioners, DOE added units to the youngest RECS age bin and to the AHS total stock to represent half of the new construction for the final year of the survey, which were known to have installed the appliance type in question, using data from the U.S. Census for new construction starts.

- DOE assumed that 93% of appliances were installed in residences, while 7% were installed in commercial or other applications not counted by AHS or RECS.
- Households that shared an air conditioner were counted as owning half of one air conditioner, and households who reported owning more than one air conditioner were counted as owning two. (For AHS surveys before 1997, the number of air conditioners was not reported; DOE assumed a linear increase with time in the fraction of homes with two air-conditioning units.)

Assumptions

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

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

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

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

Central Air Conditioners

Table 8.2.44 shows the RECS and AHS data for air conditioners and the corresponding total shipments and best-fit Weibull calculation of stock by age bin. Figure 8.2.9 plots the data from the RECS portion of the third and fourth columns of Table 8.2.44 against each other to show the quality of the fit. Figure 8.2.10 plots the AHS survey total stock against the Weibull-based calculated stock. DOE allowed the delay parameter, θ, to vary only between 1 and 5 years, which corresponds to common warranty periods (see discussion below); for air conditioners and heat pumps the best fit within this range is 1 year. This Weibull distribution is characterized by the parameters $\alpha = 20.29$, $\beta = 1.89$, and $\theta = 1.0$, and shown in Figure 8.2.11. This distribution has a mean air conditioner lifetime of 19.01 years and a median lifetime of 17.70 years.

Table 8.2.44 Central Air Conditioners: Comparison of RECS and AHS with Modeled Stock

RECS 2005			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	23,384,298	21,121,201	23,202,596
5 to 9 yrs.	20,606,096	15,568,739	18,628,161
10 to 19 yrs.	26,252,849	15,840,393	16,908,120
20 or more yrs.	29,643,170	6,611,168	5,434,630
RECS 2001			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	20,833,446	16,179,828	20,669,235
5 to 9 yrs.	15,707,082	14,511,234	14,252,361
10 to 19 yrs.	20,982,218	14,367,204	13,670,285
20 or more yrs.	23,056,758	5,583,734	4,771,136
RECS 1997			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	16,822,938	12,213,941	16,697,701
5 to 9 yrs.	12,555,897	12,441,915	11,311,053
10 to 19 yrs.	16,825,109	10,799,049	10,843,901
20 or more yrs.	17,112,973	4,046,096	4,137,030
RECS 1993			
Age Bin	**Shipments**	**RECS Stock**	**Modeled stock**
0 to 4 yrs.	12,781,848	11,450,065	12,671,267
5 to 9 yrs.	10,579,559	9,198,439	9,572,156
10 to 19 yrs.	14,275,598	9,410,523	8,960,434
20 or more yrs.	11,535,301	3,727,973	3,257,844
RECS 1990			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	11,836,478	10,544,271	11,745,800
5 to 9 yrs.	7,930,531	7,343,580	7,200,298
10 to 19 yrs.	15,067,767	10,136,090	9,435,899
20 or more yrs.	6,644,873	3,025,410	1,897,721
AMERICAN HOUSING SURVEY			
Survey Year		**Adjusted AHS Stock**	**Modeled Stock**
2007		66,850,067	67,116,846
2005		63,023,984	64,173,507
2003		56,640,747	58,293,705
2001		54,080,318	53,363,017
1999		48,189,582	48,428,026

1997	41,173,857	42,989,684
1995	38,446,053	38,517,301
1993	35,072,816	31,793,586
1991	32,893,755	31,733,007

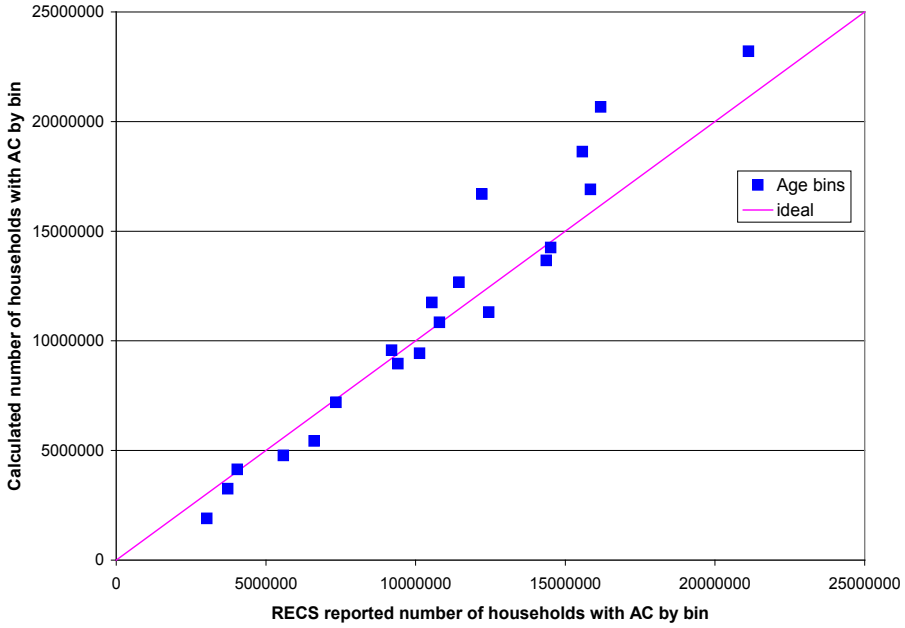

Figure 8.2.9 Comparison of DOE Modeled Air Conditioner Age Distribution with RECS Reported Stock

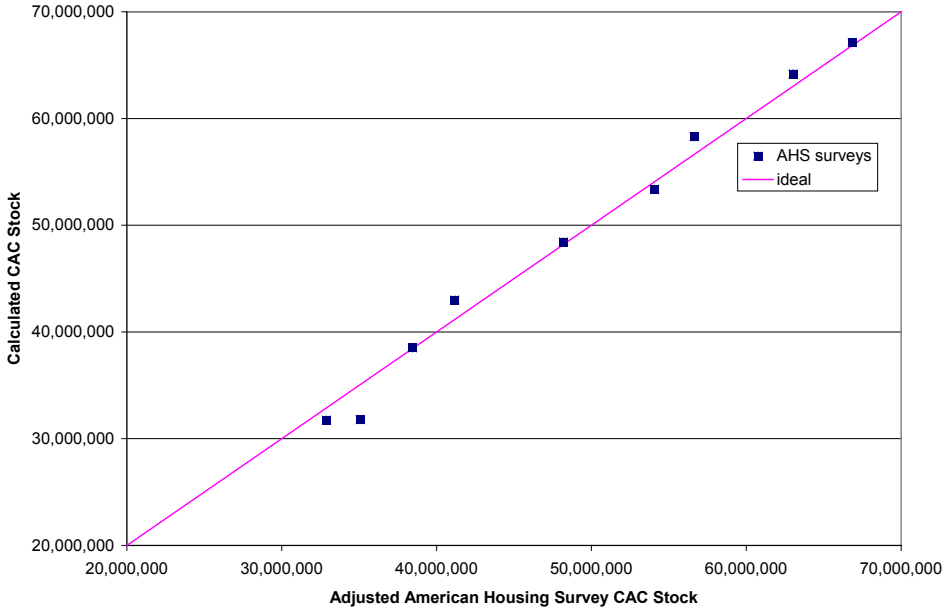

Figure 8.2.10 Comparison of DOE Modeled Total Air Conditioner Stock with Adjusted AHS Stock

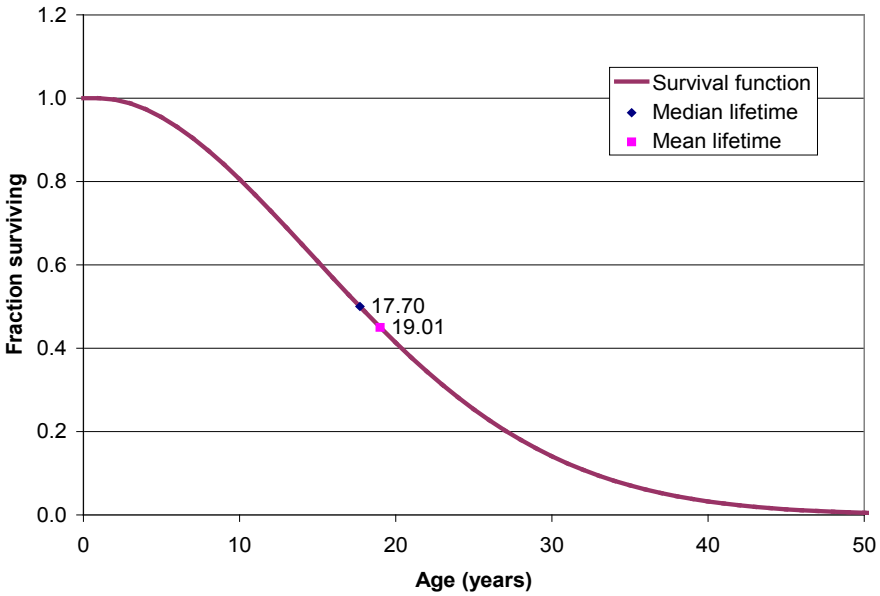

Figure 8.2.11 Central AC Survival Function, Characterized by Weibull Parameters α = 20.29, β = 1.89, and θ = 1.0.

Heat Pumps

DOE undertook a calculation for heat pumps that is very similar to the one it did for central air conditioners. The only difference between the heat pump and central air conditioner analyses was in the number of AHS survey years included. DOE found that when the heat pump stock analysis was done with AHS-reported stock from all nine AHS surveys between 1991 and 2007 with manufacturer-reported shipments history, an assumed unchanging heat pump lifetime, and an assumed 95% to 5% residential-to-commercial market split, the results were inconsistent. In the interest of timeliness and consistency, DOE chose to use only the most recent four surveys (2001, 2003, 2005, and 2007). Using only the most recent four AHS surveys, DOE was able to develop a consistent survival function. Figure 8.2.12 shows the AHS survey results plotted against the modeled stock and shows the contrast between earlier and more recent data.

The best-fit Weibull parameters for heat pump lifetime are α = 17.04, β = 1.64, and θ = 1.0. The resulting calculated mean heat pump lifetime is 16.24 years; the median lifetime is 14.63 years. Table 8.2.45 lists the (adjusted) heat pumps reported in each of the RECS age bins and AHS survey year, along with the modeled stock based on the best fit Weibull survival function and the manufacturer-provided shipments history. Figure 8.2.13 shows the survival function used in the life-cycle cost and national impact analyses.

Table 8.2.45 Heat Pumps: Comparison of RECS and AHS Stock to Stock Calculated from a Weibull Survival Function

RECS 2005			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	7,656,050	5,903,720	7,531,948
5 to 9 yrs.	5,437,867	4,186,956	4,545,002
10 to 19 yrs.	7,609,488	4,167,868	3,947,892
20 or more yrs.	5,421,606	1,172,137	947,223
RECS 2001			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	5,693,105	4,564,988	5,593,500
5 to 9 yrs.	4,318,866	3,641,519	3,626,504
10 to 19 yrs.	6,413,059	3,191,956	3,383,920
20 or more yrs.	3,320,977	1,273,838	622,144
RECS 1997			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	4,615,287	4,550,375	4,536,486
5 to 9 yrs.	3,500,621	3,871,200	2,914,225
10 to 19 yrs.	5,271,716	3,828,288	2,852,397
20 or more yrs.	1,671,785	575,473	319,727
RECS 1993			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	3,582,387	3,847,273	3,515,747
5 to 9 yrs.	3,514,244	3,043,034	2,938,354
10 to 19 yrs.	3,308,542	2,425,988	1,803,756
20 or more yrs.	822,935	523,705	139,039
RECS 1990			
Age Bin	**Shipments**	**RECS Stock**	**Modeled Stock**
0 to 4 yrs.	3,637,163	2,929,208	3,565,942
5 to 9 yrs.	2,494,052	3,030,644	2,112,769
10 to 19 yrs.	2,327,546	1,846,344	1,356,527
20 or more yrs.	600,009	168,614	111,330

AMERICAN HOUSING SURVEY		
Survey Year	**Adjusted AHS Stock**	**Modeled Stock**
2007	16,718,490	18,037,674
2005	16,130,513	16,123,461
2003	14,318,151	14,017,726
2001	13,653,239	12,564,764
1999	13,331,680	11,290,213
1997	13,658,054	10,091,692
1995	11,460,574	8,980,076
1993	10,412,946	7,977,051
1991	9,349,377	7,165,773

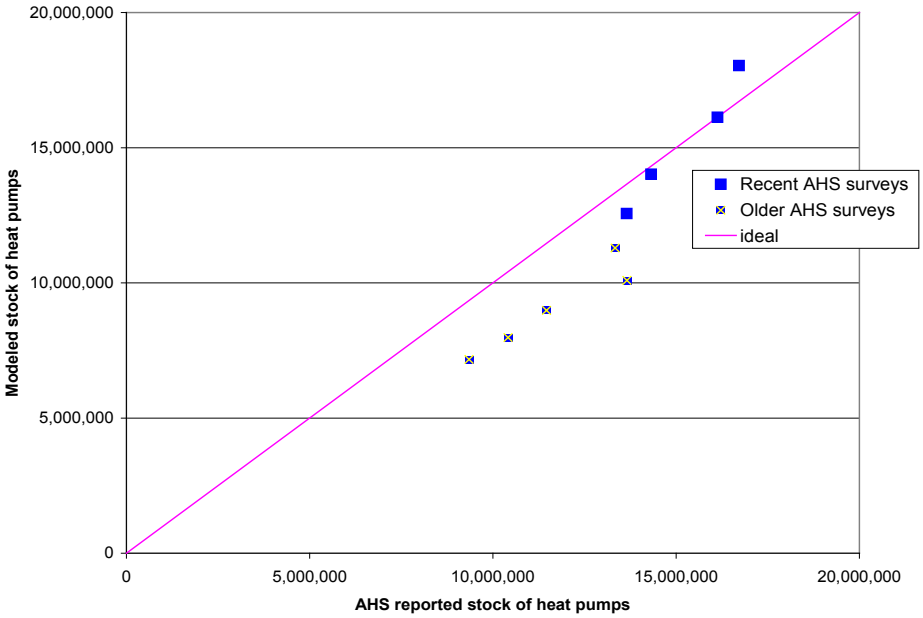

Figure 8.2.12 Comparison of DOE Modeled Total Heat Pump Stock with Adjusted AHS Stock

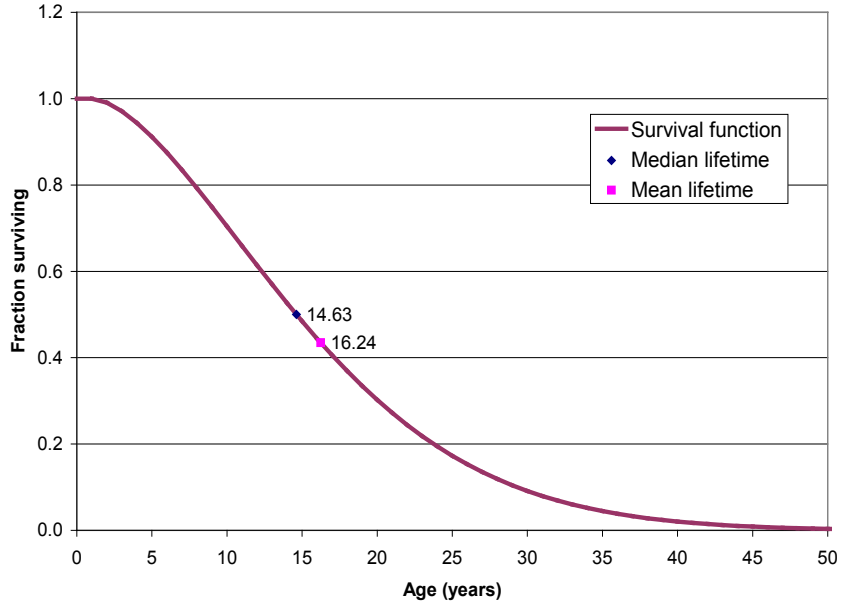

Figure 8.2.13 Heat Pump Survival Function, Characterized by Weibull Parameters $\alpha = 17.04$, $\beta = 1.64$, and $\theta = 1.0$

Furnaces

Similar to central air conditioners and heat pumps, furnace lifetime is derived from RECS, AHS, and shipments data. The 2008 American Comfort Survey was also used to increase the accuracy of the estimate. Table 8.2.46 shows the minimum, median, and average lifetime, as well as the Weibull distribution parameters alpha and beta for furnaces.

Table 8.2.46 Lifetime parameter for Furnaces

Product Class	Weibull Parameters				
	Minimum *years*	**Median** *years*	**Average** *years*	**Alpha (scale)**	**Beta (shape)**
Non-Weatherized Gas Furnaces	1	22.6	23.6	26.7	2.218
Manufactured Home Gas Furnaces	1	16.9	18.7	21.0	1.682
Oil-Fired Furnaces	1	26.3	26.5	29.7	3.019

8.2.3.6 Discount Rate

The discount rate is the rate at which future expenditures are discounted to establish their present value. DOE derived the discount rates for the LCC analysis by estimating the cost of capital for individuals and companies that purchase central air conditioner or furnace products.

In the case of individual households, the financing of purchasing products installed in new homes is different from the financing of appliances bought directly by consumers *(i.e.*, as a replacement for a failed unit or as a new purchase for an existing household that does not already own the appliance). Thus, DOE used different discount rates for these residential purchases.

Residential Discount Rates for Products Purchased in Existing Households

Households use various methods to finance the purchase of major appliances. In principle, one could estimate the interest rates on the actual financing vehicles used to purchase appliances. However, the frequency with which each financing vehicle is used to purchase an appliance is unknown.

DOE's approach involved identifying all possible debt or asset classes that might be used to purchase the considered appliances, including household assets that might be affected indirectly.[e] DOE excluded debt from primary mortgages and the equity of assets considered non-liquid (such as retirement accounts), because those financing methods are unlikely to be used by households in existing housing to purchase appliances. DOE estimated the average percentage shares of the various types of debt and equity in the average U.S. household using data from the

[e] An indirect effect would arise if a household sold assets in order to pay off a loan or credit card debt that might have been used to finance the appliance purchase.

Federal Reserve Board's *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[38] Table 8.2.47 shows the average percentages of each considered type of debt or equity. DOE derived the mean percentages of each source of financing for the 7 years surveyed.

Table 8.2.47 Types of Household Debt and Equity by Percentage Shares

Type of Debt or Equity	Distribution %							
	1989	1992	1995	1998	2001	2004	2007	Mean
Home equity loan	4.3	4.5	2.7	2.8	2.8	4.4	4.6	3.7
Credit card	1.6	2.1	2.6	2.2	1.7	2.0	2.4	2.1
Other installment loan	2.8	1.7	1.4	1.7	1.1	1.3	1.1	1.6
Other residential loan	4.4	6.9	5.2	4.3	3.1	5.8	7.1	5.3
Other line of credit	1.1	0.6	0.4	0.2	0.3	0.5	0.3	0.5
Checking account	5.8	4.7	4.9	3.9	3.6	4.2	3.4	4.4
Savings or money market account	19.2	18.8	14.0	12.8	14.2	15.1	13.0	15.3
Certificate of deposit	14.5	11.7	9.4	7.0	5.4	5.9	6.5	8.6
Savings bond	2.2	1.7	2.2	1.1	1.2	0.9	0.7	1.4
Bonds	13.8	12.3	10.5	7.0	7.9	8.4	6.7	9.5
Stocks	22.4	24.0	25.9	36.9	37.5	28.0	28.6	29.0
Mutual funds	8.0	11.1	20.9	20.1	21.3	23.4	25.5	18.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.

DOE also estimated interest or return rates associated with each type of equity and debt. The source for interest rates for loans, credit cards, and lines of credit was the Federal Reserve Board's SCF for 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Table 8.2.48 shows the average nominal rates in each year and the inflation factors used to calculate real rates. DOE calculated effective interest rates for home equity loans in a similar manner as for mortgage rates, because interest on both such loans is tax deductible. Table 8.2.49 shows the average effective real rates in each year and the mean rate across years. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2016.

Table 8.2.48 Average Nominal Interest Rates for Household Debt

Type of Debt	Average Nominal Interest Rate %							
	1989	1992	1995	1998	2001	2004	2007	Mean
Home equity loan	11.5	9.6	9.6	9.8	8.7	5.7	6.3	7.9
Credit card*	-	-	14.2	14.5	14.2	11.7	7.9	9.0
Other installment loan	9.0	7.8	9.3	7.8	8.7	7.4	12.6	13.4
Other residential loan	8.8	7.6	7.7	7.7	7.5	6.0	10.4	8.6
Other line of credit	14.8	12.7	12.4	11.9	14.7	8.8	6.3	7.4
Inflation rate	4.82	3.01	2.83	1.56	2.85	2.66	2.85	

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.
* No data on interest rates available for credit cards in 1989 or 1992.

Table 8.2.49 Average Real Effective Interest Rates for Household Debt

Type of Debt	Average Real Effective Interest Rate %							
	1989	1992	1995	1998	2001	2004	2007	Mean
Home equity loan	3.8	4.3	4.4	5.8	3.8	1.9	2.1	3.0
Credit card*	-	-	11.0	12.7	11.1	9.1	3.3	3.9
Other installment loan	4.9	5.8	7.0	6.6	6.1	5.4	9.7	10.7
Other residential loan	4.0	4.7	4.8	6.0	4.6	3.3	5.8	6.0
Other line of credit	9.6	9.4	9.3	10.2	7.3	6.0	3.4	4.4

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.
* No data on interest rates available for credit cards in 1989 or 1992.

No similar rate data are available from the *SCF* for classes of assets, so the Department derived that information from national historical data. The interest rates associated with certificates of deposit,[39] savings bonds,[40] and bonds (AAA corporate bonds)[41] were collected from Federal Reserve Board time-series data for 1977–2008. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts came from Cost of Savings Index data covering 1984–2008.[42] The rates for stocks are the annual returns on the Standard and Poor's 500 for 1977–2008.[43] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year for 1977–2008. DOE adjusted the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.50. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2016.

Table 8.2.50 Average Nominal and Real Interest Rates for Household Equity

Type of Equity	Average Nominal Rate %	Average Real Rate %
Checking account	-	0.0
Savings and money market accounts	5.4	2.2
Certificate of deposit	6.6	2.3
Savings bond	7.7	3.3
Bonds	8.5	4.1
Stocks	11.6	7.1
Mutual funds	10.3	5.8

Table 8.2.51 summarizes the mean real effective rates of each type of equity or debt. DOE determined the average percentage of each type of debt and asset using *SCF* data for 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Each year of SCF data provides the percents of debts and assets for U.S. households. DOE averaged those percentages for the 7 years of survey data to

arrive at the percentages shown in Table 8.2.51. The average rate across all types of household debt and equity, weighted by the percentages of each type, is 4.8 percent.

Table 8.2.51 Average Interest on Household Debt and Equity

Type of Debt or Equity	Average Percentage of Household Debt plus Equity %*	Mean Effective Real Rate %**
Home equity loan	3.7	3.9
Credit card	2.1	10.7
Other installment loan	1.6	6.0
Other residential loan	5.3	4.4
Other line of credit	0.5	8.8
Checking account	4.4	0.0
Savings and money market account	15.3	2.2
Certificate of deposit	8.6	2.3
Savings bond	1.4	3.3
Bonds	9.5	4.1
Stocks	29.0	7.1
Mutual funds	18.6	5.8
Total/weighted-average discount rate	100.0	4.8

* Not including primary mortgage or retirement accounts.

** Adjusted for inflation and, for home equity loans, tax deduction of interest.

DOE developed a normal probability distribution of interest rates for each asset type by using the mean value and standard deviation from the distribution. To account for variation among households, DOE sampled a rate for each household from the distributions for the appropriate asset class. Appendix 8-C presents the probability distributions for each class that DOE used in the LCC and PBP analyses.

Residential Discount Rates for Products Installed in New Housing

Appliances installed in new homes ("new-housing appliances") are purchased as part of the home, which is almost always financed with a mortgage loan. DOE estimated discount rates for new-housing appliances using the effective real (after-inflation) mortgage rate for homebuyers. This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation (using the Fisher formula).[f] For example, a 6% nominal mortgage rate has an effective nominal rate of 4.5% for a household at the 25% marginal tax rate. When adjusted for an inflation rate of 2%, the effective real rate becomes 2.45%.

The data sources DOE used for mortgage interest rates were the SCF in 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Using the appropriate SCF data for each year, DOE adjusted

[f] Fisher formula is given by: Real Interest Rate = [(1 + Nominal Interest Rate) / (1 + Inflation Rate)] – 1.

the mortgage interest rate for each relevant household in the SCF for mortgage tax deduction and inflation (see Table 8.2.52). In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

The average nominal mortgage rate carried by homeowners in these 6 years was 7.9%. Since the mortgage rates carried by households in these years were established over a range of time, DOE believes they are representative of rates that may apply when amended standards take effect. After adjusting for inflation and interest tax deduction, effective real interest rates on mortgages across the six surveys averaged 3.0%.

Table 8.2.52 Data Used to Calculate Real Effective Mortgage Rates

Year	Mortgage Interest Rates in Selected Years %			
	Average Nominal Interest Rate	Inflation Rate[44]	Marginal Tax Rate Applicable to Mortgage Interest[45]	Average Real Effective Interest Rate
1989	9.7	4.82	24.3	2.4
1992	9.1	3.01	23.4	3.8
1995	8.2	2.83	24.1	3.3
1998	7.9	1.56	23.9	4.4
2001	7.6	2.85	22.9	2.9
2004	6.2	2.66	20.6	2.2
2007	6.3	2.85	21.6	2.1
Average	7.9			**3.0**

To account for variation among households, DOE sampled a rate for each household in the RECS samples from a distribution of mortgage rates. DOE developed the distribution based on the SCF data. Appendix 8-C presents the probability distribution that DOE used in the LCC and PBP analyses.

Commercial Discount Rate

The commercial discount rate for central air conditioners is estimated using cost of capital data for firms that might occupy or rent out office space in small office buildings. DOE estimated the cost of equity using the capital asset pricing model (CAPM). The CAPM assumes that the cost of equity (k_e) for a particular company is proportional to the systematic risk faced by that company, where high risk is associated with a high cost of equity and low risk is associated with a low cost of equity. The systematic risk facing a firm is determined by several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (ERP). The risk coefficient of the firm indicates the risk associated with that firm relative to the price variability in the stock market. The expected return on risk-free assets is defined by the yield on long-term government bonds. The ERP represents the difference between the expected stock market return and the risk-free rate.

Described below, DOE estimates the cost of equity for each sector with the CAPM model as follows:

$$k_e = R_f + (\beta \bullet ERP) \qquad \textbf{Eq. 8.2.10}$$

Where:

k_e = the cost of equity,

R_f = the expected return of the risk-free asset (long term treasury bonds), and

β = the beta of the sector, and ERP is the expected equity risk premium.

Calculations were performed using data available on β for individual U.S. commercial companies, estimated market ERP from a 40-year rolling geometric average of the Standard and Poor's 500 stock index from Damodaran Online,[46] and 40-year rolling average of long term treasury bond rates for R_f from the Federal Reserve (6.88 percent in 2009),[47, 48] DOE calculated the cost of equity k_e for each firm. The difference for 2009 was 3.07%.

The cost of debt financing (k_d) is the interest rate paid on money borrowed by a company. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate.

$$k_d = R_f + R_a, \qquad \textbf{Eq. 8.2.11}$$

Where:

k_d = the cost of debt financing for each firm,

R_f = the expected return on risk-free assets, and

R_a = is the risk adjustment factor to risk-free rate for each firm.

The risk adjustment factor depends on the variability of stock returns represented by standard deviations in stock prices and was taken from Damodaran Online weighted average cost of capital worksheets for 2001–2008.

Finally, as inflation has already been accounted for in both the cost of debt and the cost of equity, the real weighted average cost of capital $WACC_r$ (real discount rate) is calculated as follows:

$$WACC_r = k_e \bullet w_e + k_d \bullet w_d \qquad \textbf{Eq. 8.2.12}$$

Where:

k_e = the cost of equity,

w_e = the percent of equity financing,

k_d = the cost of debt, and

w_d = the percent of debt financing.

The discount rate is estimated for each firm for 2009, based on January 2010 data. The source of cost of capital data that are used in the calculations are individual company data from Damodaran Online's Data Page. DOE used Damodaran Online data from the SIC categories with Standard Industrial Classification (SIC) 6000-9975, with the exception of Hotels and Gaming (SIC code 7000). Broadly speaking, this includes all of the commercial subsectors that could occupy small offices that might use a residential-sized central air conditioner. The sample includes 1,816 companies with usable data. It includes both large and small companies, because it is not clear that small offices necessarily would be occupied or owned by an entity that was also a small business. The weighted average cost of capital for this sample of U.S. companies was 8.85%. Nominal rates for individual firms in the January 2010 sample varied from 3.54% to 13.40%, which were fitted to a normal distribution truncated at 0 to prevent negative rates. The standard deviation of the statistical sample was 1.21%. Adjusted for the long-term expected inflation rate of 1.8% percent from the January 2010 FY 2011 U.S. Government Budget supporting documention,[48] the inflation- and risk-adjusted discount rate was 6.93%, which is used as the average real discount rate for central air conditioners purchased for small offices.

8.2.3.7 Effective Date of Standard

The effective date is the future date when a new standard becomes operative. Pursuant to 42 U.S.C. 6295(m), the effective date of any new energy efficiency standard for central air conditioner and furnace equipment will be 5 years after the final rule is published. DOE calculated the LCC for all customers as if they each would purchase a new air conditioner or heat pump in the year the standard takes effect. Consistent with its published regulatory agenda, DOE assumed that the final rule would be issued in 2011 and that, therefore, the new standards would take effect in 2016 and used these dates in the NOPR analyses. It based the cost of the equipment on this year; however, all dollar values are expressed in constant 2009$. Annual energy prices are included for the life of the central air conditioner, heat pump, or furnace.

8.2.3.8 Base Case Distribution of Efficiency Levels

DOE did not have access to sales data describing the actual distribution of efficiencies in current sales, nor was such information provided by industry for this rulemaking. As a consequence, DOE developed estimates of the distribution of SEER levels for four classes of product: split-system CAC, single-package CAC, split-system HP, and single-package HP. The development of these distributions was based on the following key data inputs:

- From AHRI data, the average SEER of equipment sold in each product class in 2006 as well as the relative shipments by product class for the market as a whole.
- An industry trade press article that indicated approximate sales segmentation by SEER for the CAC and HP industry in 2007.[49]
- AHRI Directory of Certified Product Performance,[50] which allowed review of specific efficiencies sold into the market for each product class.

According to the trade press article, the distribution in 2007 had approximately 9% of sales at 14 SEER, 3% of sales at 15 SEER, 2% at 16 SEER, and 2% for 17 SEER. The remainder of the product sales was assumed to fall below 14 SEER.

According to AHRI data,[51] product sales in 2007 were as follows: 63.0% percent split-system CAC, 5.9% single-package central air conditioner, 27.6% split-system HP, and 3.5% single-package HP Product sales in 2008 through September were as follows: 63.0% split-system CAC, 4.8% single-package CAC, 28.8% split-system HP, and 3.4% single-package HP. AHRI reported average shipped SEER by product class for 2007: split-system central air conditioner, 13.72; single-package CAC, 12.83; split-system HP, 13.86; single-package HP 13.16. DOE did not know if the average 12.83 for single-package CAC represented continued sales of pre-SEER 13 equipment or if it included through-the-wall or other classes with lower efficiency. As these data were provided by AHRI for this rulemaking, it was assumed to be representative of single-phase equipment only. AHRI reported average shipped SEER for 2008 and 2009 as: split-system CAC, 13.77 and 13.90; single-package CAC, 13.02 and 13.41; split-system HP, 13.99 and 14.25; single-package HP, 13.41 and 13.73.

DOE first created 16 SEER bins corresponding roughly to the SEER efficiency levels developed in the engineering analysis, with those levels serving as a representative efficiency for each bin. These bins are shown in Table 8.2.53. Then, through an iterative process that took into account available efficiency levels in each product class, DOE developed an efficiency distribution for each product class that was consistent with the above data sources in that it provided average efficiency by split-system CAC, split-system HP, and single-package HP product class as reported by AHRI in 2007, as well as provided an overall distribution by SEER that corresponded with the industry trade press article cited above. Bins that included 14 and 15 SEER were assumed to be uniformly distributed efficiencies above and below the characteristic efficiency in the bin. It was obviously not possible to develop a shipment-weighted efficiency below 13 SEER as was seen for single-package central air conditioner using this distribution. Instead DOE chose to match the 2008 shipment weighted average value for this product class. The estimated distribution for all classes for 2007 is shown in Table 8.2.53.

Table 8.2.53 CAC and HP Efficiency Distributions Estimated for 2007

SEER Bins			SEER Distribution by Equipment Class				Industry-Wide SEER Distribution (Four Classes) %
Bottom of Bin	Top of Bin	Characteristic Efficiency in Bin	Split CAC %	Single Package CAC %	Split HP %	Single Package HP %	
13	13.25	13	25.00	76.20	15.00	76.20	27.07
13.25	13.75	13.5	56.00	18.80	57.00	18.80	52.77
13.75	14.25	14	6.00	2.00	8.00	2.00	6.18
14.25	14.75	14.5	2.50	2.00	7.50	2.00	3.83
14.75	15.25	15	3.00	1.00	5.00	1.00	3.36
15.25	15.75	15.5	2.00	0.00	2.00	0.00	1.81
15.75	16.5	16	3.10	0.00	2.00	0.00	2.50
16.5	17.5	17	1.00	0.00	1.50	0.00	1.04
17.5	18.5	18	0.60	0.00	1.50	0.00	0.79
18.5	19.5	19	0.30	0.00	0.50	0.00	0.33
19.5	20.5	20	0.20				0.13
20.5	21.5	21	0.20				0.13
21.5	22.5	22	0.10				0.06
22.5	23.5	23					
23.5	24.5	24					
24.5	25.5	24.5					
Wt. Average SEER			13.71	13.16	13.85	13.16	13.70
				13.66		13.78	

DOE was not able to develop a distribution using the same methodology for the 2008 and 2009 data that would be consistent with the industry trade press article overall distribution. DOE made slight changes to the relative shipment weights by efficiency bin from the 2007 distribution, in order to match the higher average SEERs in 2008 and 2009 while maintaining the general flavor of the distribution by product class.

To establish an efficiency distribution in 2016, the anticipated compliance date of the rule, DOE first developed an estimate of the sales-weighted efficiency for each product class in 2016. To estimate the change in sales–weighted efficiency up through 2016, , DOE first used data provided by AHRI which demonstrated the growth in the average SEER of CAC and HP equipment from 2006 to 2009. As evidenced in Table 8.2.54, the efficiency growth for each product class was significant, ranging from 0.75 to 1.02 SEER. DOE attributed this rapid efficiency growth to federal manufacturer tax credits for the production and sale of high efficiency household space-conditioning equipment. Because the latest federal tax credits are not set to expire until the end of 2011, DOE estimated the average SEER of CAC and HP equipment would continue to grow at the rate observed between 2006 and 2009 through 2011. Table 8.2.54 provides the estimated average SEER for 2010 and 2011 based on the 2006 to 2009 growth rates. After 2011, DOE assumed that the sales-weighted efficiency for each class would return to the growth rate trend they would have been on without the 2006 to 2011 tax credits. DOE established the 2016 sales-weighted efficiencies by using the efficiency growth rate by product class between 1992-2003 and applying it to the sales-weighted efficiencies in 2006. DOE considered only the 1993 to 2002 time period to forecast sales-weighted efficiency growth

rates in order to factor out: (1) any lingering effects on equipment efficiencies from industry efforts to comply with the 1992 standards; (2) any anticipatory efforts by the industry to comply with the 2006 standards that DOE issued in 2001; and (3) the effects of the 2006 to 2011 tax credits to promote the purchase of high-efficiency central air conditioners and heat pumps. DOE assumed that market pull programs in existence during 1992-2003 are more reflective of typical market-pull effectiveness, i.e., the 2006 to 2011 tax credits are seen as extraordinarily aggressive. Application of the 1992-2003 growth rates results in a significant drop in sales weighted efficiency from 2011 to 2012 as shown in Table 8.2.54. A detailed discussion of the historical sales-weighted efficiencies is presented in chapter 10, section 10.2, National and Regional Impact Analyses.

Table 8.2.54 CAC and HP Average SEER Values for 2006 through 2016

Year	Split CAC	Single Package CAC	Split HP	Single Package HP
2006	13.16	12.39	13.45	12.74
2007	13.72	12.83	13.86	13.16
2008	13.77	13.02	13.99	13.41
2009	13.90	13.41	14.25	13.73
2010*	14.16	13.77	14.53	14.08
2011*	14.42	14.14	14.81	14.43
2012**	13.60	12.92	13.85	13.23
2013**	13.68	13.01	13.92	13.31
2014**	13.76	13.11	13.98	13.40
2015**	13.83	13.20	14.05	13.48
2016**	13.91	13.29	14.12	13.56

*Estimated based on average growth rate from 2006 through 2009.
** Estimated using efficiency growth trend from 1992-2003 applied to 2006 average SEER values.

Based on the average SEER of equipment for 2016, DOE redistributed the distribution of efficiencies that it determined for 2007 to match the average SEER in 2016 for each product class. The resulting efficiency distributions are shown in Table 8.2.55.

Note that in Table 8.2.55 the efficiency distribution for SDHV systems is also reported. DOE was not provided with any efficiency data for SDHV systems and therefore estimated that the entire market is currently at an efficiency of 13 SEER.

DOE did not have similar data on space heating efficiencies for HP equipment. For analysis of the market baseline HSPF efficiencies, DOE used the HSPF values that corresponded to each HP SEER level as identified in the engineering analysis. Because these engineering levels represented typical market averages based on the AHRI data, they were deemed sufficient for characterizing average market HSPF by SEER level and corresponding average HP heating energy use in the market baseline.

See chapter 10, section 10.2, National and Regional Impact Analyses for details of forecasted changes in efficiency distributions.

Table 8.2.55 Central Air Conditioners and Heat Pumps: 2016 Market Distribution of Efficiency Levels by Product Class

Bin	Assumed Average SEER in Bin	Split-System AC %		Split-System HP %	Single Package AC %	Single Package HP %	Small-Diameter High Velocity AC %
		Coil-Only	Blower-Coil				
1	13.0	24.62	18.46	13.00	62.70	32.10	100.00
2	13.5	48.21	36.15	40.00	20.00	32.00	NA
3	14.0	4.10	3.08	10.00	14.30	28.90	NA
4	14.5	7.44	5.58	13.00	2.00	5.00	NA
5	15.0	5.90	4.42	11.50	1.00	2.00	NA
6	15.5	2.05	1.54	3.50	0.00	0.00	NA
7	16.0	7.18	5.39	5.00	0.00	0.00	NA
8	16.5	0.51	0.39	2.00	NA	NA	NA
9	17.0	NA	10.00	1.50	NA	NA	NA
10	18.0	NA	7.00	0.50	NA	NA	NA
11	19.0	NA	3.00	NA	NA	NA	NA
12	20.0	NA	2.00	NA	NA	NA	NA
13	21.0	NA	2.00	NA	NA	NA	NA
14	22.0	NA	1.00	NA	NA	NA	NA
15	23.0	NA	NA	NA	NA	NA	NA
16	24.5	NA	NA	NA	NA	NA	NA

For non-weatherized furnaces, AHRI provided historical shipments data showing the fraction of sales of condensing (90% AFUE and above) products from 1994 though 2009. The fraction of sales was provided at a national level as well as regionally (i.e., for the North and South). To estimate the market baseline fraction of condensing units in 2010, DOE used the growth in the share of condensing units from 2006 to 2009. As evidenced in Table 8.2.56, the growth rate was significant. DOE attributed this rapid efficiency growth to federal manufacturer tax credits for the production and sale of high efficiency household space-conditioning equipment. Because the latest federal tax credits are not set to expire until the end of 2011, DOE estimated that the market share of condensing equipment would continue to grow at the rate observed between 2006 and 2009 through 2011. Table 8.2.57 provides the estimated fraction of condensing equipment for 2010 and 2011 based on the 2006 to 2009 growth rates. After 2011, DOE assumed that the market share of condensing equipment would return to the growth rate trend they would have been on without the 2006 to 2011 tax credits. DOE established the 2016 fraction of condensing equipment by using the growth rate between 1994-2005 and applying it to the condensing equipment fraction in 2011. DOE considered only the 1994 to 2005 time period to forecast thr condensing equipment market share growth rate in order to factor out the lingering effects of new furnace standards that required compliance in 1992 as well as the effects of the 2006 to 2011 tax credits to promote the purchase of high-efficiency condensing furnaces. DOE assumed that market pull programs in existence during 1994-2005 are more reflective of typical

market-pull effectiveness, i.e., the 2006 to 2011 tax credits are seen as extraordinarily aggressive. Application of the 1994-2005 growth rate results in a significant drop in condensing equipment market share from 2011 to 2012 as shown in Table 8.2.56. A detailed discussion of the historical sales-weighted efficiencies is presented in chapter 10, section 10.2, National and Regional Impact Analyses.

Table 8.2.56 Non-Weatherized Gas Furnace Fraction of Condensing Unit Sales for 2006 through 2016

Year	National	North	South
2006	36.5%	54.2%	19.9%
2007	37.1%	53.0%	21.2%
2008	43.3%	59.2%	24.2%
2009	50.2%	67.6%	29.0%
2010*	54.1%	71.7%	31.7%
2011*	58.0%	75.8%	34.3%
2012**	41.2%	62.6%	22.2%
2013**	42.1%	64.2%	22.8%
2014**	43.1%	65.9%	23.3%
2015**	44.1%	67.5%	23.8%
2016**	45.0%	69.1%	24.4%

*Estimated based on average growth rate from 2006 through 2009.
** Estimated using efficiency growth trend from 1994-2005 applied to 2006 condensing equipment market share.

DOE disaggregated the non-weatherized gas furnace condensing market share into specific efficiency levels based on model availability as specified in the AHRI Directory of Certified Product Performance. DOE assumed that the market share of non-condensing equipment was entirely at 80% AFUE. The resulting efficiency distribution for 2016 is shown in Table 8.2.57.

Note that in Table 8.2.57 efficiency distributions for mobile home gas and oil furnaces are also reported. DOE was not provided with any efficiency data for this furnace equipment. Therefore, DOE estimated the distribution of efficiencies based solely on model availability as specified in the AHRI Directory of Certified Product Performance.

See chapter 10, section 10.2, National and Regional Impact Analyses for details of forecasted changes in efficiency distributions.

Table 8.2.57 Furnaces: 2016 Market Distribution of Efficiency Levels by Product Class

Bin	Non-Weatherized Gas				Mobile Home Gas		Oil	
	Assumed Average AFUE in Bin	National %	North %	South %	Assumed Average AFUE in Bin	National %	Assumed Average AFUE in Bin	National %
1	80	48.1	29.1	75.9	80%	90.5	82%	41.7
2	90	10.0	13.7	4.4	90%	2.0	83%	19.7
3	92	24.6	33.6	11.5	92%	4.0	84%	5.6
4	95	16.9	23.0	7.9	96%	3.5	85%	32.1
5	98	0.4	0.6	0.3	-	-	97%	0.9

For non-weatherized gas furnaces, basecase efficiencies are assigned to each household randomly depending on the census division or large state as shown in Table 8.2.58.

Table 8.2.58 Basecase Distribution of Furnaces by Region (2016)

Division or large state	80% AFUE	90% AFUE	92% AFUE	95% AFUE	98% AFUE
1	4.2	18.5	45.7	30.9	0.7
2	25.7	14.3	35.5	24.0	0.6
3	26.5	14.2	35.0	23.7	0.5
4	20.9	15.3	37.7	25.5	0.6
5 (South)	55.9	8.5	21.0	14.2	0.3
5 (North)	5.0	18.3	45.3	30.6	0.7
6	54.2	8.8	21.8	14.8	0.3
7	90.6	1.8	4.5	3.0	0.1
8 (North)	60.5	7.6	18.8	12.7	0.3
8 (South)	81.2	3.6	9.0	6.1	0.1
9 (North)	57.7	8.2	20.2	13.6	0.3
9 (South)	37.3	12.1	29.9	20.2	0.5
10	37.7	12.0	29.7	20.1	0.5
11	82.1	3.4	8.5	5.8	0.1
12	93.5	1.3	3.1	2.1	0.0
13	96.0	0.8	1.9	1.3	0.0

8.3 PAYBACK PERIOD INPUTS

8.3.1 Definition

The PBP is the amount of time it takes the customer to recover the assumed higher purchase cost of more energy-efficient equipment as a result of lower operating costs.

Numerically, the PBP is the ratio of the increase in purchase cost (*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 it does not take into account changes in the operating cost value of money—that is, the calculation is done at an effective discount rate of 0 percent.

The equation for PBP is:

$$PBP = \Delta IC / \Delta OC \qquad \textbf{Eq. 8.3.1}$$

Where:

PBP = payback period in years,
Δ IC = difference in the total installed cost between the more efficient standard-level equipment (efficiency levels 2, 3, etc.) and the baseline efficiency equipment, and
ΔOC = difference in first year annual operating costs.

Payback periods are expressed in years. Payback periods greater than the life of the equipment mean that the increased total installed cost of the more efficient equipment is not recovered fast enough in reduced operating costs.

DOE also calculates a rebuttable PBP, which is the time it takes the consumer to recover the assumed higher purchase cost of more energy-efficient equipment as a result of lower energy costs. Numerically, the rebuttable PBP is the ratio of the increase in purchase cost (*i.e.*, from a less efficient design to a more efficient design) to the decrease in annual energy expenditures; that is, the difference in first year annual energy cost as calculated from the DOE test procedure. The calculation excludes repair costs and maintenance costs. This type of calculation also is a "simple" payback period.

8.3.2 Inputs

The data inputs to PBP are the total installed cost of the equipment to the customer for each efficiency level and the annual (first year) operating costs for each efficiency level. The inputs to the total installed cost are the equipment price and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost (or in the case of rebuttable PBP, only the annual energy cost). The PBP uses the same inputs as the LCC analysis described in section 8.2, except that electricity price trends and discount rates are not required. Since the PBP is a "simple" (undiscounted) payback, the required electricity cost is only for the year in which a new efficient standard is to take effect—in this case, the year 2016. The electricity price used in the PBP calculation was the price projected for 2016, expressed in 2009$. Discount rates are not used in the PBP calculation.

8.4 LCC AND PBP RESULTS

This section presents the LCC and PBP results for residential CAC, HPs, and furnaces that are used in residential and commercial (small office) applications. As discussed in section 8.1.1, DOE's approach for conducting the LCC and PBP analysis relied on developing samples of households that use each of the products. DOE also characterized the uncertainty of many of the inputs to the analysis with probability distributions. DOE used a Monte Carlo simulation technique to perform the LCC and PBP calculations on the households in the sample. For each set of sample households using the equipment in each product class, DOE calculated the average LCC and LCC savings and the median and average PBP for each of the efficiency levels. These efficiency levels are also referred to as candidate standard levels (CSLs).

DOE calculated LCC savings and PBPs relative to the market baseline equipment that it assigned to the households and commercial consumers. In some cases, DOE assigned market baseline equipment that is more efficient than some of the CSLs. For that reason, in those cases the average LCC impacts are not equal to the difference between the LCC of a specific CSL and the LCC of the market baseline equipment.

LCC and PBP calculations were performed 10,000 times on the sample of households established for each residential product. Each LCC and PBP calculation was performed on a single household that was selected from the sample of the residential observations or alternatively, from one of the commercial buildings using the CAC or HP equipment. The first sampling conducted was based on the probability of whether the given observation was a residential or a commercial application. The probability of a residential observation was 93%, while that of a commercial observation was 7%. If the observation was residential, then the selection of a household was based on its sample weight (*i.e.*, how representative a particular household is of other households in the distribution—either regionally or nationally) in the 2005 RECS Public Use Sample, as described in chapter 7 of the TSD. Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

For the commercial applications, DOE sampled from commercial small office building simulations using weights representative of 526 combinations of Typical Meteorological Year (TMY) weather file and state. The weights assigned were population weights assigned to each combination as described in chapter 7.

Based on the Monte Carlo simulations that DOE performed, for each standard level, DOE calculated the share of households and commercial consumers receiving a net LCC benefit, a net LCC cost, and no impact. DOE considered a household or commercial user to receive no impact at a given standard level if DOE assigned it base case equipment whose efficiency is the same as, or is more than, the CSL.

8.4.1 Split-System Air Conditioners

This section presents summary LCC results for the efficiency improvement levels specified in the engineering analysis (chapter 5) and also presented in section 8.2.2.3, Standard-

Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs, repair costs, and maintenance costs developed for each individual observation. Section 8.2 presents the electricity price inputs, as well as all other LCC inputs.

As stated earlier, DOE used the Monte Carlo method of analysis relying on Crystal Ball (*i.e.*, random sampling from distributions) to conduct the LCC analysis. The results presented here are based on 10,000 samples per Monte Carlo run. DOE's first step in developing LCC results was to establish the market baseline LCC for each of the product classes. The baseline efficiency level in each region is SEER 13, but LCC savings and PBP are calculated only for the consumers affected by the regulation at each efficiency level. Particularly at lower efficiency standards, significant numbers of consumers would have bought products more efficient than those required by the standard and would not have been affected by the regulation.

8.4.1.1 Mean LCC Savings for Split-System Air Conditioners by Region

Because the values of most inputs are uncertain in this analysis, DOE represents them as a distribution of values rather than a single-point value. Thus, DOE also represents the LCC results as a distribution of values. Before proceeding with the presentation of the distribution of LCC results, DOE presents average values for LCC savings to show how these savings vary with efficiency for each of the split-system central air conditioner product classes and by region. Table 8.4.1 presents results for coil-only improvements. Mean LCC savings are positive with national level standards and, in the hot-humid and hot-dry regions, with regional standards up through SEER 14.5. No SEER level beyond SEER 13 produces LCC savings for a coil-only standard in the rest of the country. Table 8.4.2 shows that LCC savings are positive at national level blower-coil standards up to SEER 18 and, in the hot-humid and hot-dry regions, savings are positive up to SEER 21and SEER 20, respectively. No SEER level beyond SEER 13 produces LCC savings for a blower-coil standard in the rest of the country.

Table 8.4.1 Mean LCC Savings for Split-System Air Conditioners (Coil-Only) by Region by Efficiency Level (SEER Value)

Efficiency Level	SEER	LCC Savings by Region *2009$*			
		Nation	Hot-Humid	Hot-Dry	Rest of Country
2	**13.5**	55	86	104	(8)
3	**14**	51	93	107	(26)
4	**14.5**	67	137	152	(59)
5	**15**	(433)	(303)	(468)	(603)
6	**15.5**	(915)	(728)	(1,067)	(1,128)
7	**16**	(939)	(726)	(1,071)	(1,191)
8	**16.5**	(925)	(706)	(1,040)	(1,188)
9	**17**	(990)	(751)	(1,102)	(1,278)
10	**18****	(1,046)	(797)	(1,182)	(1,343)

*Values in parentheses denote negative savings.
**Varies by capacity of equipment: 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER.

Table 8.4.2 Mean LCC Savings for Split-System Air Conditioners (Blower-Coil) by Region by Efficiency Level (SEER Value)

Efficiency Level	SEER	LCC Savings by Region *2009$*			
		Nation	Hot-Humid	Hot-Dry	Rest of Country
2	**13.5**	46	77	90	(18)
3	**14**	49	89	101	(30)
4	**14.5**	76	140	158	(52)
5	**15**	92	177	196	(74)
6	**15.5**	96	201	219	(105)
7	**16**	96	223	239	(142)
8	**16.5**	82	223	234	(181)
9	**17**	66	231	235	(234)
10	**18**	6	197	181	(331)
11	**19**	(52)	157	123	(407)
12	**20**	(125)	108	50	(507)
13	**21**	(214)	42	(45)	(623)
14	**22**	(316)	(39)	(157)	(747)
15	**23**	(355)	(72)	(214)	(791)
16	**24.5****	(421)	(130)	(311)	(903)

*Values in parentheses denote negative savings.

**Varies by capacity of equipment: 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER.

It is worth reiterating that the results shown in Table 8.4.1 and Table 8.4.2 are mean values and do not show the distributions of savings. Thus, although observations can be made as to how the various inputs impact LCC and, in turn, how the resulting LCCs change with efficiency, conclusions should only be drawn from the distribution of LCC results that are presented in the box plots of Figure 8.4.1 and Figure 8.4.2. These figures show not only the mean savings, but also the LCC savings in the median case (50 percent of cases have smaller savings), the 75^{th} and 25^{th} percentile cases (at the upper and lower ends of the box) and the 95^{th} and 5^{th} percentiles (at the ends of the finer lines). For example, although a blower-coil standard at SEER 18 (efficiency level 10) shows positive mean LCC savings, the corresponding figure shows that more than half of affected consumers experience LCC losses. Their losses are outweighed by the minority of cases where very high LCC savings occur. Section 8.4.1.3 provides information on the percentages of consumers in each region at each efficiency level that would experience LCC savings benefits, LCC cost increases, and no impact from the standard.

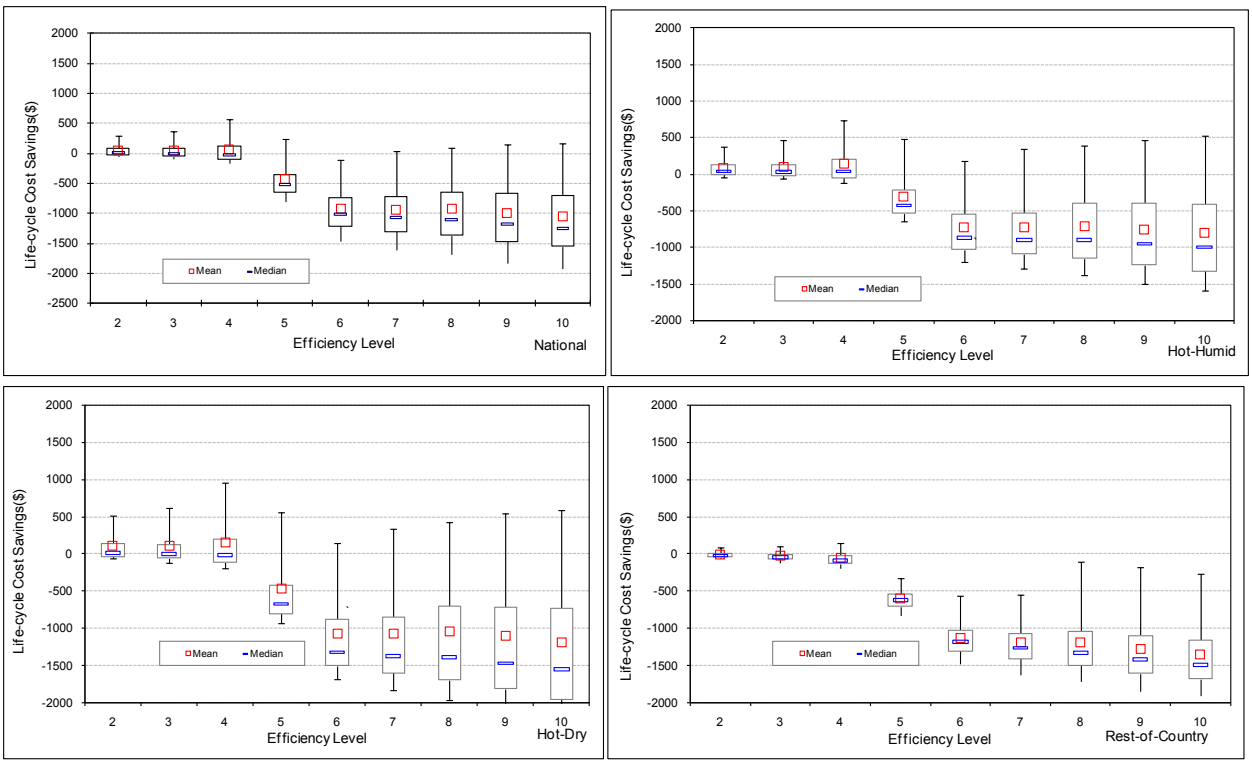

Figure 8.4.1 Plots of the Distributions of LCC Savings for Split-System Air Conditioners (Coil-Only) by Region

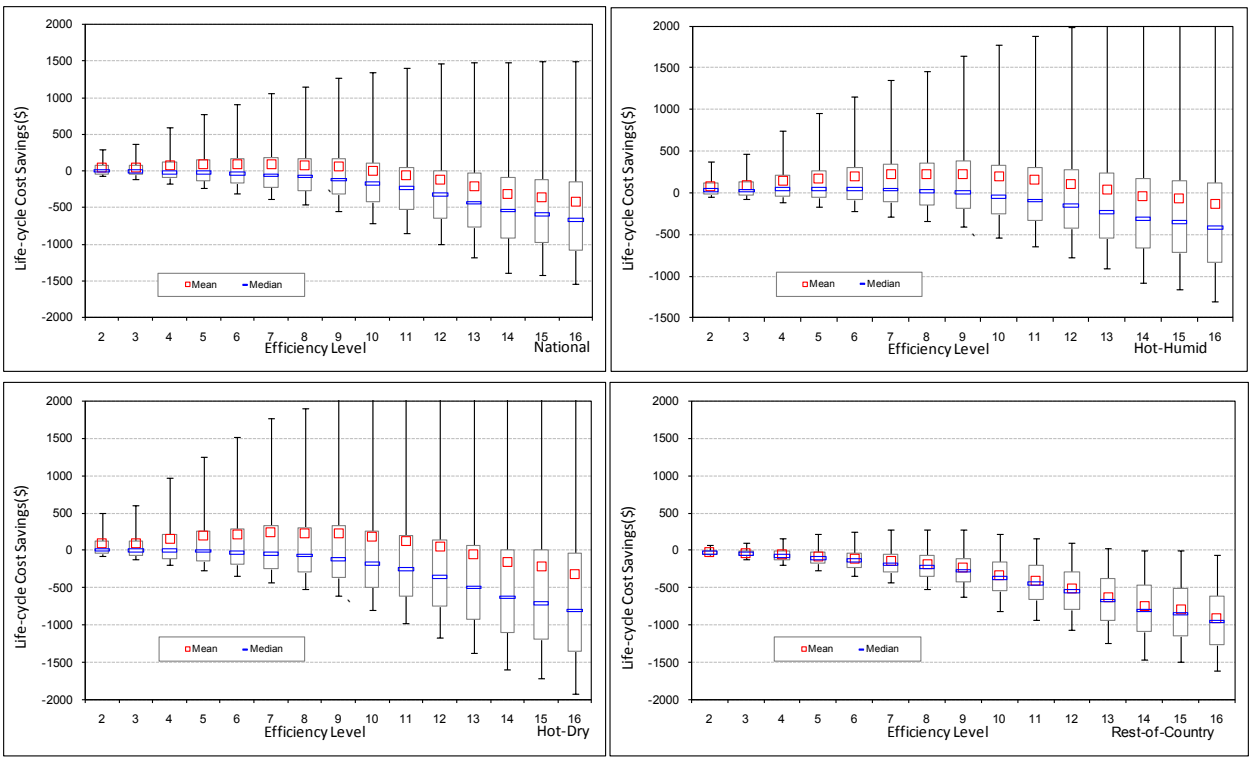

Figure 8.4.2 Plots of the Distributions of LCC Savings for Split-System Air Conditioners (Blower-Coil) by Region

8.4.1.2 Payback Period Results for Split-System Air Conditioners by Region

This section presents PBP results for the efficiency improvement levels specified in the engineering analysis (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs. Section 8.3 describes the PBP inputs.

Similar to LCC, the analysis provides an estimate of the simple PBP at different ranges of energy prices, sales taxes, and installation costs that prevail across the country for each efficiency level and each region. Table 8.4.3 and Table 8.4.4 show the effect on median PBP as the level of efficiency changes from the market baseline for central air conditioner products in residential and commercial buildings for each region's energy prices, sales taxes, and installation costs.

Similar to the LCC differences, DOE estimated PBP results as a distribution of values. The median values of these distributions are shown in Table 8.4.3 and Table 8.4.4. Rebuttable PBP for each efficiency level is shown in Table 8.4.5. Regional values are not shown because by regulation the rebuttable payback period is calculated using national average prices and energy savings calculated by the DOE test procedure. Regional distributions of PBP results are shown in Figure 8.4.3 and Figure 8.4.4.

Table 8.4.3 Median Payback Period for Split-System Air Conditioners (Coil-Only) by Region

Efficiency Level	SEER	Payback Period by Region *years*			
		Nation	Hot-Humid	Hot-Dry	Rest of Country
2	13.5	9.1	5.6	8.0	23.1
3	14	12.5	7.2	10.3	33.1
4	14.5	13.6	8.1	11.2	39.9
5	15	62.4	34.4	49.0	100.0+
6	15.5	97.9	52.5	75.3	100.0+
7	16	89.6	46.1	66.4	100.0+
8	16.5	94.1	45.0	67.3	100.0+
9	17	100.0+	46.2	69.8	100.0+
10	18*	100.0+	46.6	71.2	100.0+

*Varies by capacity of equipment: 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER.

Table 8.4.4 Median Payback Period for Split-System Air Conditioners (Blower-Coil) by Region

Efficiency Level	SEER	Payback Period by Region *years*			
		Nation	Hot-Humid	Hot-Dry	Rest of Country
2	13.5	11.4	7.2	9.5	26.1
3	14	12.6	7.9	10.7	27.5
4	14.5	12.6	8.1	10.7	28.3
5	15	13.0	8.4	10.8	29.9
6	15.5	13.8	8.9	11.4	33.0
7	16	14.6	9.4	12.0	35.6
8	16.5	16.1	10.2	13.2	41.1
9	17	17.2	10.9	14.2	45.2
10	18	21.1	12.6	17.0	60.6
11	19	24.9	14.1	19.7	80.0
12	20	28.1	15.7	22.2	100.0+
13	21	32.1	17.5	25.0	100.0+
14	22	36.4	19.5	28.0	100.0+
15	23	38.2	20.0	29.0	100.0+
16	24.5*	41.0	20.8	30.6	100.0+

*Varies by capacity of equipment: 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER.

Table 8.4.5 Rebuttable Payback Period for Split-System Air Conditioners

Efficiency Level	SEER	Rebuttable Payback Period *years*	
		Coil Only	Blower-Coil
2	13.5	4.3	6.2
3	14	5.4	6.7
4	14.5	6.2	6.9
5	15	24.8	7.1
6	15.5	36.2	7.5
7	16	32.2	7.8
8	16.5	29.8	8.2
9	17	28.5*	8.6
10	18	NA	9.5
11	19	NA	10.4
12	20	NA	11.4
13	21	NA	12.4
14	22	NA	13.5*
15	23	NA	NA
16	24.5	NA	NA

*Max tech varies by capacity of equipment: Coil–only max tech units 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER. Blower-coil max tech 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER. Results are shown for 3-ton units.

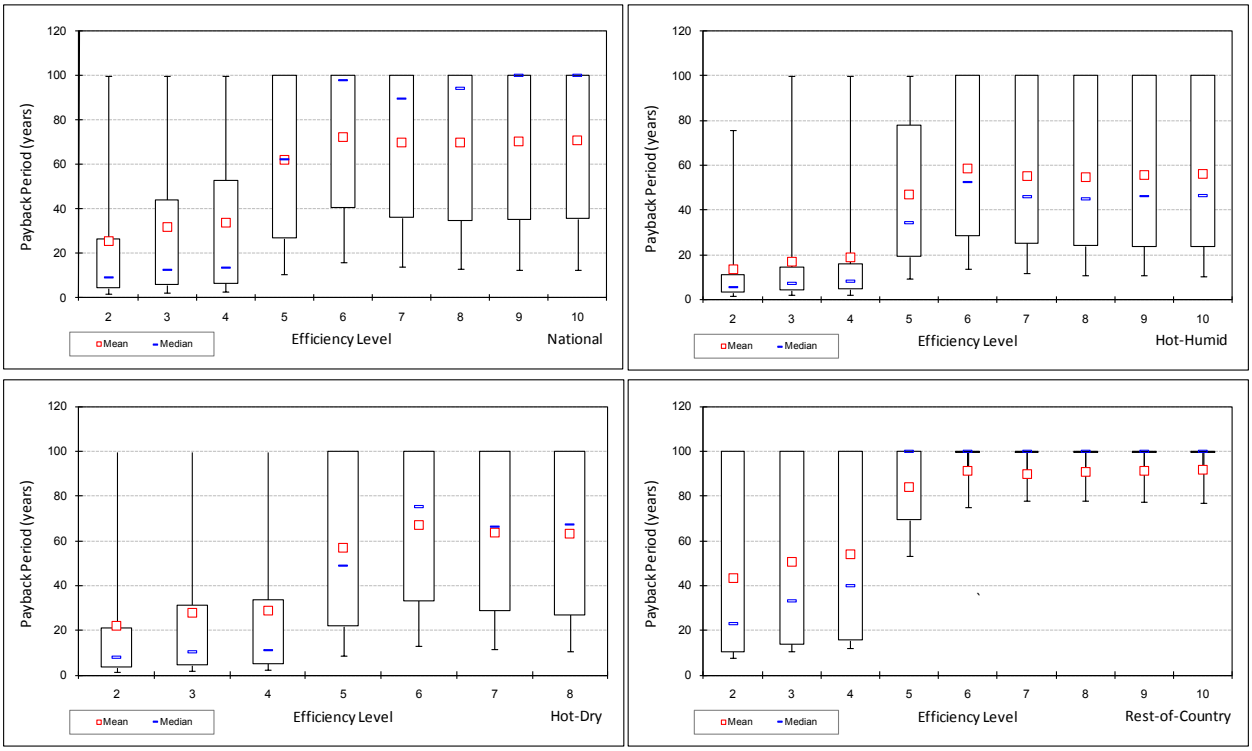

Figure 8.4.3 Plots of the Distributions of PBP for Split-System Air Conditioners (Coil-Only) by Region

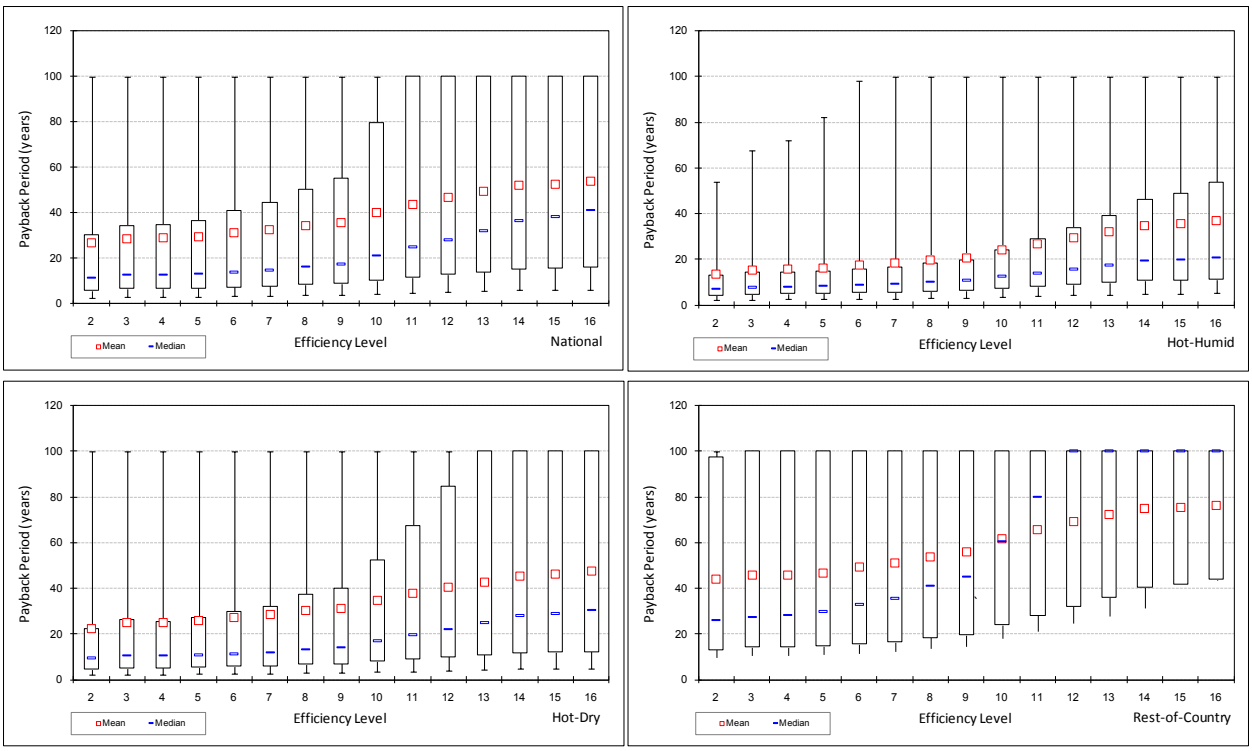

Figure 8.4.4 Plots of the Distributions of PBP for Split-System Air Conditioners (Blower-Coil) by Region

8.4.1.3 Detailed Regional Results for Split-System Air Conditioners

This section provides data on the detailed LCC results for split-system central air conditioners, the components of LCC, LCC savings, and PBP. Table 8.4.6 through Table 8.4.13 present these details separately for coil-only central air conditioner units and blower-coil central air conditioner units, and for each region by efficiency level. The detailed results indicate that more than half of all consumers are unaffected by standards up to about 14 SEER for coil-only systems and about 14 SEER for blower-coil systems. For a coil-only national standard, only at 13.5 SEER do as many affected "winner" consumers experience savings as experience losses ("losers"). For a blower-coil standard, those experiencing a net cost are always at least as great as those experiencing a net gain. In the hot-humid region, a regional coil-only standard would yield more winners than losers up through 14.5 SEER; a regional blower-coil standard would yield more winners than losers through 17 SEER. In the hot-dry region, the regional coil-only standard would yield more winners than losers at 13.5 SEER and a regional blower-coil standard would yield more winners than losers at 13.5 SEER. Losers outnumber winners for regional standards at all SEER levels above the baseline in the rest of the country.

Table 8.4.6 National LCC and PBP Results for Split-System Air Conditioners (Coil-Only) by Efficiency Level (SEER Value): Nation

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	2,026	4,872	6,898	n/a	0	100	0	n/a
13.5	2,074	4,770	6,844	55	11	75	14	9.1
14	2,130	4,680	6,811	51	39	27	34	12.5
14.5	2,193	4,599	6,792	67	43	23	34	13.6
15	2,755	4,531	7,286	(433)	77	16	7	62.4
15.5	3,324	4,472	7,796	(915)	87	10	4	97.9
16	3,416	4,424	7,840	(939)	87	8	5	89.6
16.5	3,497	4,397	7,894	(925)	93	1	6	94.1
17	3,586	4,377	7,963	(990)	93	0	7	100.0+
18**	3,655	4,365	8,020	(1,046)	93	0	7	100.0+

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER.

Table 8.4.7 LCC and PBP Results for Split-System Air Conditioners (Blower-Coil) by Efficiency Level (SEER Value): Nation

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,015	4,869	7,884	n/a	0	100	0	n/a
13.5	3,078	4,762	7,840	46	9	82	9	11.4
14	3,142	4,664	7,807	49	30	45	25	12.6
14.5	3,206	4,572	7,778	76	31	42	26	12.6
15	3,269	4,487	7,756	92	35	37	28	13.0
15.5	3,337	4,409	7,746	96	39	32	29	13.8
16	3,407	4,338	7,744	96	41	31	29	14.6
16.5	3,477	4,275	7,752	82	46	25	28	16.1
17	3,549	4,218	7,767	66	48	25	27	17.2
18	3,701	4,119	7,820	6	59	15	26	21.1
19	3,824	4,053	7,877	(52)	67	8	25	24.9
20	3,953	3,998	7,951	(125)	71	5	24	28.1
21	4,089	3,954	8,043	(214)	75	3	22	32.1
22	4,231	3,918	8,149	(316)	79	1	20	36.4
23	4,283	3,906	8,189	(355)	79	1	20	38.2
24.5**	4,362	3,893	8,255	(421)	80	1	19	41.0

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER.

Hot-Humid Region

Table 8.4.8 LCC and PBP Results for Split-System Air Conditioners (Coil-Only) by Efficiency Level (SEER Value): Hot-Humid Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	1,834	5,649	7,484	n/a	0	100	0	n/a
13.5	1,880	5,514	7,393	86	7	75	18	5.6
14	1,934	5,393	7,326	93	26	27	46	7.2
14.5	1,993	5,283	7,276	137	30	23	47	8.1
15	2,515	5,188	7,702	(303)	73	16	12	34.4
15.5	3,044	5,104	8,147	(728)	84	10	6	52.5
16	3,130	5,031	8,161	(726)	84	8	8	46.1
16.5	3,208	4,986	8,193	(706)	89	1	10	45.0
17	3,293	4,949	8,242	(751)	90	0	10	46.2
18**	3,365	4,923	8,288	(797)	90	0	10	46.6

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER.

Table 8.4.9 LCC and PBP Results for Split-System Air Conditioners (Blower-Coil) by Efficiency Level (SEER Value): Hot-Humid Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	2,774	5,640	8,413	n/a	0	100	0	n/a
13.5	2,833	5,500	8,333	77	6	82	12	7.2
14	2,894	5,371	8,265	89	21	45	34	7.9
14.5	2,955	5,251	8,205	140	22	42	36	8.1
15	3,015	5,139	8,154	177	25	37	39	8.4
15.5	3,079	5,036	8,115	201	28	32	39	8.9
16	3,145	4,941	8,086	223	31	31	39	9.4
16.5	3,211	4,857	8,068	223	35	25	39	10.2
17	3,279	4,779	8,057	231	37	25	38	10.9
18	3,422	4,640	8,063	197	47	15	38	12.6
19	3,541	4,546	8,087	157	55	8	37	14.1
20	3,666	4,466	8,132	108	60	5	35	15.7
21	3,797	4,399	8,196	42	64	3	33	17.5
22	3,933	4,342	8,275	(39)	69	1	30	19.5
23	3,986	4,322	8,308	(72)	69	1	30	20.0
24.5**	4,069	4,298	8,367	(130)	70	1	29	20.8

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER.

Hot-Dry Region

Table 8.4.10 LCC and PBP Results for Split-System Air Conditioners (Coil-Only) by Efficiency Level (SEER Value): Hot-Dry Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	2,582	6,134	8,716	n/a	0	100	0	n/a
13.5	2,642	5,977	8,619	104	10	75	14	8.0
14	2,713	5,837	8,550	107	37	27	36	10.3
14.5	2,791	5,709	8,500	152	40	23	37	11.2
15	3,510	5,598	9,108	(468)	75	16	9	49.0
15.5	4,238	5,500	9,738	(1,067)	85	10	5	75.3
16	4,351	5,415	9,765	(1,071)	85	8	7	66.4
16.5	4,455	5,357	9,812	(1,040)	91	1	9	67.3
17	4,570	5,310	9,880	(1,102)	91	0	9	69.8
18**	4,673	5,288	9,960	(1,182)	91	0	9	71.2

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER.

Table 8.4.11 LCC and PBP Results for Split-System Air Conditioners (Blower-Coil) by Efficiency Level (SEER Value): Hot-Dry Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,825	6,171	9,995	n/a	0	100	0	n/a
13.5	3,903	6,009	9,912	90	9	82	10	9.5
14	3,984	5,860	9,844	101	28	45	27	10.7
14.5	4,063	5,721	9,784	158	29	42	28	10.7
15	4,142	5,592	9,734	196	33	37	31	10.8
15.5	4,226	5,473	9,699	219	36	32	31	11.4
16	4,313	5,363	9,676	239	38	31	31	12.0
16.5	4,399	5,265	9,665	234	44	25	31	13.2
17	4,488	5,175	9,663	235	45	25	30	14.2
18	4,677	5,014	9,691	181	55	15	30	17.0
19	4,837	4,899	9,736	123	63	8	29	19.7
20	5,004	4,800	9,805	50	67	5	28	22.2
21	5,182	4,717	9,898	(45)	71	3	26	25.0
22	5,365	4,646	10,011	(157)	75	1	24	28.0
23	5,442	4,627	10,069	(214)	75	1	24	29.0
24.5**	5,559	4,606	10,166	(311)	76	1	23	30.6

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER.

Rest of Country

Table 8.4.12 LCC and PBP Results for Split-System Air Conditioners (Coil-Only) by Efficiency Level (SEER Value): Rest of Country

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	2,127	3,476	5,603	n/a	0	100	0	n/a
13.5	2,175	3,434	5,609	(8)	17	75	8	23.1
14	2,231	3,401	5,633	(26)	56	27	16	33.1
14.5	2,295	3,372	5,667	(59)	62	23	15	39.9
15	2,864	3,353	6,216	(603)	83	16	1	100.0+
15.5	3,440	3,340	6,780	(1,128)	90	10	0	100.0+
16	3,534	3,335	6,869	(1,191)	92	8	0	100.0+
16.5	3,611	3,340	6,951	(1,188)	99	1	1	100.0+
17	3,696	3,352	7,048	(1,278)	99	0	1	100.0+
18**	3,753	3,360	7,113	(1,343)	99	0	1	100.0+

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 18 SEER, 3-ton units are 17 SEER, 5-ton units are 16 SEER.

Table 8.4.13 LCC and PBP Results for Split-System Air Conditioners (Blower-Coil) by Efficiency Level (SEER Value): Rest of Country

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,110	3,468	6,577	n/a	0	100	0	n/a
13.5	3,172	3,422	6,594	(18)	14	82	4	26.1
14	3,236	3,381	6,617	(30)	43	45	12	27.5
14.5	3,300	3,340	6,640	(52)	45	42	13	28.3
15	3,364	3,303	6,667	(74)	50	37	13	29.9
15.5	3,432	3,270	6,702	(105)	55	32	13	33.0
16	3,502	3,241	6,742	(142)	57	31	13	35.6
16.5	3,572	3,219	6,792	(181)	63	25	12	41.1
17	3,645	3,200	6,845	(234)	64	25	11	45.2
18	3,798	3,172	6,970	(331)	76	15	9	60.6
19	3,915	3,156	7,071	(407)	84	8	8	80.0
20	4,038	3,147	7,184	(507)	89	5	6	100.0+
21	4,167	3,143	7,310	(623)	92	3	5	100.0+
22	4,302	3,145	7,447	(747)	94	1	5	100.0+
23	4,344	3,146	7,490	(791)	95	1	4	100.0+
24.5**	4,410	3,193	7,603	(903)	96	1	3	100.0+

*Values in parentheses denote negative values.
**Varies by capacity of equipment: 2-ton units are 24.5 SEER, 3-ton units are 22 SEER, 5-ton units are 18 SEER.

8.4.2 Split-System Heat Pumps

This section presents LCC results for the efficiency improvement levels specified in the engineering analysis for split-system HPs (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs, repair costs, and maintenance costs developed for each individual observation. Section 8.2 presents the electricity price inputs, as well as all other LCC inputs.

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.

8.4.2.1 Mean LCC Savings for Split-System Heat Pumps by Region

Because the values of most inputs are uncertain in this analysis, DOE represents them as a distribution of values rather than a single-point value. Thus, DOE also represents the LCC

results as a distribution of values. In Table 8.4.14 DOE presents average values for LCC savings of affected consumers to show how these savings vary with efficiency for the split-system HP product classes and by region. In contrast to the situation with split-system CAC units, LCC savings for split-system heat pump standards are positive at the national level and in both hot-humid and hot-dry regions up to one level below the max-tech level (21 SEER). No standard level above 14 SEER showed LCC savings in the colder part of the country (rest of country).

Table 8.4.14 Mean LCC Savings for Split-System Heat Pumps by Region by Efficiency Level (SEER Value and HSPF Value)

Efficiency Level	SEER	HSPF***	Mean LCC Savings by Region *2009$*			
			Nation	Hot-Humid	Hot-Dry	Rest of Country
2	13.5	8.0	71	82	148	5
3	14	8.1	85	102	175	4
4	14.5	8.2	124	151	264	(4)
5	15	8.3	97	137	274	(89)
6	15.5	8.5	68	119	266	(156)
7	16	8.6	57	117	291	(208)
8	16.5	8.7	65	132	328	(233)
9	17	8.8	73	148	372	(263)
10	18	8.9	63	152	426	(347)
11	19	9.1	61	159	479	(404)
12	20	9.4	38	146	498	(478)
13	21	9.6	1	118	493	(562)
14	22**	9.8	(20)	103	477	(604)

*Values in parentheses denote negative values.
**Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER.
***For a given SEER the corresponding HSPF values also vary slightly by unit capacity. Those shown are for a 2-ton unit.

It is worth reiterating that the results shown in Table 8.4.14 are mean values and do not show the distributions of savings. Thus, although observations can be made as to how the various inputs impact LCC and, in turn, how the resulting LCCs change with efficiency, conclusions should only be drawn from the distribution of LCC results that are presented in Figure 8.4.5. For example, only in the hot-dry region do median LCC savings remain positive at a SEER value greater than 18 (50 percent of affected consumers would show a loss), even though mean savings are positive at far higher SEER values, and losers outnumber winners at all levels above the baseline in the North (rest of country region). Section 8.4.2.3 provides information on the percentages of consumers in each region at each efficiency level that would experience LCC savings benefits, LCC cost increases, and no impact from the standard.

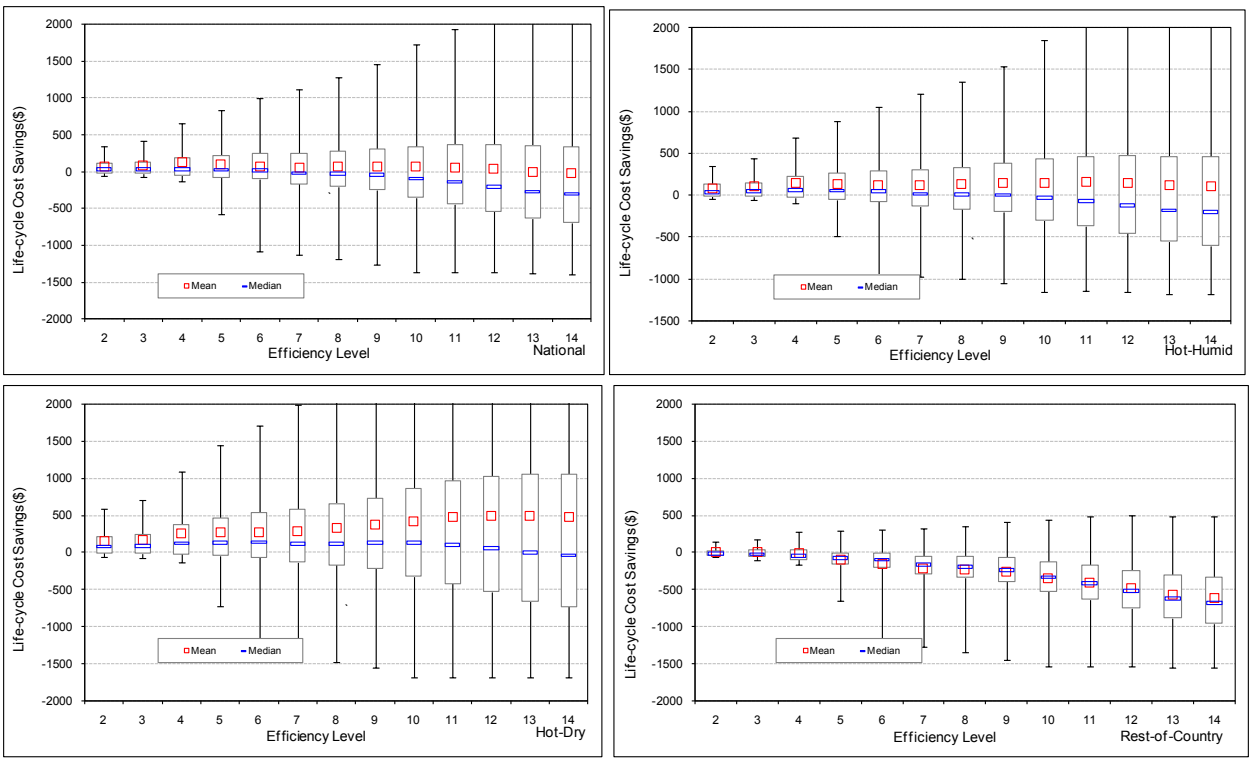

Figure 8.4.5 Plots of the Distributions of LCC Savings for Split-System Heat Pumps by Region

8.4.2.2 Payback Period Results for Split-System Heat Pumps by Region

This section presents PBP results for the efficiency improvement levels specified in the engineering analysis (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs. Section 8.3 describes the PBP inputs.

Similar to LCC, the analysis provides an estimate of the simple PBP at different ranges of energy prices, sales taxes, and installation costs that prevail across the country for each efficiency level and each region. Table 8.4.15 shows the effect on PBP as the level of efficiency changes from the market baseline for split-system HP products in residential and commercial buildings for each region's energy prices, sales taxes, and installation costs.

Similar to the LCC differences, DOE depicted PBP results as a distribution of values. The medians of these distributions are shown in Table 8.4.15, and the distributions of values for PBP are shown in Figure 8.4.6. Rebuttable PBP for each efficiency level is shown in Table 8.4.16. No levels met the criterion of less than 3 years payback. In addition, DOE provides data on the median PBP for each efficiency level in each region in section 8.4.2.3.

Table 8.4.15 Median Payback Period for Split-System Heat Pumps by Region

Efficiency Level	SEER	HSPF**	Payback Period by Region *years*			
			Nation	Hot-Humid	Hot-Dry	Rest of Country
2	13.5	8.0	6.6	6.1	4.5	13.2
3	14	8.1	6.7	6.0	4.8	13.3
4	14.5	8.2	7.4	6.6	5.2	14.8
5	15	8.3	7.9	7.2	5.4	20.1
6	15.5	8.5	8.4	7.6	5.7	20.5
7	16	8.6	10.1	9.1	6.8	24.5
8	16.5	8.7	10.4	9.5	7.0	24.8
9	17	8.8	10.5	9.6	7.2	24.4
10	18	8.9	11.5	10.4	7.7	26.6
11	19	9.1	12.0	10.9	8.1	27.6
12	20	9.4	12.8	11.6	8.6	29.6
13	21	9.6	13.6	12.4	9.2	32.0
14	22*	9.8	13.9	12.6	9.4	32.7

*Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER.
**For a given SEER the corresponding HSPF values also vary slightly by unit capacity. Those shown are for a 2-ton unit.

Table 8.4.16 Rebuttable Payback Period for Split-System Heat Pumps

Efficiency Level	SEER	HSPF**	Rebuttable Payback Period *years*
			Nation
2	13.5	8.0	4.1
3	14	8.1	3.1
4	14.5	8.2	3.7
5	15	8.3	4.1
6	15.5	8.5	4.2
7	16	8.6	4.9
8	16.5	8.7	5.0
9	17	8.8	4.7
10	18	8.9	5.0
11	19	9.1	5.3
12	20	9.4	5.5
13	21	9.6	5.8
14	22*	9.8	NA***

*Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER.
**For a given SEER the corresponding HSPF values also vary slightly by unit capacity. Those shown are for a 2-ton unit.
***Values are calculated only for 3-ton units, which achieve a max tech level at 21 SEER.

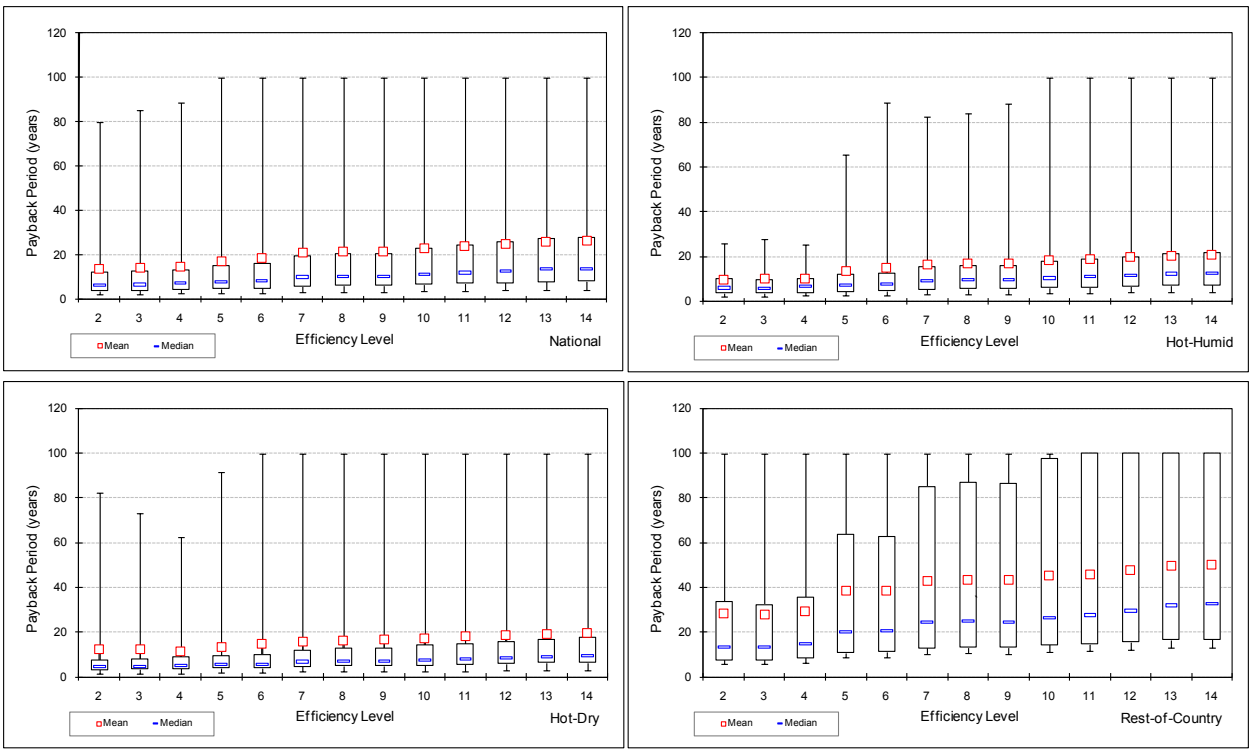

Figure 8.4.6 Plots of the Distributions of PBP for Split-System Heat Pumps by Region

8.4.2.3 Detailed Regional Results for Split-System Heat Pumps

This section provides data on the detailed LCC results for split-system central heat pumps, the components of LCC, LCC savings, and PBP. These details are shown separately by region and efficiency level. Table 8.4.17 through Table 8.4.20 present these details for each region by efficiency level. The detailed results indicate that more than half of all consumers are unaffected by standards up to about 14 SEER. For a national standard, at up through 15.5 SEER more affected consumers experience savings ("winners") than experience losses ("losers"). In the hot-humid region, a regional standard would yield more winners than losers up through 17 SEER. In the hot-dry region, the regional standard would yield more winners than losers up through 20 SEER). Losers outnumber winners for regional standards at all SEER levels above the baseline in the rest of the country.

Nation

Table 8.4.17 LCC and PBP Results for Split-System Heat Pumps by Efficiency Level (SEER Value): Nation

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	2,934	6,882	9,816	n/a	0	100	0	n/a
13.5	2,999	6,743	9,742	71	5	86	9	6.6
14	3,065	6,607	9,672	85	20	45	35	6.7
14.5	3,135	6,484	9,618	124	26	36	39	7.4
15	3,254	6,366	9,619	97	33	23	44	7.9
15.5	3,372	6,262	9,634	68	41	12	47	8.4
16	3,471	6,171	9,642	57	49	9	43	10.1
16.5	3,546	6,085	9,631	65	52	4	44	10.4
17	3,621	6,000	9,621	73	54	2	45	10.5
18	3,770	5,861	9,630	63	57	0	42	11.5
19	3,874	5,758	9,632	61	59	0	41	12.0
20	3,988	5,667	9,655	38	62	0	38	12.8
21	4,102	5,591	9,692	1	64	0	36	13.6
22**	4,149	5,564	9,713	(20)	65	0	35	13.9

*Values in parentheses denote negative values.

**Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER. For a given SEER the corresponding HSPF values also vary slightly by unit capacity.

Hot-Humid Region

Table 8.4.18 LCC and PBP Results for Split-System Heat Pumps by Efficiency Level (SEER Value): Hot-Humid Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	2,804	6,943	9,747	n/a	0	100	0	n/a
13.5	2,867	6,791	9,658	82	4	86	10	6.1
14	2,932	6,644	9,576	102	17	45	38	6.0
14.5	3,000	6,511	9,511	151	22	36	43	6.6
15	3,114	6,383	9,496	137	29	23	48	7.2
15.5	3,226	6,270	9,496	119	36	12	52	7.6
16	3,323	6,170	9,494	117	43	9	48	9.1
16.5	3,396	6,077	9,473	132	47	4	49	9.5
17	3,470	5,984	9,454	148	49	2	50	9.6
18	3,617	5,831	9,448	152	52	0	47	10.4
19	3,718	5,721	9,439	159	55	0	45	10.9
20	3,829	5,624	9,453	146	57	0	43	11.6
21	3,940	5,541	9,481	118	59	0	41	12.4
22**	3,983	5,513	9,496	103	60	0	40	12.6

*Values in parentheses denote negative values.

**Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER. For a given SEER the corresponding HSPF values also vary slightly by unit capacity.

Hot-Dry Region

Table 8.4.19 LCC and PBP Results for Split-System Heat Pumps by Efficiency Level (SEER Value): Hot-Dry Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,808	9,221	13,029	n/a	0	100	0	n/a
13.5	3,890	8,987	12,877	148	4	86	11	4.5
14	3,973	8,763	12,735	175	15	45	40	4.8
14.5	4,061	8,558	12,619	264	19	36	46	5.2
15	4,212	8,348	12,560	274	25	23	52	5.4
15.5	4,361	8,171	12,532	266	30	12	58	5.7
16	4,483	8,014	12,497	291	36	9	55	6.8
16.5	4,575	7,868	12,443	328	39	4	57	7.0
17	4,667	7,725	12,393	372	40	2	58	7.2
18	4,851	7,482	12,333	426	43	0	56	7.7
19	4,998	7,280	12,278	479	45	0	55	8.1
20	5,158	7,101	12,259	498	48	0	52	8.6
21	5,318	6,946	12,264	493	50	0	50	9.2
22**	5,387	6,894	12,280	477	51	0	49	9.4

*Values in parentheses denote negative values.

**Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER. For a given SEER the corresponding HSPF values also vary slightly by unit capacity.

Rest of Country

Table 8.4.20 LCC and PBP Results for Split-System Heat Pumps by Efficiency Level (SEER Value): Rest of Country

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,065	5,927	8,993	n/a	0	100	0	n/a
13.5	3,129	5,861	8,990	5	9	86	5	13.2
14	3,193	5,792	8,986	4	35	45	20	13.3
14.5	3,262	5,731	8,992	(4)	43	36	21	14.8
15	3,380	5,693	9,073	(89)	58	23	19	20.1
15.5	3,499	5,652	9,150	(156)	67	12	21	20.5
16	3,597	5,611	9,208	(208)	74	9	18	24.5
16.5	3,670	5,574	9,244	(233)	78	4	18	24.8
17	3,744	5,534	9,278	(263)	80	2	18	24.4
18	3,889	5,476	9,365	(347)	83	0	16	26.6
19	3,990	5,434	9,424	(404)	84	0	16	27.6
20	4,099	5,399	9,498	(478)	86	0	15	29.6
21	4,208	5,374	9,582	(562)	87	0	13	32.0
22**	4,262	5,362	9,624	(604)	87	0	13	32.7

*Values in parentheses denote negative values.
**Varies by capacity of equipment: max tech 2-ton units are 22 SEER, 3-ton units are 21 SEER, 5-ton units are 18 SEER. For a given SEER the corresponding HSPF values also vary slightly by unit capacity.

8.4.3 Single-Package Air Conditioners

This section presents LCC results for the efficiency improvement levels specified in the engineering analysis for single-package central air conditioners (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs, repair costs, and maintenance costs developed for each individual observation. Section 8.2 presents the electricity price inputs, as well as all other LCC inputs.

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.

8.4.3.1 Mean LCC Savings for Single-Package Air Conditioners for the Nation

Because the values of most inputs are uncertain in this analysis, DOE represents them as a distribution of values rather than a single-point value. Thus, DOE also represents the LCC results as a distribution of values. In Table 8.4.21 DOE presents average values for LCC savings to show how these savings vary with efficiency for each of the single-package central air conditioner product classes for the nation. The LCC savings for single-package central air conditioners are negative at the national level for a standard at any level beyond 14 SEER.

Table 8.4.21 Mean LCC Savings for Single-Package Air Conditioners for the Nation by Efficiency Level (SEER Value)

Efficiency Level	SEER	Mean LCC Savings for the Nation *2009$*
2	13.5	9
3	14	37
4	14.5	(15)
5	15	(68)
6	15.5	(150)
7	16	(244)
8	16.5	(492)

*Values in parentheses denote negative values.

The results shown in Table 8.4.21 are mean values and do not show the distributions of savings. Thus, although observations can be made as to how the various inputs impact LCC and, in turn, how the resulting LCCs change with efficiency, conclusions should only be drawn from the distribution of LCC results that are presented in Figure 8.4.7. Section 8.4.3.3 provides information on the percentages of consumers in for the nation at each efficiency level that would experience LCC savings benefits, LCC cost increases, and no impact from the standard. Median savings are generally negative, indicating that more consumers would experience losses than gains for standards above 13 SEER.

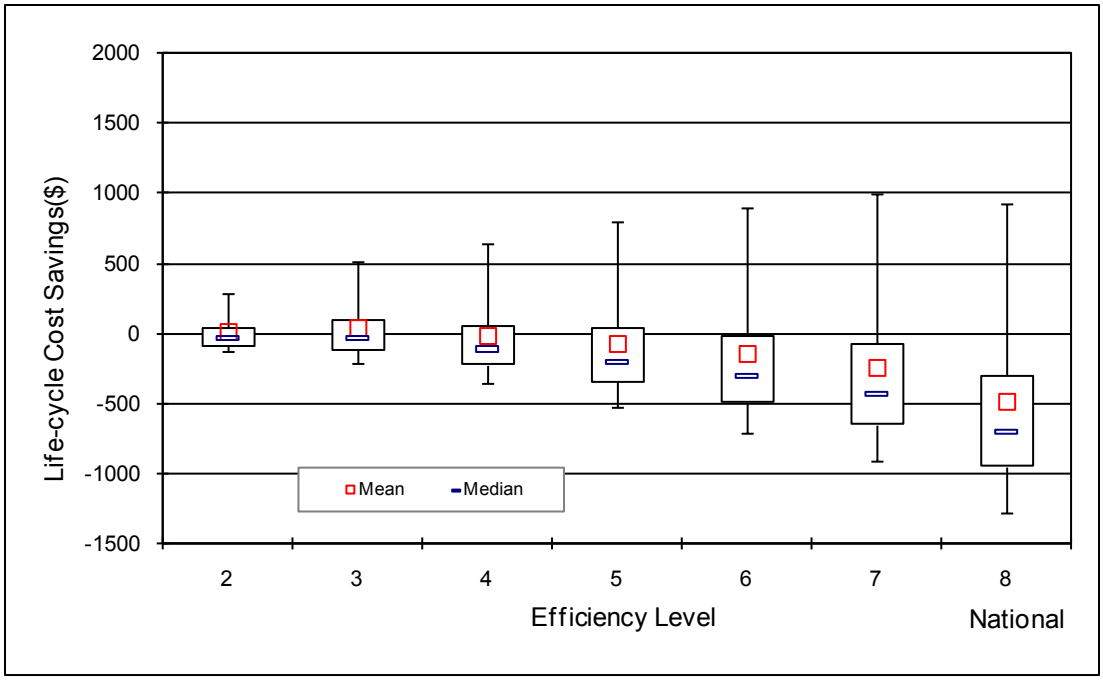

Figure 8.4.7 Plot of the Distribution of LCC Savings for Single-Package Air Conditioners

8.4.3.2 Payback Period Results for Single-Package Air Conditioners for the Nation

This section presents PBP results for the efficiency improvement levels specified in the engineering analysis (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs. Section 8.3 describes the PBP inputs.

Similar to LCC, the analysis provides an estimate of the simple PBP at different ranges of energy prices, sales taxes, and installation costs that prevail across the country for each efficiency level and each building type. Table 8.4.22 shows the effect on PBP as the level of efficiency changes from the market baseline for central air conditioner products in residential and commercial buildings for each region's energy prices, sales taxes, and installation costs.

Similar to the LCC differences, DOE estimated PBP results as a distribution of values. The medians of these distributions are shown in Table 8.4.22, and the distributions of values for PBP are shown in Figure 8.4.8. Rebuttable PBP is shown in Table 8.4.23. No level met the criterion of less than three years. In addition, DOE provides data on the median PBP for each efficiency level for the nation in section 8.4.3.3.

Table 8.4.22 Median Payback Period for Single Package Air Conditioners

Efficiency Level	SEER	Payback Period for the Nation *years*
2	13.5	17.7
3	14	15.1
4	14.5	21.3
5	15	24.2
6	15.5	28.1
7	16	31.9
8	16.5	46.3

Table 8.4.23 Rebuttable Payback Period for Single Package Air Conditioners

Efficiency Level	SEER	Rebuttable Payback Period *years*
		Nation
2	13.5	9.9
3	14	9.0
4	14.5	11.3
5	15	12.5
6	15.5	13.9
7	16	15.0
8	16.5	18.0

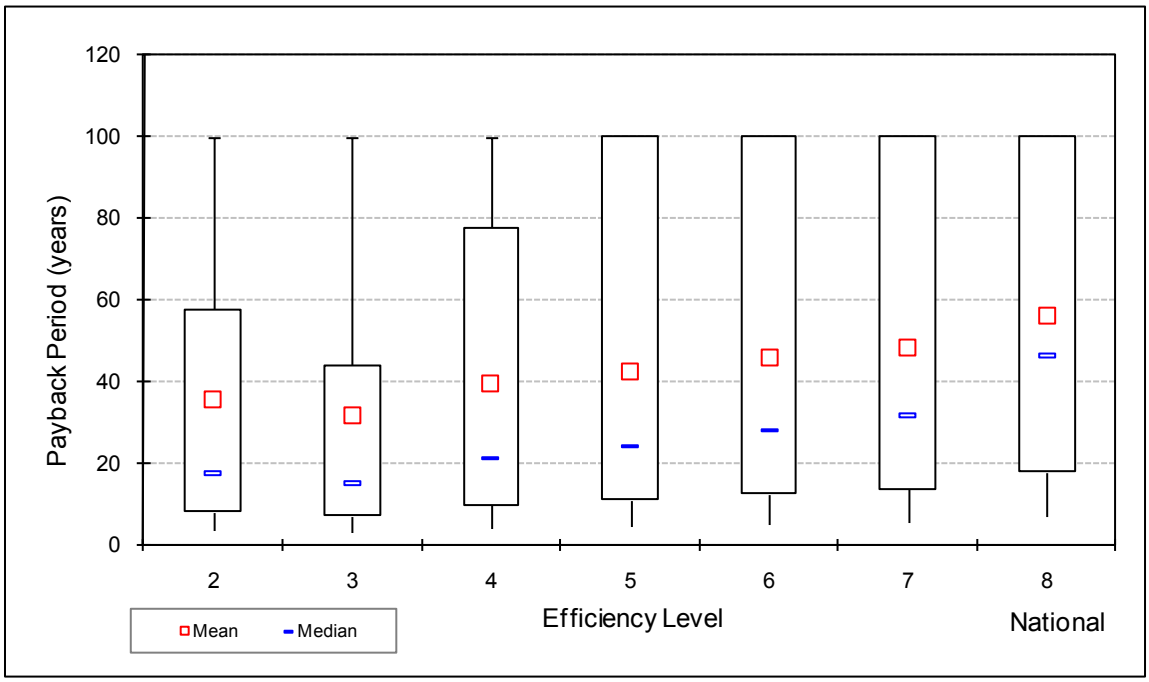

Figure 8.4.8 Plot of the Distribution of PBP for Single Package Air Conditioners

8.4.3.3 Detailed Results for Single-Package Air Conditioners

This section provides data on the detailed LCC results for single-package central air conditioner, the components of LCC, LCC savings, and PBP. Table 8.4.24 presents these details separately for single-package central air conditioner units for the nation by efficiency level. The detailed results indicate that although average savings are positive at SEER 14, no national standard above the 13 SEER baseline yields more affected consumers that experience savings ("winners") than experience losses ("losers").

Table 8.4.24 LCC and PBP Results for Single-Package Air Conditioners by Efficiency Level (SEER Value): Nation

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,040	5,303	8,343	n/a	0	100	0	n/a
13.5	3,143	5,189	8,332	9	40	37	23	17.7
14	3,223	5,077	8,301	37	50	17	33	15.1
14.5	3,358	4,989	8,346	(15)	67	3	30	21.3
15	3,492	4,908	8,400	(68)	72	1	27	24.2
15.5	3,643	4,840	8,483	(150)	76	0	24	28.1
16	3,798	4,779	8,577	(244)	78	0	22	31.9
16.5	4,064	4,760	8,825	(492)	84	0	16	46.3

*Values in parentheses denote negative values.

8.4.4 Single-Package Heat Pumps

This section presents LCC results for the efficiency improvement levels specified in the engineering analysis for single-package HPs (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs, repair costs, and maintenance costs developed for each individual observation. Section 8.2 presents the electricity price inputs as well as all other LCC inputs.

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.

8.4.4.1 Mean LCC Savings for Single Package Heat Pumps for the Nation

Because the values of most inputs are uncertain in this analysis, DOE represents them as a distribution of values rather than a single-point value. Thus, DOE also represents the LCC

results as a distribution of values. In Table 8.4.25 DOE presents average values for LCC savings to show how these savings vary with efficiency for the single-package HP product classes for the nation. The LCC savings for single-package HPs are positive at the national level for a standard up to 15 SEER.

Table 8.4.25 Mean LCC Savings for Single-Package Heat Pumps for the Nation by Efficiency Level (SEER Value)

Efficiency Level	SEER	HSPF	Mean LCC Savings for the Nation *2009$*
2	13.5	7.9	124
3	14	8.1	104
4	14.5	8.3	58
5	15	8.4	15
6	15.5	8.6	(45)
7	16	8.8	(195)
8	16.5	9.0	(363)

*Values in parentheses denote negative values.

The results shown in Table 8.4.25 are mean values and do not show the distributions of savings. Thus, although observations can be made as to how the various inputs impact LCC and, in turn, how the resulting LCCs change with efficiency, conclusions should only be drawn from the distribution of LCC results that are presented in Figure 8.4.9. Section 8.4.4.3 provides information on the percentages of consumers for the nation at each efficiency level that would experience LCC savings benefits, LCC cost increases, and no impact from the standard. Median savings are positive only up to 14 SEER for a national standard, indicating that more consumers would experience losses than gains for standards above 14 SEER.

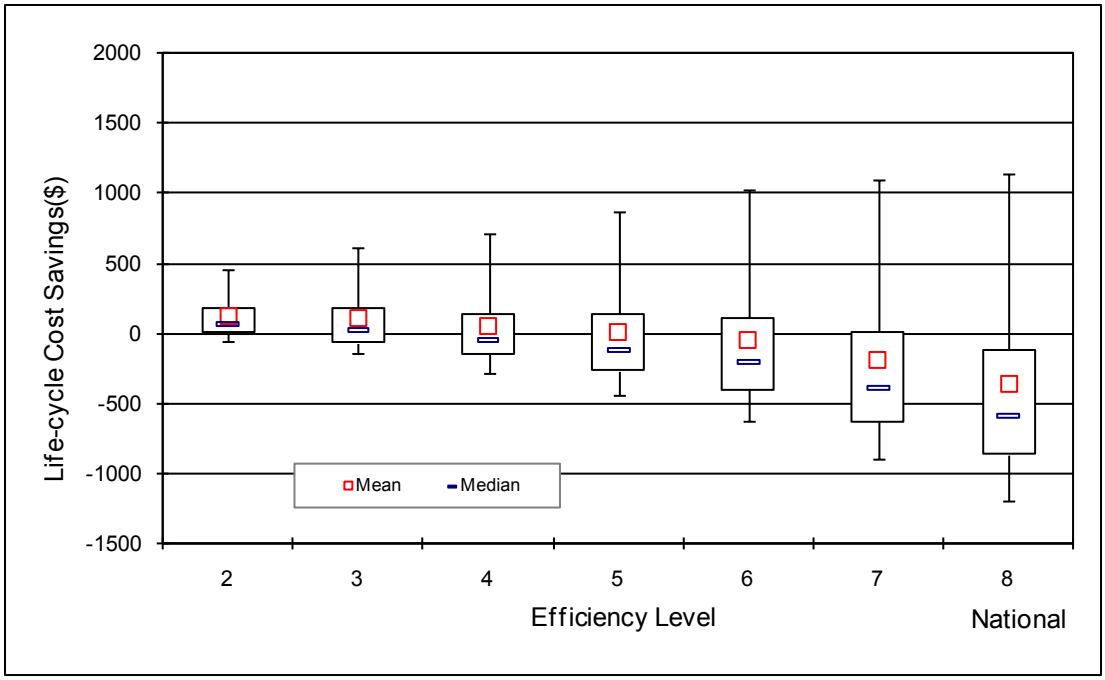

Figure 8.4.9 Plots of the Distributions of LCC Savings for Single-Package Heat Pumps

8.4.4.2 Payback Period Results for Single-Package Heat Pumps

This section presents PBP results for the efficiency improvement levels specified in the engineering analysis (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs. Section 8.3 describes the PBP inputs.

Similar to LCC, the analysis provides an estimate of the simple PBP at different ranges of energy prices, sales taxes, and installation costs that prevail across the country for each efficiency level for the nation. Table 8.4.26 shows the effect on PBP as the level of efficiency changes from the market baseline for single-package HP products in residential and commercial buildings for each region's energy prices, sales taxes, and installation costs.

Similar to the LCC differences, DOE depicted PBP results as a distribution of values. The medians of these distributions are shown in Table 8.4.26 and the distributions of values for PBP are shown in Figure 8.4.10. Rebuttable PBP for each efficiency level is shown in Table 8.4.27. Only SEER level 13.5 met the criterion of payback in less than three years. In addition, DOE provides data on the median PBP for each efficiency level for the nation in section 8.4.4.3.

Table 8.4.26 Median Payback Period for Single-Package Heat Pumps

Efficiency Level	SEER	HSPF	Payback Period for the Nation *years*
2	13.5	7.9	4.7
3	14	8.1	8.4
4	14.5	8.3	11.6
5	15	8.4	13.6
6	15.5	8.6	15.0
7	16	8.8	18.0
8	16.5	9.0	20.7

Table 8.4.27 Rebuttable Payback Period for Single-Package Heat Pumps

Efficiency Level	SEER	HSPF	Rebuttable Payback Period *years*
			Nation
2	13.5	7.9	2.6
3	14	8.1	4.1
4	14.5	8.3	5.3
5	15	8.4	6.5
6	15.5	8.6	7.0
7	16	8.8	7.9
8	16.5	9.0	8.7

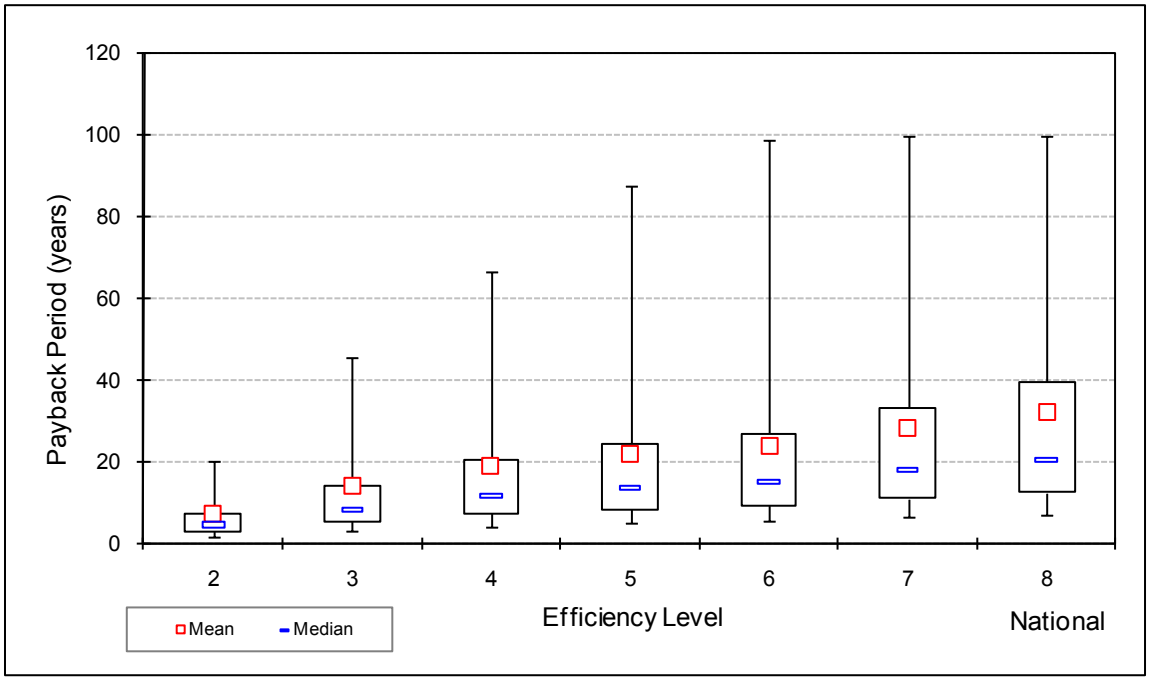

Figure 8.4.10 Plots of the Distributions of PBP for Single-Package Heat Pumps

8.4.4.3 Detailed Results for Single-Package Heat Pumps

This section provides data on the detailed LCC results for single-package central heat pump, the components of LCC, LCC savings, and PBP. These details are shown separately by efficiency level for the nation in Table 8.4.28. The detailed results indicate that more than half of all consumers are unaffected by standards up to about 13.5 SEER. The tables show that a national standard yields positive average LCC savings up through 15 SEER. No national standard above 14 SEER yields more affected consumers that experience savings ("winners") than experience losses ("losers"). Losers outnumber winners for regional standards at all SEER levels above the 14 SEER level for the nation as a whole.

Table 8.4.28 LCC and PBP Results for Single-Package Heat Pumps by Efficiency Level (SEER Value): Nation

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	3,623	7,834	11,457	n/a	0	100	0	n/a
13.5	3,696	7,635	11,332	124	8	68	25	4.7
14	3,828	7,463	11,291	104	29	36	35	8.4
14.5	3,996	7,309	11,305	58	55	7	38	11.6
15	4,163	7,182	11,345	15	63	2	35	13.6
15.5	4,353	7,052	11,404	(45)	69	0	31	15.0
16	4,607	6,948	11,555	(195)	75	0	25	18.0
16.5	4,866	6,856	11,722	(363)	79	0	21	20.7

*Values in parentheses denote negative values.

8.4.5 Small-Diameter High-Velocity Products

This section presents LCC results for the efficiency improvement levels specified in the engineering analysis for SDHV products (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs, repair costs, and maintenance costs developed for each individual observation. Section 8.2 presents the electricity price inputs as well as all other LCC inputs.

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.

8.4.5.1 Mean LCC Savings for Small-Diameter High-Velocity Products by Region

Because the values of most inputs are uncertain in this analysis, DOE represents them as a distribution of values rather than a single-point value. Thus, DOE also represents the LCC results as a distribution of values. In Table 8.4.29 DOE presents average values for LCC savings

to show how these savings vary with efficiency for the small-diameter high velocity product classes and by region. The results indicate that with the possible marginal exception of the hot humid region at 13.5 SEER, no standard above the 13 SEER baseline produces positive average LCC savings.

Table 8.4.29 Mean LCC Savings for SDHV by Region by Efficiency Level (SEER Value)

Efficiency Level	SEER	Mean LCC Savings by Region *2009$*			
		Nation	Hot-Humid	Hot-Dry	Rest of Country
2	13.5	(38)	1	(22)	(96)
3	14	(92)	(14)	(65)	(202)
4	14.5	(138)	(25)	(106)	(294)

*Values in parentheses denote negative values.

The results shown in Table 8.4.29 are mean values and do not show the distributions of savings. Thus, although observations can be made as to how the various inputs impact LCC and, in turn, how the resulting LCCs change with efficiency, conclusions should only be drawn from the distribution of LCC results that are presented in Figure 8.4.11. Section 8.4.5.3 provides information on the percentages of consumers in each region at each efficiency level that would experience LCC savings benefits, LCC cost increases, and no impact from the standard. Median savings are consistently negative.

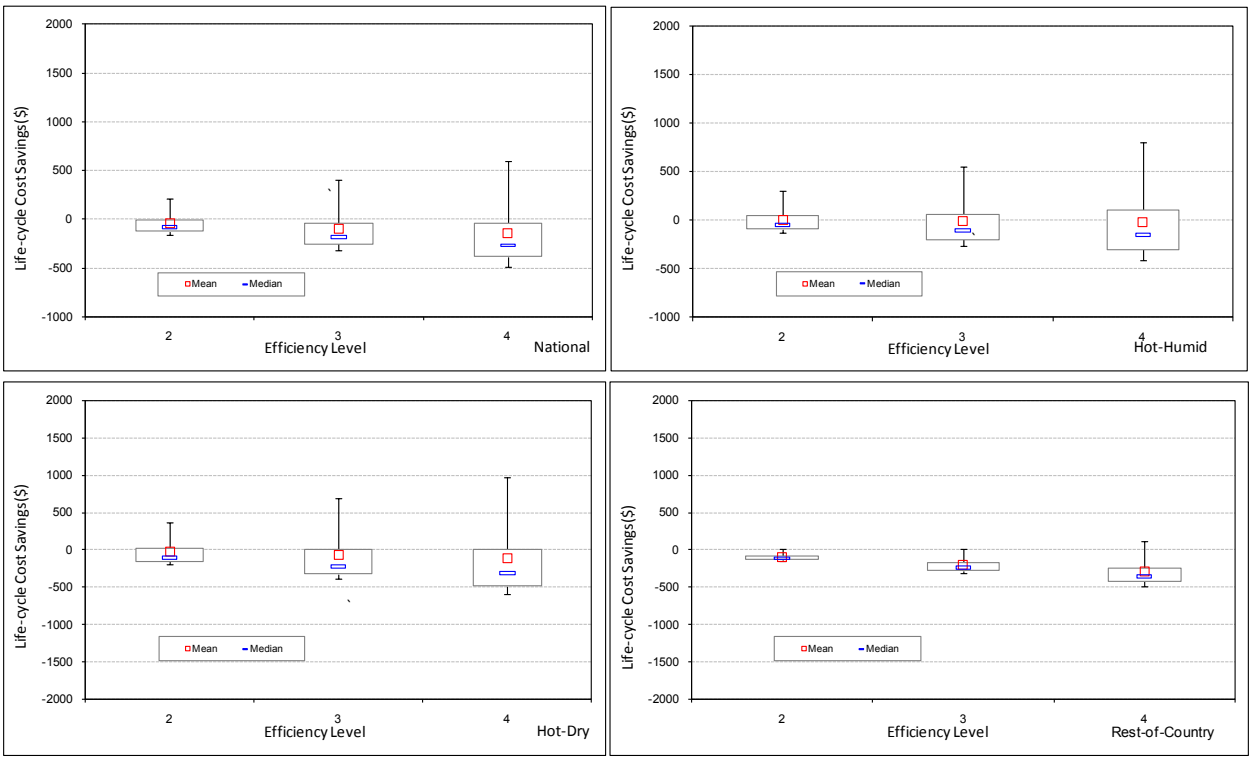

Figure 8.4.11 Plots of the Distributions of LCC Savings for SDHVs by Region

8.4.5.2 Payback Period Results for Small-Diameter High-Velocity Products by Region

This section presents PBP results for the efficiency improvement levels specified in the engineering analysis (chapter 5) and also presented in section 8.2.2.3, Standard-Level Manufacturer Price Increases. The results presented here are based on annual operating costs calculated from residential and commercial electricity tariffs. Section 8.3 describes the PBP inputs.

Similar to LCC, the analysis provides an estimate of the simple PBP at different ranges of energy prices, sales taxes, and installation costs that prevail across the country for each efficiency level and each building type. Table 8.4.30 shows the effect on PBP as the level of efficiency changes from the market baseline for small-diameter high velocity products in residential and commercial buildings for each region's energy prices, sales taxes, and installation costs.

Similar to the LCC differences, DOE depicted PBP results as a distribution of values. The medians of these distributions are shown in Table 8.4.30 and the distributions of values for PBP are shown in Figure 8.4.12. Median PBPs exceed the lifetime of the SDHV products. Rebuttable PBP for each efficiency level is shown in Table 8.4.31. No level met the rebuttable payback criterion. In addition, DOE provides data on the median PBP for each efficiency level in each region in section 8.4.5.3.

Table 8.4.30 Median Payback Period for SDHVs by Region

Efficiency Level	SEER	Payback Period by Region *years*			
		Nation	Hot-Humid	Hot-Dry	Rest of Country
2	13.5	28.7	16.6	24.3	66.7
3	14	30.9	17.8	26.1	74.3
4	14.5	29.2	17.3	23.3	74.7

Table 8.4.31 Rebuttable Payback Period for SDHVs

Efficiency Level	SEER	Rebuttable Payback Period *years*
		Nation
2	13.5	11.4
3	14	12.0
4	14.5	12.7

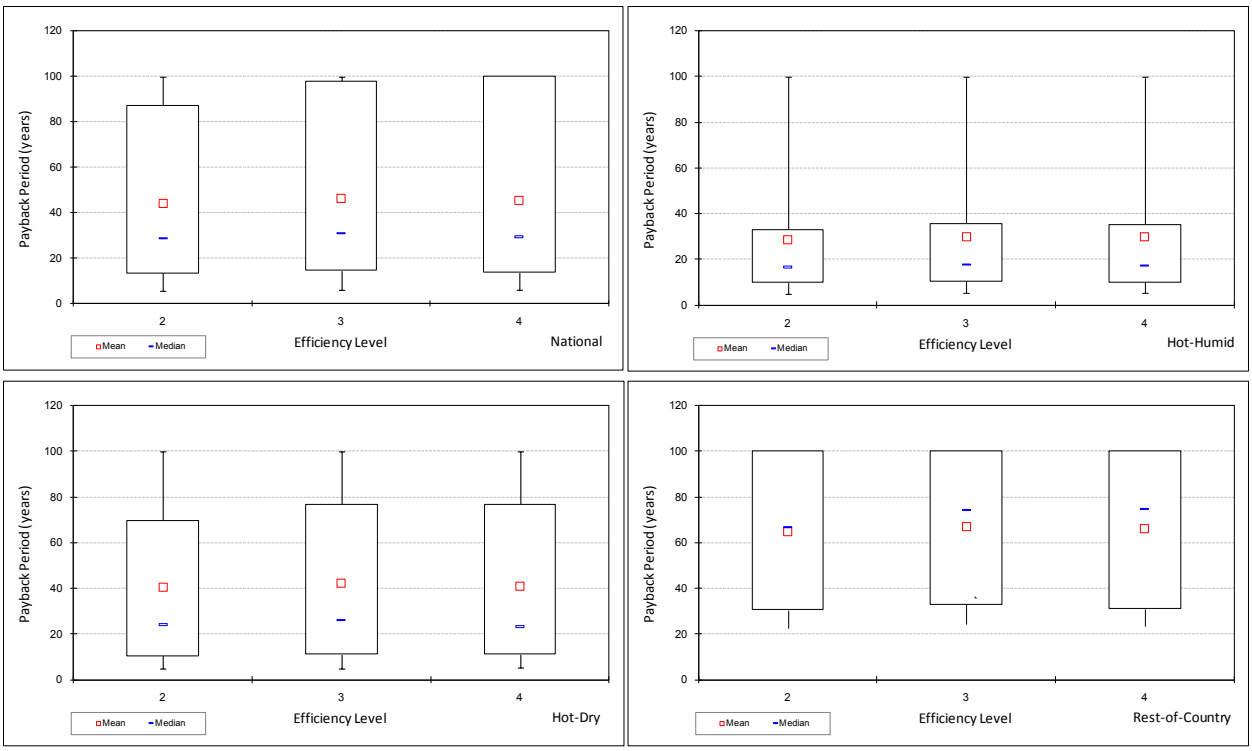

Figure 8.4.12 Plots of the Distributions of PBP for SDHVs by Region

8.4.5.3 Detailed Regional Results for Small-Diameter High-Velocity Products

This section provides data on the detailed results for small-diameter high-velocity LCC, the components of LCC, LCC savings, and PBP. These details are shown separately by region and efficiency level. Table 8.4.32 through Table 8.4.35 present these details for each region by efficiency level. Because the market is assumed to be at 13 SEER, 100 percent of consumers are assumed to be affected by any higher standard. However, consumers who experience LCC losses outnumber those who experience savings at all standard levels above 13 SEER, both nationally and regionally.

Table 8.4.32 LCC and PBP Results for SDHVs by Efficiency Level (SEER Value): Nation

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	4,915	4,853	9,768	n/a	0	100	0	n/a
13.5	5,055	4,751	9,806	(38)	77	0	23	28.7
14	5,200	4,660	9,860	(92)	79	0	21	30.9
14.5	5,353	4,553	9,906	(138)	78	0	22	29.2

*Values in parentheses denote negative values.

Hot-Humid Region

Table 8.4.33 LCC and PBP Results for SDHVs by Efficiency Level (SEER Value): Hot-Humid Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	4,610	5,643	10,253	n/a	0	100	0	n/a
13.5	4,744	5,508	10,252	1	66	0	34	16.6
14	4,883	5,385	10,268	(14)	68	0	32	17.8
14.5	5,029	5,250	10,279	(25)	67	0	33	17.3

*Values in parentheses denote negative values.

Hot-Dry Region

Table 8.4.34 LCC and PBP Results for SDHVs by Efficiency Level (SEER Value): Hot-Dry Region

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	6,302	6,105	12,407	n/a	0	100	0	n/a
13.5	6,480	5,949	12,429	(22)	73	0	27	24.3
14	6,665	5,807	12,472	(65)	74	0	26	26.1
14.5	6,859	5,654	12,513	(106)	74	0	26	23.3

*Values in parentheses denote negative values.

Rest of Country

Table 8.4.35 LCC and PBP Results for SDHVs by Efficiency Level (SEER Value): Rest of Country

Efficiency Level *SEER*	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings	Experience			Median
					Net Cost	No Impact	Net Benefit	
13 (Baseline)	4,919	3,447	8,367	n/a	0	100	0	n/a
13.5	5,056	3,406	8,462	(96)	94	0	6	66.7
14	5,198	3,370	8,568	(202)	95	0	5	74.3
14.5	5,347	3,313	8,660	(294)	92	0	8	74.7

*Values in parentheses denote negative values.

8.4.6 Non-Weatherized Gas Furnace

Table 8.4.36 shows the LCC and PBP results for non-weatherized gas furnaces by region. As mentioned earlier, for some households DOE assigned base case products that are more energy efficient than some of the standard levels. For that reason, the average LCC impacts are not equal to the difference between the LCC of a specific standard level and the LCC of the baseline products. Similarly with regard to the PBPs shown below, DOE determined the median and average values by excluding the percentage of households not impacted by a standard at a given efficiency level. The values for average lifetime operating cost in the tables are discounted sums of the annual operating costs over the product lifetime.

Table 8.4.36 LCC and PBP Results for Non-Weatherized Gas Furnaces

Efficiency Level	*AFUE*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings *2009$*				Median Payback Period *years*
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households with			
						Net Cost	No Impact	Net Benefit	
Nation									
0	80%	1,786	9,551	11,337	N/A	0	100	0	N/A
1	90%	2,357	8,621	10,978	87	25	52	22	15.8
2	92%	2,419	8,456	10,875	136	26	42	32	11.9
3	95%	2,564	8,220	10,785	205	36	17	47	11.7
4	98%	2,830	8,114	10,944	46	64	0	35	20.1
North									
0	80%	1,901	11,553	13,454	N/A	0	100	0	N/A
1	90%	2,474	10,409	12,883	155	10	71	19	10.1
2	92%	2,536	10,206	12,742	215	11	56	33	7.7
3	95%	2,685	9,916	12,601	323	23	23	54	9.4
4	98%	2,943	9,784	12,727	198	59	1	41	17.1
South (Rest of Country)									
0	80%	1,614	6,566	8,180	N/A	0	100	0	N/A
1	90%	2,182	5,955	8,137	(13)	48	24	28	24.1
2	92%	2,244	5,846	8,090	19	48	20	32	21.3
3	95%	2,384	5,692	8,076	28	56	8	36	20.5
4	98%	2,661	5,624	8,286	(181)	72	0	27	28.9

*Values in parentheses denote negative values.

Figures 8.4.13 through 8.3.14 show the range of LCC savings for the efficiency levels considered for non-weatherized gas furnaces by region. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have lifecycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

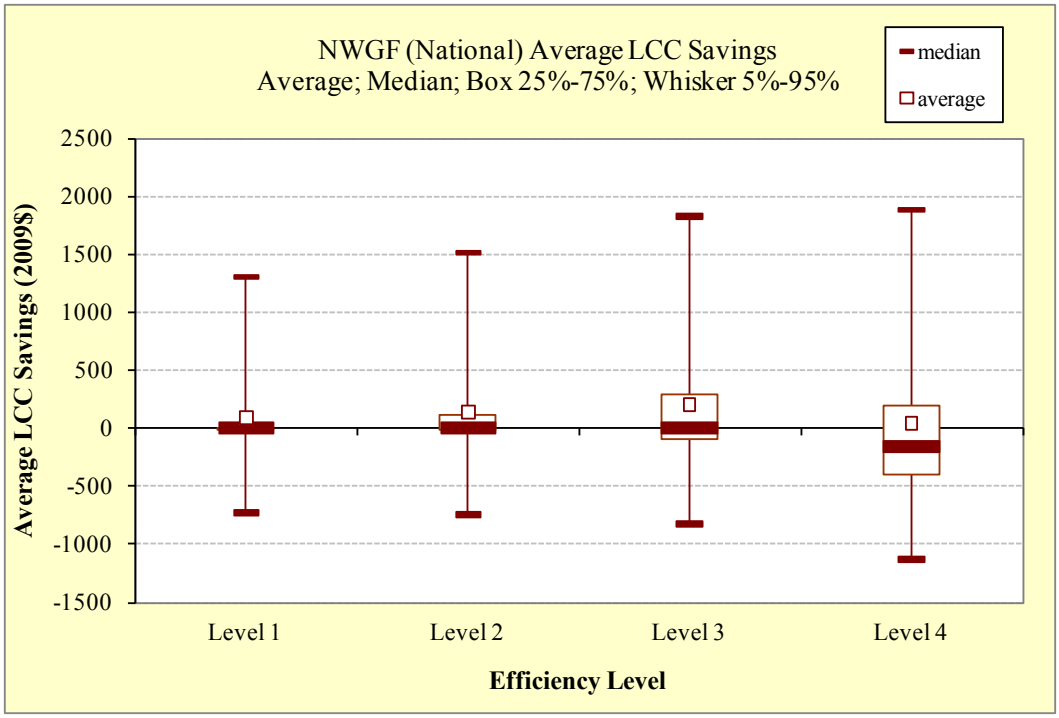

Figure 8.4.13 Plot of the Distributions of LCC Savings for Non-Weatherized Gas Furnaces – National

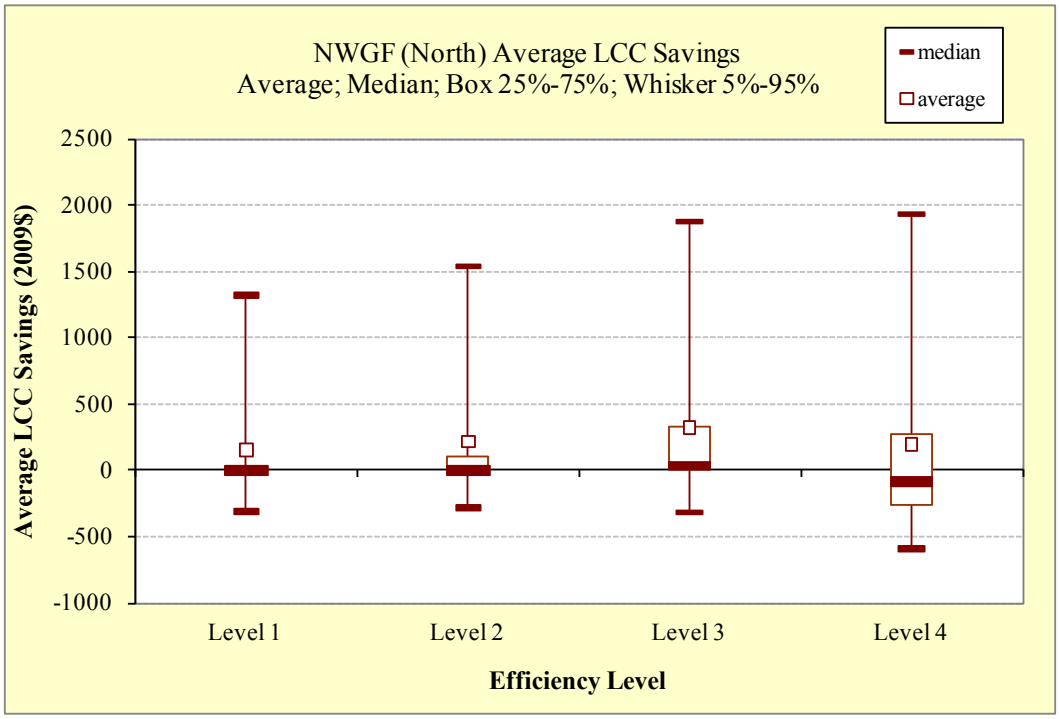

Figure 8.4.14 Plot of the Distributions of LCC Savings for Non-Weatherized Gas Furnaces – North Region

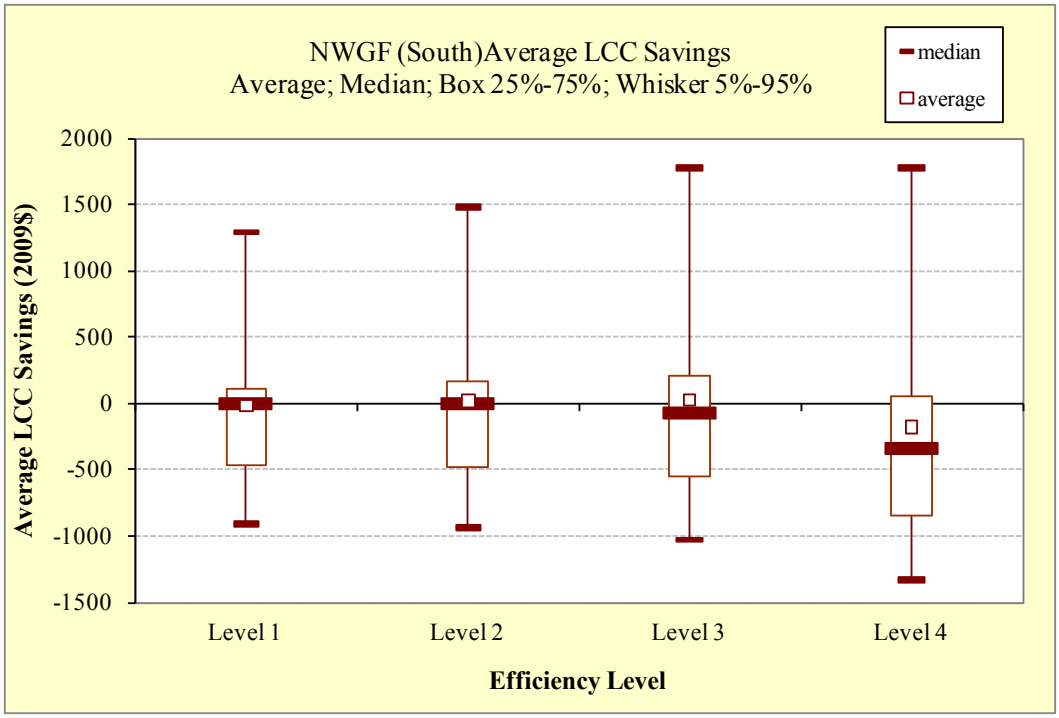

Figure 8.4.15 Plot of the Distributions of LCC Savings for Non-Weatherized Gas Furnaces – South Region

Figures 8.4.16 through 8.4.18 show the range of PBPs for all efficiency levels considered for non-weatherized gas furnaces by region. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have a payback period above this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average PBP for each efficiency level.

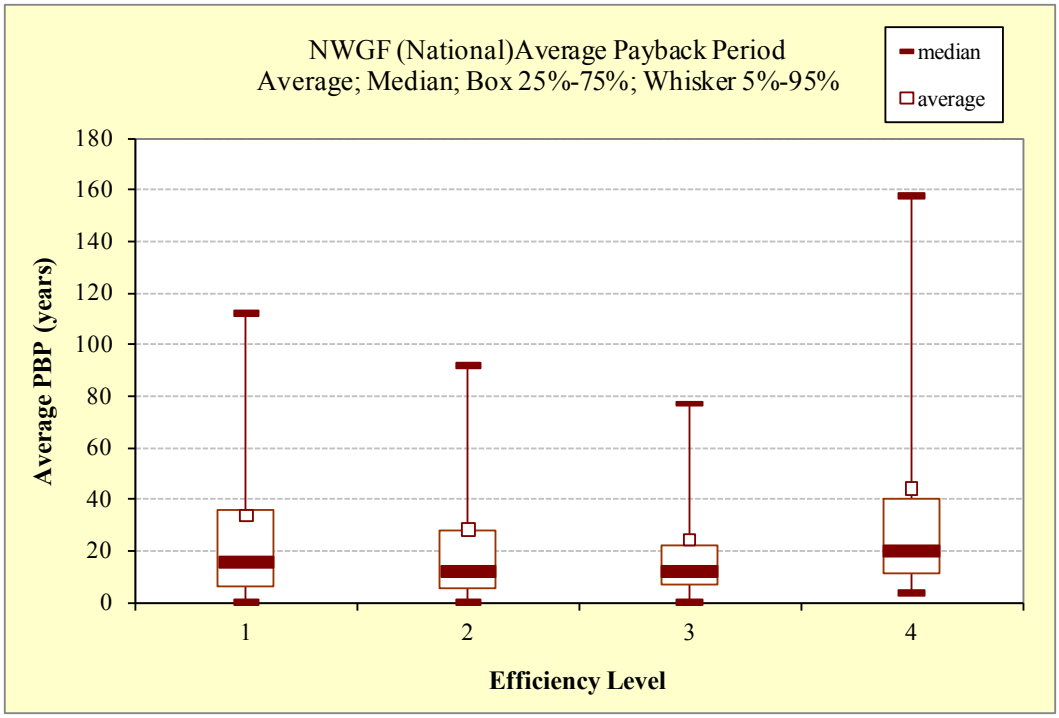

Figure 8.4.16 Plot of the Distributions of PBB for Non-Weatherized Gas Furnaces – National

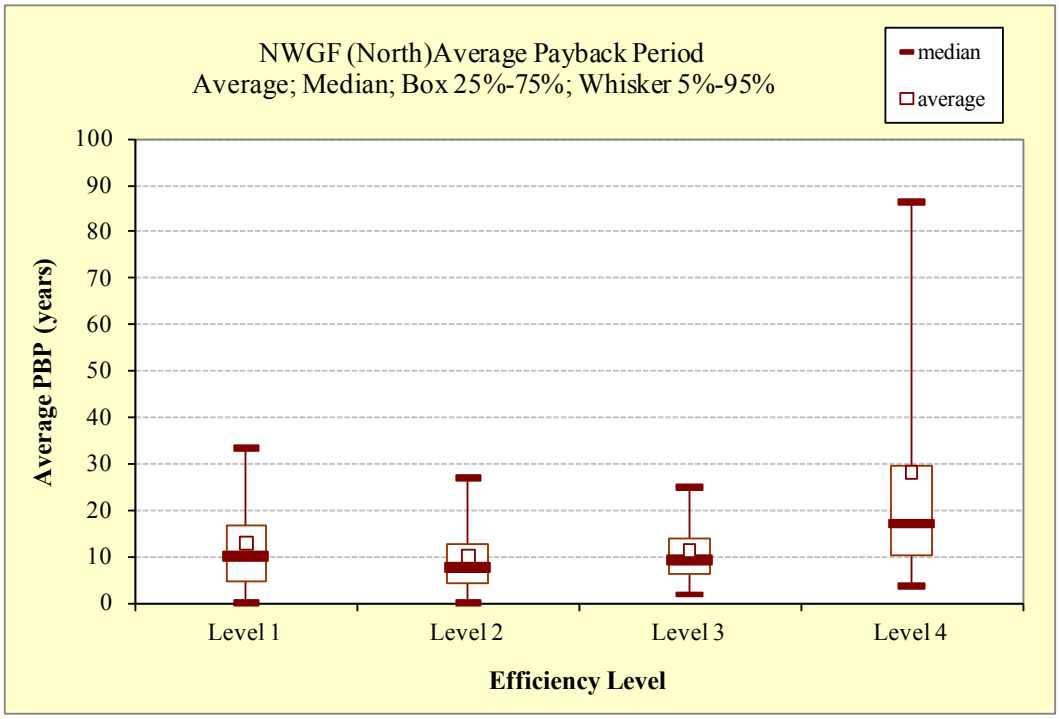

Figure 8.4.17 Plot of the Distributions of PBB for Non-Weatherized Gas Furnaces – North Region

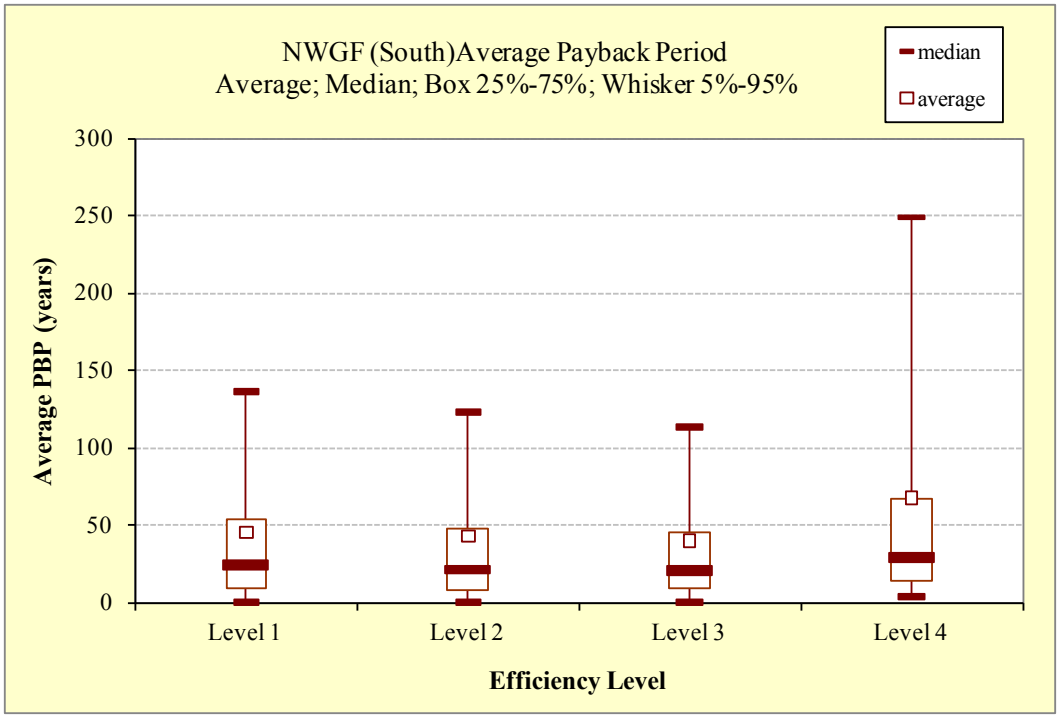

Figure 8.4.18 Plot of the Distributions of PBB for Non-Weatherized Gas Furnaces – South Region

Rebuttable PBP for each efficiency level is shown in Table 8.4.37.

Table 8.4.37 Rebuttable Payback Period for Non-Weatherized Gas Furnaces

Efficiency Level	AFUE	Total Costs		Rebuttable Payback Period *years*
		Total Installed Costs	Total Operating Costs	
0	80%	1,590	917	
1	90%	2,135	818	5.5
2	92%	2,188	800	5.1
3	95%	2,301	776	5.1
4	98%	2,495	733	4.9

8.4.7 Manufactured Home Gas Furnace

Table 8.4.38 shows the LCC and PBP results for manufactured home gas furnaces by region. As mentioned earlier, for some households DOE assigned base case products that are more energy efficient than some of the standard levels. For that reason, the average LCC impacts are not equal to the difference between the LCC of a specific standard level and the LCC of the baseline products. Similarly with regard to the PBPs shown below, DOE determined the median and average values by excluding the percentage of households not impacted by a standard at a given efficiency level. The values for average lifetime operating cost in the tables are discounted sums of the annual operating costs over the product lifetime.

Table 8.4.38 LCC and PBP Results for Manufactured Home Gas Furnaces

Efficiency Level	*AFUE*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings *2009$*				Median Payback Period *years*
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households that Experience			
						Net Cost	No Impact	Net Benefit	
Nation									
0	80%	1,518	11,851	13,368	n/a	0	100	0	n/a
1	90%	2,151	10,802	12,952	372	44	10	46	10.7
2	92%	2,366	10,590	12,956	369	48	8	44	11.6
3	96%	2,674	10,193	12,867	456	51	4	45	12.2
North									
0	80%	1,577	13,730	15,308	n/a	0	100	0	n/a
1	90%	2,226	12,576	14,801	452	43	10	47	10.7
2	92%	2,440	12,329	14,769	482	47	8	46	11.3
3	96%	2,748	11,866	14,615	633	49	4	48	11.7
South (Rest of Country)									
0	80%	1,422	10,903	12,326	n/a	0	100	0	n/a
1	90%	2,023	9,870	11,893	298	45	9	46	10.7
2	92%	2,236	9,676	11,912	262	49	8	43	12.1
3	96%	2,545	9,312	11,857	288	54	4	43	13.0

*Values in parentheses denote negative values.

Figures 8.4.19 through 8.3.21 show the range of LCC savings for the efficiency levels considered for mobile home gas furnaces by region. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have lifecycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

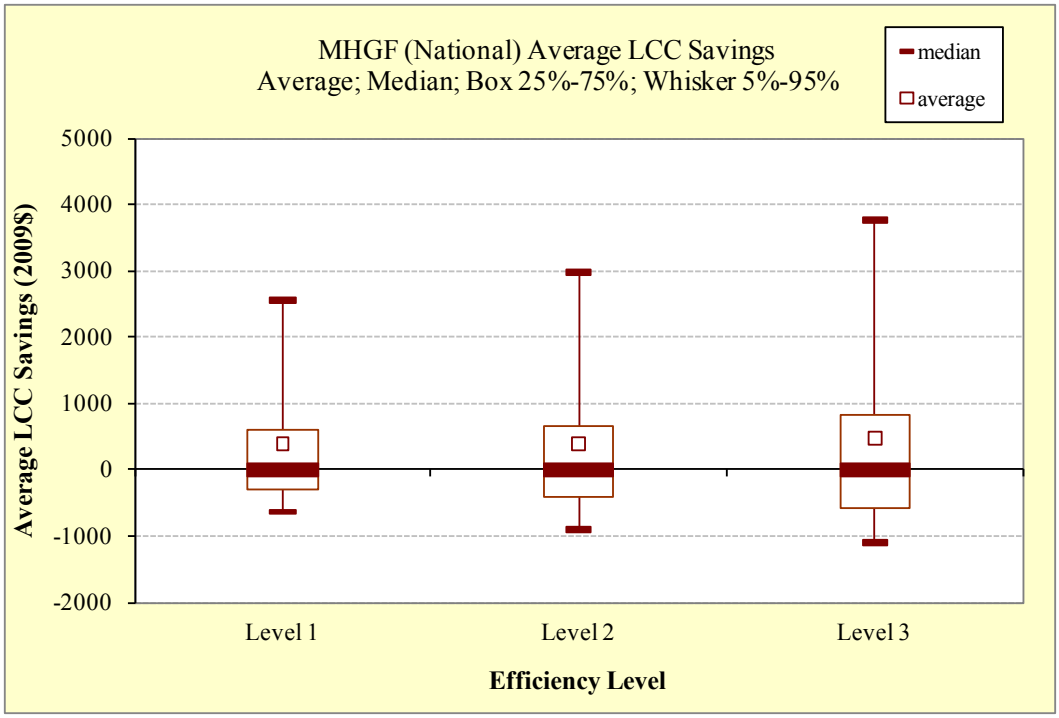

Figure 8.4.19 Plot of the Distributions of LCC Savings for Mobile Home Gas Furnaces – National

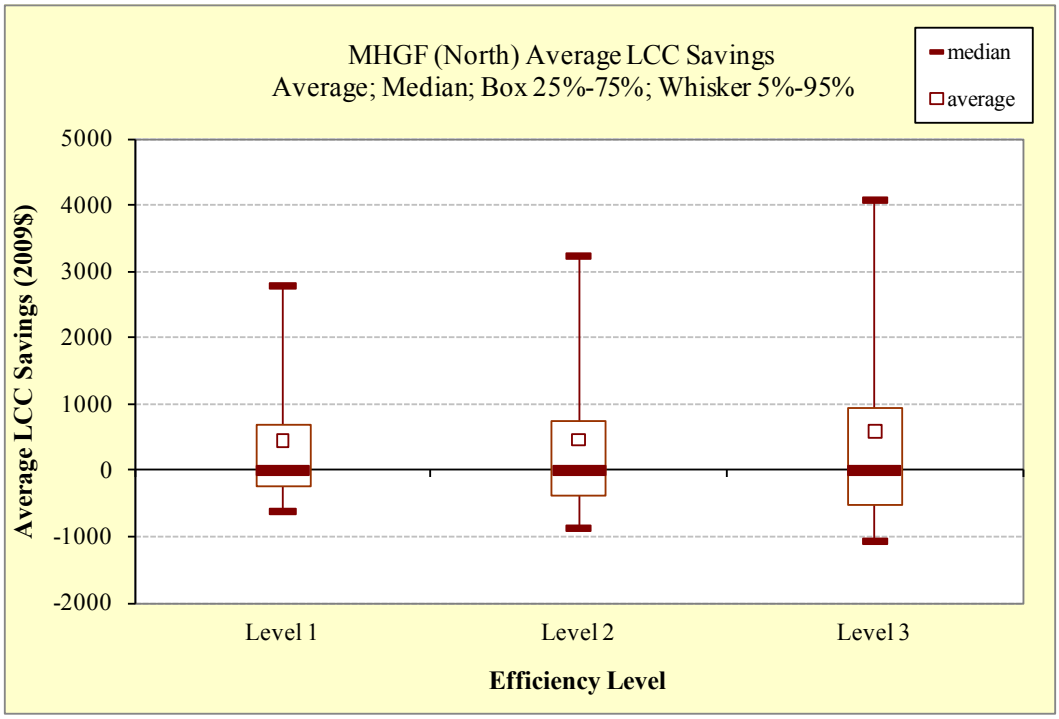

Figure 8.4.20 Plot of the Distributions of LCC Savings for Mobile Home Gas Furnaces – North Region

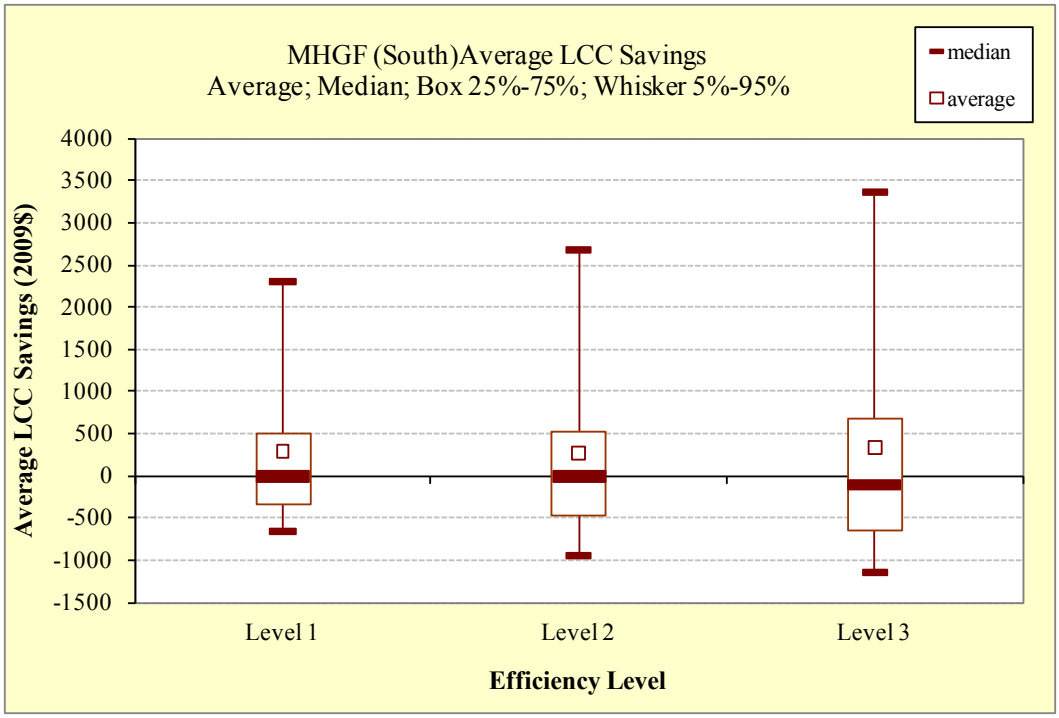

Figure 8.4.21 Plot of the Distributions of LCC Savings for Mobile Home Gas Furnaces – South Region

Figures 8.4.22 through 8.4.24 show the range of PBPs for all efficiency levels considered for mobile home gas furnaces by region. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have a payback period above this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average PBP for each efficiency level.

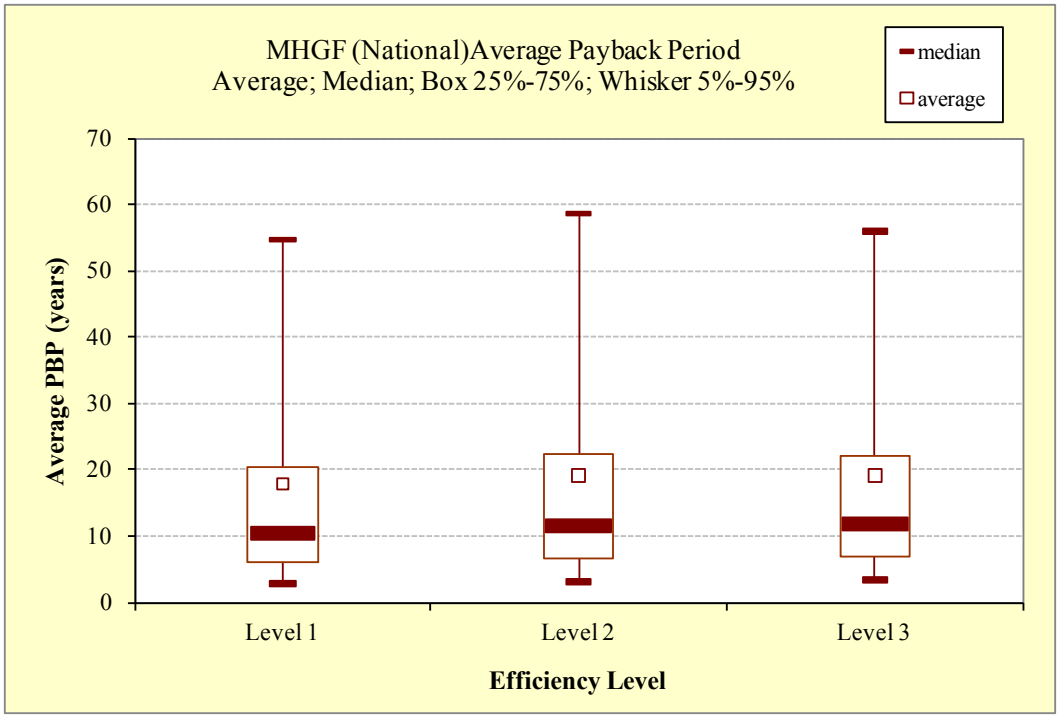

Figure 8.4.22 Plot of the Distributions of PBB for Mobile Home Gas Furnaces – National

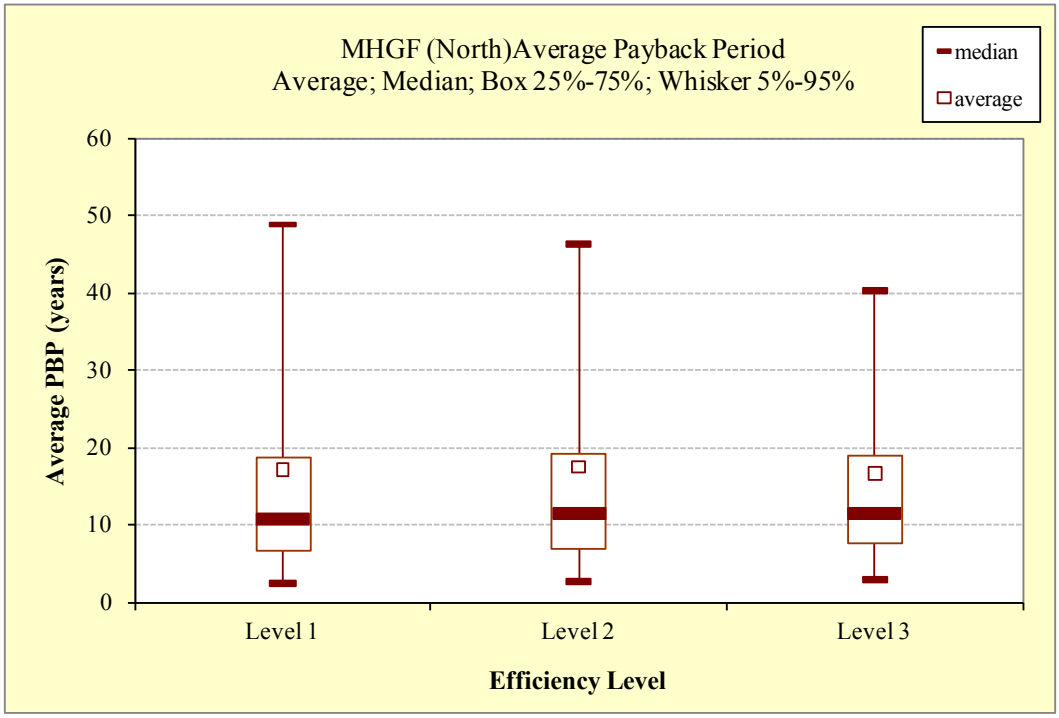

Figure 8.4.23 Plot of the Distributions of PBB for Mobile Home Gas Furnaces – North Region

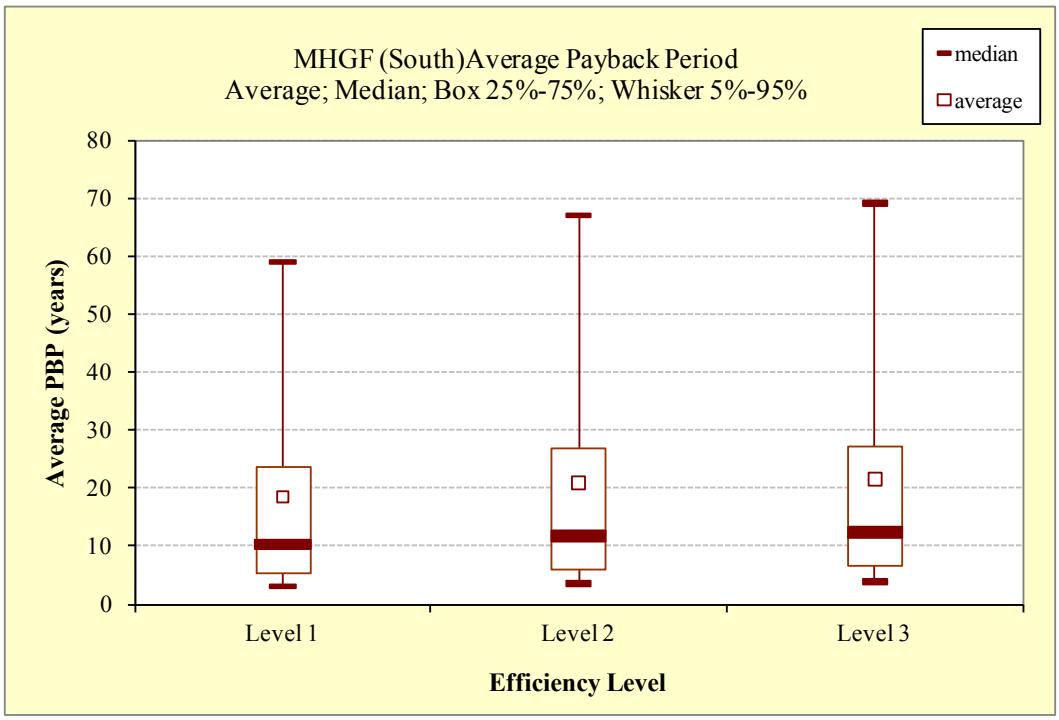

Figure 8.4.24 Plot of the Distributions of PBB for Mobile Home Gas Furnaces – South Region

Rebuttable PBP for each efficiency level is shown in Table 8.4.39.

Table 8.4.39 Rebuttable Payback Period for Manufactured Home Gas Furnaces

Efficiency Level	AFUE	Total Costs		Rebuttable Payback Period *years*
		Total Installed Costs	Total Operating Costs	
0	80%	1,410	1,210	
1	90%	2,017	1,079	4.7
2	92%	2,224	1,056	5.3
3	95%	2,516	1,013	5.6

8.4.8 Oil-Fired Furnace

Table 8.4.40 shows the LCC and PBP results for oil-fired furnaces. As mentioned earlier, for some households DOE assigned base case products that are more energy efficient than some of the standard levels. For that reason, the average LCC impacts are not equal to the difference between the LCC of a specific standard level and the LCC of the baseline products. Similarly with regard to the PBPs shown below, DOE determined the median and average values by excluding the percentage of households not impacted by a standard at a given efficiency level. The values for average lifetime operating cost in the tables are discounted sums of the annual operating costs over the product lifetime.

Table 8.4.40 LCC and PBP Results for Oil-Fired Furnaces

Efficiency Level	*AFUE*	Life-Cycle Cost *2009$*			Life-Cycle Cost Savings *2009$*				Median Payback Period *years*
		Installed Cost	Discounted Operating Cost	LCC	Average Savings *2009$*	% of Households with			
						Net Cost	No Impact	Net Benefit	
0	80%	3,008	30,287	33,295	n/a	0	100	0	n/a
1	90%	3,157	29,946	33,103	15	10	58	32	1.0
2	92%	3,394	29,613	33,007	(13)	24	39	37	1.9
3	95%	3,622	29,287	32,909	(18)	35	33	32	19.8
4	98%	4,810	27,809	32,619	272	51	1	48	18.2

*Values in parentheses denote negative values.

Figures 8.4.25 shows the range of LCC savings for the efficiency levels considered for oil-fired furnaces by region. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have lifecycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

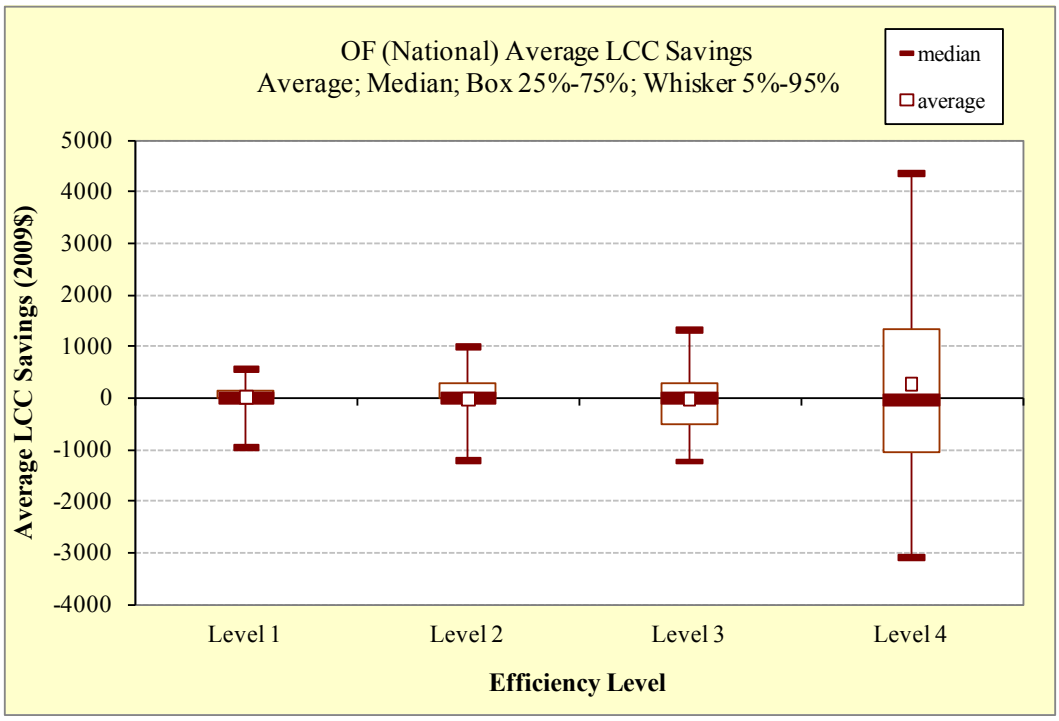

Figure 8.4.25 Plot of the Distributions of LCC Savings for Mobile Home Gas Furnaces – National

Figures 8.4.26 shows the range of PBPs for all efficiency levels considered for oil-fired furnaces by region. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have a payback period above this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average PBP for each efficiency level.

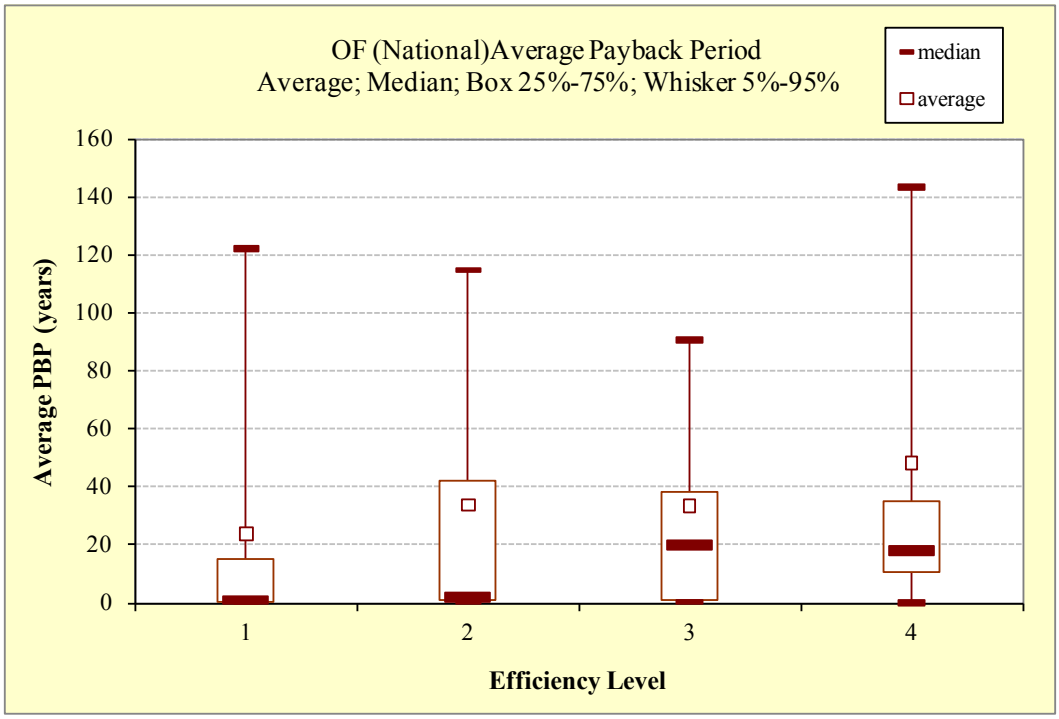

Figure 8.4.26 Plot of the Distributions of PBB for Mobile Home Gas Furnaces – National

Rebuttable PBP for each efficiency level is shown in Table 8.4.41.

Table 8.4.41 Rebuttable Payback Period for Oil-fired Furnaces

Efficiency Level	AFUE	Total Costs		Rebuttable Payback Period *years*
		Total Installed Costs	Total Operating Costs	
0	80%	2,919	1,653	
1	90%	3,067	1,634	7.6
2	92%	3,317	1,615	10.4
3	95%	3,572	1,596	11.5
4	98%	4,804	1,403	7.5

8.5 OFF MODE AND STANDBY POWER CONSUMPTION

8.5.1 Central Air Conditioner and Heat Pump

Residential air conditioners and heat pumps use a small amount of electricity during their "off mode" (neither cooling nor heating). The principal sources of this off mode power consumption are crankcase heaters (CCHs) in the outside unit (nominally 40 watts) and transformers providing low voltage power for controls in the inside unit. For this analysis, DOE calculated the impact on LCC of efficiency levels based on various combinations of improved control techniques for crankcase heaters and more efficient low voltage transformers. Between one and four efficiency levels, including the baseline, were identified in the engineering analysis, depending on product class and whether or not the equipment would utilize a crankcase heater. These levels were subsequently included in the off mode LCC analysis.

The baseline unit was assumed to have no temperature control on the crankcase heater, so that the crankcase heater is "on" whenever the air conditioner or heat pump is in the off mode. For equipment with crankcase heaters, DOE identified three efficiency levels above the baseline for air conditioners and two efficiency levels above the baseline for heat pumps. These are described as follows:

For air conditioners:

Level 1 – Temperature controls so that the CCH is only activated below 60°F

Level 2 – Level 1 plus the use of a self regulating CCH with an insulated compressor cover

Level 3 – Level 2 plus the use of an improved (toroidal) low voltage transformer

For heat pumps:

Level 1 – Temperature controls which reduce CCH usage during the shoulder season period

Level 2 – Level 2 plus the use of an improved (toroidal) low voltage transformer

Several additional considerations exist within the air conditioner and heat pump markets. For coil-only air conditioners, efficiency level 3 was not considered a viable design option since the indoor unit housing the low voltage transformer is physically not part of the test of coil-only units. In addition, DOE recognized that because of the small change in power consumption associated with improving the low voltage transformer, an off mode power standard written that would permit the additional off mode power consumption due to blowers using electronically commutated motors (ECM), approximately 3 watts, would necessarily be set high enough that manufacturers utilizing permanent split capacitor (PSC) motors would be able to comply with the same CCH design options but without improving the low voltage transformer. DOE assumed that only the fraction of the market with ECMs would be affected by efficiency level 3. DOE

estimated that 71% of the air conditioner and heat pump market would utilize PSC motors, based on data for furnaces, which indicated that 29% of furnace blowers utilized ECMs.

Finally, while the largest power-using component during off mode is a CCH, it is not found in all products. For air conditioner products and heat pump products without a crankcase heater, the only available efficiency level above the baseline is the improved low voltage transformer, indentified as efficiency level 1 for these products and for the reasons identified above, applicable only to products with an ECM.

As discussed in chapter 5, with the exception of coil-only split-system central air conditioners, two different off mode power consumption levels exist for each engineering efficiency level. These power consumption levels are dependent on whether the system utilizes a PSC or an ECM blower motor. However, the cost of each design option and the energy savings from each design option utilized in the efficiency levels are unaffected by the blower motor choice. The off mode LCC analysis was done assuming ECMs; however, the LCC results are identical for systems with PSC motors, with the exception that the low voltage transformer is not considered a viable design option for equipment with PSC blower motors.

This off mode analysis was conducted using single point national average estimates for the LCC inputs and was conducted only at the national level. Energy use for each efficiency level was based on the seasonal operating hours at rated conditions from the proposed DOE test procedure as discussed in chapter 7. Table 8.5.1 shows key input assumptions for the LCC analysis. Details on these inputs follow.

Table 8.5.1 Summary of Inputs and Methods for the LCC and PBP Analysis for Central Air Conditioners and Heat Pumps

LCC Analysis Inputs	Equipment Class	
	Air Conditioners (Split-System, Single Package, Space Constrained, and SDHV)	Heat pumps (Split-System, Single Package, and Space Constrained)
Product Cost	Derived by multiplying manufacturer baseline cost and incremental costs by national average baseline and incremental manufacturer markups and sales tax. New and replacement markets considered separately.	
Installation Cost	No installation costs assumed. Efficiency level costs are part of equipment design and do not impact installation.	
Annual Off Mode Energy Consumption	Based on P1 and P2 power consumption established in engineering analysis multiplied by shoulder and heating season hours, respectively, from proposed DOE test procedure.	Based on P1 power consumption established in engineering analysis multiplied by shoulder season hours from proposed DOE test procedure.
Energy Prices	Electricity prices based on national average and marginal residential electricity prices for heating season for heat pumps from residential tariff analysis	
Energy Price Trends	Forecast based on national-average residential electricity price indices developed from the AEO2010 Reference case.	
Repair and Maintenance Costs	No repair and maintenance costs assumed for any efficiency levels	
Measure Life	19 years based on average equipment life	16.3 years based on average equipment life
Discount Rate	5 percent real, based on weighted average of residential discount rate and commercial discount rate (calculated as weighted average cost of capital)	
Compliance Date of New Standard	2016	

8.5.1.1 Product Cost

The price of off mode equipment to the consumer was estimated by applying distribution chain markups to the MSP. The MSP was estimated based on a single markup factor of 1.3 applied to the manufacturers' production cost. To estimate distribution chain markups, national average baseline and incremental markup factors were used. The average markup factors are shown in the summary of national average markups table in chapter 6 for wholesalers, mechanical contractors, and general contractors. Baseline markups are applied to the baseline manufacturer's selling price. Incremental markups were applied to the incremental cost for each efficiency level above the baseline. Derivation of these distribution chain markups is discussed in detail in chapter 6 of the TSD.

8.5.1.2 Installation Costs

DOE assumed that there would be no additional installation costs. Each efficiency level considered reflects component and labor costs that are entirely captured in the equipment price. No additional installation costs for the off mode efficiency levels are required or anticipated beyond the base air conditioner or heat pump installation costs.

8.5.1.3 Energy Prices

Electricity prices for the off mode energy consumption were based on national average and marginal residential electricity prices for heating season for heat pumps as developed from the residential tariff analysis. Electricity prices for heating were assumed to best reflect the electricity costs for off mode power consumption during the heating seasons (for air conditioners). In lieu of a separate and detailed analysis of shoulder season electricity costs, electricity costs for heating were used as these were presumed to be less volatile and more reflective of prices suitable for shoulder seasons than cooling costs. See section 8.2.3.1 for details on the calculation of average electricity prices

8.5.1.4 Energy Price Trends

Future electricity prices were based on national-average residential electricity price indices developed from the *AEO 2010* reference case forecasts. See section 8.2.3.2 for details.

8.5.1.5 Repair and Maintenance Costs

No repair and maintenance costs were assumed for any off mode efficiency levels. CCHs and CCH controls are simple devices and should be relatively robust, and, because CCHs do not directly impact the utility of the air conditioner or heat pump, their problems are expected to be difficult to diagnose in the field. A failure of a CCH may result in premature compressor failure and early replacement, but these would be captured within the lifetime estimates of the air conditioner or heat pump. DOE had no data on the frequency of repair for CCHs or CCH controls and for this reason assigned no repair or maintenance costs to changes in design options associated with the defined off mode efficiency levels. In the case of efficiency levels incorporating the toroidal transformer, DOE believes that low voltage transformers are robust and failures infrequent. No incremental repair or maintenance costs were assigned to efficiency levels using toroidal transformers.

8.5.1.6 Off Mode Measure Lifetime

DOE based the measure lifetime used for the off mode analysis on the average equipment life for CACs or HPs as appropriate. These are 19 years for central air conditioners and 16.3 years for central heat pumps as established in section 8.2.3.5.

8.5.1.7 Discount Rate

The discount rate used for the off mode LCC analysis was based on a weighted average of national average residential consumer discount rates and commercial weighted average cost of capital. Residential shipments were estimated at 93% of the market, with commercial shipments estimated at 7%. The average calculated discount rate was 5% using the analytical approach established in section 8.2.3.6.

8.5.1.8 Compliance Date

The initial starting year for the LCC analysis was 2016, the anticipated compliance date for new central air conditioner and heat pump standards.

8.5.1.9 Off Mode Base Case

In addition to the LCC inputs discussed previously, DOE developed a base case distribution to attempt to project the off mode energy consumption and use of off mode technologies in 2016 in the absence of off mode standards. DOE was not able to identify a data source establishing the fraction of central air conditioner or heat pump products in the U.S. market that would be tested with CCHs or would be expected to have CCHs installed in the field. CCHs are used to protect compressors from refrigerant vapor migrating to the compressor crankcase, condensing and mixing with the crankcase oil, and potentially damaging the compressor during start up. Reciprocating compressors are considered more sensitive to liquid refrigerant in the crankcase and are believed to more commonly utilize CCHs, but scroll compressors also may utilize CCHs, depending on application and total refrigerant charge. Little information on the overall use of CCHs was identified. A 2004 study for the Australian market estimated that one in six air conditioners in that market utilized CCHs.[52] However, changes in compressor type utilization since 2004, in particular market growth in the use of scroll compressors, are expected to result in a lower fraction of the U.S. central air conditioner market having CCHs. DOE estimated that 10 percent of central air conditioners within each product class would utilize CCHs. CCHs are much more commonly used in HPs, which are intended to be able to cycle on in cold weather. DOE assumed that two-thirds of HPs would utilize CCHs in each product class in the base case.

DOE also estimated base-case efficiency distributions for CAC and HP off mode power for units with and without CCHs. For split-system central air conditioners with CCHs DOE estimated that 60% of the affected market would be at the baseline level, 30% would utilize thermostat controls and be at approximately efficiency level 1, and 10% would use more advanced controls, including use of self-regulating heaters, and would be approximately equivalent to efficiency level 2. Based on manufacturer feedback with regard to the toroidal transformer technology, 0% of the market was assigned to level 3 for air conditioners. Since the design options in efficiency levels 1 and 2 are applied to the condensing unit, DOE assumed the same market fractions for blower-coil or coil-only units. However, since the low voltage transformer is part of the indoor unit, and does not exist when testing coil-only equipment, this design option is not applicable to coil-only equipment. For split-system and single-package HPs with CCHs, DOE estimated that 50% of the affected market would be at the baseline level and 50% at efficiency level 1 in 2016. For equipment without a crankcase heater, 100% of the market was assumed to be at the baseline level.

8.5.1.10 Off Mode LCC Results for Central Air Conditioners and Heat Pumps

Estimated installed cost, average operating costs, and average LCC for each efficiency level are shown. It addition, the average LCC savings compared with the base case and the median PBP are shown. While the analysis is based on single point estimates for most of the

inputs, there is variation in the LCC results due to the shipments to new and to replacement markets, as well as due to the fraction of the market at each efficiency level in the base case. The proportions of the market estimated to be impacted positively, negatively, or not impacted by standards set at each efficiency level based on this variation are also shown.

Table 8.5.2 National LCC and Payback Period Results for Off Mode Power Analysis – Air Conditioners

Split-System Air Conditioner (Blower-Coil), Single-Package Air Conditioner, and SDHV with CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience %**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	20	344	364	n/a	0	100	0	n/a
1	26	255	281	84	0	40	60	0.8
2	80	217	297	39	30	10	60	5.6
3	97	211	309	24	40	0	60	8.6
Split-System Air Conditioner (Blower-Coil), Single-Package Air Conditioner, and SDHV without CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*[*]	**Experience %**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	16	79	95	n/a	0	100	0	n/a
1	34	73	107	(12)	100	0	0	35.6
Split-System Air Conditioner (Coil-Only) with CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience %**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	9	265	274	n/a	0	100	0	n/a
1	15	176	191	84	0	40	60	0.8
2	69	138	207	39	30	10	60	5.6
Split-System Air Conditioner (Coil-Only) without CCH[**]								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience %**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	0	0	0	n/a	0	100	0	n/a
Space Constrained Air Conditioner with CCH								
Off Mode	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median**

	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience %			
					Net Cost	No Impact	Net Benefit	
(Baseline)	20	348	368			100		
1	26	258	284	85	0	40	60	0.8
2	80	219	299	41	30	10	60	5.6
3	97	214	311	25	40	0	60	8.6
Space Constrained Air Conditioner without CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience %**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	16	80	96			100		
1	34	74	108	(11)	100	0	0	35.6

*Values in parentheses denote negative values.
** Provided for completeness in tables. No efficiency level options identified

Table 8.5.3 National LCC and Payback Period Results for Off Mode Power Analysis – Split-System and Space Constrained Heat Pumps

Split-System and Space Constrained Heat Pumps with CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	20	41	61	n/a	0	100	0	n/a
1	26	26	52	9	0	50	50	4.2
2	43	25	69	(12)	100	0	0	19.9
Split-System and Space Constrained Heat Pumps without CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	16	11	28	n/a	0	100	0	n/a
1	34	11	44	(17)	100	0	0	>100

*Values in parentheses denote negative values.

Table 8.5.4 National LCC and Payback Period Results for Off-Mode Power Analysis – Single-Package Heat Pumps

Single Package Heat Pump with CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	21	41	62	n/a	0	100	0	n/a
1	27	26	54	9	0	50	50	4.2
2	45	26	71	(13)	100	0	0	19.9
Single Package Heat Pump without CCH								
Off Mode Efficiency Level	**Life-Cycle Cost**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
	Average Installed Cost *2009$*	**Average Operating Cost** *2009$*	**Average LCC** *2009$*	**Average Savings** *2009$*	**Experience**			
					Net Cost	**No Impact**	**Net Benefit**	
(Baseline)	17	11	29	n/a	0	100	0	n/a
1	35	11	46	(17)	100	0	0	>100

*Values in parentheses denote negative values.

8.5.2 Furnaces

The furnace off mode analysis was conducted only at the national level and was conducted using many of the same distributions and variables as the furnace LCC analysis. Energy use for each efficiency level was based on the seasonal operating hours calculated in the furnace LCC analysis. Table 8.5.5 shows key input assumptions for the LCC analysis.

Table 8.5.5 Summary of Inputs and Methods for the LCC and PBP Analyses for Furnaces

LCC Analysis Inputs	Equipment Class
Product Cost	Derived by multiplying manufacturer baseline cost and incremental costs by regional baseline and incremental manufacturer markups and sales taxes. New and replacement markets considered separately.
Installation Cost	No installation costs assumed. Efficiency level costs are part of equipment design and do not impact installation.
Annual Off Mode Energy Consumption	Power consumption established in engineering analysis multiplied by 8760 minus furnace burner operating hours calculated for each sampled household during the furnace simulation run.
Energy Prices	Electricity prices based on monthly regional average residential electricity prices.
Energy Price Trends	Forecast based on regional-average residential electricity price indices developed from the *AEO 2010* Reference case.
Repair and Maintenance Costs	No repair and maintenance costs assumed for any efficiency levels
Component Lifetime	Same as the furnace equipment lifetime.
Discount Rate	Same as for the furnace LCC analysis.
Compliance Date of New Standard	2016

Estimated installed cost, average operating costs, and average LCC for each efficiency level are shown in Table 8.5.6 for each furnace product class.

Table 8.5.6 National LCC and Payback Period Results for Off Mode Power Analysis – Furnaces

Off Mode Efficiency Level	Life-Cycle Cost			Life-Cycle Cost Savings				Median Payback Period *years*
	Average Installed Cost *2009$*	Average Operating Cost *2009$*	Average LCC *2009$*	Average Savings *2009$*	Experience			
					Net Cost	No Impact	Net Benefit	
Non-Weatherized Gas Furnaces								
(Baseline)	0	133	133	n/a	0	100	0	n/a
1	3	128	132	2	9	72	18	10.7
2	8	125	133	(0)	17	72	11	16.1
Manufactured Home Gas Furnaces								
(Baseline)	0	103	103	n/a	0	100	0	n/a
1	1	102	103	(0)	6	91	4	11.9
2	4	101	104	(1)	8	91	2	17.9
Oil-fired Furnaces								
(Baseline)	0	180	180	n/a	0	100	0	n/a
1	1	178	179	1	1	91	8	7.9
2	3	177	179	1	4	91	6	11.9
Electric Furnaces								
(Baseline)	0	111	111	n/a	0	100	0	n/a
1	1	110	111	0	4	90	5	10.3
2	3	109	111	(1)	7	90	3	15.5

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