CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

This chapter describes the methodology for analyzing the economic impacts of possible revisions to energy-efficiency standards on individual customers. The effect of revised standards on individual customers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). This chapter describes two metrics DOE used to determine the effect of possible revised standards on individual customers:

- Life-cycle cost (LCC) is the present value of total customer expense over the life of an appliance, including purchase expense and operating costs (including energy expenditures). Future operating costs are discounted to the time of purchase and summed over the lifetime of the equipment.
- Payback period (PBP) measures the amount of time it takes to recover the higher purchase price of more energy-efficient equipment through lower operating costs.

Inputs to the LCC and PBP are discussed in sections 8.3 and 8.4 of this chapter, respectively. The calculated results for each metric are presented in section 8.5. Key variables and calculations are presented for each metric. DOE performed the calculations discussed here with a series of Microsoft Excel spreadsheets which are accessible on the Internet at: http://www.eere.energy.gov/buildings/appliance_standards/residential/furnaces_boilers.html. Details and instructions for using the spreadsheets are discussed in Appendix N.

To determine whether a revision of the energy efficiency standard is economically justified, the Energy Policy and Conservation Act directs DOE to consider the economic impact of potential standards on consumers. To address that impact, DOE calculated changes in LCC for consumers that are likely to result from each candidate standard level; it also calculated the PBP for each candidate standard level. The effects of standards on individual consumers include changes in operating expenses (usually lower) and changes in total installed cost (usually higher). DOE analyzed the net effect of these changes by calculating the changes in LCC compared to a base case forecast. The LCC calculation considers total installed cost (equipment purchase price plus installation cost), operating expenses (energy and maintenance costs), equipment lifetime, and discount rate. The analysis compares the LCC of equipment with various design options—models with efficiency improvements designed to meet possible energy efficiency standards—with the LCC of the equipment that would have been chosen in the absence of new standards.

The PBP represents the number of years of operation required to achieve savings sufficient to pay for the increased efficiency features. It is the change in total installed cost due to an increased efficiency standard divided by the change in the first year operating cost from increased efficiency.

8.2 METHODOLOGY OVERVIEW

8.2.1 General Approach

DOE performed the LCC and PBP analysis for representative equipment in a sample of housing units that represent the segment of the U.S. housing stock that uses furnaces and boilers. DOE selected a sample of housing units from the 2001 Residential Energy Consumption Survey (RECS 2001),[1] as described in Chapter 7 (section 7.3, Housing Sample). For each housing unit, DOE calculated the LCC and PBP for the furnace or boiler at a range of efficiency levels. The calculation examines furnaces purchased in 2015, the first year new standards would take effect. A distinct advantage of this approach is that DOE can identify the percentage of consumers achieving LCC savings or attaining certain payback values due to an increased efficiency standard, in addition to the average LCC savings or average payback for that standard.

To capture the range of sizes of furnaces installed in different housing units, DOE created several "virtual models" for each product class. The virtual models have input capacities and air flow capabilities that are common for each product class.

The LCC and PBP analysis estimates furnace and boiler energy consumption under field conditions. These conditions include the outdoor climate during the heating season, which influences the operating hours of the equipment. The LCC and PBP approach differs from the approach used in the engineering analysis, for which DOE based the payback period calculations on the DOE test procedure. The test procedure uses specific, prescribed values to calculate annual energy consumption.

To account for the uncertainty and variability in the inputs to the calculation for a given household and between different households, DOE used a Monte Carlo simulation. A Monte Carlo simulation uses a distribution of values to allow for variability and/or uncertainty on inputs for complex calculations. For each input, there is a distribution of values, with probabilities (weighting) attached to each value. Monte Carlo simulations sample input values randomly from the probability distributions. For each product class, DOE calculated the LCC and PBP 10,000 times per Monte Carlo simulation run. DOE used Microsoft Excel spreadsheets with Crystal Ball, an add-on software,[a] to perform the Monte Carlo analysis.

For some variables, such as energy price and climate, each calculation used the values associated with the specific RECS housing unit (see Appendix O for a list of the RECS 2001 variables used in the LCC analysis). For these variables, the RECS housing units were sampled according to the weighting the Energy Information Administration (EIA)[b] assigned to them. The EIA designed this weighting to reflect the prevalence of various features in the national

---

[a] http://www.decisioneering.com/crystal_ball/ (last accessed on May 28, 2004)

[b] See: http://www.eia.doe.gov/emeu/recs/recs2001/append_a.html (last accessed on May 28, 2004) for more information on EIA's weighting methods.

population of housing units. Sampling according to the weighting means that some of the RECS housing units may be sampled more than once, while others may not be sampled at all. This sampling process simulates the likelihood that a specific type of household would occur in the entire U.S. housing stock.

DOE conducted LCC and PBP analyses for:

- non-weatherized gas furnaces,
- weatherized gas furnaces,
- mobile-home gas furnaces,
- oil-fired furnaces,
- hot-water gas boilers, and
- hot-water oil-fired boilers.

8.2.2 Design Options Considered

DOE calculated the LCC and PBP of furnaces and boilers incorporating a variety of design options that improve efficiency. For each product class, DOE considered one or more design options for reaching each specific annual fuel utilization efficiency (AFUE) level above the baseline model, as shown in Tables 8.2.1 through 8.2.6.

Table 8.2.1 Non-Weatherized Gas Furnace Design Options

AFUE	Baseline	Increased Heat Exchanger Area	Two-Stage Modulation	Continious Modulation	Condensing Operation
78%	X				
80%		X	X		
81%		X	X		
90%		X			
92%		X	X	X	X
96%				X	X

Table 8.2.2 Weatherized Gas Furnace Design Options

AFUE	Baseline	Increased Heat Exchanger Area
78%	X	
80%		X
81%		X
82%		X
83%		X

Table 8.2.3 Mobile Home Gas Furnace Design Options

AFUE	Baseline	Increased Heat Exchanger Area	Two-Stage Modulation	Condensing
75%	X			
80%		X	X	
81%		X	X	
82%		X	X	
90%		X		X

Table 8.2.4 Oil Furnace Design Options

AFUE	Baseline	Increased Heat Exchanger Area	Interrupted Ignition	Two-Stage Modulation
78%	X			
80%		X		
81%		X	X	X
82%		X	X	X
83%		X	X	X
84%		X	X	X
85%		X	X	X

Table 8.2.5 Hot-Water Oil Boiler Design Options

AFUE	Baseline	Increased Heat Exchanger Area	Interrupted Ignition	Two-Stage Modulation	Condensing
80%	X				
81%		X	X		
82%		X	X	X	
83%		X	X	X	
84%		X	X	X	
86%		X	X	X	
90%		X	X		X
95%		X	X		X

Table 8.2.6 Hot-Water Gas Boiler Design Options

AFUE	Baseline	Improved Heat Transfer Coefficient	Two-Stage Modulation	Condensing
80%	X			
81%		X	X	
82%		X	X	
83%		X	X	
84%		X	X	
85%		X	X	
86%		X		
91%		X		X
99%		X		X

8.2.3 Housing Data Set Used to Calculate LCC and PBP

For the LCC and PBP analysis, DOE divided the RECS 2001 sample housing units into two subsets—corresponding to new-construction or replacement applications—for three reasons:

1) Heating-equipment prices are different for new construction and replacement applications due to differences in the application of markups and sales tax (see section 8.3.1.2).
2) The estimated discount rate for new construction is lower than the discount rate for replacement installations (see section 8.3.4).
3) New construction tends to be built with more insulation and more energy-efficient products, compared to housing units that receive replacement installations. New construction is also more concentrated in certain parts of the country.

The Monte Carlo analysis sampled a certain fraction of the total iterations from the new construction subset and from the replacement installation subset for each product class. These fractions correspond to the projected shares of furnace shipments going to new housing and replacement applications in 2015 in the shipments model, as shown in Table 8.2.7 (see Chapter 9 for discussion of the shipments forecast).

For non-weatherized and weatherized gas furnaces, DOE assigned housing units built in the 1996-2001 period to the new construction subset. For other product classes, it was necessary to select housing units for the new construction subset from a longer time period in order to have an adequate sample size. The analysis sampled markups and discount rates from separate distributions for new home and replacement applications, depending on whether the sample unit was from the new construction or replacement subset. The subset of housing units for replacement applications is the entire set of RECS 2001 housing units selected for each product class.

Table 8.2.7 Percent of RECS Housing Sample Units Assigned to New Construction Subset

Product Class	Percent of Total Class Shipment in 2015
Non-weatherized gas furnace	29%
Weatherized gas furnace	27%
Mobile home gas furnace	35%
Oil-fired furnace	8%
Hot-water gas boiler	31%
Hot-water oil boiler	23%

8.3 LIFE-CYCLE COST INPUTS

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

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

where:

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

8.3.1 Total Installed Cost Inputs

DOE defines the total installed cost to the customer using the following equation:

$$IC = EQP + INST$$

where:

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

The flow chart in Figure 8.3.1 represents the inputs for total installed cost for non-weatherized gas furnaces. The sections below describe the manufacturing costs, the markups DOE used to arrive at the equipment price for the consumer, and installation costs.

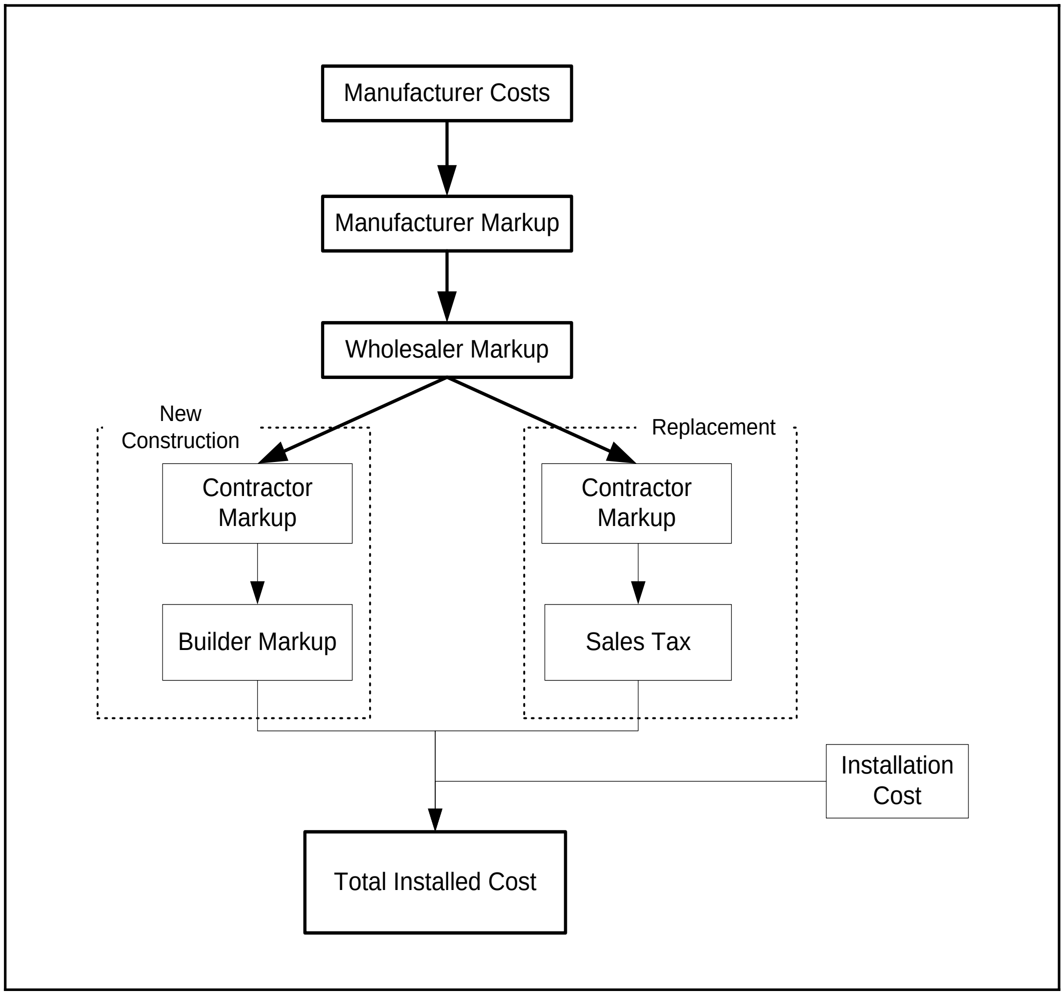

Figure 8.3.1 Total Installed Cost of Non-Weatherized Gas Furnaces

8.3.1.1 Manufacturing Cost

As described in Chapter 6, Engineering Analysis, DOE determined manufacturing costs at different efficiency levels using a reverse-engineering cost analysis for one size of equipment for each product class.

DOE based its manufacturer cost estimates on material prices determined from a five-year average spanning the years 2000 to 2004. However, because there have been recent spikes in the price of steel, DOE conducted a sensitivity analysis using 1st quarter 2005 material prices to determine the impact of these higher material prices on the LCC savings and PBPs of more-efficient equipment. As a lower bound, DOE created a scenario based on material prices in 2002 (the calender year with the lowest $/pound for M6 core steel). Appendix T presents the key LCC and PBP results based on the alternative material price scenarios.

The LCC analysis requires the cost for equipment of various sizes that would be used in the RECS 2001 sample homes. To derive the manufacturing costs for various sizes of furnaces and boilers, DOE scaled the average cost for the size used in the engineering analysis, as described below.

Non-Weatherized Gas Furnace. To develop a range of equipment sizes that represents the majority of combinations of input capacity and nominal maximum airflow, DOE developed virtual models to represent 25 different combinations of those two variables. Each virtual model has its own characteristics. The virtual models include models with the most commonly occurring input capacities and corresponding maximum nominal airflow rates at 0.5 inches water gauge. (See Chapter 7, Energy Consumption of Furnaces and Boilers, for more details about virtual models.)

To develop the manufacturing cost for each virtual model, DOE used the cost from the engineering analysis for one basic model size (input capacity = 75 thousand British thermal units per hour (kBTU/h) and airflow capacity = 3 tons). DOE scaled the cost for other input capacities from the basic model cost for both non-condensing and condensing models, as shown in Table 8.3.1. DOE adjusted costs with a cost adder for furnaces of different maximum nominal airflow capacity. Table 8.3.2 shows manufacturing costs by input capacity and airflow capacity for baseline model non-weatherized gas furnaces. Airflow capacity adders are in the left column.

For each virtual model, DOE estimated the cost for furnaces at different efficiency levels using the incremental cost estimates from the engineering analysis. It scaled these estimated costs to characterize incremental cost for each virtual model.

Table 8.3.1 Manufacturing Cost Scalars for Furnaces

Input Capacity (kBtu)	Non-Condensing	Condensing
45	0.930	0.910
50	0.940	0.925
60	0.965	0.955
70	0.990	0.985
75*	**1.000**	**1.000**
80	1.015	1.020
90	1.045	1.055
100	1.075	1.090
115	1.120	1.150
120	1.135	1.170
125	1.150	1.190
140	1.195	1.240

* Basic model

Table 8.3.2 Manufacturing Costs ($) for Baseline Model Non-Weatherized, Non-Condensing Gas Furnaces by Input Capacity and Airflow Capacity

			Input Capacity (kBtu/h)											
			45	50	60	70	75	80	90	100	115	120	125	140
Maximum Airflow	800 CFM (2 Ton)	-$10.44	$314	$318	$326									
	1200 CFM (3 Ton)	$0.00	$325	$328	$337	$345	$349*	$354	$365	$375				
	1600 CFM (4 Ton)	$6.18				$352	$355	$360	$371	$381	$397	$402	$407	
	2000 CFM (5 Ton)	$15.81						$370	$380	$391	$407	$412	$417	$433

* Basic Model

Other Product Classes. For weatherized gas furnaces and mobile home furnaces, DOE used the same virtual models as it used in the analysis of non-weatherized gas furnaces. For oil-fired furnaces, DOE described a number of different sizes using the distribution of models in the GAMA March 2005 directory.[2] For each input capacity size, DOE assigned an appropriate air handler size based on model information. For boilers, DOE described a number of different sizes using the distribution of models in the GAMA March 2005 directory. For these product classes, DOE scaled the cost for each input size from the cost identified for a basic (typical) model for the specific product class (e.g., the basic model for oil-fired furnaces is 105 kBtu/hour).

In the SNOPR, DOE considered additional costs for weatherized gas furnaces and gas boilers. For weatherized gas furnaces, it assumed stainless steel heat exchanger at 82% and 83% AFUE. For gas boilers, it assumed that units that require Category III venting also incorporate a draft inducer. Section 6.4.1.2 in Chapter 6 provides details regarding these changes.

8.3.1.2 Markups

DOE applied markups to the manufacturer cost of each virtual model to arrive at the equipment price paid by the purchaser. As described in Chapter 5, Markups, DOE determined markups on each stage of the distribution chain from the manufacturer to the consumer. In addition to estimating average markups, DOE characterized the markups with probability distributions through a statistical analysis of U.S. Census data.[3]

DOE assigned markups to housing units in the new construction subsample from the distribution for new construction markups. These markups include a builder markup. DOE assigned markups to units in the replacement equipment subsample from the distribution for replacement equipment. These markups include sales tax.

In the markups analysis, DOE determined that the markup on incremental costs (relative to a baseline model) is lower than the markup on the baseline model cost for wholesalers and contractors. Thus, for calculating the equipment cost of baseline equipment, DOE sampled the markups from the distribution of baseline markups. For the incremental cost of equipment at efficiency levels above the baseline, the Department sampled and applied markups from the distribution of incremental markups.

8.3.1.3 Installation Cost

The installation cost is the cost to the consumer of installing a furnace or a boiler; it covers all labor associated with the installation of a new unit or the replacement of an existing one. It includes costs of changes, such as venting modifications, that would be required for the correct installation of the equipment.

Chapter 6, Engineering Analysis, describes the estimation of installation costs at various efficiency levels for each product class. For the LCC analysis, DOE assigned each housing unit an installation cost from a distribution of weighted-average values appropriate for each product class and efficiency level. For non-weatherized gas furnaces, oil-fired furnaces, and gas and oil boilers, DOE developed distributions of installation cost at various efficiency levels with the Installation Model (as described in Appendix C). As explained in Section 6.5.4, Chapter 6, for weatherized gas furnaces, DOE used calculations based on the RS Means approach to calculate a mean value, and applied a triangular distribution of ±15 percent around the mean. The installation cost for baseline mobile home furnaces is included in the markup for the mobile home manufacturer, which was assigned to mobile homes in RECS from a distribution of markups. For mobile home furnaces of higher efficiency, DOE used a triangular distribution of ±15 percent around the mean estimates of the additional installation costs for proper venting.

8.3.1.4 Finance Costs

Many consumers purchase heating equipment with some type of financing. To facilitate the LCC calculations, DOE's approach assumed that a consumer pays the total installed cost at the time of installation or, in the case of new-home equipment, at the time of home occupancy. As discussed in section 8.3.4 below, DOE used discount rates that reflect finance costs. The discounted sum of annual payments on a loan or credit amount would be equal to the total consumer cost if it were paid in full at the time of purchase. Thus, it was not necessary to separately account for financing costs.

8.3.2 Operating Cost Inputs

The operating cost consists of energy and maintenance costs. The energy cost consists of separate costs for natural gas or oil, and for electricity. Electricity is used by blower fans or pumps and other electrical components in furnaces and boilers.

DOE based the operating cost for the LCC analysis on energy consumption calculated for a sample of buildings from RECS 2001. DOE defined the operating cost by the following equation:

$$OC = EC + (MC + RC)$$

where:

OC = operating cost,
EC = energy expenditure associated with operating the equipment,
MC = maintenance cost for maintaining equipment operation, and
RC = repair cost to replace failed components.

The remainder of this section provides information about the variables DOE used to calculate the operating cost for furnace and boilers.

8.3.2.1 Annual Energy Consumption

DOE's approach for calculating the annual energy consumption of furnaces and boilers in the sample housing units is presented in Chapter 7, Energy Consumption of Furnaces and Boilers. For non-weatherized gas furnaces, DOE used 25 virtual models to represent the range of input capacity and airflow capacity of models currently available on the market. DOE used specifications from actual models to select the specifications for each virtual model for blower size, motor size, supply-air outlet area, power consumption of the draft inducer and the igniter, delay times, and fan curves. It assigned one virtual model to each of the sample housing units. The particular virtual model assigned to each housing unit depended on the characteristics of the housing unit and the climate where it is located. For other product classes, DOE assigned virtual models that it adapted from the non-weatherized gas furnace models.

Accounting for the Rebound Effect

A rebound effect (also called a take-back effect or offsetting behavior) refers to increased energy consumption that results from actions that increase efficiency and reduce consumer costs. The logic behind the rebound effect is that higher efficiency equipment lowers the marginal cost of the end-use service relative to lower efficiency equipment. Because the marginal cost of the service is reduced, a service demand response occurs. For example, a home insulation program that reduces heat losses by 50 percedoes not usually result in a full 50 percent reduction in energy consumption, because residents of insulated homes find that they can afford to keep their homes warmer. As a result, they reinvest a portion of potential energy savings on comfort.

To determine the impact of the rebound effect on furnace/boiler efficiency standards, DOE examined a summary of the literature regarding the rebound effect in relation to space heating equipment.[4] Based on five studies chosen for their robust methodology, the summary concluded that, for a 100 percent increase in fuel efficiency, values of "take-back" or rebound for space heating are between 10 and 30 percent of the energy consumption savings. The National Energy Modeling System (NEMS), which is used for developing EIA's *Annual Energy Outlook* (*AEO*), incorporates a rebound effect for space heating.[5] The rebound effect for the residential module in

NEMS results in a 0.15 percent increase in energy consumption for a one-percent increase in efficiency. In keeping with EIA's approach, DOE chose to apply a rebound effect of 15 percent (for a 100 percent increase in efficiency) in its analysis of furnace and boiler standards.

The take-back in energy consumption associated with the rebound effect provides consumers with increased value (e.g., a warmer indoor environment). The net impact on consumers is thus the sum of the change in the cost of owning the heating equipment (i.e., life-cycle cost) and the increased value for the warmer indoor environment. DOE believes that, if it were able to monetize the increased value to consumers added by the rebound effect, this value would be similar in value to the foregone energy savings. For this analysis, DOE estimated that this value is equivalent to the monetary value of the energy savings that would have occurred without the rebound effect. Therefore, the economic impacts on consumers with or without the rebound effect, as measured in the LCC analysis, are the same.

8.3.2.2 Energy Prices

Energy Prices for RECS Households. DOE calculated average and marginal natural gas and electricity prices for each sample household in 2001 using RECS 2001 billing data.[6] Along with household data, EIA collects billing data (for up to 16 billing cycles) for a subset of households in the total RECS sample. For each household with billing data, the RECS data set includes, for each billing cycle: the start and end date, the electricity cost in dollars, the electricity consumption in kilowatt-hours (kWh), the natural gas bill in dollars, and the gas consumption in hundreds of cubic feet.

DOE estimated marginal electricity and natural gas prices from the RECS 2001 billing data by calculating a linear regression of monthly customer bill to monthly customer energy consumption for each household for which billing data were available. DOE interpreted the slope of the regression line for each household as the marginal energy price for that household.[c] It kept in its sample housing records with r^2 values greater than or equal to 85 percent.

The RECS 2001 billing data were insufficient to develop seasonal marginal prices and maintain an r^2 value of at least 85 percent. Therefore, DOE estimated annual prices. In developing the annual prices, the r^2 values for the regressions of RECS electricity bills were generally very high. DOE eliminated some outliers by rejecting marginal prices where the linear regression had an r^2 value less than 0.85. Based on this methodology, DOE rejected 16 percent of the 3999 households with electricity billing data, leaving 3368 households that had marginal price slopes with an acceptable r^2 value. DOE rejected 29 percent of the 2246 households with natural gas billing data, leaving 1587 households that had marginal price slopes with an acceptable r^2 value.

[c] For confidentiality reasons, the spreadsheets DOE developed were given to EIA, which then provided the marginal price results together with the “r^2” value for the households with billing data.

Within the sample of 2683 households from RECS 2001 used in the LCC analysis,[d] 874 (33 percent) do not have marginal prices for electricity and 1463 (55 percent) do not have marginal prices for natural gas. To calculate marginal prices for these households, DOE assigned marginal prices from the set of households that did have marginal prices, were in close proximity, and had similar average electricity prices. To determine the closest proximity, DOE used the root mean square of the sum of the difference equation with variables from RECS 2001, including Census division plus large State, heating degree days (HDD), cooling degree days (CDD), and average electricity prices. It assigned values for the households without electricity marginal prices from a set of 3085 households with electricity marginal prices. DOE assigned values for the households without natural gas marginal prices from a set of 1444 households with natural gas marginal prices.

To calculate the closest proximity household, DOE started with households with acceptable marginal prices in the same Census divisions. The equation calculating the root mean sum of the squares of differences determines the "distance" between the household without marginal price and the households with marginal prices:

$$"Distance" = \sqrt{(HDD_2 - HDD_1)^2 + (CDD_2 - CDD_1)^2 + (ElectPrice_2 - ElectPrice_1)^2}$$

where:

HDD1	=	heating degree-days for household with marginal price,
HDD2	=	heating degree-days for household without marginal price,
CDD1	=	cooling degree-days for household with marginal price,
CDD2	=	cooling degree-days for household without marginal price,
ElectPrice1	=	average electricity price for household with marginal price, and
ElectPrice2	=	average electricity price for household without marginal price.

DOE calculated annual average liquefied petroleum gas (LPG) prices based on data for RECS 2001 housing units with LPG-fired equipment, using the estimated cost of LPG divided by gallons of LPG used . Monthly data necessary to calculate marginal prices were not available for households using LPG heating. DOE used the same method for housing units with oil-fired equipment: estimated cost of oil divided by gallons of oil used.

For all classes of gas-using equipment, DOE used the average energy price from RECS 2001 for each gas-using household to calculate the energy cost for the base case equipment. It used the marginal energy prices determined for each household for the cost of saved energy associated with higher-efficiency equipment. Marginal energy prices are the prices consumers pay for the last unit of energy used.[7] Since marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with efficiency standards.

[d] The 2683 sample households is a subset of the 4822 houses surveyed in RECS 2001. For a full description of how DOE derived this sample, refer to Chapter 7 (section 7.3, Housing Sample).

For oil-fired furnaces and boilers, DOE used the average oil prices for the RECS 2001 oil-using households for both base case equipment and higher-efficiency equipment, since the data necessary for estimating marginal prices were not available. DOE used this same method for LPG-fired equipment.

Projecting Energy Prices to 2015 and Beyond. As in past rulemakings, DOE used price forecasts by the EIA to estimate the future trends in natural gas, oil, and electricity prices. It multiplied the average and marginal prices for each sampled household by the forecast annual average price changes in EIA's *AEO* 2007[8] to arrive at prices in 2015 and beyond. DOE calculated energy prices using three separate projections from *AEO* 2007: Reference, Low Economic Growth, and High Economic Growth. These three cases reflect the uncertainty of economic growth in the forecast period. The high and low growth cases show the projected effects of alternative growth assumptions on energy markets.

8.3.2.3 Maintenance and Repair Cost

Maintenance cost is the annual cost of maintaining a furnace or boiler in working condition. Each product class has distinct maintenance costs. Chapter 6 describes the approach for determining maintenance costs and the average values at various efficiency levels. To capture the variability of these costs, DOE assigned a maintenance cost to each house from a distribution of values. It was not aware of any reliable data that provide a distribution of maintenance costs. DOE used a triangular distribution for maintenance costs, with a minimum and maximum of 20 percent of the average cost, based on recommendations in a Gas Technology Institute (GTI) report.[9]

The repair cost is the cost to the consumer for replacing or repairing components which have failed. Chapter 6 describes the approach for determining repair costs and the average values at various efficiency levels. To capture the variability of these costs, DOE assigned a repair cost to each house from a distribution of values. DOE was not aware of any reliable data that provide a distribution of repair costs, so it used a similar distribution as for maintenance costs.

8.3.3 Lifetime

The lifetime is the age at which furnaces or boilers are retired from service. Table 8.3.3 shows the lifetime range for the six product classes.

In the analysis for the advance notice of proposed rulemaking (ANOPR), DOE used gas boiler lifetime data from *Appliance Magazine* (1987), which reports an average lifetime of 17 years, and oil-fired boiler lifetime data from a Gas Research Institute (GRI) study (1990), which reports an average lifetime of 15 years. Stakeholder comments suggested that these lifetimes were too low, so DOE performed a literature review to obtain more recent estimates of boiler lifetime. The collected data come from four main types of sources: government, consumer/research groups, manufacturers and retailers, and utilities. Several sources report the lifetime for gas boilers, with values ranging between 15 and 30 years.[10, 11, 12] The median value for gas boiler lifetime is approximately 25 years. A single source gives the lifetime of condensing oil-fired boilers as 20-30 years.[13] It is more current (2003) than the source used in the ANOPR analysis. A 1994 GRI report gives the lifetime of residential boilers as 25 years.[14] Based on this review, DOE used a median lifetime value of 25 years for both gas and oil-fired boilers, with ranges as shown in Table 8.3.3.

Table 8.3.3 Furnace and Boiler Lifetimes Used in the LCC Analysis (years)

Product Class	**Low**	**Average**	**High**
Non-weatherized gas furnace*	10	20	30
Weatherized gas furnace*	12	18	24
Mobile home furnace†	14	19	23
Oil-fired furnace*	10	15	20
Hot-water gas boiler‡	20	25	30
Hot-water oil-fired boiler‡	20	25	30

Sources:
* *Appliance Magazine*[15]
† *Mobile Home Technical Support Document, 1993*[16]
‡ See text above.

8.3.4 Discount Rates

DOE derived the discount rates for the LCC and PBP analysis 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 equipment, or (2) the opportunity cost of any equity used to purchase equipment. For residential products, the purchase of equipment for new homes entails different finance costs for consumers than the purchase of replacement equipment. Thus, DOE used different discount rates for new construction and replacement installations.

8.3.4.1 Discount Rate for New Housing Equipment

New-housing equipment is purchased as part of the home, which is almost always financed with a mortgage loan. DOE estimated discount rates for new-housing equipment 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).[e] For example, a six-percent nominal mortgage rate has an effective nominal rate of 4.5 percent for a household at the 25-percent marginal tax rate. When adjusted for inflation of two percent, the effective real rate becomes 2.45 percent.

The data source DOE used for mortgage interest rates is the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1989, 1992, 1995, 1998, 2001, and 2004.[17] Using the appropriate *SCF* data for each year, DOE adjusted the mortgage interest rate for each relevant household in the *SCF* for mortgage interest tax deduction[18] and inflation[19] (see Table 8.3.4). In

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

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 six years was 8.1 percent. 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 be in effect in 2015 (the assumed effective date of new efficiency standards). After adjusting for inflation and mortgage interest tax deduction, effective real interest rates on mortgages across the six surveys averaged 3.2 percent.

Table 8.3.4 Data Used to Calculate Real Effective Mortgage Rates

Year	Average Nominal Interest Rate (%)	Inflation Rate (%)	Marginal Tax Rate Applicable to Mortgage Interest (%)*	Average Real Effective Interest Rate (%)
1989	9.7	4.82	23.7	2.5
1992	9.1	3.01	22.9	3.9
1995	8.2	2.83	23.8	3.4
1998	7.9	1.56	23.7	4.4
2001	7.6	2.85	22.6	3.0
2004	6.2	2.66	19.6	2.3
Average	8.1			3.2

* The values given are the inverse of the marginal tax rate on mortgage interest.

8.3.4.2 Discount Rate for Replacement Equipment

Households use a variety of methods to finance replacement equipment. In principle, one could estimate the interest rates on the actual financing vehicles used to purchase replacement equipment. However, the shares of different financing vehicles in total replacement equipment purchases are unknown.

DOE's approach involves identifying all possible debt or asset classes that might be used to purchase replacement equipment, including household assets that might be affected indirectly.[f] DOE did not include debt from primary mortgages and equity of assets considered non-liquid (such as retirement accounts), since these would likely not be affected by replacement equipment purchases. DOE estimated the average shares of the various debt and equity classes in the average U.S. household equity and debt portfolios using *SCF* data for 1989, 1992, 1995, 1998, 2001, and 2004.[17] Table 8.3.5 shows the average shares of each considered class. DOE used the mean share of each class across the six years as a basis for estimating the effective financing of replacement equipment.

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

Table 8.3.5 Average Shares of Considered Household Debt and Equity Types (percent)

Type	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	Mean
Home equity loans	4.3	4.5	2.7	2.8	2.8	4.4	3.6
Credit cards	1.6	2.1	2.6	2.2	1.7	2.0	2.0
Other installment loans	2.8	1.7	1.4	1.7	1.1	1.3	1.7
Other residential loans	4.4	6.9	5.2	4.3	3.1	5.8	4.9
Other line of credit	1.1	0.6	0.4	0.2	0.3	0.5	0.5
Checking accounts	5.8	4.7	4.9	3.9	3.6	4.2	4.5
Savings & money market	19.2	18.8	14.0	12.8	14.2	15.1	15.7
Certificate of deposit (CD)	14.5	11.7	9.4	7.0	5.4	5.9	9.0
Savings bond	2.2	1.7	2.2	1.1	1.2	0.9	1.5
Bonds	13.8	12.3	10.5	7.0	7.9	8.4	10.0
Stocks	22.4	24.0	25.9	36.9	37.5	28.0	29.1
Mutual funds	8.0	11.1	20.9	20.1	21.3	23.4	17.5
Total	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, and 2004.[17] Table 8.3.6 shows the average nominal rates in each year, and the inflation rates DOE 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 8.3.6 Average Nominal Interest Rates for Household Debt Classes (percent)

Type	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	Mean
Home equity loans	11.5	9.6	9.6	9.8	8.7	5.7	9.2
Credit cards*	-	-	14.2	14.5	14.2	11.7	13.6
Other installment loans	9.0	7.8	9.3	7.8	8.7	7.4	8.3
Other residential loans	8.8	7.6	7.7	7.7	7.5	6.0	7.5
Other line of credit	14.8	12.7	12.4	11.9	14.7	8.8	12.5
Inflation Rate	4.82	3.01	2.83	1.56	2.85	2.66	

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

Table 8.3.7 shows the average effective real rates in each year and the mean rate across the years.

Table 8.3.7 Average Real Effective Interest Rates for Household Debt Classes (percent)

Type	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	Mean
Home equity loans	3.8	4.3	4.4	5.8	3.8	1.9	4.0
Credit cards*	-	-	11.0	12.7	11.1	9.1	11.0
Other installment loans	4.9	5.8	7.0	6.6	6.1	5.4	6.0
Other residential loans	4.0	4.7	4.8	6.0	4.6	3.3	4.6
Other line of credit	9.6	9.4	9.3	10.2	7.3	6.0	8.7

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

Similar rate data are not available from the *SCF* for the equity classes, so DOE derived data for these classes from national-level historical data. The interest rates associated with certificates of deposit (CDs),[20] savings bonds,[21] and bonds (AAA bonds)[22] are from Federal Reserve Board time-series data covering 1977–2006. Rates on savings and money market accounts are from Cost of Savings Index data covering 1984–2006.[23] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500 in the 1977–2006 period.[24] 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 of the 1977–2006 period. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year. DOE assumed real rates on checking accounts to be zero. Average nominal and real interest rates for the equity classes are shown in Table 8.3.8.

Table 8.3.8 Average Nominal and Real Interest Rates for Household Equity Types

Type	Average Nominal Rate (%)	Average Real Rate (%)
Checking accounts	-	0.0
Savings and money market	5.5	2.3
CDs	6.9	2.4
Savings bonds	8.0	3.5
Bonds	8.8	4.2
Stocks	13.3	8.8
Mutual funds	11.6	7.0

Since the above interest and return rates cover a range of time, DOE believes they are representative of rates that may be in effect in 2015. Table 8.3.9 summarizes 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 5.6 percent.

Table 8.3.9 Shares and Interest or Return Rates Used for Household Debt and Equity Types

Type	Average Share of Household Debt plus Equity (%)*	Mean Effective Real Rate (%)**
Home equity loans	3.6	4.0
Credit cards	2.0	11.0
Other installment loans	1.7	6.0
Other residential loans	4.9	4.6
Other line of credit	0.5	8.7
Checking accounts	4.5	0.0
Savings and money market accounts	15.7	2.3
CDs	9.0	2.4
Savings bonds	1.5	3.5
Bonds	10.0	4.2
Stocks	29.1	8.8
Mutual funds	17.5	7.0
Total/Weighted-average discount rate	100	5.6

* Not including primary mortgage or retirement accounts.
** Adjusted for inflation and, for home equity loans, loan interest tax deduction.

To account for variation among households in rates for each of the types, DOE sampled a rate for each household from a distribution of rates for each debt and equity type based on the *SCF* data. Appendix P describes the distribution of rates obtained from the data sources previously mentioned.

8.3.5 Equipment Assignment in Base Case Forecast

DOE calculated the change in LCC resulting from a change to higher-efficiency equipment relative to the equipment housing units would have chosen in 2015 in the absence of any change to the efficiency standards. The base case for 2015 requires an estimate of the efficiency of equipment each household would purchase in the absence of new standards.

For non-weatherized gas furnaces, in the analysis for the notice of proposed rulemaking (NOPR), DOE assigned furnaces to sampled housing units in the base case to reflect the trend toward a higher market share for condensing furnaces, as shown in shipments data through 2003 provided by GAMA. DOE also based the projected market share of condensing furnaces in 2015 on an evaluation of the correlation between condensing furnace market share and the natural gas price for the 1990–2003 period, projected natural gas prices from *AEO2006*, and non-price market factors that contribute to growth in the condensing furnace market share. Figure 8.3.2 clearly shows a strong correlation between condensing furnace market share and the natural gas price. The projected condensing furnace market share for 2015 was 35.6 percent. Therefore, for the base case, DOE assigned condensing furnaces to 35.6 percent of the sampled housing units with non-weatherized gas furnaces.

In its analysis for the SNOPR, DOE reviewed shipments data through 2005 provided by GAMA[2] and confirmed the NOPR assumptions about condensing furnace market share. The natural gas projections DOE used in this rulemaking (*AEO2007*) forecast that the national-average natural gas price in 2015 is well below the 2005 level, which suggest that the condensing furnace market share may be lower in the future than in 2005. However, other factors, such as the growing acceptance of condensing furnaces among builders and home owners, are likely to support the condensing furnace market even with a lower natural gas price. DOE believes that the impact of the price and non-price factors may be roughly similar, and therefore maintained its projected condensing furnace market share for 2015 at 35.6 percent. Within the condensing and non-condensing groups, DOE used the distribution of 2003 shipments[25] by efficiency levels to select AFUE shares for 2015.

DOE assigned a condensing furnace to the housing units with the highest number of HDDs, since households in colder climates are most likely to purchase a condensing furnace. In the NOPR analysis, for the assignment of different AFUE levels for all non-weatherized gas furnaces, DOE aggregated the 2003 GAMA State-level shipments data on the distribution of shipments by efficiency into Census divisions. In its analysis for the SNOPR, DOE refined its assignment methodology by splitting some of the Census divisions into two climate zones: States with average HDDs of above 6,000 and States with average HDDs below 6,000. Using the GAMA State-level shipments data, DOE matched the household HDD percentile with the AFUE percentile within each climate zone, rather than for the whole division, to establish the efficiency of the base case furnace. This procedure is described in Appendix V. The results of the revised analysis correspond to the shares of condensing furnaces reported in GAMA's State-level data.

For weatherized gas furnaces, DOE developed the efficiency (AFUE) of the base case equipment based on data for air conditioning packaged units with gas furnaces from DOE's 2001 central air conditioners standards rulemaking. 67 FR 36383.

For other furnace product classes, DOE developed the efficiency of the base case equipment assigned to each housing unit according to the distribution of 2003 shipments[25] by efficiency levels. For gas and oil-fired boilers, DOE used the distribution of 2001 shipments,[26] since the 2003 data do not provide data on shipments by AFUE level.

Table 8.3.10 shows the shares of specific efficiency levels in the base case forecast for each product class. Note that the base case equipment is not limited to the baseline model. It is the equipment that a household would have purchased in 2015 in the absence of new standards.

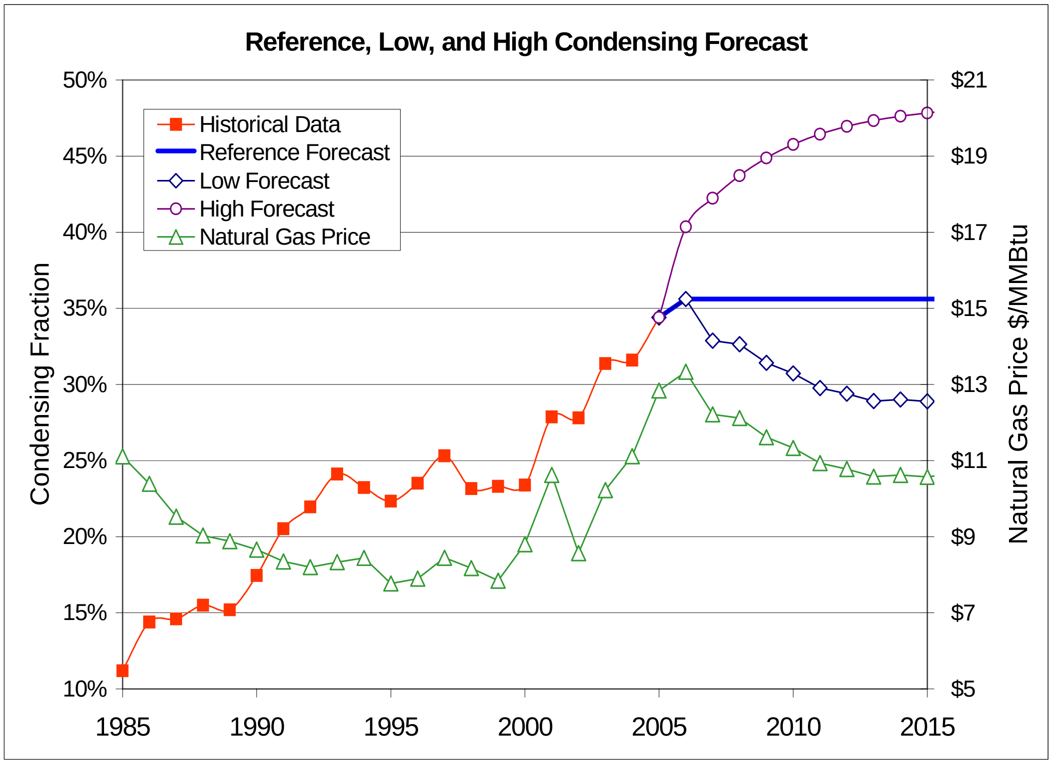

Figure 8.3.2 Historic and Projected Market Share of Condensing Furnaces in Non-Weatherized Gas Furnace Shipments

Table 8.3.10 Market Shares of Specific Efficiency Levels in Base Case 2015 Forecast (%)

AFUE (%)	NWGF	WGF	MHGF	OF	GB	OB
75			15.0			
78	1.3	18.0		4.0		
79		13.0				
80	62.5	62.0	80.0	57.0	34.7	5.3
81	0.6	7.0		9.0	21.8	5.3
82		0.0		7.5	13.9	5.3
83				7.5	14.9	23.3
84				7.5	8.9	23.3
85				7.5		23.3
86						7.0
87						7.0
88					3.0	
90	9.2		5.0			
91	3.4				3.0	
92	19.6					
93	1.7					
96	1.7					

NWGF = non-weatherized gas furnace
WGF = weatherized gas furnace
MHGF = mobile home gas furnace
OF = oil-fired furnace
GB = gas-fired boiler
OB = oil-fired boiler

8.3.6 Summary of Inputs

Table 8.3.11 provides a summary of the inputs used in the LCC and PBP analysis.

Table 8.3.11 Summary of Inputs Used in the LCC and Payback Period Analysis

Input	**Description**
Equipment Price	Derived by multiplying manufacturer cost by manufacturer, distributor, contractor, and builder markups and sales tax, as appropriate for replacement and new construction. Used average materials prices for the period 2002-2006. For weatherized gas furnaces, assumed stainless steel heat exchanger for 82% and 83% AFUE. For gas boilers, assumed that units that require Category III venting incorporate a draft inducer.
Installation Cost	Used a distribution of weighted-average installation costs from the Installation Model. Installation configurations were weight-averaged by frequency of occurrence in the field. The Installation Model is RS Means-based, and comparable to available known data.
Maintenance and Repair Cost	Used GRI data for gas furnaces and boilers, water heater rulemaking survey results for oil-fired equipment, and data from the 1993 rulemaking for mobile home furnaces. Supplemented with information that indicates higher maintenance frequency for modulating equipment and identical maintenance costs for condensing and non-condensing equipment. Included repair costs for gas-fired equipment based on the equipment price.
Annual Energy Use	Used virtual models based on actual furnace characteristics to capture the range of common sizes. Energy calculations reflect heating loads calculated using RECS 2001data. The furnace input capacity and airflow capacity were assumed based on the vintage of the equipment and characteristics of each housing unit.
Energy Prices	Calculated average and marginal annual energy prices for each RECS household. Used *AEO2007* forecasts to estimate future average and marginal energy prices.
Lifetime	Used *Appliance Magazine* survey results and, for boilers, a recent literature review.
Discount Rate	Uses data from *Survey of Consumer Finances* in 1989-2004 period and other sources to estimate separate discount rate distributions for replacement and new housing applications.

8.4 PAYBACK PERIOD INPUTS

The inputs to the PBP calculation are the total installed cost of the equipment to the customer and the annual (first-year) operating expenditures. The PBP calculation uses the same inputs as the LCC analysis, except that electricity price trends and discount rates are not required. Since the PBP is a “simple” payback, the required energy prices are only for the year in which a new standard is to take effect—in this case the year 2015. The energy prices that DOE used in the PBP calculation were the prices projected for that year.

The payback period equation is:

$$Payback_{option} = \frac{EquipCost_{option} - EquipCost_{base}}{OprCost_{base} - OprCost_{option}}$$

where *base* is the base case and *option* is the design option being considered.

Numerically, the simple payback period is the ratio of the increase in purchase (and installation) price to the decrease in annual operating expenditures (including maintenance). DOE made the comparisons based on replacing the base case furnace or boiler with a furnace or boiler incorporating another design option. Payback periods are expressed in years. A payback period of three years means that the increased purchase price for the energy-efficient furnace or boiler is equal to three times the value of reduced operating expenses in the year of purchase; in other words, the increased purchase price is recovered in three years because of lower operating expenses. Payback periods greater than the life of the product mean that the increased purchase price is never recovered in reduced operating expenses. Negative payback periods are not relevant and DOE disregarded them.

8.5 RESULTS

This section presents LCC and PBP results using the energy price forecast in the Reference case from *AEO2007*. Appendix Q presents results using the energy price forecasts in the Low and High Economic Growth cases from *AEO2007*.

For each set of sample housing units for each product class, DOE calculated the average LCC and LCC savings and the median and average PBP for each of the design options. DOE calculated LCC savings and PBP relative to the base case equipment assigned to the housing units. The average base case efficiency is always higher than the efficiency of the baseline equipment. For that reason, the average LCC savings are not equal to the difference between the LCC of a specific option and the LCC of the baseline equipment.

For each design option, DOE also calculated the share of households with a net LCC benefit, a net LCC cost, and the share with no impact. A household is assumed to experience no impact from a given design option if its assigned base case equipment has an AFUE that is the same or higher than the AFUE of that design option. For example, for non-weatherized gas furnaces, at the 80-percent AFUE design option, 98.6-percent of the households have no impact because their assigned base case equipment has an AFUE equal to or higher than 80-percent AFUE.

To illustrate the range of LCC and PBP impacts among the sample households, this section presents figures that provide such information for each product class.

8.5.1 Non-Weatherized Gas Furnaces

Table 8.5.1 shows the LCC and PBP for non-weatherized gas furnaces. The 81 percent AFUE level (single-stage) shows an average LCC savings of $15. The 90 percent AFUE condensing furnace shows an average LCC savings of $55. The average LCC savings for the 90 percent AFUE design option reflects the fact that around one-third of the sample housing units in 2015 are assumed to have already purchased a condensing furnace in the base case, and thus have zero savings from a standard at 90 percent AFUE.

Table 8.5.1 LCC and PBP Results for Non-Weatherized Gas Furnaces

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with			Median	Average
					Net Cost	No Impact*	Net Benefit		
78%	$2,036	$10,980	$13,016						
80%	$2,044	$10,760	$12,804	$2	0%	98.6%	1%	1.0	1.7
80% Modulation (Two-Stage)	$2,349	$10,847	$13,196	-$250	62%	36%	1%	51	86
81%	$2,118	$10,653	$12,771	$15	29%	36%	35%	12	22
81% Modulation (Two-Stage)	$2,423	$10,741	$13,164	-$240	62%	36%	3%	41	75
90%	$2,737	$9,880	$12,617	$55	37%	36%	27%	14	20
92%	$2,915	$9,712	$12,627	$37	44%	27%	29%	15	21
92% Modulation (Two-Stage)	$3,177	$9,836	$13,013	-$340	82%	2%	16%	22	46
92% Modulation (Continuous)	$3,221	$9,961	$13,182	-$505	86%	2%	12%	25	59
96% Modulation (Continuous)	$3,894	$9,652	$13,547	-$865	89%	2%	9%	35	76

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.5.1 shows the range of LCC savings for the design options for non-weatherized gas furnaces. For each design option, 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 LCC 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 design option. For condensing design options, such as 90 percent AFUE and 92 percent AFUE, the wide range of LCC savings reflects the differences across regions of the country. Figure 8.5.2 shows the range of payback periods for non-weatherized gas furnaces.

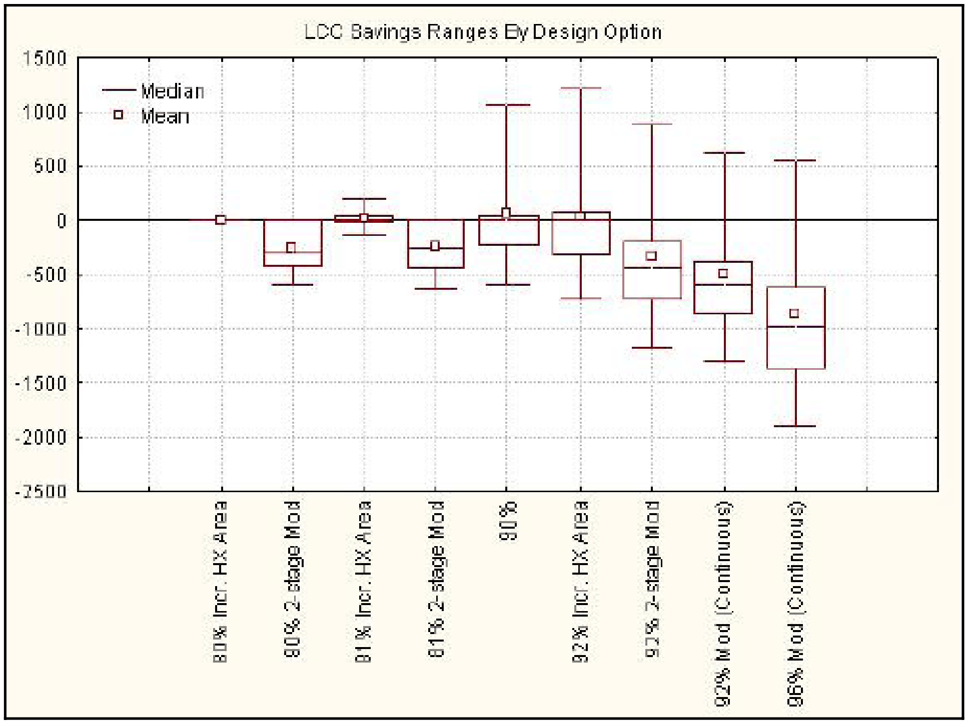

Figure 8.5.1 Range of LCC Savings for Non-Weatherized Gas Furnaces

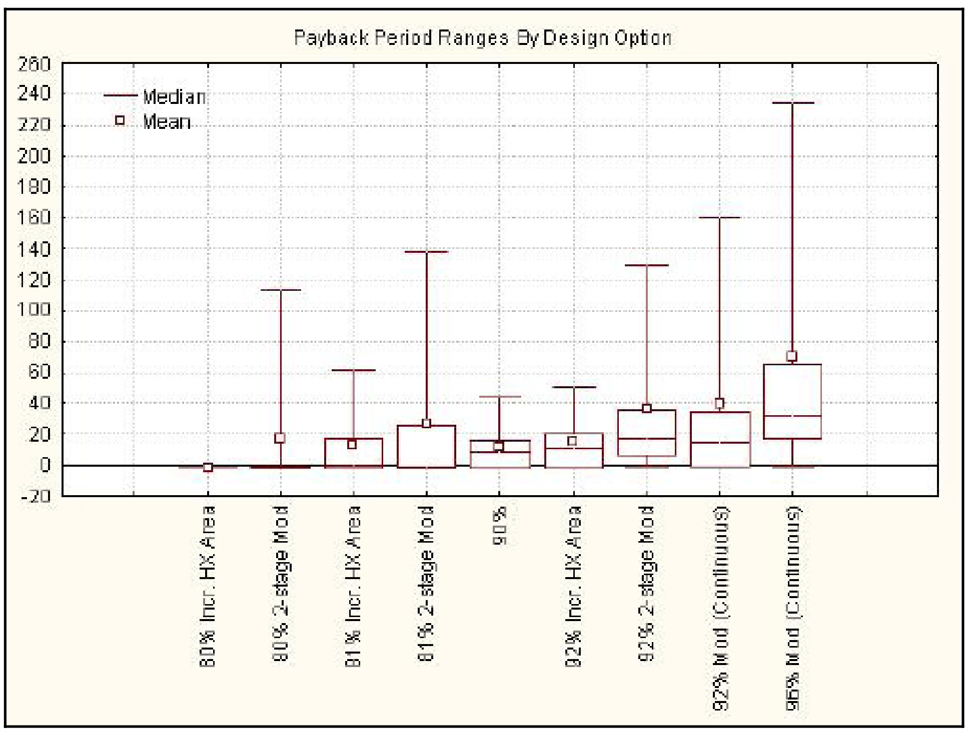

Figure 8.5.2 Range of Payback Period in Years for Non-Weatherized Gas Furnaces

8.5.2 Other Product Classes

Tables 8.5.2 and 8.5.3 include the LCC and PBP results for weatherized gas furnaces that utilize stainless steel heat exchangers at 82% and 83% AFUE in the high and low cost scenarios.

Table 8.5.2 LCC and PBP Results for Weatherized Gas Furnaces (High Cost)

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with			Median	Average
					Net Cost	No Impact*	Net Benefit		
78%	$3,888	$6,607	$10,495						
80%	$3,897	$6,491	$10,388	$19	0%	82%	18%	1.3	1.6
81%	$3,906	$6,435	$10,342	$62	2%	7%	91%	2.6	3.4
82%	$4,532	$6,527	$11,059	-$655	100%	0%	0%	90	117
83%	$4,571	$6,482	$11,053	-$649	99%	0%	1%	64	83

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Table 8.5.3 LCC and PBP Results for Weatherized Gas Furnaces (Low Cost)

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with			Median	Average
					Net Cost	No Impact*	Net Benefit		
78%	$3,888	$6,602	$10,491						
80%	$3,897	$6,486	$10,383	$19	0%	82%	18%	1.3	1.6
81%	$3,907	$6,430	$10,337	$62	3%	7%	91%	2.7	3.4
82%	$4,020	$6,405	$10,426	-$26	75%	0%	25%	17	23
83%	$4,059	$6,361	$10,419	-$20	71%	0%	29%	16	20

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Figures 8.5.3 through 8.5.6 show the range of LCC savings and PBPs by design option for weatherized gas furnaces.

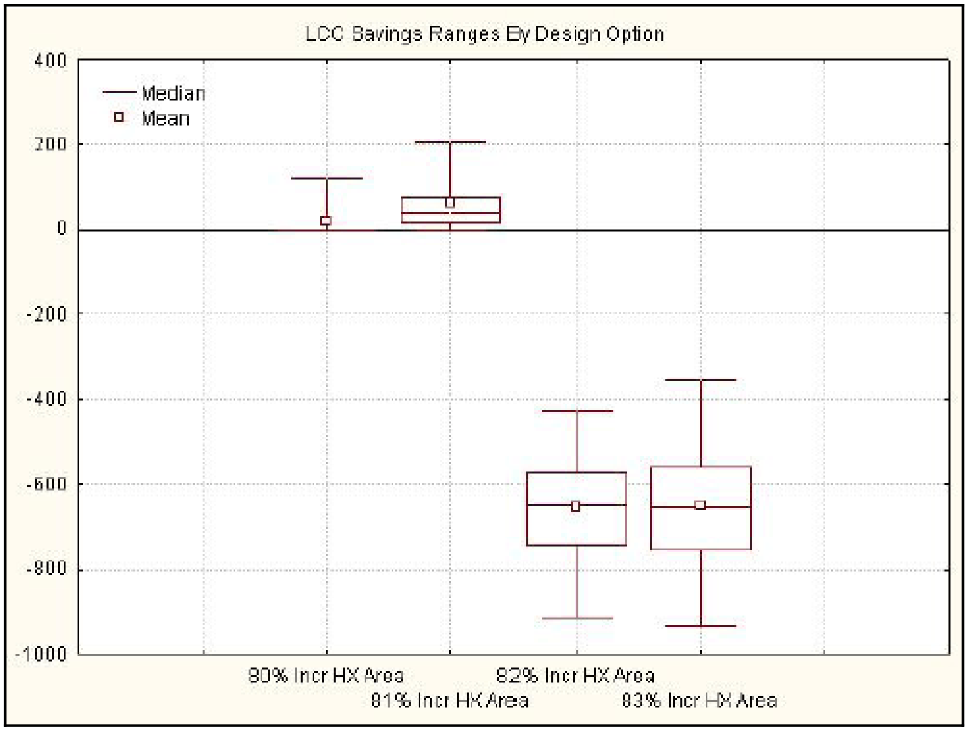

Figure 8.5.3 Range of LCC Savings for Weatherized Gas Furnaces for High Cost Scenario

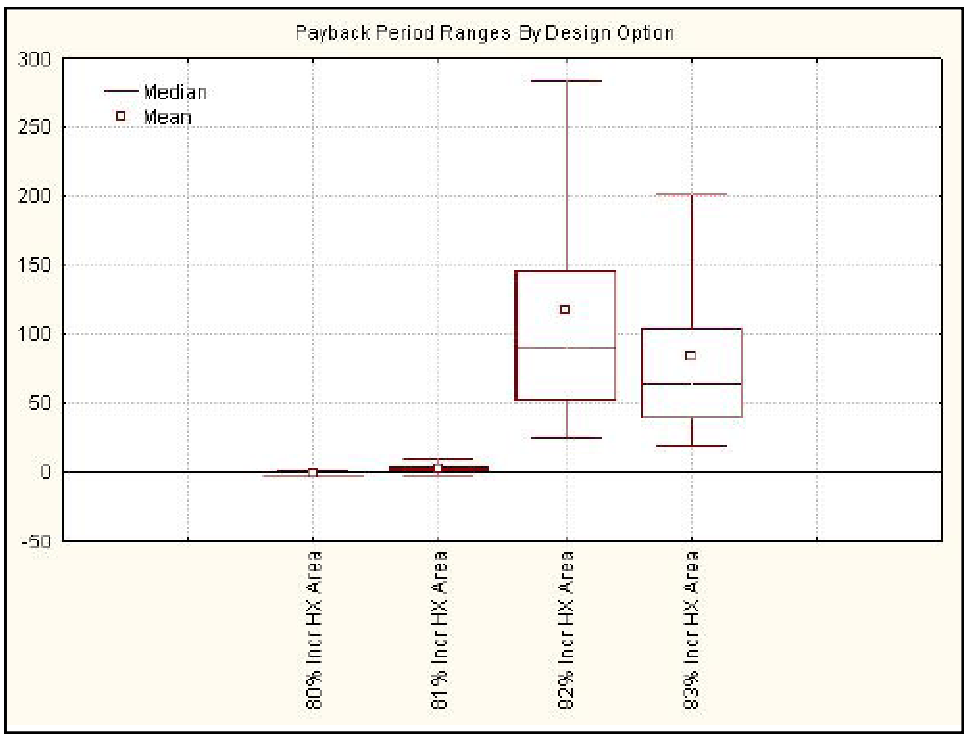

Figure 8.5.4 Range of Payback Period in Years for Weatherized Gas Furnaces for High Cost Scenario

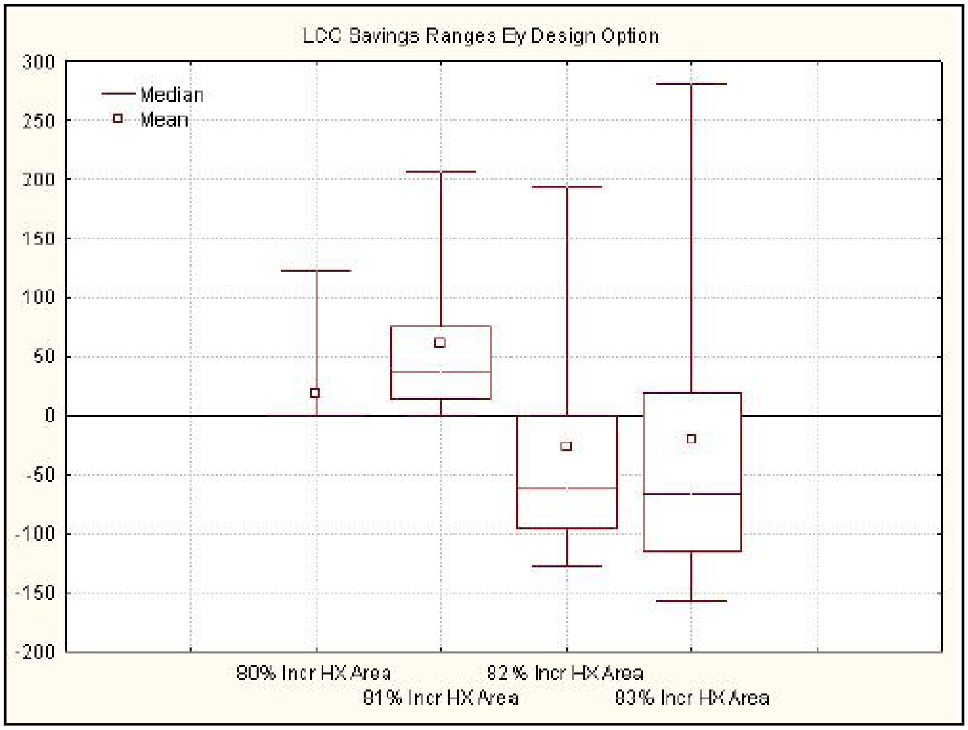

Figure 8.5.5 Range of LCC Savings for Weatherized Gas Furnaces for Low Cost Scenario

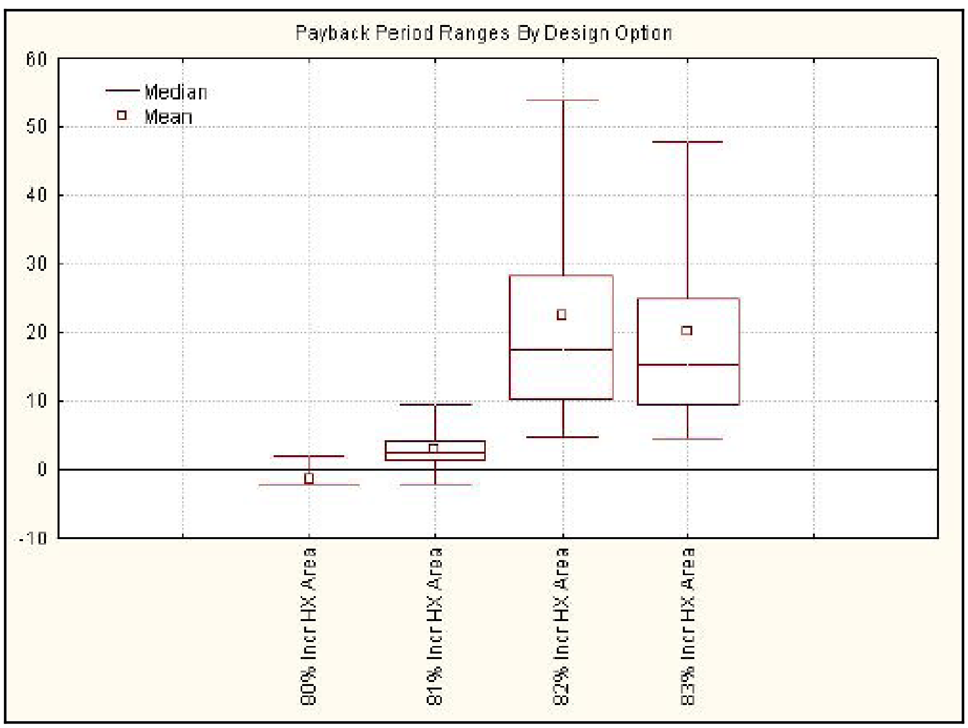

Figure 8.5.6 Range of Payback Period in Years for Weatherized Gas Furnaces for Low Cost Scenario

Table 8.5.4 shows the LCC and PBP results for mobile home gas furnaces.

Table 8.5.4 LCC and PBP Results for Mobile Home Gas Furnaces

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact*	Households with Net Benefit	Median	Average
75%	$844	$10,427	$11,271						
80%	$940	$9,590	$10,529	$111	1%	85%	14%	2.1	3.7
80% Modulation (Two-Stage)	$1,313	$9,688	$11,001	-$337	85%	5%	10%	30	84
81%	$1,032	$9,492	$10,523	$116	51%	5%	44%	16	23
81% Modulation (Two-Stage)	$1,412	$9,590	$11,002	-$338	85%	5%	10%	58	98
82%	$1,062	$9,396	$10,459	$178	31%	5%	64%	11	15
82% Modulation (Two-Stage)	$1,441	$9,494	$10,935	-$275	83%	5%	12%	38	66
90% Condensing	$1,306	$8,881	$10,187	$434	30%	5%	65%	9	18

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Figures 8.5.7 and 8.5.8 show the range of LCC savings and PBPs by design option for mobile home gas furnaces.

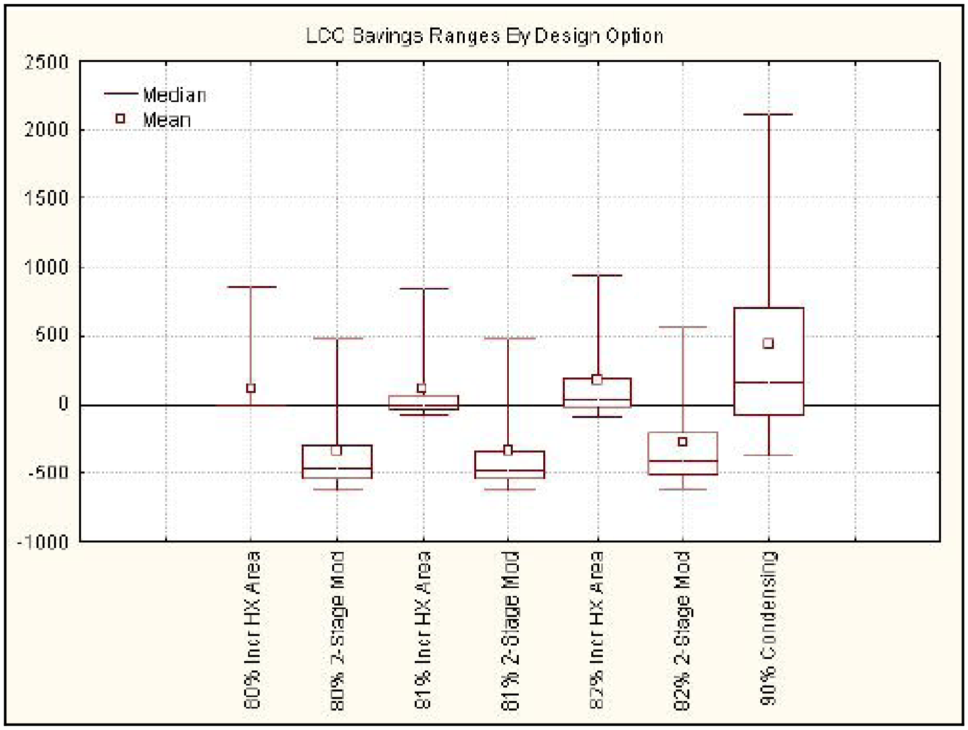

Figure 8.5.7 Range of LCC Savings for Mobile Home Furnaces

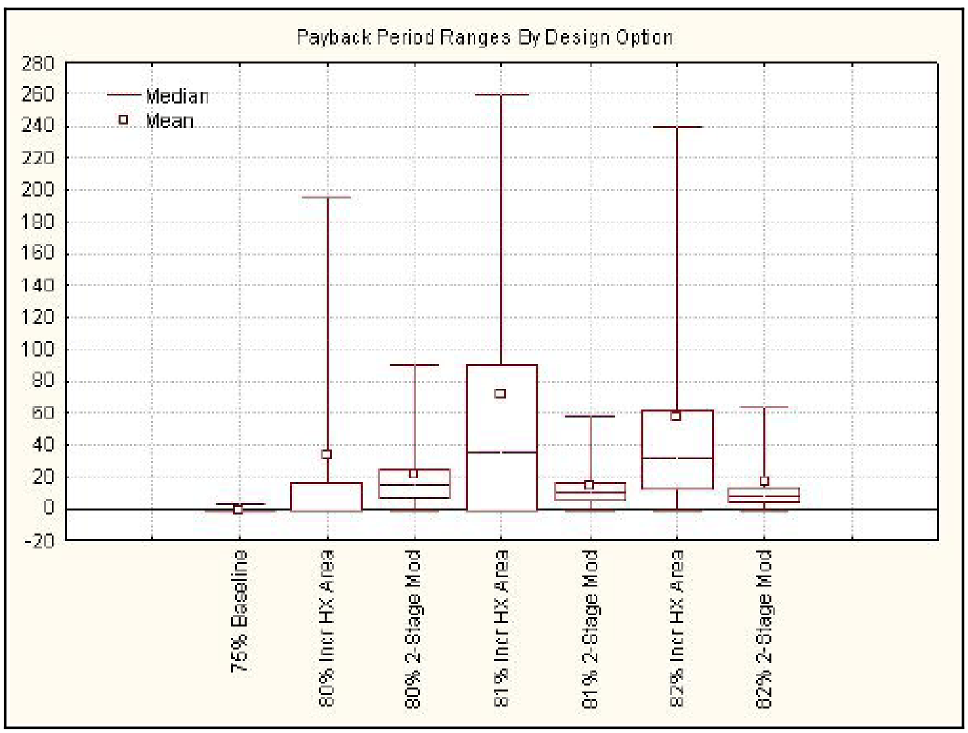

Figure 8.5.8 Range of Payback Period in Years for Mobile Home Furnaces

Table 8.5.5 shows the LCC and PBP results for oil-fired furnaces.

Table 8.5.5 LCC and PBP Results for Oil-Fired Furnaces

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with			Median	Average
					Net Cost	No Impact*	Net Benefit		
78%	$3,125	$13,123	$16,248						
80%	$3,129	$12,842	$15,971	$10	0%	96%	4%	0.2	0.3
81%	$3,138	$12,706	$15,844	$88	0%	39%	61%	0.7	0.9
81% Interrupted Ignition	$3,161	$12,622	$15,783	$131	2%	30%	68%	1.8	2.6
81% Atom Burner w/ Two-Stage Modulation	$3,454	$12,524	$15,977	-$5	45%	30%	25%	13	18
82%	$3,142	$12,574	$15,716	$177	0%	30%	70%	0.5	0.7
82% Interrupted Ignition	$3,178	$12,489	$15,667	$215	3%	22%	75%	1.8	2.7
82% Atom Burner w/ Two-Stage Modulation	$3,458	$12,391	$15,849	$74	36%	22%	41%	10	14
83%	$3,320	$12,445	$15,764	$139	20%	22%	58%	6	9
83% Interrupted Ignition	$3,356	$12,360	$15,715	$181	20%	15%	65%	6	8
83% Atom Burner w/ Two-Stage Modulation	$3,636	$12,261	$15,897	$26	50%	15%	35%	12	16
84%	$3,496	$12,319	$15,815	$96	38%	15%	47%	10	14
84% Interrupted Ignition	$3,532	$12,233	$15,765	$142	35%	7%	57%	8	11
84% Atom Burner w/ Two-Stage Modulation	$3,812	$12,134	$15,947	-$26	59%	7%	33%	14	18
85%	$3,681	$12,195	$15,876	$40	51%	7%	42%	12	16
85% Interrupted Ignition	$3,717	$12,109	$15,826	$89	48%	0%	52%	10	13
85% Atom Burner w/ Two-Stage Modulation	$3,997	$12,010	$16,008	-$92	68%	0%	32%	15	19

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Figures 8.5.9 and 8.5.10 show the range of LCC savings and PBPs by design option for oil-fired furnaces.

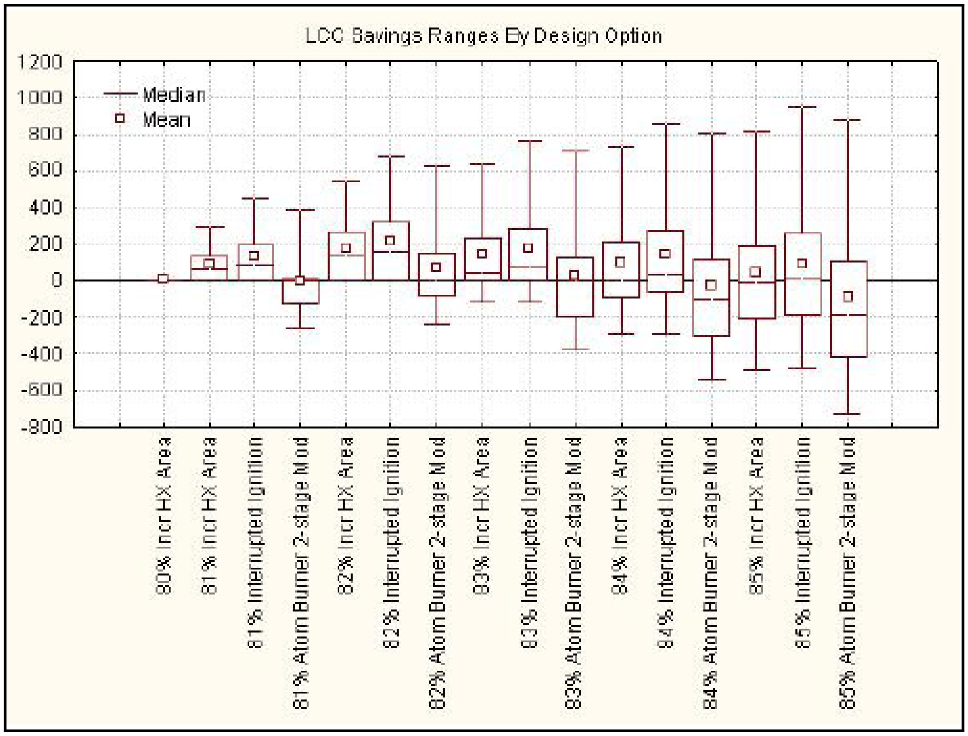

Figure 8.5.9 Range of LCC Savings for Oil-Fired Furnaces

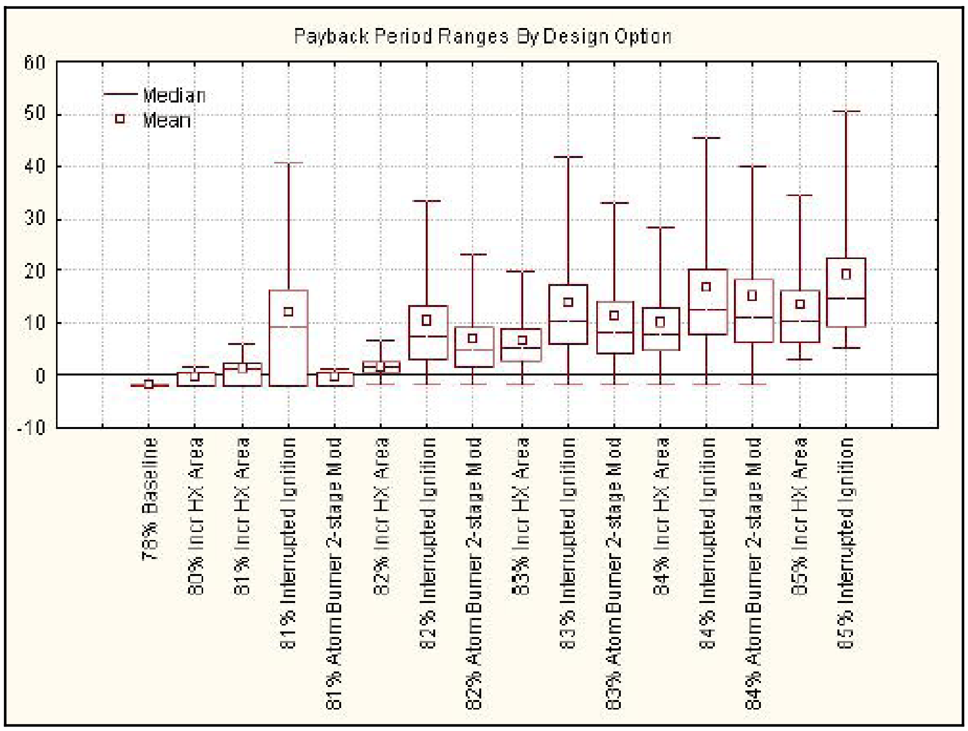

Figure 8.5.10 Range of Payback Period in Years for Oil-Fired Furnaces

Tables 8.5.6 and 8.5.7 include the LCC and PBP results for hot-water gas boilers that utilize draft inducers for installations that require Cat. III venting systems in the high and low cost scenarios.

Table 8.5.6 LCC and PBP Results for Hot-Water Gas Boilers (High Cost)

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact*	Households with Net Benefit	Median	Average
80%	$3,630	$16,846	$20,475						
81%	$3,707	$16,228	$19,935	$189	0%	65%	35%	2.1	2.3
81% Modulation (Two-Stage)	$3,872	$16,307	$20,179	$51	26%	44%	30%	7	9
82%	$3,835	$16,075	$19,910	$203	11%	44%	45%	6	12
82% Modulation (Two-Stage)	$4,000	$16,153	$20,153	$32	42%	30%	29%	12	34
83%	$4,063	$15,930	$19,993	$145	31%	30%	39%	12	24
83% Modulation (Two-Stage)	$4,227	$16,009	$20,236	-$62	61%	15%	24%	20	46.
84%	$4,053	$15,775	$19,828	$285	20%	15%	66%	7	13
84% Modulation (Two-Stage)	$4,218	$15,854	$20,072	$56	59%	6%	35%	16	32
85%	$4,468	$15,648	$20,116	$15	59%	6%	35%	18	36
85% Modulation (Two-Stage)	$4,633	$15,727	$20,360	-$215	71%	6%	23%	26	56
86%	$5,264	$15,582	$20,846	-$671	81%	6%	13%	33	62
91%	$5,583	$14,952	$20,535	-$378	69%	6%	26%	21	35
99%	$6,792	$14,251	$21,043	-$872	75%	3%	22%	21	35

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Table 8.5.7 LCC and PBP Results for Hot-Water Gas Boilers (Low Cost)

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)**	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact*	Households with Net Benefit	Median	Average
80%	$3,627	$16,845	$20,472						
81%	$3,705	$16,227	$19,932	$189	0%	65%	35%	2.1	2.3
81% Modulation (Two-Stage)	$3,870	$16,306	$20,176	$51	26%	44%	30%	7	9
82%	$3,826	$16,072	$19,898	$208	11%	44%	46%	6	12
82% Modulation (Two-Stage)	$3,991	$16,151	$20,142	$37	41%	30%	29%	12	33
83%	$4,040	$15,925	$19,965	$161	29%	30%	41%	12	23
83% Modulation (Two-Stage)	$4,204	$16,004	$20,208	-$46	60%	15%	25%	20	45
84%	$4,032	$15,770	$19,802	$300	18%	15%	67%	7	12
84% Modulation (Two-Stage)	$4,197	$15,849	$20,046	$70	58%	6%	36%	16	31
85%	$4,420	$15,637	$20,057	$60	55%	6%	39%	17	33
85% Modulation (Two-Stage)	$4,585	$15,716	$20,301	-$170	69%	6%	25%	24	54
86%	$5,178	$15,562	$20,740	-$582	79%	6%	15%	31	58
91%	$5,582	$14,952	$20,534	-$387	69%	6%	25%	21	35
99%	$6,791	$14,251	$21,042	-$881	75%	3%	22%	21	35

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Figures 8.5.11 through 8.5.14 show the range of LCC savings and PBPs by design option for hot-water gas boilers.

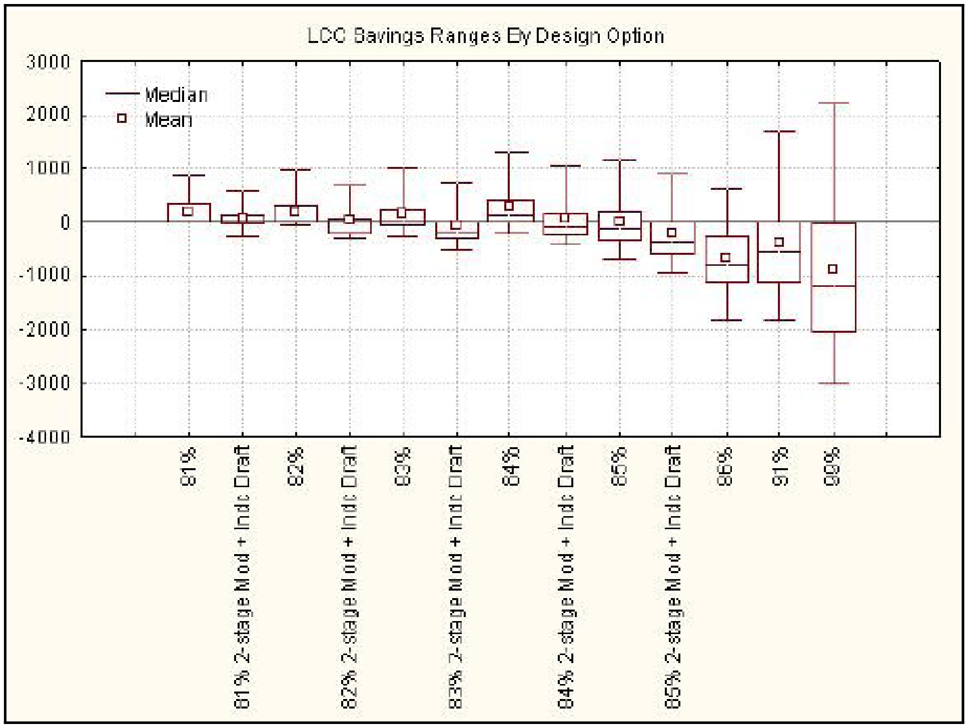

Figure 8.5.11 Range of LCC Savings for Hot-Water Gas Boilers for High Cost Scenario

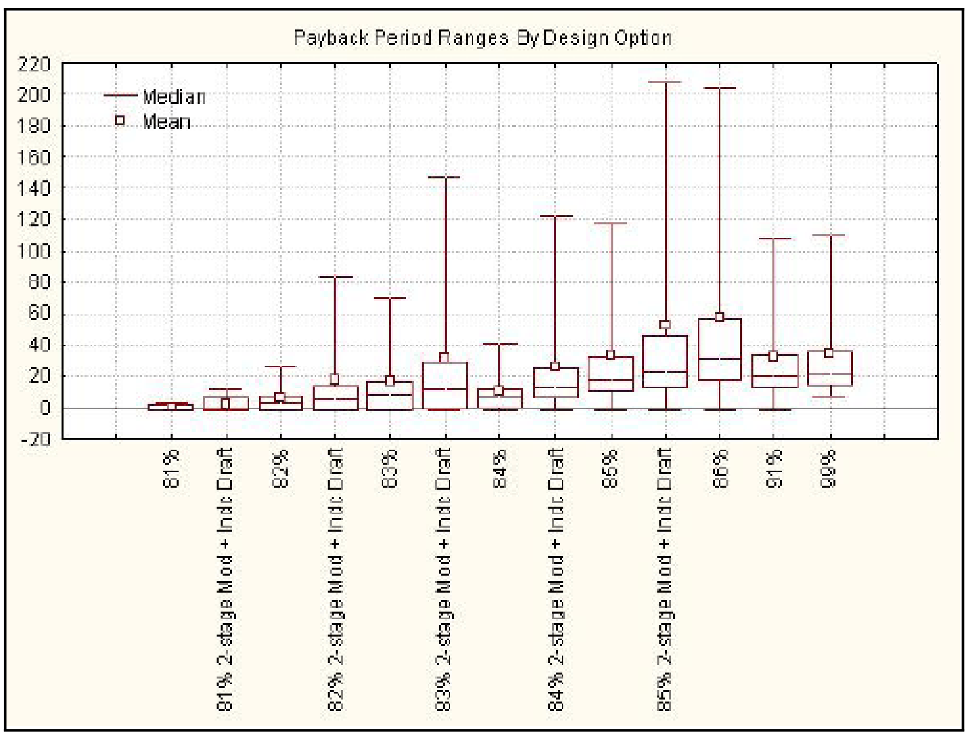

Figure 8.5.12 Range of Payback Period in Years for Hot-Water Gas Boilers for High Cost Scenario

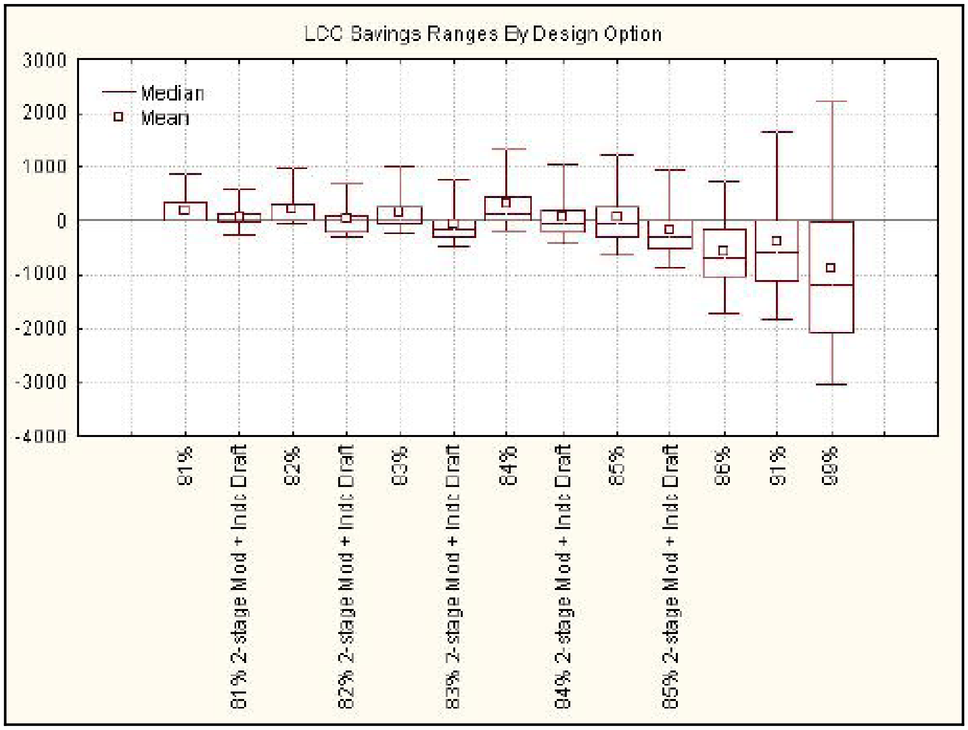

Figure 8.5.13 Range of LCC Savings for Hot-Water Gas Boilers for Low Cost Scenario

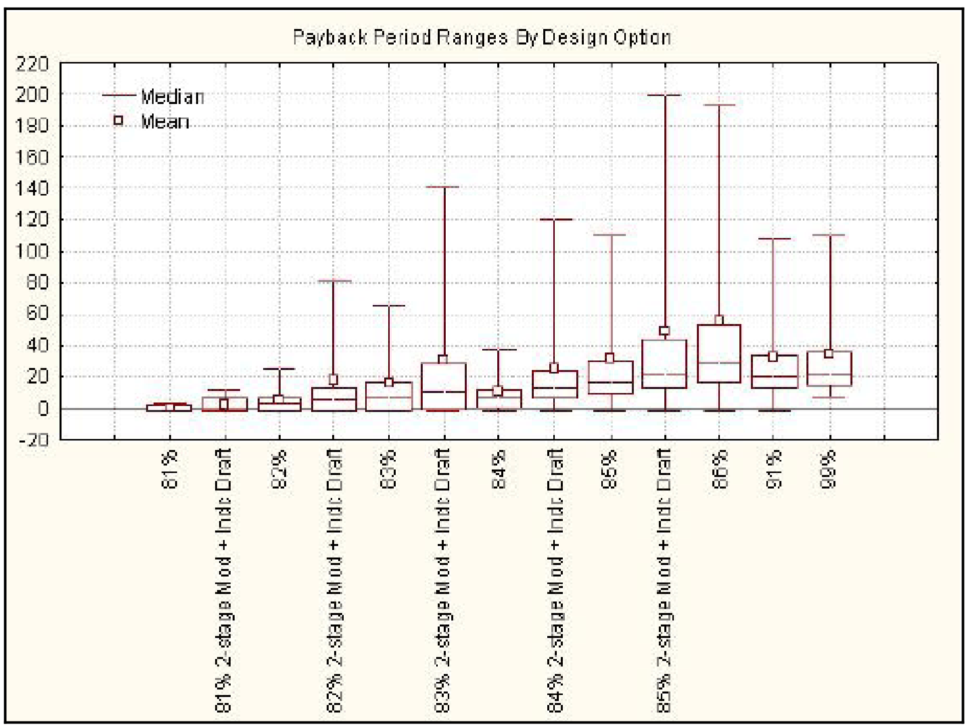

Figure 8.5.14 Range of Payback Period in Years for Hot-Water Gas Boilers for Low Cost Scenario

Table 8.5.8 shows the LCC and PBP results for hot-water, oil-fired boilers.

Table 8.5.8 LCC and PBP Results for Hot-Water, Oil-fired Boilers

Design Option by AFUE	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (Years)	
	Average Installed Price	Average Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact*	Households with Net Benefit	Median	Average **
80%	$3,892	$20,702	$24,594						
81%	$3,901	$20,473	$24,374	$12	0%	95%	5%	0.7	0.9
81% Interrupted Ignition	$3,939	$20,413	$24,351	$15	2%	89%	8%	5	9
82%	$3,911	$20,250	$24,161	$35	0%	89%	11%	0.8	0.9
82% Interrupted Ignition	$3,948	$20,189	$24,138	$39	2%	84%	14%	3.3	7
82% Atom Burner w/ Two-Stage Modulation	$4,242	$20,271	$24,513	-$21	12%	84%	4%	22	31
83%	$3,920	$20,032	$23,952	$69	0%	84%	16%	0.8	0.9
83% Interrupted Ignition	$3,958	$19,971	$23,929	$77	10%	61%	30%	5	9
83% Atom Burner w/ Two-Stage Modulation	$4,251	$20,053	$24,304	-$70	32%	61%	8%	17	28
84%	$4,167	$19,819	$23,987	$56	17%	61%	22%	14	19
84% Interrupted Ignition	$4,205	$19,759	$23,964	$70	25%	37%	38%	12	16
84% Atom Burner w/ Two-Stage Modulation	$4,499	$19,841	$24,339	-$165	55%	37%	8%	38	52
85%	$4,424	$19,611	$24,035	$27	34%	37%	29%	17	23
85% Interrupted Ignition	$4,462	$19,551	$24,013	$46	42%	14%	44%	15	19
85% Atom Burner w/ Two-Stage Modulation	$4,755	$19,633	$24,388	-$276	77%	14%	9%	39	53
86%	$4,668	$19,408	$24,076	-$7	49%	14%	37%	18	25
86% Interrupted Ignition	$4,705	$19,348	$24,053	$14	50%	7%	43%	17	22
86% Atom Burner w/ Two-Stage Modulation	$4,999	$19,430	$24,429	-$336	81%	7%	12%	36	52
90%	$5,881	$18,580	$24,461	-$366	70%	7%	23%	23	29
95%	$6,840	$17,711	$24,551	-$456	72%	0%	28%	22	27

* "No impact" means that the base case forecast furnace assigned to the household has greater efficiency than the level indicated, so the household is not affected.

** Based on the payback calculation, a very small change in operating cost can result in a few extremely large paybacks, which will skew the average payback. In these cases, median is probably a better indicator.

Figures 8.5.15 and 8.5.16 show the range of LCC savings and PBPs by design option for hot-water, oil-fired boilers.

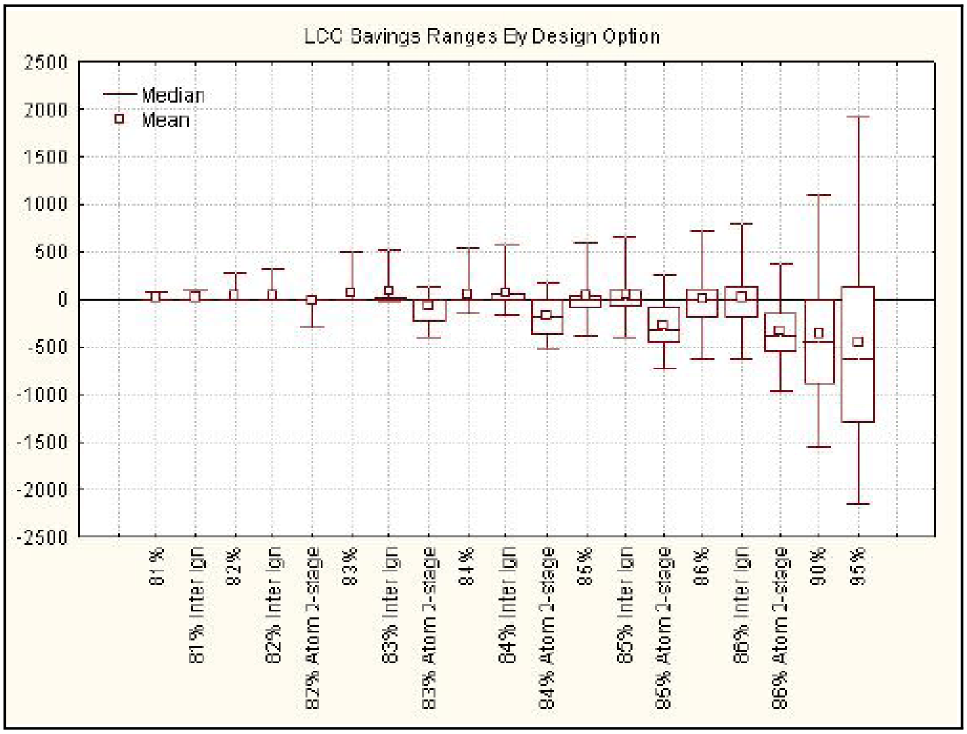

Figure 8.5.15 Range of LCC Savings for Hot-Water Oil-Fired Boilers

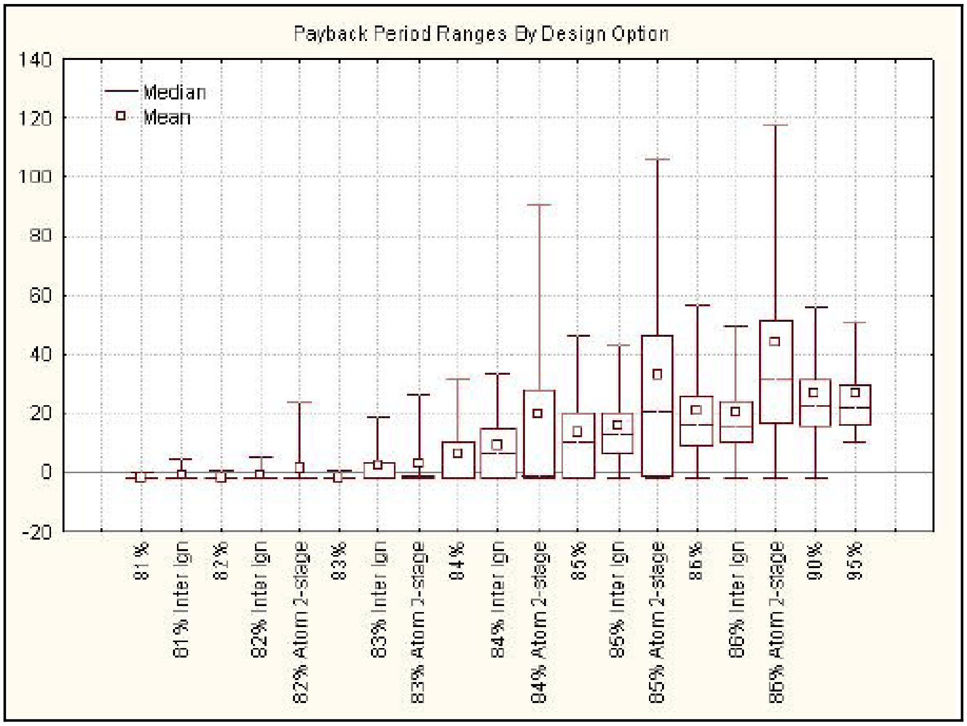

Figure 8.5.16 Range of Payback Period in Years for Hot-Water Oil-Fired Boilers

REFERENCES

1. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey (RECS): Household Energy Consumption and Expenditures 2001*, 2001. (Last accessed May 18, 2005.) <http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html>

2. Gas Appliance Manufacturers Association (GAMA), *GAMA Directory March 2005*, 2005. (Last accessed March, 2005.) <http://www.gamanet.org/gama/inforesources.nsf/vAllDocs/Product+Directories?OpenDocument>

3. U.S. Department of Commerce - Bureau of the Census, *Housing Completions*, 2001. 2001.) <http://www.census.gov/const/compann.pdf>

4. Greening, L. A., D.L. Greene, Carmen Difiglio, and L. Schipper, Energy Efficiency and Consumption: The Rebound Effect. *Energy Policy*, 2000. 28(6-7): pp. 389-401. <www.elsevier.com/locate/enpol>

5. Energy Information Administration, *Price Responsiveness in the AEO2003 NEMS Residential and Commerical Buildings Sector Model, Table 13. Natural Gas Wellhead Prices, Actual vs. Forecasts*, 2003. (Posted October 2003).) <http://www.eia.doe.gov/oiaf/analysispaper/>

6. U.S. Department of Energy - Energy Information Administration, *RECS 2001 Billing Data*, 2001. (Last accessed March, 2005.) Data provided electronically to LBNL.

7. Chaitkin, S., J. E. McMahon, C. D. Whitehead, R. Van Buskirk, and J. Lutz, Estimating Marginal Residential Energy Prices in the Analysis of Proposed Appliance Energy Efficiency Standards. In *ACEEE 2000 Summer Study on Energy Efficiency in Buildings.* 2000. Asilimar, CA, August 20-25. American Council for an Energy-Efficient Economy.9: pp. 25-36. LBNL-44230.

8. U.S. Department of Energy - Energy Information Administration, *Annual Energy Outlook 2007: With Projections Through 2030*, February, 2007. Washington, DC. Report No. DOE/EIA-0383(2007). <http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2007).pdf>

9. Gas Research Institute, *Efficiency Improvements for New Residential Gas Furnaces and Boilers*, May 23-24, 1995. GRI. Arlington, VA.

10. PM Engineer Magazine, *Boiler Editorial Study*, December, 2001. Business News Publishing Company.

11. Rand Engineering, *Ask the Engineer: Heating Plant Upgrades,* 2004. (Last accessed March 1, 2005.) <http://www.randpc.com/AskTheEngineer/genAsktheEngineerHeating.asp>

12. Atlanta Gas Light Company, *Replacement Gas Boiler*, 2005. (Last accessed February 28, 2005.) <http://www.energydepot.com/aglc/library/newpages/gasboil.asp>

13. Solutions, N. S. E., *Monitor Condensing Boilers for Homeowners,* 2003. (Last accessed February 28, 2005.) <http://www.savemoreonheat.com/residential_products/default.asp>

14. Gas Research Institute, *Assessment of Technology for Improving the Efficiency of Residential Gas Furnaces and Boilers, Volume 1,* 1994. Gas Research Institute. Report No. GRI-94/0175.1.

15. The Life Expectancy/Replacement Picture. *Appliance Magazine*, 2001. 58(9)

16. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets,* 1993. Washington, DC Vol. 1 of 3. Report No. DOE/EE-0009.

17. The Federal Reserve Board, *Survey of Consumer Finances (SCF),* 1989-2004. (Last accessed December 10, 2006.) <http://www.federalreserve.gov/pubs/oss/oss2/scfindex.html>

18. National Bureau of Economic Research, *U.S. Federal and State Average Marginal Income Tax Rates,* 2006. (Last accessed October 10, 2006.) <http://www.nber.org/~taxsim/marginal-tax-rates/plusstate.html>

19. U.S. Department of Labor-Bureau of Labor Statistics, *Consumer Price Index,* 2007. <http://data.bls.gov>

20. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates. Instruments: CDs (secondary market). Maturity: 6-month. Frequency: Annual. Description: Average rate on 6-month negotiable certificates of deposit (secondary market), quoted on an investment basis.*, 2007. <http://www.bog.frb.fed.us/releases/H15/data.htm>

21. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates. Instruments: State and local bonds. Maturity: 20-year. Frequency: Monthly. Description: Bond buyer go 20-bond municipal bond index.*, 2007. <http://www.bog.frb.fed.us/releases/H15/data.htm>

22. The Federal Reserve Board, *Federal Reserve Statistical Release, Selected Interest Rates. Instruments: Corporate bonds/Moody's Seasoned AAA. Maturity: 20-year. Frequency: Annual. Description: Moody's yield on seasoned corporate bonds-all industries, AAA.*, 2007. <http://www.bog.frb.fed.us/releases/H15/data.htm>

23. Golden West Financial Corporation (GDW), *Cost of Savings Index*, 2007. (Last accessed February 10, 2007.) <http://mortgage-x.com/general/indexes/default.asp>

24. Damodaran, A., *Damodaran Online: The Data Page*, 2007. Stern School of Business at New York University. (Last accessed February 10, 2007.) <http://pages.stern.nyu.edu/~adamodar/>

25. Gas Appliance Manufacturers Association (GAMA), Updated Shipment Data for Residential Furnaces and Boilers, *personal communication.* April 25, 2005.

26. Department Of Energy, 10 CFR Part 431 Energy Efficiency Program for Commercial and Industrial Equipment: Efficiency Standards for Commercial Heating, Air Conditioning and Water Heating Equipment; Final Rule. *Federal Register*, 2001. 66(9): pp. 3336-3356