CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

8.1 INTRODUCTION

This chapter describes the U.S. Department of Energy (DOE)'s methodology for analyzing the economic impacts of possible energy efficiency standards for microwave oven standby power on individual consumers. The effect of standards on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). This chapter describes three metrics DOE used to determine the effect of standards on individual consumers:

- **Life-cycle cost** (LCC) is the total consumer expense over the life of an appliance, including purchase expense and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase, and sums them over the lifetime of the product.

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

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

Inputs to the LCC and PBP calculations are discussed in section 8.2 of this chapter. Results for the LCC and PBP are presented in section 8.3. The rebuttable PBP is discussed in section 8.4. Key variables and calculations are presented for each metric. DOE performed the calculations discussed here using a series of Microsoft Excel® spreadsheets which are accessible on the Internet (http://www.eere.energy.gov/ buildings/appliance_standards/). Details and instructions for using the spreadsheets are discussed in appendix 8-A.

8.1.1 General Approach for LCC and PBP Analyses

Life-cycle cost is the total consumer expense over the life of an appliance, including purchase expense and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase, and sums them over the lifetime of the product. DOE defines LCC by the following equation:

$$LCC = IC + \sum_{t=1}^{N} \frac{OC_t}{(1+r)^t}$$

Where:

LCC = Life-cycle cost in dollars,
IC = Total installed cost in dollars,
$\sum$ = Sum over the lifetime, from year 1 to year N,
N = Lifetime of appliance in years,
OC = Operating cost in dollars,
r = Discount rate, and
t = Year for which operating cost is being determined.

The payback period is the amount of time it takes the consumer to recover the estimated higher purchase expense of more energy-efficient products as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase expense (i.e., from a less energy-efficient design to a more energy-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 operating expense over time or the time value of money; i.e., the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Where:

ΔIC = Difference in the total installed cost between the more energy efficient design and the baseline design, and
ΔOC = difference in annual operating expenses.

Payback periods are expressed in years. Payback periods greater than the life of the product indicate that the increased total installed cost is not recovered with the reduced operating expenses.

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analyses by modeling both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. A detailed explanation of Monte Carlo simulation and the use of probability distributions is contained in appendix 8-B. DOE developed LCC and PBP spreadsheet models incorporating both Monte Carlo simulation and probability distributions by using Microsoft Excel® spreadsheets combined with Crystal Ball® (a commercially available add-in program).

In addition to characterizing several of the inputs to the analyses with probability distributions, DOE developed a sample of individual households that use each of the appliances. By developing household samples, DOE was able to perform the LCC and PBP calculations for each household to account for the variability in energy consumption and/or energy price associated with each household.

As described in chapter 7, DOE used the DOE Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey (RECS) to develop household samples for microwave and combination ovens.[1] The 2005 RECS consists of 4,382 housing units and was constructed by the EIA to be a national representation of the household population in the United States. DOE used RECS to establish the variability of annual appliance use and of energy prices. DOE was able to assign unique annual hours of operation to each household in the sample. The variability across households in annual appliance use and/or energy pricing contributes to the range of LCCs and PBPs calculated for any particular candidate standard level (CSL).

DOE displays the LCC and PBP results as distributions of impacts compared to the baseline conditions. Results are presented at the end of this chapter and are based on 10,000 samples per Monte Carlo simulation run. To illustrate the implications of the analyses, DOE generated a frequency chart depicting the variation in LCC and PBP for each CSL considered.

8.1.2 Overview of LCC and PBP Inputs

DOE categorizes inputs to the LCC and PBP analyses as follows: (1) inputs for establishing the purchase expense, otherwise known as the total installed cost, and (2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer cost*: The costs incurred by the manufacturer to produce products meeting existing minimum efficiency standards.

- *Standard-level manufacturer cost increases*: The change in manufacturer cost associated with producing products to meet a particular CSL.

- *Markups and sales tax*: The markups and sales tax associated with converting the manufacturer cost to a consumer product cost.

- *Installation cost*: The cost to the consumer of installing the product. The installation cost represents all costs required to install the product other than the marked-up consumer product cost. The installation cost includes labor, overhead, and any miscellaneous materials and parts. Thus, the total installed cost equals the consumer product cost plus the installation cost.

- *Learning rate:* The cost reduction factor associated with economies of scale and technology learning.

The primary inputs for calculating the operating cost are:

- *Product energy consumption*: The product energy consumption is the site energy use associated with operating the product.

- *Product efficiency*: The product efficiency dictates the product energy consumption associated with standard-level products (i.e., products with efficiencies greater than baseline products).

- *Energy prices*: Energy prices are the prices paid by consumers for energy (i.e., electricity or gas).

- *Energy price trends*: DOE used the EIA *Annual Energy Outlook 2010* (*AEO2010*)[2] to forecast energy prices for the results presented in this chapter.

- *Repair and maintenance costs*: Repair costs are associated with repairing or replacing components that have failed. Maintenance costs are associated with maintaining the operation of the product.

- *Lifetime*: The age at which the product is retired from service.

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

The data inputs to PBP are the total installed cost of the product to the consumer for each energy efficiency level and the annual (first year) operating expenditures for each CSL. The inputs to the total installed cost are the product cost and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost. The PBP uses the same inputs as the LCC analysis, except that energy price trends and discount rates are not required. Since the PBP is a "simple" payback, the required energy price is only for the year in which a new energy conservation standard is to take effect. The energy price DOE used in the PBP calculation was the price projected for that year. Discount rates are also not required for the simple PBP calculation.

Figure 8.1.1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP. In the figure below, the yellow boxes indicate the inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate the final outputs (the LCC and PBP).

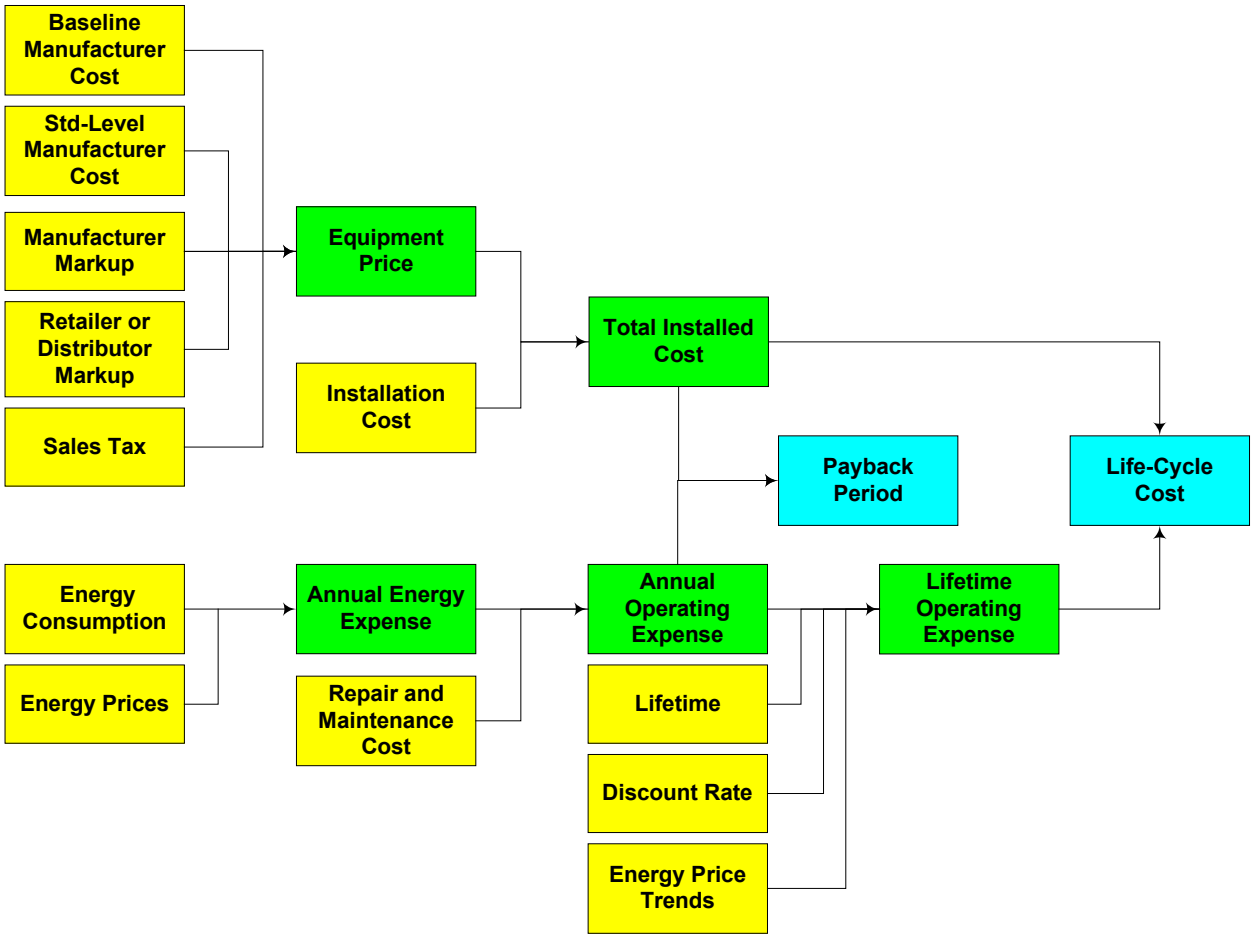

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Tables 8.1.1 and 8.1.2 summarize the input values that DOE used to calculate the LCC and PBP for each microwave oven product class. DOE characterized all of the total cost inputs with single-point values, but characterized several of the operating cost inputs with probability distributions that capture the input's uncertainty and/or variability. For those inputs characterized with probability distributions, the values provided in the following tables are the average or typical values.

Table 8.1.1 Microwave Ovens and Countertop Combination Ovens: LCC and PBP Input Summary

Input	Efficiency Level	Average or Typical Value	Characterization
Baseline Manufacturer Cost (2010$)	Baseline	4 W Standby = $114.00	Single-Point Value
Standard-Level Manufacturer Cost Increase (2010$)	CSL 1	2 W Standby = $0.27	Single-Point Value
	CSL 2	1.5 W Standby = $0.6	Single-Point Value
	CSL 3	1 W Standby = $1.31	Single-Point Value
	CSL 4	0.02 W Standby = $4.58	Single-Point Value
Retailer Markup	All	Baseline = 1.45	Single-Point Value
		Incremental = 1.17	
Manufacturer Markup	All	1.26	Single-Point Value
Sales Tax	All	7.2%	Variability based on region
Annual Energy Use (kWh)	Baseline	34.75	Variability based on usage
	CSL 1	17.38	Variability based on usage
	CSL 2	13.03	Variability based on usage
	CSL 3	8.69	Variability based on usage
	CSL 4	0.17	Variability based on usage
2014 Average Energy Prices (2010$)	All	12 c/kWh	Variability based on region
Repair and Maintenance Costs	All	No cost increase with efficiency	No cost increase with efficiency
Installation Costs	All	n/a	No cost increase with efficiency
Lifetime	All	9 years	Weibull distribution
Discount Rate	All	4.8%	Custom distribution
Energy Price Trend	All	AEO 2010 Reference Case	Single-Point Values

Table 8.1.2 Over the Range Combination Ovens: LCC and PBP Input Summary

Input	Efficiency Level	Average or Typical Value	Characterization
Baseline Manufacturer Cost (2010$)	Baseline	4.5 W Standby = $246.19	Single-Point Value
Standard-Level Manufacturer Cost Increase (2010$)	CSL 1	3.7 W Standby = $0	Single-Point Value
	CSL 2	2.7 W Standby = $2.29	Single-Point Value
	CSL 3	2.2 W Standby = $9.44	Single-Point Value
	CSL 4	0.04 W Standby = $5.18	Single-Point Value
Retailer Markup	All	Baseline = 1.45	Single-Point Value
		Incremental = 1.17	
Manufacturer Markup	All	1.26	Single-Point Value
Sales Tax	All	7.2%	Variability based on region
Annual Energy Use (kWh)	Baseline	39.10	Variability based on usage
	CSL 1	32.15	Variability based on usage
	CSL 2	23.46	Variability based on usage
	CSL 3	19.11	Variability based on usage
	CSL 4	0.35	Variability based on usage
2014 Average Energy Prices (2010$)	All	12 c/kWh	Variability based on region
Repair and Maintenance Costs	All	No cost increase with efficiency	No cost increase with efficiency
Installation Costs	All	n/a	No cost increase with efficiency
Lifetime	All	9 years	Weibull distribution
Discount Rate	All	4.8%	Custom distribution
Energy Price Trend	All	AEO 2010 Reference Case	Single-Point Values

8.2 LIFE-CYCLE COST AND PAYBACK PERIOD INPUTS

Because DOE gathered most of its data for the LCC and PBP analysis in 2010, DOE expresses dollar values in 2010$.

8.2.1 Total Installed Cost Inputs

DOE defines the total installed cost using the following equation:

$$IC = CPC + INST$$

Where:

CPC = consumer product cost (i.e., consumer cost for the product only), and
INST = installation cost or the consumer cost to install products.

The product cost is based on how the consumer purchases the product. As discussed in chapter 6, DOE defined markups and sales taxes for converting manufacturing costs into consumer product costs.

Table 8.2.1 summarizes the inputs for the determination of total installed cost.

Table 8.2.1 Inputs for Total Installed Cost

Baseline Manufacturer Cost
Standard-Level Manufacturer Cost
Distribution Chain Markups
Sales Tax (replacement applications)
Installation Cost

The *baseline manufacturer cost* is the cost incurred by the manufacturer to produce products meeting existing minimum efficiency standards. *Standard-level manufacturer selling price increases* are the change in manufacturer cost associated with producing products at a standard level. *Markups and sales tax* convert the manufacturer cost to a consumer product cost. The *installation cost* is the cost to the consumer of installing the product and represents all costs required to install the product other than the marked-up consumer product cost. The installation cost includes labor, overhead, and any miscellaneous materials and parts.

DOE calculated the total installed cost for baseline products based on the following equation:

$$IC_{BASE} = CPC_{BASE} + INST_{BASE}$$
$$= COST_{MFG} \times MU_{OVERALL\_BASE} + INST_{BASE}$$

Where:

IC_{BASE} = baseline total installed cost,
CPC_{BASE} = consumer product cost for baseline models,
$INST_{BASE}$ = baseline installation cost,
$COST_{MFG}$ = manufacturer cost for baseline models, and
$MU_{OVERALL\_BASE}$ = baseline overall markup (product of manufacturer markup, baseline retailer or distributor markup, and sales tax).

DOE calculated the total installed cost for standard-level products based on the following equation:

$$
\begin{aligned}
IC_{STD} &= CPC_{STD} + INST_{STD} \\
&= \left(CPC_{BASE} + \Delta CPC_{STD}\right) + \left(INST_{BASE} + \Delta INST_{STD}\right) \\
&= \left(CPC_{BASE} + INST_{BASE}\right) + \left(\Delta CPC_{STD} + \Delta INST_{STD}\right) \\
&= IC_{BASE} + \left(\Delta COST_{MFG} \times MU_{OVERALL\_INCR} + \Delta INST_{STD}\right)
\end{aligned}
$$

Where:

IC_{STD} = standard-level total installed cost,
CPC_{STD} = consumer product cost for standard-level models,
$INST_{STD}$ = standard-level installation cost,
CPC_{BASE} = consumer product cost for baseline models,
ΔCPC_{STD} = change in product cost for standard-level models,
$INST_{BASE}$ = baseline installation cost,
$\Delta INST_{STD}$ = change in installation cost for standard-level models,
IC_{BASE} = baseline total installed cost,
$\Delta COST_{MFG}$ = change in manufacturer cost for standard-level models, and
$MU_{OVERALL\_INCR}$ = incremental overall markup (product of manufacturer markup, incremental retailer or distributor markup, and sales tax).

The remainder of this section provides information about each of the above input variables that DOE used to calculate the total installed cost for microwave ovens.

8.2.1.1 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 project future product prices by incorporating learning over time, consistent with the analysis in the available literature. DOE used this approach to derive learning rates to forecast future prices of microwave ovens at the considered efficiency levels.

An extensive literature discusses the "learning" or "experience" curve phenomenon, typically based on observations in the manufacturing sector. 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: product price (or cost), and cumulative production, which is a function of shipments during a long time span.

To derive a learning rate parameter for microwave ovens, DOE obtained historical Producer Price Index (PPI) data for electric cooking equipment from the Bureau of Labor Statistics' (BLS). DOE understands that electric cooking equipment is a higher aggregation level to microwave ovens only; however, because PPI data specific to microwave ovens were not available, DOE used PPI data for electric cooking equipment as representative of microwave ovens. Additionally, microwave oven shipments have become a significant part of the total electric household cooking equipment shipments since 1975. For electric cooking equipment, DOE used PPI data spanning the time period 1969-2010. An inflation-adjusted price index for electric cooking equipment was calculated by dividing the PPI series by the Consumer Price Index (CPI) "all items" index for the same years.

DOE assembled a time-series of annual shipments for 1969-2009 for electric household cooking equipment (including microwave ovens, cooktops, and ranges), referred as "electric cooktops, ranges, and ovens" in the following context, and for 1972-2009 for microwave ovens from data submittals from AHAM, AHAM Fact Books, and Appliance Magazine. The shipments data were used to estimate cumulative shipments (production).

To estimate a learning rate parameter, a least-squares power-law fit was performed on the unified price index versus cumulative shipments. The form of the fitting equation is:

$$P(X) = P_o X^{-b},$$

where the two parameters, b (the learning rate parameter) and P_o (the price or cost of the first unit of production), are obtained by fitting the model to the data.

The parameter values obtained are:

$P_o = 21.93^{+3.31}_{-2.87}$ (95% confidence) for electric cooking equipment;
b = 0.492±0.027 (95% confidence) for electric cooking equipment.

The estimated learning rate (defined as the fractional reduction in price expected from each doubling of cumulative production) is 28.9±1.3% (95% confidence). For the LCC and PBP analysis, DOE used the central value, along with the shipments forecast in 2011-2014, to estimate the price of microwave ovens in 2014.

DOE's derivation of learning rates for microwave ovens is described in further detail in appendix 8-E.

8.2.1.2 Baseline Manufacturer Cost

DOE developed the baseline manufacturer costs for microwave and combination ovens as described in chapter 5, Engineering Analysis. The baseline manufacturer costs are shown in Table 8.2.2.

Table 8.2.2 Baseline Manufacturer Costs

Product Class	Standby Power (W)	Manufacturer Cost (2010$)
Microwave and Countertop Combination Ovens	4.00	114.00
Over the Range Combination Ovens	2.50	246.19

8.2.1.3 Standard-Level Manufacturer Cost Increases

DOE used a combination of cost data submitted by AHAM and a reverse engineering analysis to develop manufacturer cost increases associated with increases in microwave combination oven efficiency levels. Refer to chapter 5 for details. Table 8.2.3 presents the standard-level manufacturer cost increase for each considered efficiency level.

Table 8.2.3 Standard-Level Manufacturer Cost Increases

Microwave and Countertop Combination Ovens		Over the Range Combination Ovens	
Standby Power (W)	Manufacturer Cost Increase	Standby Power (W)	Manufacturer Cost Increase
2.00	$0.27	3.70	$0.00

1.50	$0.60	2.70	$2.29
1.00	$1.31	2.20	$9.44
0.02	$4.58	0.04	$5.18

8.2.1.4 Overall Markup

The overall markup is the value determined by multiplying the manufacturer and retailer markups and the sales tax together to arrive at a single markup value. Table 8.2.4 shows the overall baseline and incremental markups for microwave ovens. Refer to chapter 6 for details.

Table 8.2.4 Microwave Ovens: Overall Markups

Markup	Baseline Cost Markup	Incremental Cost Markup
Manufacturer	1.26	
Retailer	1.45	1.17
Sales Tax	0.072	
Overall	1.96	1.58

8.2.1.5 Installation Cost

DOE determined that any installation costs would not be impacted by increased efficiency levels. A similar finding was made in the previous rulemaking conducted for microwave ovens.[3]

8.2.1.6 Total Installed Cost

The total installed cost is the sum of the consumer product cost and the installation cost. Tables 8.2.5 and 8.2.6 present the total installed costs for microwave and combination ovens. Prices and costs are presented at the baseline level and each energy efficiency level.

Table 8.2.5 Total Installed Costs

Microwave and Countertop Combination Ovens		Over the Range Combination Ovens	
Standby (W)	**Total Installed Cost (2010$)**	**Standby (W)**	**Total Installed Cost (2010$)**
4.00	$223.27	4.50	$482.17
2.00	$223.67	3.70	$482.17
1.50	$224.16	2.70	$485.60
1.00	$225.23	2.20	$496.29
0.02	$230.12	0.04	$489.93

8.2.2 Operating Cost Inputs

DOE defines the operating cost (*OC)* by the following equation:

$$OC = EC + RC + MC$$

Where:

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

Table 8.2.6 shows the inputs for determining the annual operating costs and their discounted value over the product lifetime.

Table 8.2.6 Inputs for Operating Cost

Annual Energy Consumption
Energy Prices and Price Trends
Repair and Maintenance Costs

The *annual energy consumption* is the site energy use associated with operating the product. The annual energy consumption varies with the product efficiency. *Energy prices* are the prices paid by consumers for energy (i.e., electricity or gas). Multiplying the annual energy consumption by the energy prices yields the annual energy cost. *Repair costs* are associated with repairing or replacing components that have failed. *Maintenance costs* are associated with maintaining the operation of the product. DOE used *energy price trends* to forecast energy prices into the future and, along with the product lifetime and discount rate, to establish the present value of lifetime energy costs.

DOE calculated the annual operating cost for baseline products based on the following equation:

$$OC_{BASE} = (AEC_{BASE} \times PRICE_{ENERGY}) + RC_{BASE} + MC_{BASE}$$

Where:

OC_{BASE} = operating cost for baseline product,
AEC_{BASE} = annual energy consumption for baseline product,
$PRICE_{ENERGY}$ = energy price,
RC_{BASE} = repair cost associated with component failure for baseline product, and
MC_{BASE} = cost for maintaining baseline product operation,

DOE calculated the annual operating cost for standard-level products based on the following equation:

$$OC_{STD} = (AEC_{STD} \times PRICE_{ENERGY}) + RC_{STD} + MC_{STD}$$

Where:

OC_{STD} = operating cost for standard-level products,
AEC_{STD} = annual energy consumption for standard-level products,
$PRICE_{ENERGY}$ = energy price,
RC_{STD} = repair cost associated with component failure for standard-level products, and
MC_{STD} = cost for maintaining standard-level products operation.

The remainder of this section provides information about each of the above input variables that DOE used to calculate the operating costs for room air conditioners and clothes dryers.

8.2.2.1 Annual Energy Consumption

As described in chapter 7 and the beginning of this chapter in section 8.1.1, DOE developed a sample of individual households from RECS 2005 that use these appliances. By developing a household sample, DOE was able to perform the LCC and PBP calculations for each household to account for the variability in both energy use and energy price associated with each household. The annual energy consumption values in the tables below are averages. DOE captured the variability in energy consumption when it conducted its LCC and PBP analyses. Table 8.2.7 provides the average annual energy consumption by efficiency level for each product class.

Table 8.2.7 Annual Energy Consumption

Standard Level	Microwave and Countertop Combination Ovens		Over the Range Combination Ovens	
	Standby Power (W)	Average Energy Consumption (kWh/year)	Standby Power (W)	Average Energy Consumption (kWh/year)
Baseline	4.00	34.75	4.50	39.10
1	2.00	17.38	3.70	32.15
2	1.50	13.03	2.70	23.46
3	1.00	8.69	2.20	19.11
4	0.02	0.17	0.04	0.35

8.2.2.2 Residential Electricity Prices

DOE derived electricity prices for each of 13 geographic areas of the United States: the nine U.S. Census divisions plus four large states (New York, Florida, Texas, and California) that were treated individually. For Census divisions containing a large state, DOE excluded the data for the large state when calculating regional average values. Using those data, DOE analyzed the variability of electricity prices at the regional level.

DOE used data from EIA Form 861[4] to estimate electricity prices for residential consumers in each of the 13 geographic areas. These data, published annually, include annual electricity sales in kilowatt hours (kWh), revenues from electricity sales, and number of consumers in the residential, commercial, and industrial sectors, for every utility that serves final consumers. Average residential electricity prices were calculated in two steps.

1. For each utility, an average residential price was estimated by dividing residential revenues by residential sales.
2. An average regional price was calculated, weighting each utility that has customers in a region by the number of residential consumers served in that region.

Table 8.2.8 shows the average residential electricity price calculated for each geographic region.

Table 8.2.8 Average Regional Residential Electricity Prices

Geographic Area	**Average Price** ***2010$/kWh***
New England	$0.178
Middle Atlantic (excludes NY)	$0.139
East North Central	$0.113
West North Central	$0.094
South Atlantic (excludes FL)	$0.111
East South Central	$0.098
West South Central (excludes TX)	$0.087
Mountain	$0.104
Pacific (excludes CA)	$0.102
New York	$0.188
Florida	$0.151
Texas	$0.126
California	$0.126

Source: EIA Form 861 for 2010.

8.2.2.3 Energy Price Trends

DOE used price forecasts by the EIA to estimate future trends in 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 *AEO2010* Reference case.[2] 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.

DOE calculated LCC and PBP based on three separate projections from *AEO 2010* reference case, low economic growth, and high economic growth. These three cases reflect the uncertainty of economic growth in the forecast period. Figure 8.2.1 shows the trends in residential electricity prices based on the three *AEO 2010* projections.

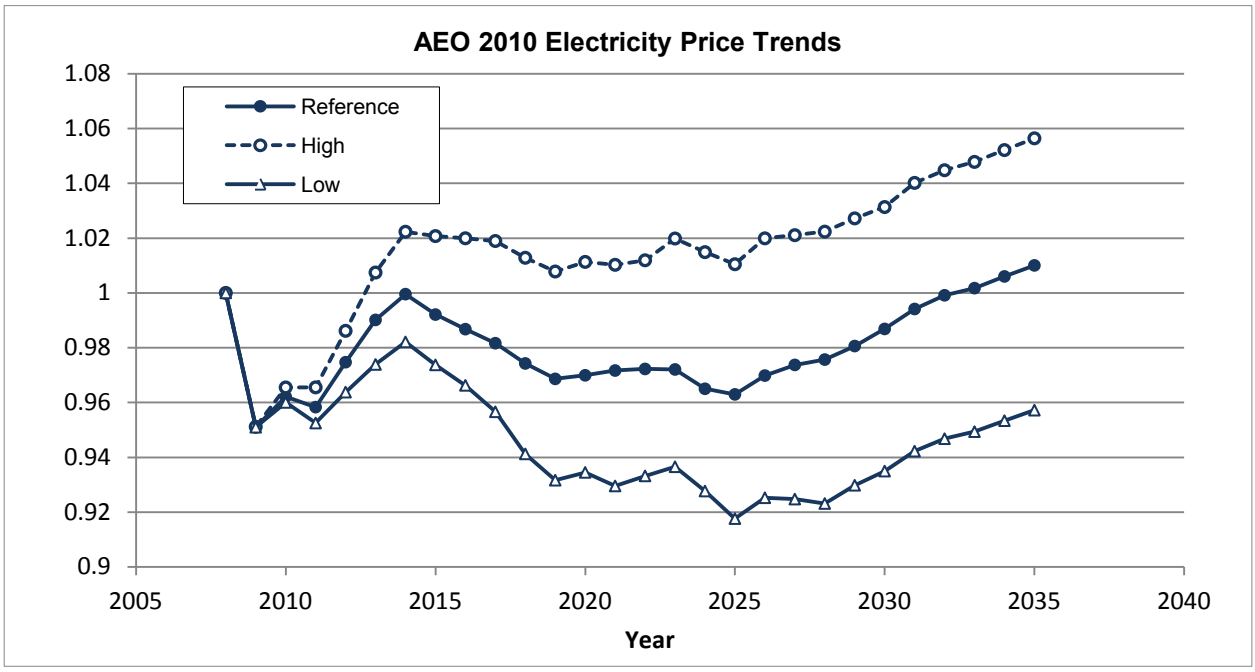

Figure 8.2.1 Residential Electricity Price Trends

8.2.2.4 Repair and Maintenance Costs

For microwave ovens, DOE included no changes in repair or maintenance costs for products that exceed baseline efficiency.

8.2.2.5 Product Lifetime

The product lifetime is the age at which the product is retired from service. *Appliance* magazine provides estimates of the low, high, and average years of an appliance's lifetime. The estimates, which are based on first-owner use of the product, represent the expert judgment of *Appliance* staff based on input obtained from various sources. DOE also identified other sources

that give lifetimes for microwave ovens (see Table 8.2.9). Because the basis for the estimates in the literature was uncertain, DOE developed a method using household survey data to estimate the distribution of microwave oven lifetimes in the field.

Table 8.2.9 Estimates and Sources for Product Lifetime

Lifetime (*years*)	**Source**
Average = 9	*Appliance Magazine* (2009)[5]
Average = 9	NAHB/Bank of America[6]
Average = 9	NFO Study (1996)[7]

Estimation of Survival Function. The Residential Energy Consumption Survey (RECS)[8] records the presence of various appliances in each household, and when combined with data from the U.S. Census's American Housing Survey (AHS),[9] which surveys all housing including vacant and second homes, enabled DOE to estimate the stock of microwaves in all households. By combining the results of both surveys with the known history of appliance shipments (collected from Appliance magazine or directly from manufacturer trade associations), DOE estimated the percentage 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 average and a median appliance lifetime.

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

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

$$P(x) = 1 \text{ for } x \leq \theta$$

Where:

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

[a] For reference on the Weibull distribution, see sections 1.3.6.6.8 and 8.4.1.3 of the *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

When $\beta = 1$, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, β commonly is greater than 1, reflecting an increasing failure rate as appliances age.

The results of DOE's analysis are shown in Table 8.2.10.

Table 8.2.10 Lifetime Parameters

Product	Calculated Values			Weibull Parameters	
	Minimum *years*	Average *years*	Maximum *years*	Alpha (scale)	Beta (shape)
Microwave Ovens	7	9.0	10	2.2	4.806

8.2.3 Discount Rates

The discount rate is the rate at which DOE discounted future consumer expenditures to establish their present value. DOE derived the discount rates for the LCC and PBP analyses from estimates of the finance cost of purchasing the considered products. Following financial theory, the finance cost of raising funds to purchase appliances can be interpreted as: (1) the financial cost of any debt incurred to purchase products, or (2) the opportunity cost of any equity used to purchase products. DOE considers both of these interpretations.

The purchase of products installed in new homes entails different finance costs for consumers than the purchase of appliances bought directly by consumers. For microwave and combination ovens, however, DOE believes that few products are installed by builders in new homes.

Households use a variety of methods to finance the purchase of major appliances. In principle, one could estimate the interest rates on the actual financing methods used to purchase appliances. However, the shares of different financing methods in total appliance purchases are unknown. DOE's approach involves identifying all possible debt or asset classes that might be used to purchase the considered appliances, including household assets that might be indirectly affected.[b] DOE did not include debt from primary mortgages or assets considered non-liquid (such as retirement accounts), since these would likely not be indirectly affected by appliance purchases. DOE estimated the average shares of the various debt and equity classes in the average U.S. household equity and debt portfolios using data from the Federal Reserve Board's Survey of Consumer Finances (SCF) for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[10] Table 8.2.11 shows the average shares of each considered class. DOE used the mean share of each

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

class across the seven surveys as a basis for estimating the weight of the classes in the direct or indirect financing of the considered appliances.

Table 8.2.11 Average Shares of Considered Household Debt and Equity Types (%)

Type	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	2007 SCF	Mean
Home equity loans	4.3	4.5	2.7	2.8	2.8	4.4	4.6	3.7
Credit cards	1.6	2.1	2.6	2.2	1.7	2.0	2.4	2.1
Other installment loans	2.8	1.7	1.4	1.7	1.1	1.3	1.1	1.6
Other residential loans	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 accounts	5.8	4.7	4.9	3.9	3.6	4.2	3.4	4.4
Savings & money market	19.2	18.8	14.0	12.8	14.2	15.1	13.0	15.3
Certificate of deposit (CD)	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	100	100	100	100	100	100	100

DOE estimated interest or return rates associated with each type of equity and debt. The data source for the interest rates for loans, credit cards, and lines of credit is the Federal Reserve Board's SCF in 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Table 8.2.36 shows the average nominal rates in each year, and the inflation rates used to calculate real rates. For home equity loans, DOE calculated effective interest rates in a similar manner as for mortgage rates, since interest on such loans is tax deductible. Table 8.2.12 shows the average effective real rates in each year and the mean rate across the years. Since the interest rates for each debt carried by households in these years were established over a range of time, DOE believes they are representative of rates in the year in which amended standards would take effect.

Table 8.2.12 Average Nominal Interest Rates for Household Debt Classes (%)

	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	2007 SCF	Mean
Home equity loans	11.5	9.6	9.6	9.8	8.7	5.7	6.3	7.9
Credit cards*	-	-	14.2	14.5	14.2	11.7	7.9	9.0
Other installment loans	9.0	7.8	9.3	7.8	8.7	7.4	12.6	13.4
Other residential loans	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	

* No interest rate data available for credit cards in 1989 or 1992.

Table 8.2.13 Average Real Effective Interest Rates for Household Debt Classes (%)

	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	2007 SCF)	Mean
Home equity loans	3.8	4.3	4.4	5.8	3.8	1.9	3.3	3.9
Credit cards*	-	-	11.0	12.7	11.1	9.1	9.7	10.7
Other installment loans	4.9	5.8	7.0	6.6	6.1	5.4	5.8	6.0
Other residential loans	4.0	4.7	4.8	6.0	4.6	3.3	3.4	4.4
Other line of credit	9.6	9.4	9.3	10.2	7.3	6.0	9.7	8.8

* No interest rate data available for credit cards in 1989 or 1992.

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

Similar rate data are not available from the *SCF* for the asset classes, so the Department derived data for these classes from national-level historical data. The interest rates associated with certificates of deposit (CDs),[11] savings bonds,[12] and bonds (AAA corporate bonds)[13] are from Federal Reserve Board time-series data covering 1977–2009. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data covering 1984–2009.[14] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500 in 1977–2009.[15] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year from 1977–2009.[16] DOE adjusted the nominal rates to real rates using an inflation index. Average nominal and real interest rates for the classes of assets are shown in Table 8.2.14. Since the interest and return rates for each asset type cover a range of time, DOE believes they are representative of rates in the year in which amended standards would take effect.

Table 8.2.14 Average Nominal and Real Interest Rates for Household Equity Classes

	Average Nominal Rate (%)	Average Real Rate (%)
Checking accounts	-	0.0
Savings and money market	5.4	2.2
CDs	6.6	2.3
Savings bonds	7.7	3.3
Bonds	8.5	4.1
Stocks	11.6	7.1
Mutual funds	10.3	5.8

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 distribution of interest rates for each asset type that DOE used in the LCC and PBP analyses.

Table 8.2.15 summarizes the average shares of the debt and asset shares over the six years of survey data and the mean real effective rates of each type of equity or debt. The average rate across all types of household debt and equity, weighted by the shares of each class, is 4.8 percent. In its analysis, DOE assigned specific discount rates to each sample household from the distributions discussed above.

Table 8.2.15 Shares and Interest or Return Rates Used for Household Debt and Equity Classes

	Average Share of Household Debt plus Equity (%)*	Mean Effective Real Rate (%)**
Home equity loans	3.7	3.9
Credit cards	2.1	10.7
Other installment loans	1.6	6.0
Other residential loans	5.3	4.4
Other line of credit	0.5	8.8
Checking accounts	4.4	0.0
Savings and money market accounts	15.3	2.2
CDs	8.6	2.3
Savings bonds	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	**4.8**

* Not including primary mortgage or retirement accounts.

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

8.2.4 Compliance Date of Standard

The compliance date is the future date when manufacturers must comply with a new or amended standard. Based on DOE's implementation report for energy conservation standards activities submitted pursuant to Section 141 of the Energy Policy Act of 2005, a final rule for the home appliances being considered for this standards rulemaking is scheduled for completion in June 2011.[17] Therefore, the compliance date of any new energy efficiency standards for these products will be three years after the final rule is published, which is June 2014. DOE calculated the LCC for all consumers as if they each would purchase a new product in 2014.

8.2.5 Product Energy Efficiency in the Base Case

To estimate the percentage of consumers who would be affected by a standard at any of the potential efficiency levels, in its LCC analysis DOE considered the projected distribution of efficiencies for products that consumers purchase under the base case (the case without new or amended energy efficiency standards). DOE refers to this distribution of product energy efficiencies as the base-case efficiency distribution. Using the projected distribution of efficiencies for each product class, DOE randomly assigned a product efficiency to each sample household. The energy efficiency distributions that DOE used in the LCC analysis are described below. For this SNOPR, DOE used the efficiency distributions calculated in the previous microwave oven rulemaking.

Tables 8.2.16 and 8.2.17 present recent market shares of the efficiency levels for microwave and combination ovens. Because there is no evidence of change in average efficiency in recent years, DOE assumed that the shares in 2014 are the same.

Table 8.2.16 Microwave and Countertop Combination Ovens: Base-Case Market Shares

Standard Level	Standby Power *W*	Annual Energy Use *kWh/yr*	Market Share *%*
Baseline	4.00	34.75	46.2%
1	2.00	17.38	34.6%
2	1.50	13.03	19.2%
3	1.00	8.69	0%
4	0.02	0.17	0%

Table 8.2.17 Over the Range Combination Ovens: Base-Case Market Shares

Standard Level	Standby Power *W*	Annual Energy Use *kWh/yr*	Market Share *%*
Baseline	4.50	39.10	100%
1	3.70	32.15	0%
2	2.70	23.46	0%
3	2.20	19.11	0%
4	0.04	0.35	0%

8.3 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

This section presents the LCC and PBP results for microwave and combination ovens. As discussed in section 8.1.1, DOE's approach for conducting the LCC analysis relied on developing samples of consumers 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 calculations on the consumers in the sample. For each set of sample consumers using the product in each product class, DOE calculated the average LCC and LCC savings and the median and average PBP for each of the candidate standard levels (CSL).

DOE calculated LCC savings and PBPs relative to the base case products that it assigned to the sample households. As discussed in section 8.2.5, for some consumers DOE assigned a base case product that is more efficient than some of the CSLs. 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 product

LCC and PBP calculations were performed 10,000 times on the sample of consumers established for each product. Each LCC and PBP calculation was performed on a single consumer that was selected from the sample. The selection of a consumer was based on its weight (i.e., how representative a particular consumer is of other consumers in the distribution). Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

Based on the Monte Carlo simulations that DOE performed, for each CSL, DOE calculated the share of consumers with a net LCC benefit, with a net LCC cost, and with no impact. DOE considered a consumer to receive no impact at a given standard level if DOE assigned it a base case product that is the same as or has higher efficiency than the standard level. To illustrate the range of LCC and PBP impacts among the sample consumers, the sections below present figures that provide such information for each product class.

8.3.1 Summary of Results

Tables 8.3.1 and 8.3.2 show the LCC and PBP results by CSL for each representative microwave and combination oven product class. The CSLs correspond to the energy efficiency levels included in the engineering analysis. With regard to the PBPs, DOE determined the median values by excluding those users not impacted by the standard.

Table 8.3.1 Microwave and Countertop Combination Ovens: LCC and PBP Results

		Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)
						Users with			
CSL	Standby (W)	Average Installed Cost	Average Lifetime Operating Cost*	Average LCC	Average Savings	Net Cost	No Impact	Net Benefit	Median
Baseline	4.00	$223	$31	$254					
1	2.00	$224	$15	$239	$7	0%	54%	46%	0.2
2	1.50	$224	$12	$236	$10	0%	19%	81%	0.4
3	1.00	$225	$8	$233	$13	0%	0%	100%	1.1
4	0.02	$230	$0	$230	$15	0%	0%	100%	2.4

* Discounted

Table 8.3.2 Over the Range Combination Ovens: LCC and PBP Results

CSL	Standby (W)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)
		Average Installed Cost	Average Lifetime Operating Cost*	Average LCC	Average Savings	Users with			Median
						Net Cost	No Impact	Net Benefit	
Baseline	4.50	$482	$35	$517					
1	3.70	$482	$29	$511	$6	0%	0%	100%	0.0
2	2.70	$486	$21	$507	$11	0%	0%	100%	2.0
3	2.20	$496	$17	$513	$4	23%	0%	77%	6.4
4	0.04	$490	$0	$490	$27	0%	0%	100%	1.8

* Discounted

8.3.1.1 Distributions of Impacts

The figures below show the distribution of LCCs in the base case for each product class. Also presented below for a specific standard level are figures showing the distribution of LCC impacts and the distribution of PBPs. The figures are presented as frequency charts that show the distribution of LCCs, LCC impacts, and PBPs with their corresponding probability of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples.

Base Case LCC Distributions. Figures 8.3.1 and 8.3.2 show the base case LCC distributions for microwave and combination ovens. DOE can generate similar figures for commercial purchasers.

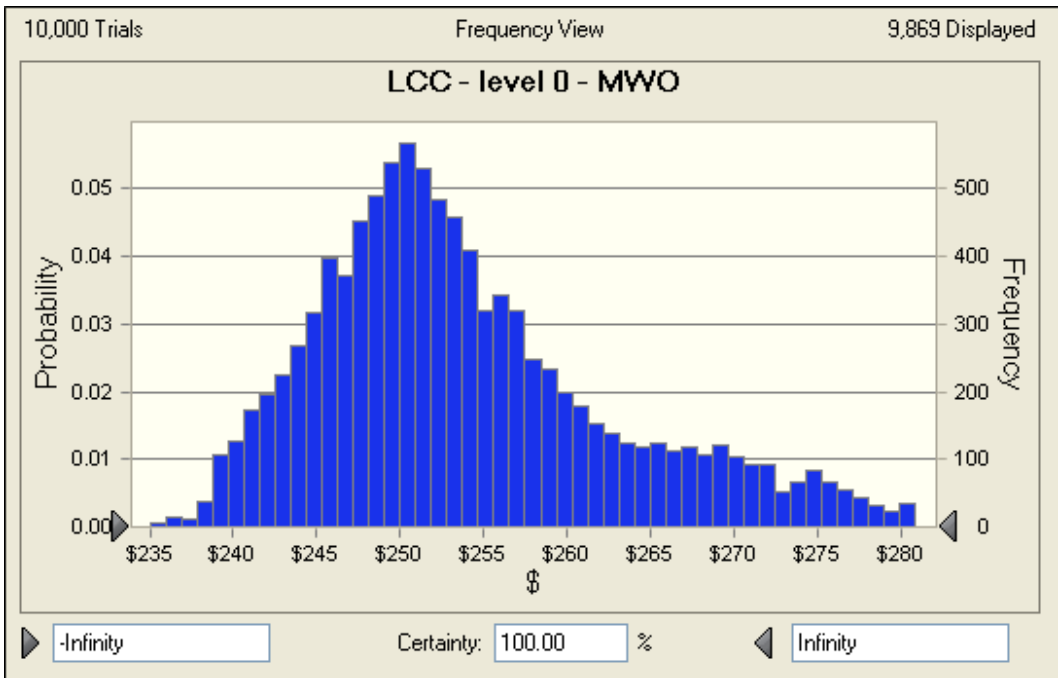

Figure 8.3.1 Microwave and Countertop Combination Ovens: Base Case LCC Distribution

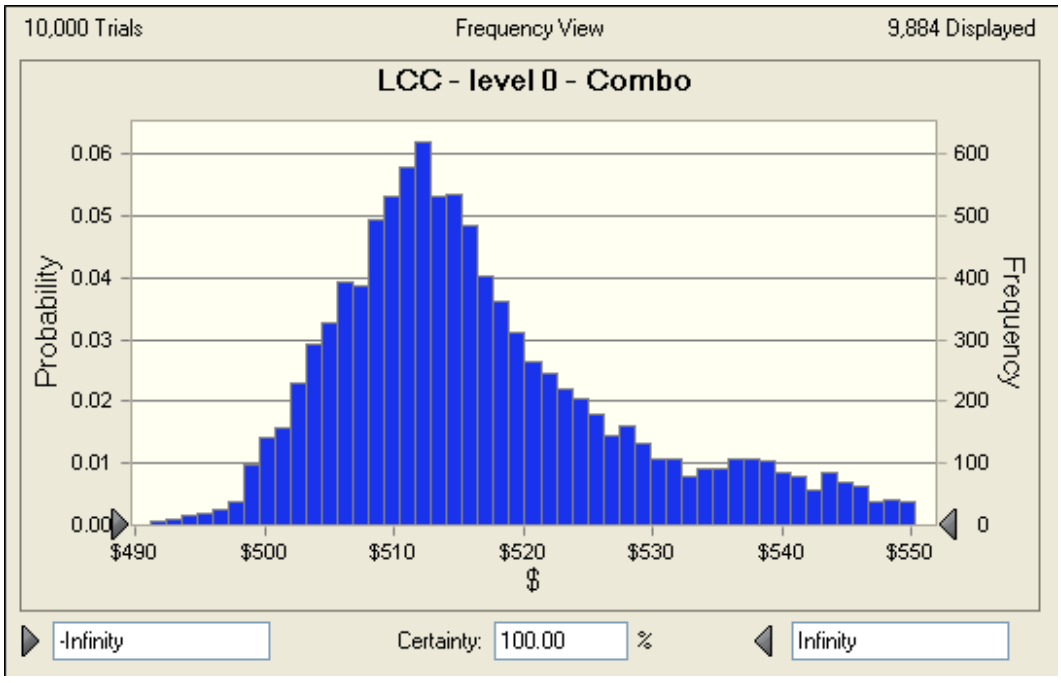

Figure 8.3.2 Over the Range Combination Ovens: Base Case LCC Distribution

Standard-Level Distribution of Impacts. Figures 8.3.3 and 8.3.4 are examples of frequency charts showing the distribution of LCC savings for microwave and combination ovens at CSL 3. DOE can generate frequency charts similar to those shown for every CSL.

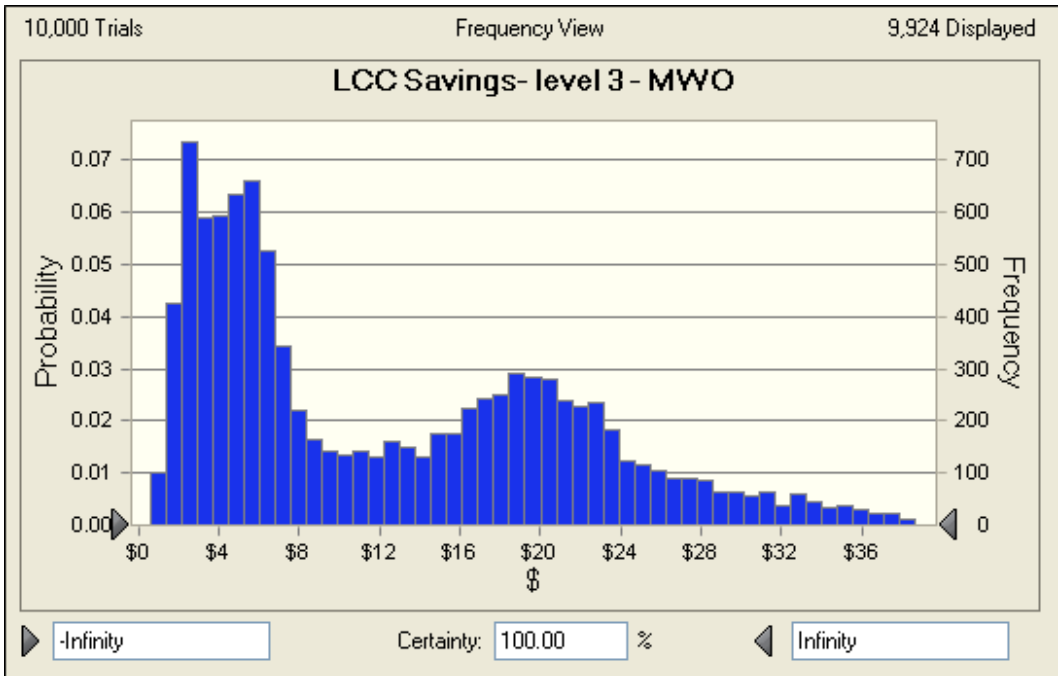

Figure 8.3.3 Microwave and Countertop Combination Ovens: CSL 3 LCC Savings Distribution

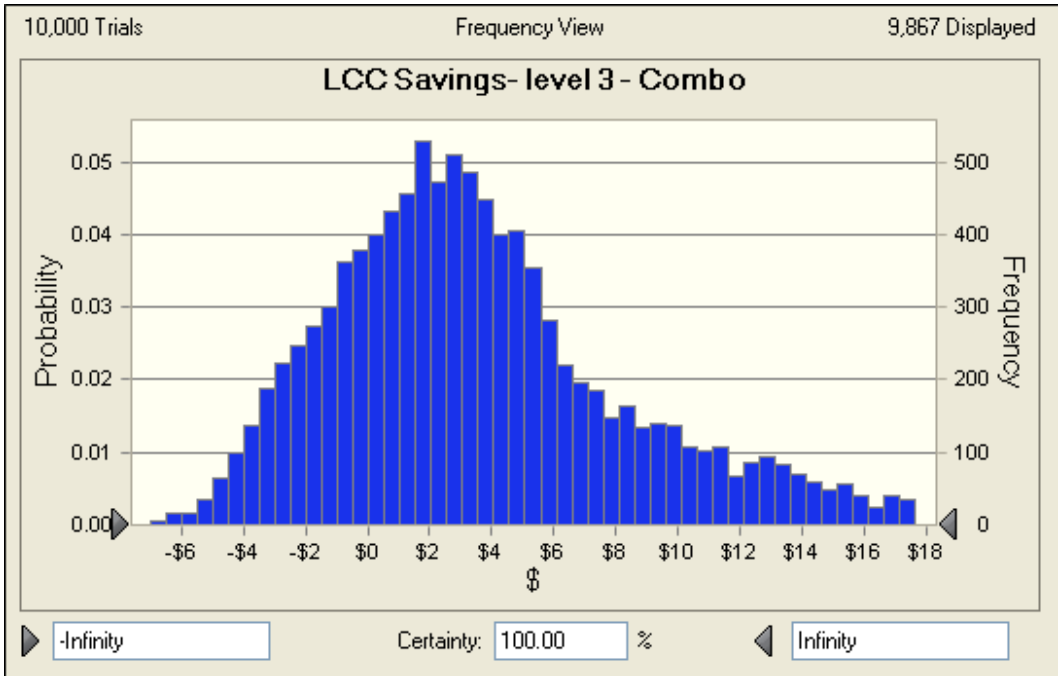

Figure 8.3.4 Over the Range Combination Ovens: CSL 3 LCC Savings Distribution

Figures 8.3.5 and 8.3.6 are examples of frequency charts showing the distribution of PBPs for microwave and combination ovens at CSL 3. DOE can generate frequency charts similar to those shown for every standard level.

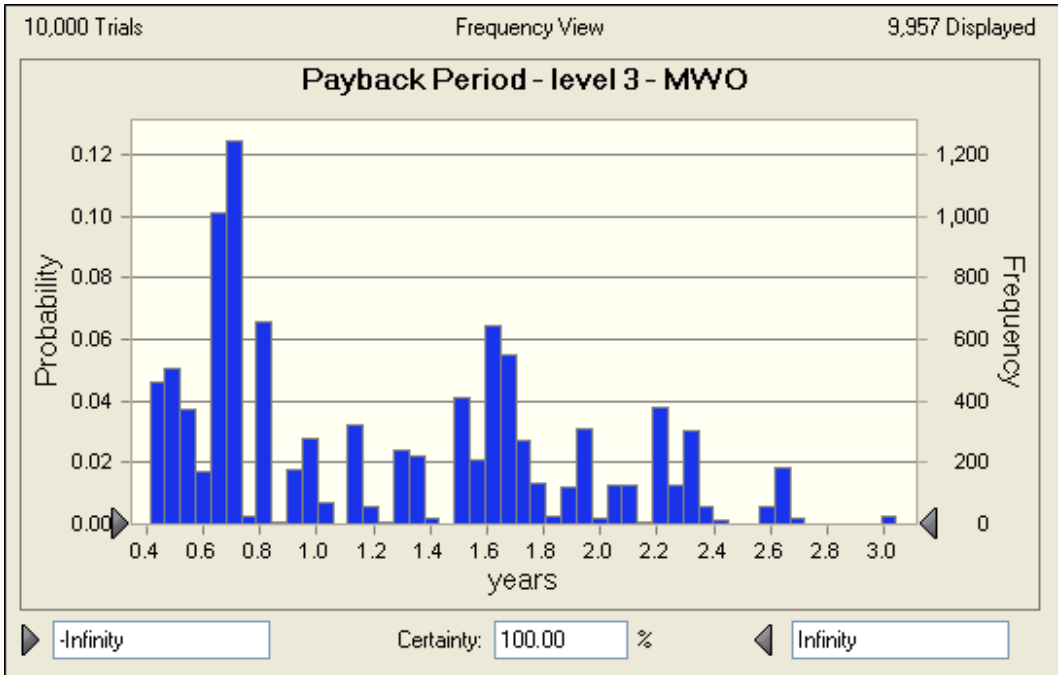

Figure 8.3.5 Microwave and Countertop Combination Ovens: CSL 3 PBP Distribution

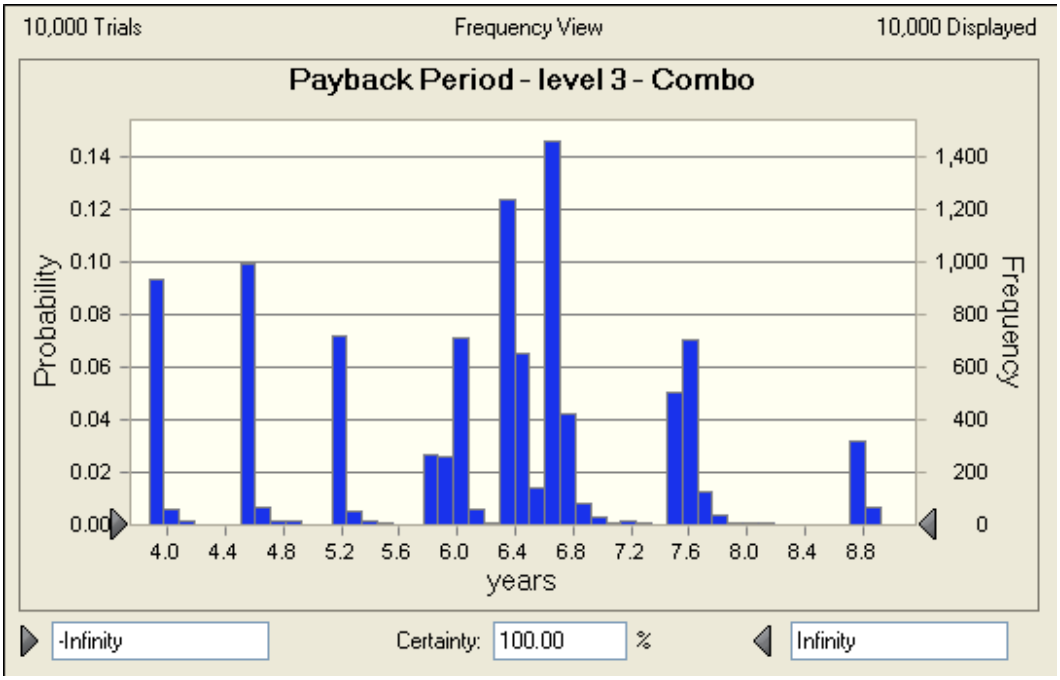

Figure 8.3.6 Over the Range Combination Ovens: CSL 3 PBP Distributions

8.3.1.2 Range of Impacts

Figures 8.3.7 and 8.3.8 show the range of LCC savings for the CSLs considered for microwave and combination ovens. 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.

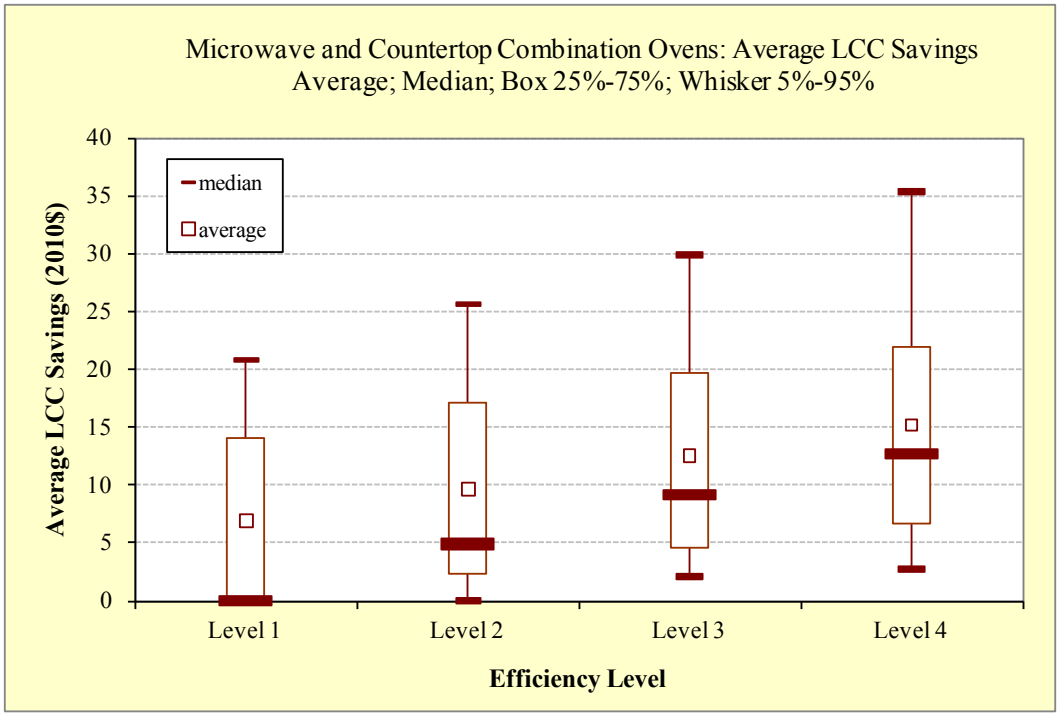

Figure 8.3.7 Microwave and Countertop Combination Ovens: Range of Average LCC Savings

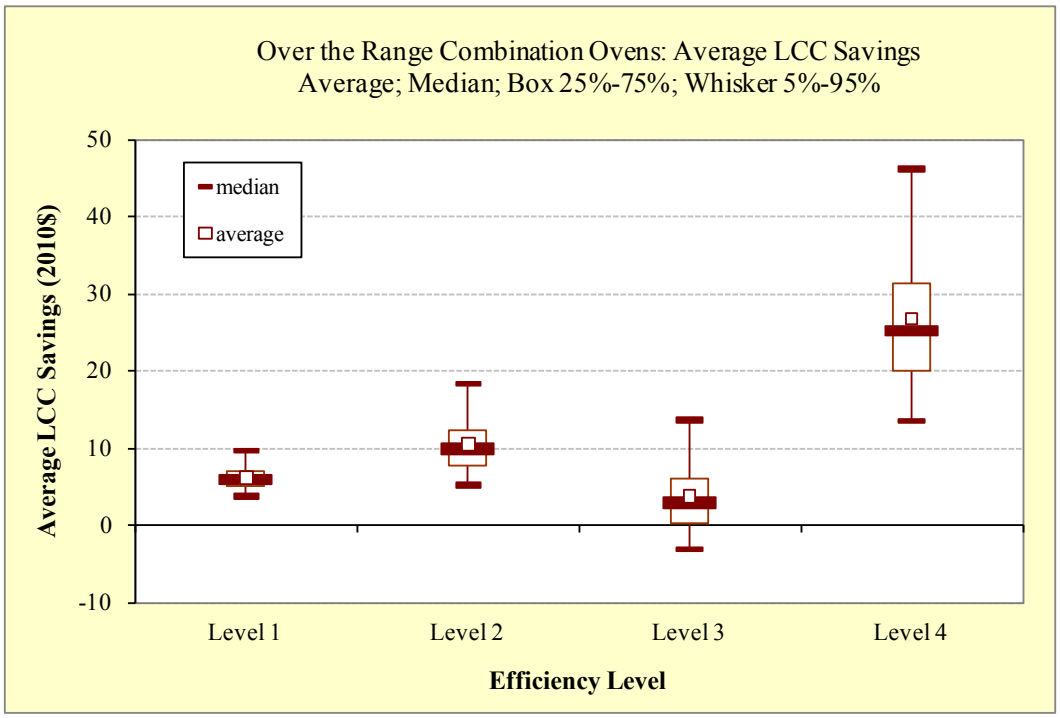

Figure 8.3.8 Over the Range Combination Ovens: Range of Average LCC Savings

Figures 8.3.9 and 8.3.10 show the range of PBPs for all CSLs considered for microwave and combination ovens. 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 CSL.

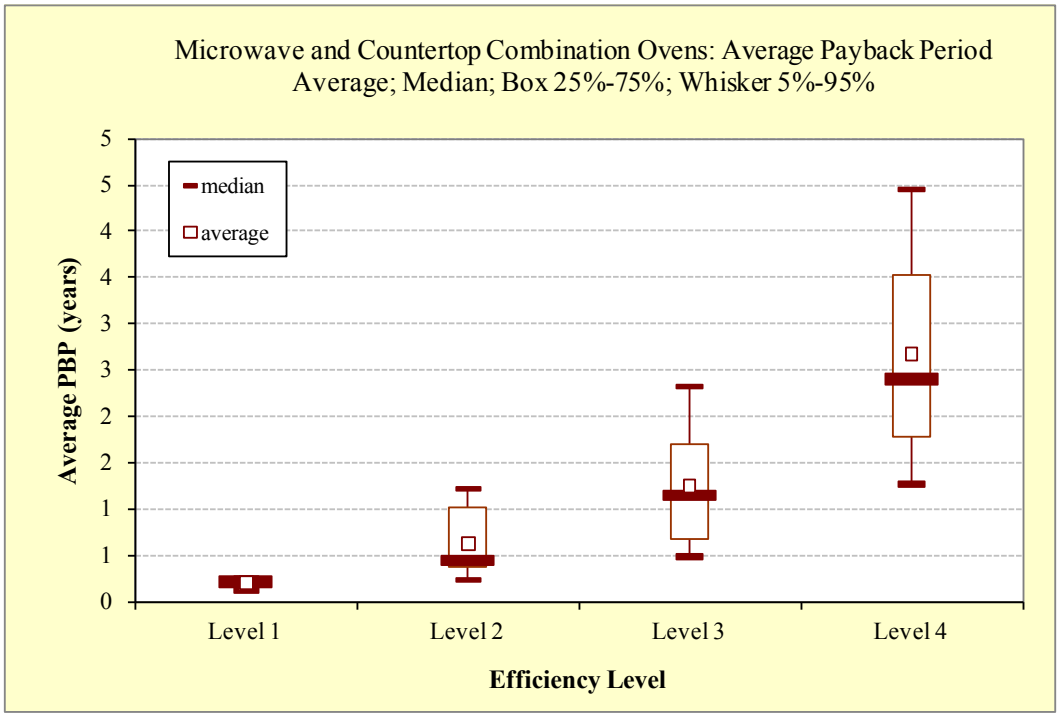

Figure 8.3.9 Microwave and Countertop Combination Ovens: Range of Average Payback Period

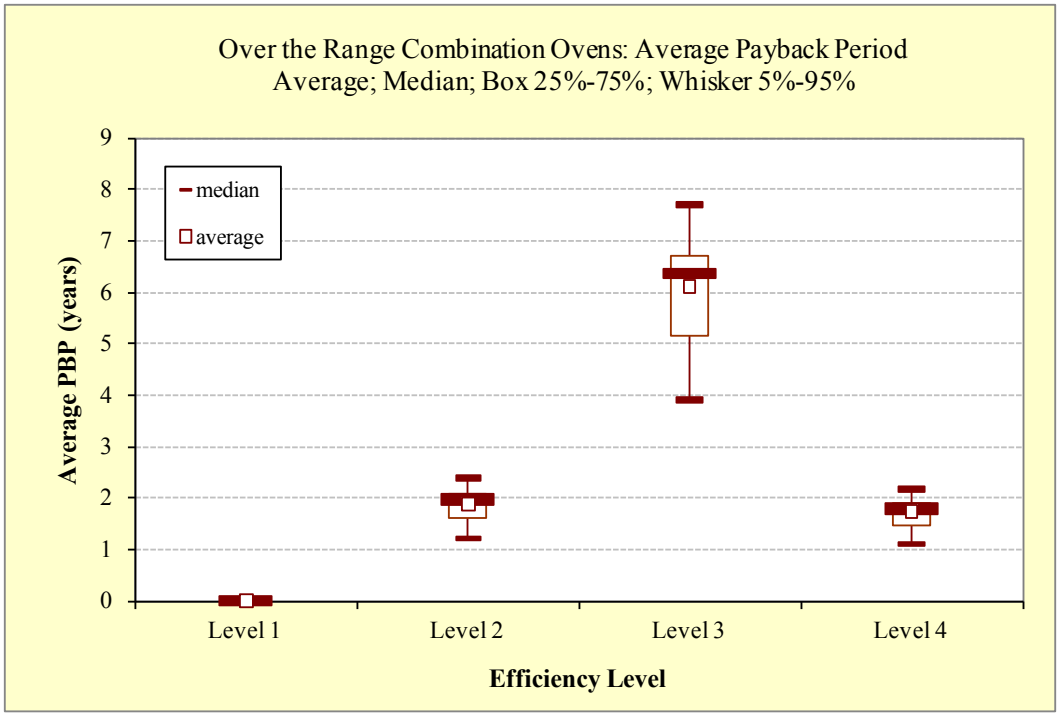

Figure 8.3.10 Over the Range Combination Ovens: Range of Average Payback Period

8.4 REBUTTABLE PAYBACK PERIOD

DOE presents rebuttable PBPs to provide the legally established rebuttable presumption that an energy efficiency standard is economically justified, if the additional product costs attributed to the standard are less than three times the value of the first-year energy cost savings. (42 U.S.C. §6295 (o)(2)(B)(iii))

The basic equation for rebuttable PBP is the same as that shown in section 8.2, Payback Period Inputs. Unlike the analyses described in section 8.3, however, the rebuttable PBP is not based on the use of household samples and probability distributions. Rather than distributions, the rebuttable PBP is based on discrete single-point values. For example, while DOE uses a probability distribution of regional energy prices in the distributional payback period analysis, it uses only the national average energy price from the probability distribution to determine the rebuttable PBP.

Other than the use of single-point values, the most notable difference between the distribution PBP and the rebuttable PBP is the latter's reliance on the DOE test procedure to determine a product's annual energy consumption. The following sections identify the differences, if any, between the annual energy consumptions determined for the distribution PBP and the rebuttable PBP.

DOE based the annual energy consumption values that it used to determine the rebuttable PBP for room air conditioners on the number of operating hours per year specified in previous microwave rulemaking.

8.4.1 Inputs

Inputs for the rebuttable PBP differ from the distribution PBP in that the calculation uses discrete values, rather than distributions, for inputs. Note that for the calculation of distribution PBP, because inputs for the determination of total installed cost were based on single-point values, only the variability and/or uncertainty in the inputs for determining operating cost contributed to variability in the distribution PBPs. The following summarizes the single-point values that DOE used in the determination of the rebuttable PBP:

- Manufacturing costs, markups, sales taxes, and installation costs were all based on the single-point values used in the distributional LCC and PBP analyses.
- Energy prices are based on national average values for the year that new standards are assumed to take effect.
- An average discount rate or lifetime is not required in the rebuttable PBP calculation.
- The effective date of the standard is assumed to be 2014.

8.4.2 Results

DOE calculated rebuttable PBPs for each standard level relative to the distribution of product energy efficiencies estimated for the base case. In other words, DOE did not determine the rebuttable PBP relative to the baseline energy efficiency level, but relative to the distribution of product energy efficiencies DOE determined for the base case (i.e., the case without new energy conservation standards).

Table 8.4.1 presents the rebuttable PBPs for microwave and combination ovens.

Table 8.4.1 Rebuttable Payback Periods

Microwave and Countertop Combination Ovens		Over the Range Combination Ovens	
Standby (W)	**PBP (years)**	**Standby (W)**	**PBP (years)**
2.00	0.2	3.70	0.0
1.50	0.3	2.70	1.8
1.00	0.6	2.20	5.7
0.02	1.6	0.04	1.6

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