CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

To determine whether an energy efficiency standard is economically justified, EPCA directs DOE to consider the economic impact of potential standards on consumers. To address that impact, the Department calculated changes in equipment life-cycle cost (LCC) for consumers that are likely to result from each candidate standard, as well as payback periods (PBP). The effects of standards on individual consumers include changes in operating expenses (usually lower) and changes in total installed cost (usually higher). The Department 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 chosen in the absence of standards.

The PBP represents the number of years of operation required to achieve savings sufficient enough 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 annual operating cost from increased efficiency.

The Department performed the calculations discussed in this chapter using a series of Microsoft Excel spreadsheets, which are available on the Internet.

8.1.1 General Approach

The goal of the LCC analysis is to calculate the LCC for representative equipment in houses that are representative of the segment of the U.S. population that is buying furnaces and boilers. The key inputs to the calculation of LCC are installation cost, operating cost, discount rate, and equipment lifetime.

The calculation of LCC is done for a representative sample of houses, one house at a time, using appropriate values for the inputs each time. To account for uncertainty and variability in specific inputs such as lifetime and discount rate, DOE used a distribution of values with probabilities attached to each value. For each house, DOE sampled values of these inputs from the probability distributions. As a result, the analysis produced a range of LCCs. 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.

The Department based the payback period calculations in the engineering analysis on the DOE test procedure. The test procedure uses specific, prescribed values to calculate annual energy consumption. At the time the test procedure was written, these values were considered to be relatively typical of conditions in U.S. homes. In contrast, the LCC analysis estimates furnace and boiler energy consumption under field conditions for a sample of houses that is representative of U.S. homes. These conditions include outdoor climate during the heating and cooling season which influence the operating hours of the equipment.

For each product class, the LCC Analysis considers design options for all candidate standard efficiency levels, as well as for the maximum-efficiency technology available.

To estimate the impact of improved efficiency across a wide range of households that use furnaces and boilers, DOE selected a sample of households from the 1997 Residential Energy Consumption Survey (RECS97).[1] For each sampled household, DOE estimated the energy consumption of furnaces or boilers, incorporating: (1) baseline model design characteristics, and (2) design options that yield higher efficiencies (see Chapter 7: Energy Consumption of Furnaces and Boilers). For each sample household, DOE calculated the LCC for that household's furnace or boiler at a range of efficiency levels.

To account for the uncertainty and variability in the inputs to the LCC calculation for a given household and between different households, the Department 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. For some variables, such as energy price and climate, each calculation used the values associated with RECS house. For these variables, the RECS houses were sampled according to the weighting assigned to them by the Energy Information Administration (EIA).[a] This weighting was designed to reflect the prevalence of various features in the national population of houses. Sampling according to the weighting means that some of the RECS houses are sampled more than once, and others may not be sampled at all.

The Department used Microsoft Excel spreadsheets with Crystal Ball, an add-on software,[b] to perform the Monte Carlo analysis. Due to the use of the RECS houses in a Monte Carlo simulation, the values displayed and calculated in the spreadsheet do not represent average values.

The Department conducted LCC analyses for:

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[a] (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.)

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

- Non-weatherized gas furnaces,
- Weatherized gas furnaces,
- Mobile home gas furnaces,
- Oil-fired furnaces,
- Hot-water gas boilers, and
- Hot-water oil-fired boilers.

The inputs to the LCC allow calculation of the first cost of the equipment and the operating cost over the equipment lifetime. The inputs to the PBP calculation are the total installed cost of the equipment to the customer and the annual operating expenditures in the first year in which new standards would take effect. Since the PBP is a "simple" payback, energy prices are required only for the year in which a new standard is to take effect—in this case, the year 2012. The energy prices that DOE used in the PBP calculation were the prices projected for 2012. Section 8.2 discusses each of the inputs further.

8.2 METHOD

Life-cycle cost consists of two main components: (1) the first cost of buying and installing a furnace or boiler (in 2001$), and (2) the annual operating costs over the lifetime of the equipment, discounted to the present (2001).

$$\text{LCC} = \text{total installed cost} + \sum_{n=1}^{lifetime} \frac{operating\ cost\,t}{(1+discount\ rate)^n}$$

The change in LCC resulting from a change to higher-efficiency equipment is calculated relative to the equipment a house would have in the absence of any change in standards. For the LCC analysis, the Department used the current distribution of efficiencies in shipments for the year 2000 as the base case forecast. Thus, some houses already have higher-efficiency furnaces, while others have furnaces at the minimum efficiency currently allowed.

8.2.1 Design Options

The Department calculated the LCC and PBP of furnaces and boilers incorporating a variety of design options that improve efficiency. Figures 8.2.1–8.2.6 show the design options that DOE analyzed for each product class. The design options in the lightly-shaded blocks are related to electricity efficiency; they are not considered further in the LCC analysis. Results for the electricity efficiency design options are presented in Appendix 8.5. The center trunk of the flow chart, shown in the heavily-lined boxes, shows the efficiency-level improvements as indicated by AFUE. The baseline model efficiency level occupies the bottom position on the flow chart. Branches off the efficiency level improvements indicate either design options to reduce electricity use or modulating designs, or both. Moving up the center trunk, the increased efficiency levels build on previous design changes. For example, the heat-exchanger area (Increase HX area) is incrementally bigger for each efficiency improvement for non-weatherized gas furnaces.

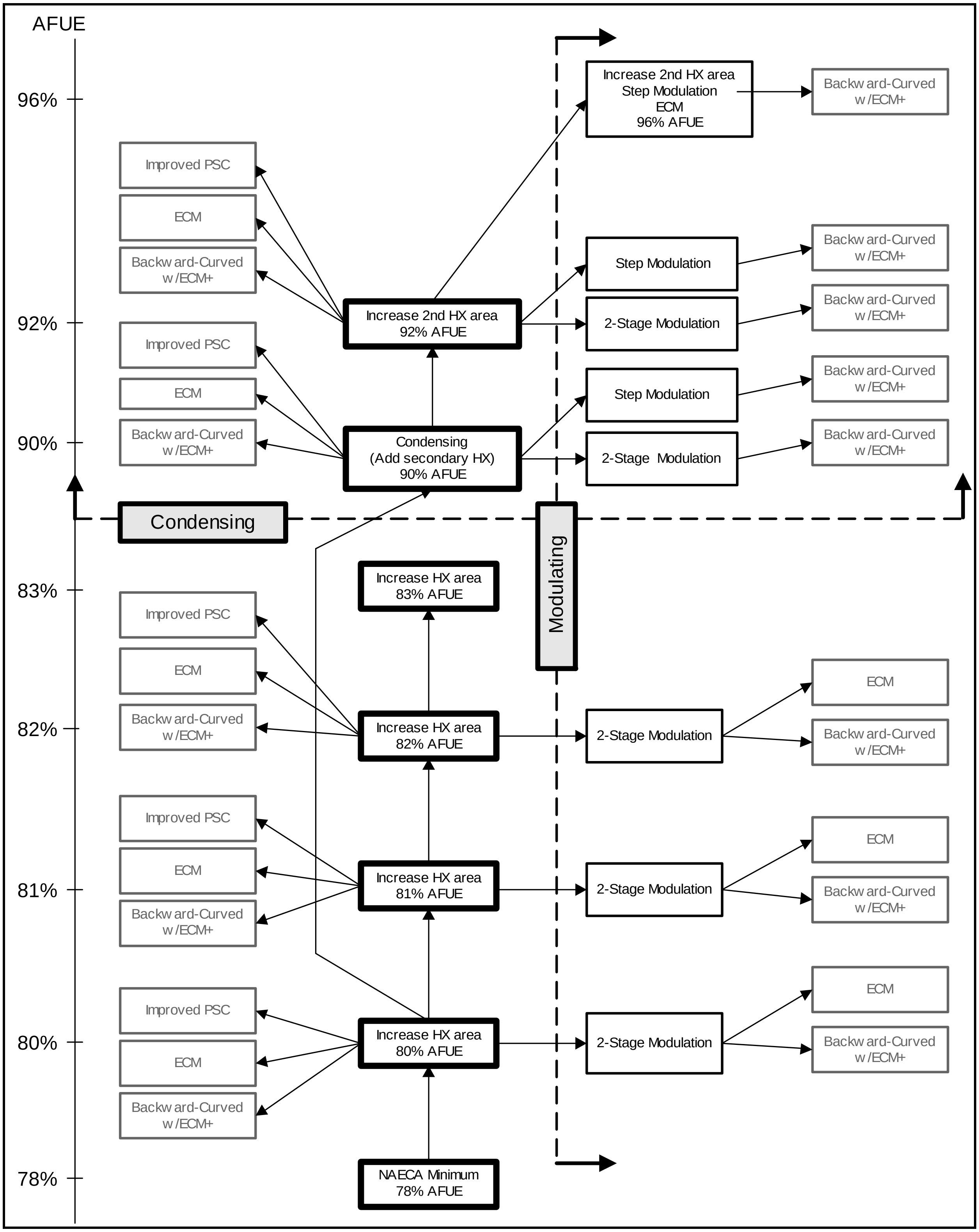

Figure 8.2.1 Non-Weathered Gas Furnace LCC Analysis–Efficiency Levels and Design Options

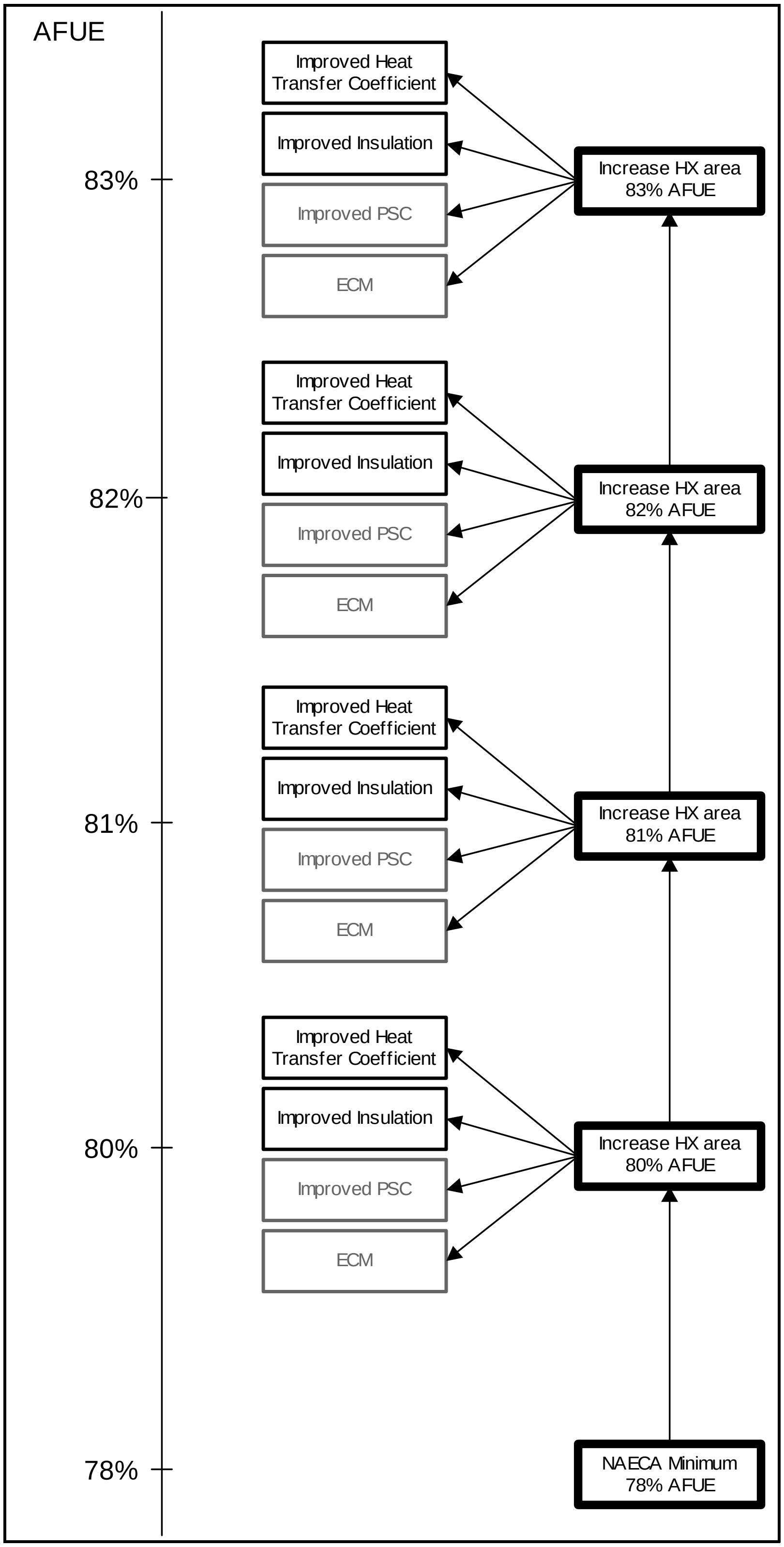

Figure 8.2.2 Weatherized Gas Furnace LCC Analysis–Efficiency Levels and Design Options

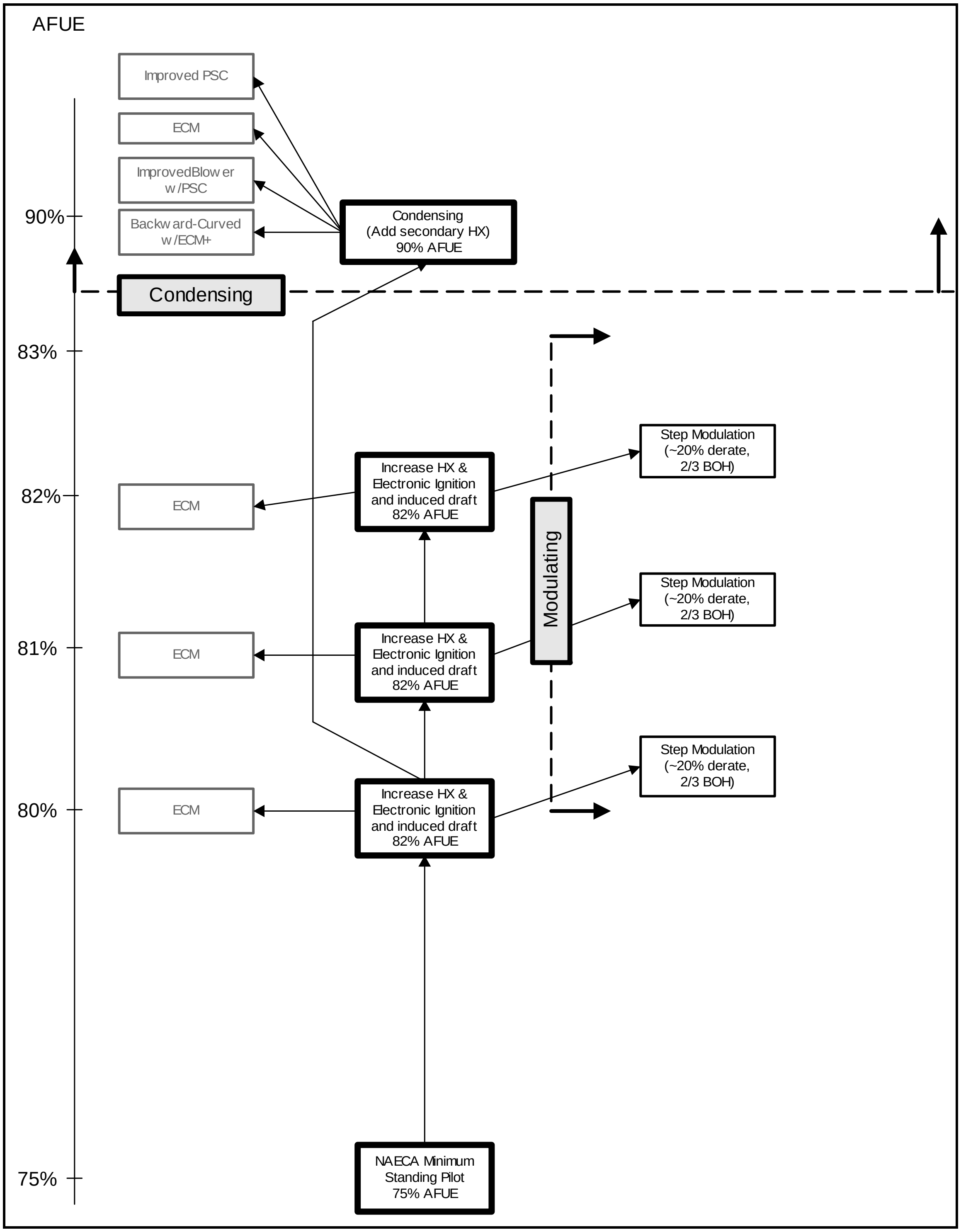

Figure 8.2.3 Mobile Home Gas Furnace LCC Analysis–Efficiency Levels and Design Options

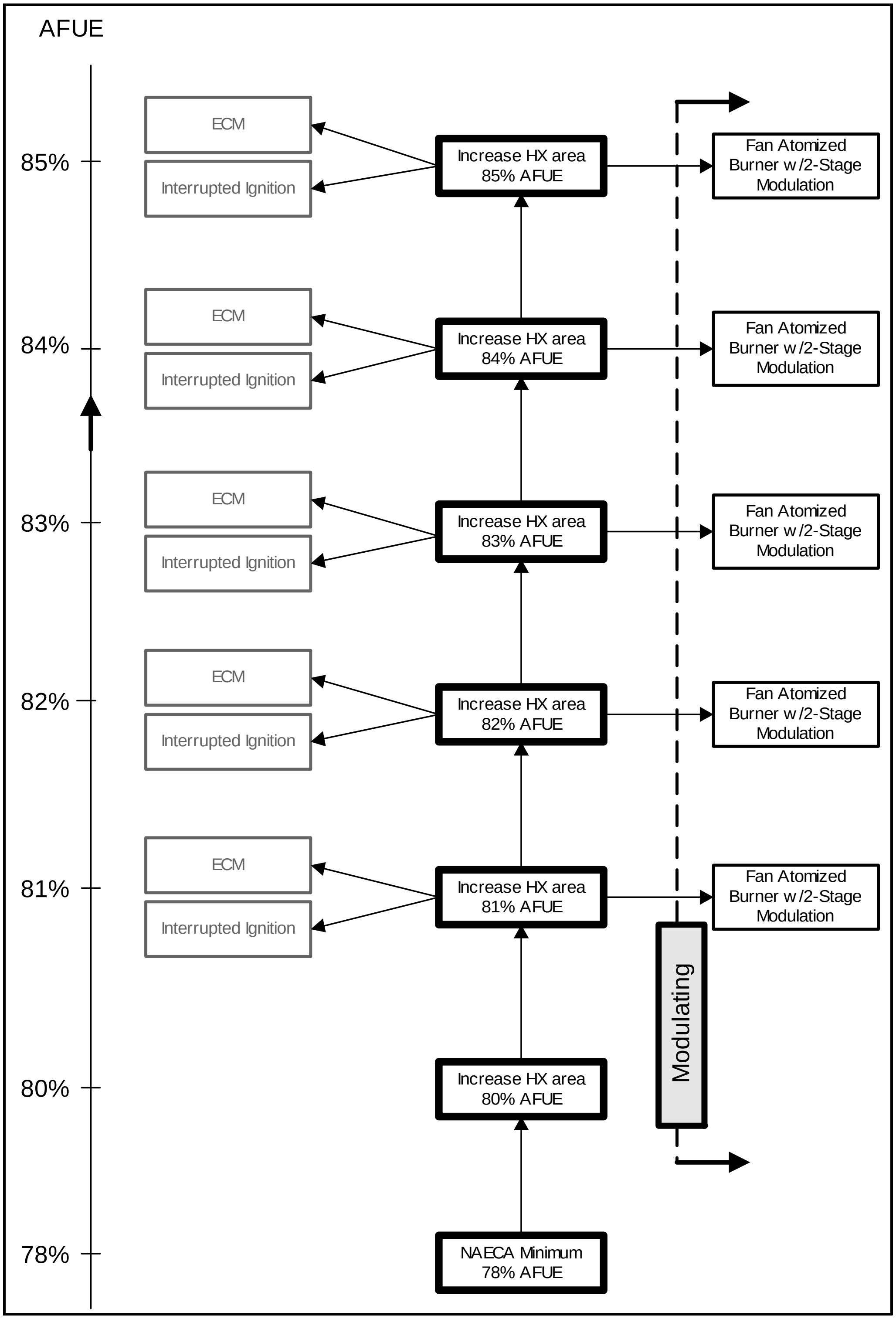

Figure 8.2.4 Oil Furnace LCC Analysis–Efficiency Levels and Design Options

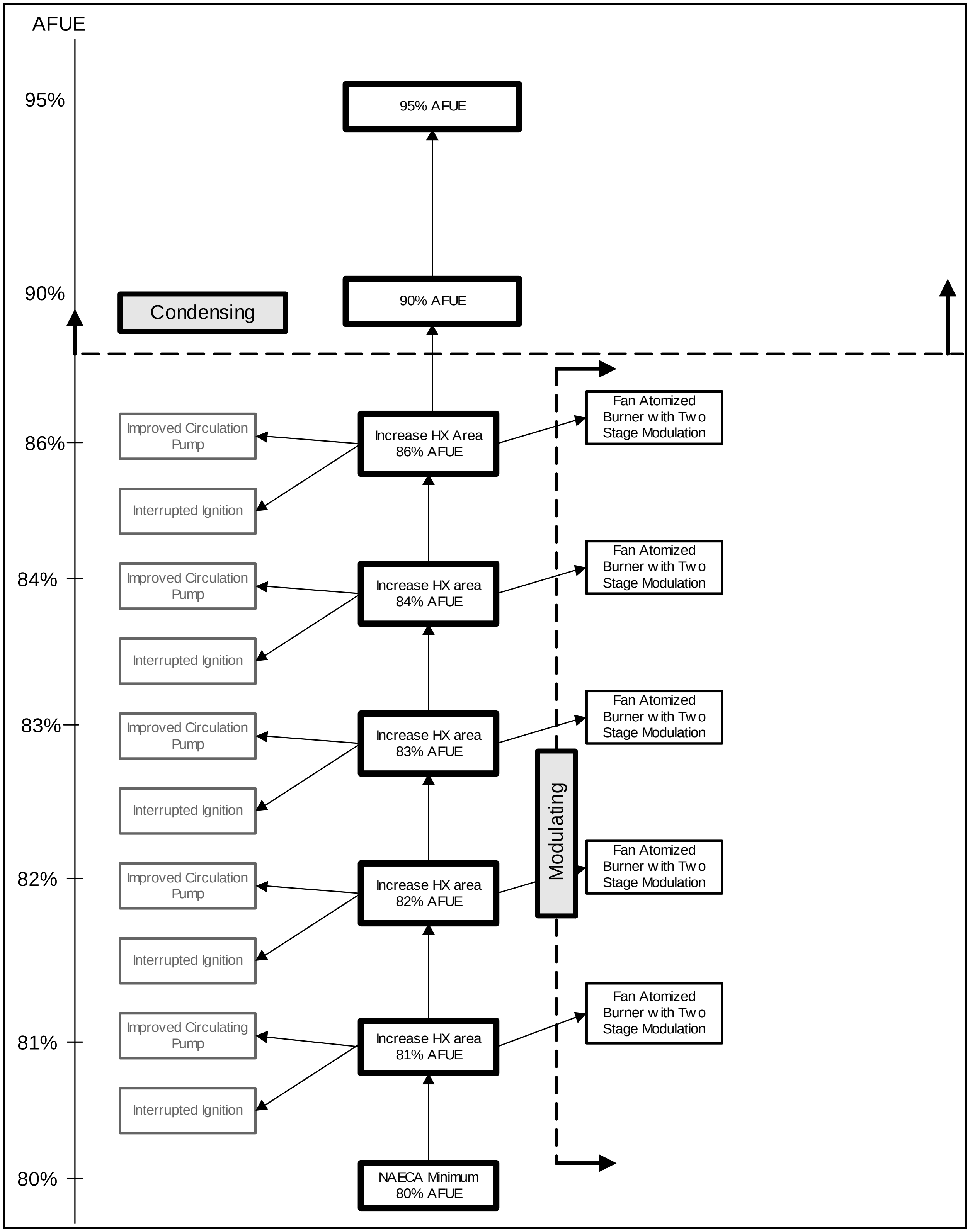

Figure 8.2.5 Hot-Water Oil Boiler LCC Analysis–Efficiency Levels and Design Options

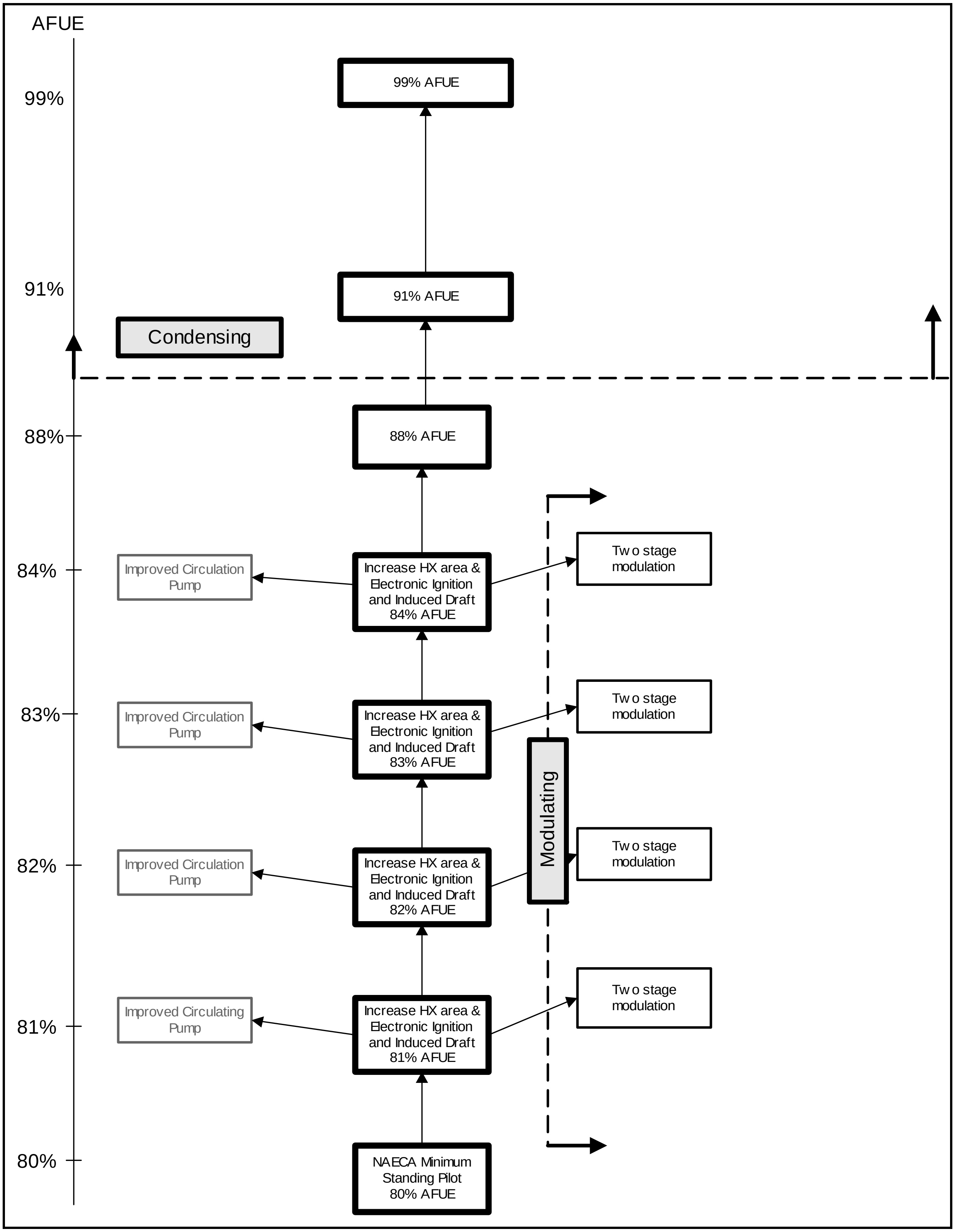

Figure 8.2.6 Hot-Water Gas Boiler LCC Analysis–Efficiency Levels and Design Options

8.2.2 Data Set for Calculating LCCs

For the LCC analysis, the Department used a subset of records from the complete RECS97 data set that met all of the following criteria:

1) Use central heating equipment,
2) Use a boiler or furnace as the main source of heat,
3) Use a heating fuel that is natural gas, liquefied petroleum gas (LPG), or fuel oil, and
4) Heat only one housing unit.

The reason for the forth criterion is that the Department assumed any furnaces heating more than one unit would be larger than a residential furnace.

Of the 5900 houses surveyed in RECS97, 2313 housing records (38.5 percent of the total weighted sample) had central, forced-air furnaces and met the above criteria; 560 housing records (8.5 percent of the weighted sample) had boilers and met the above criteria. The residential furnace and boiler subset thus represents 47 percent of the total houses in the United States (see Appendix 8.1).

The Department divided the RECS sample by product classes, using different classification algorithms based on fuel type, home type, (the presence of) central air conditioning, etc. (Table 8.2.1). The Department further divided the households with non-weatherized gas furnaces by census division and the four most populous states.

Table 8.2.1 Criteria for Selection of RECS Household Data by Product Class

Product Class	Algorithm	# of Records	# of US Households Represented (million)
Non-Weatherized Gas Furnace	Central heating equipment = furnace Heating fuel = gas Home type = single or multi-family Number of Housing Units Heated = 1	1986	37.3
Weatherized* Gas Furnace	Central heating equipment = furnace Heating fuel = gas Central air conditioning = yes (packaged unit) Home type = single or multi-family Number of Housing Units Heated = 1 Census Division = West or East South Central Large State = California, Florida or Texas	396	7.2
Mobile Home Gas Furnace	Central heating equipment = furnace Heating fuel = gas Home type = mobile home Number of Housing Units Heated = 1 House Vintage = after 1976**	90	1.4
Oil-Fired Furnace	Central heating equipment = furnace Heating fuel = oil Home type = single or multi-family Number of Housing Units Heated = 1	237	2.7
Gas Hot-Water Boiler†	Central heating equipment = boiler Heating fuel = gas Home type = single or multi-family Number of Housing Units Heated = 1	315	5.2
Oil Hot-Water Boiler	Central heating equipment = boiler Heating fuel = oil Home type = single or multi-family Number of Housing Units Heated = 1	245	3.4

* Some of the same housing records are used for analyzing both weatherized and non-weatherized furnace product classes, because equipment placement with respect to the building is not given in RECS97. To analyze weatherized furnaces, DOE looked at the subset of housing records that had gas furnaces and central air conditioners, and were located in the West South Central, or East South Central Census divisions, or in the states of California, Florida, or Texas.

** Federal regulation regarding mobile housing construction changed the quality of the structures manufactured after this year.

† Because RECS does not distinguish between steam and hot-water boilers, DOE assumed for the purposes of this analysis that all boilers in RECS are hot-water boilers. Hot-water boilers comprise 84 percent of gas boiler shipments and 88 percent of oil-fired boiler shipments.[2]

8.2.2.1 New Construction versus Replacement Installations

The Department treated a furnace or boiler in a new home differently from one purchased as replacement equipment, for three reasons:

1) Heating-equipment prices are different for new construction and retrofit applications. Equipment cost for new construction includes a builder markup and does not include sales tax. Equipment cost for replacement installations includes sales tax and does not include a builder markup.
2) The financing method (and therefore the discount rate in the LCC calculation) for new construction is usually a mortgage loan. Financing methods for replacement installations can take a variety of forms—e.g., cash, credit cards, home equity loans—that have different interest rates.
3) New construction tends to be built with more insulation and more energy-efficient products, compared to houses that receive replacement installations. New construction is also concentrated in certain parts of the country.

The share of equipment shipped to new construction varies depending on the product class. Table 8.2.2 shows what criteria the Department used to determine which housing records it treated as new construction.

The Department estimated that 26 percent of non-weatherized gas furnaces go to new construction. It arrived at this figure by multiplying the number of housing starts in 1999 (1,604,000)[3] by the proportion of new houses with gas furnaces (51.2 percent),[4] and then dividing by the total gas furnace shipments in 1999 (3,126,147).[5] The vast majority of boilers and oil-fired furnaces are sold for replacement; DOE analyzed all oil-fired furnaces, gas boilers, and oil-fired boilers as replacements. The Department assumed that all mobile home gas furnaces were sold in new construction. Insufficient data were available about the replacement market for mobile home gas furnaces.

The Department divided the RECS sample houses into two subsets— new construction or replacement. The Department assigned those houses constructed in the five-year period prior to the RECS survey to the new construction subset, and houses built prior to 1992 to the replacement installation subset. The Monte Carlo analysis sampled 26 percent of the iterations from the new construction subset and 74 percent from the replacement installation subset. The analysis sampled markups and discount rates from the appropriate distributions, depending on whether the sample house was drawn from the new construction or replacement subsets.

Table 8.2.2 New Construction Share by Product Class for Residential Furnaces and Boilers

Product Class	New Construction Subset Criterion	% of Total Class Shipment
Non-weatherized Gas Furnace	Houses constructed in the 5-year period 1992-1997.	26%
Weatherized Gas Furnace	Houses constructed in the 5-year period 1992-1997.	26%
Mobile Home Gas Furnace	Houses constructed in the 10-year period 1986-1997.	100%
Oil-Fired Furnace	DOE assumed that no new construction receives oil-fired furnaces.	0%
Hot-Water Gas Boiler	DOE assumed that no new construction receives gas boilers.	0%
Hot-Water Oil Boiler	DOE assumed that no new construction receives oil-fired boilers.	0%

8.3 INPUTS

8.3.1 First-Cost Inputs

The flow chart in Figure 8.3.1 represents the inputs for first cost. The chart represents both baseline model and higher-efficiency equipment; however, the markups differ for these two types of equipment. The chart shown represents non-weatherized gas furnaces; other product classes differ slightly.

One of the key factors determining first cost is equipment size. The Department chose typical sizes of heating equipment that appear in US households (see Chapter 7, Energy Consumption of Furnaces and Boilers, for more details). The Department then determined model manufacturing cost, using a reverse-engineering cost analysis and applied markups for each point along the distribution chain (see Chapter 5, Markups for equipment price determination, and Chapter 6, Engineering Analysis). The markup that DOE applied depended on the type of installation (i.e., in new construction or replacement). Installation costs are the final component of first cost.

The size of the equipment, the type of installation, and the installation costs depend on the households for which the equipment is bought. Characteristics listed in the RECS data set enabled DOE to make reasonable assumptions about these factors for each household in the analysis.

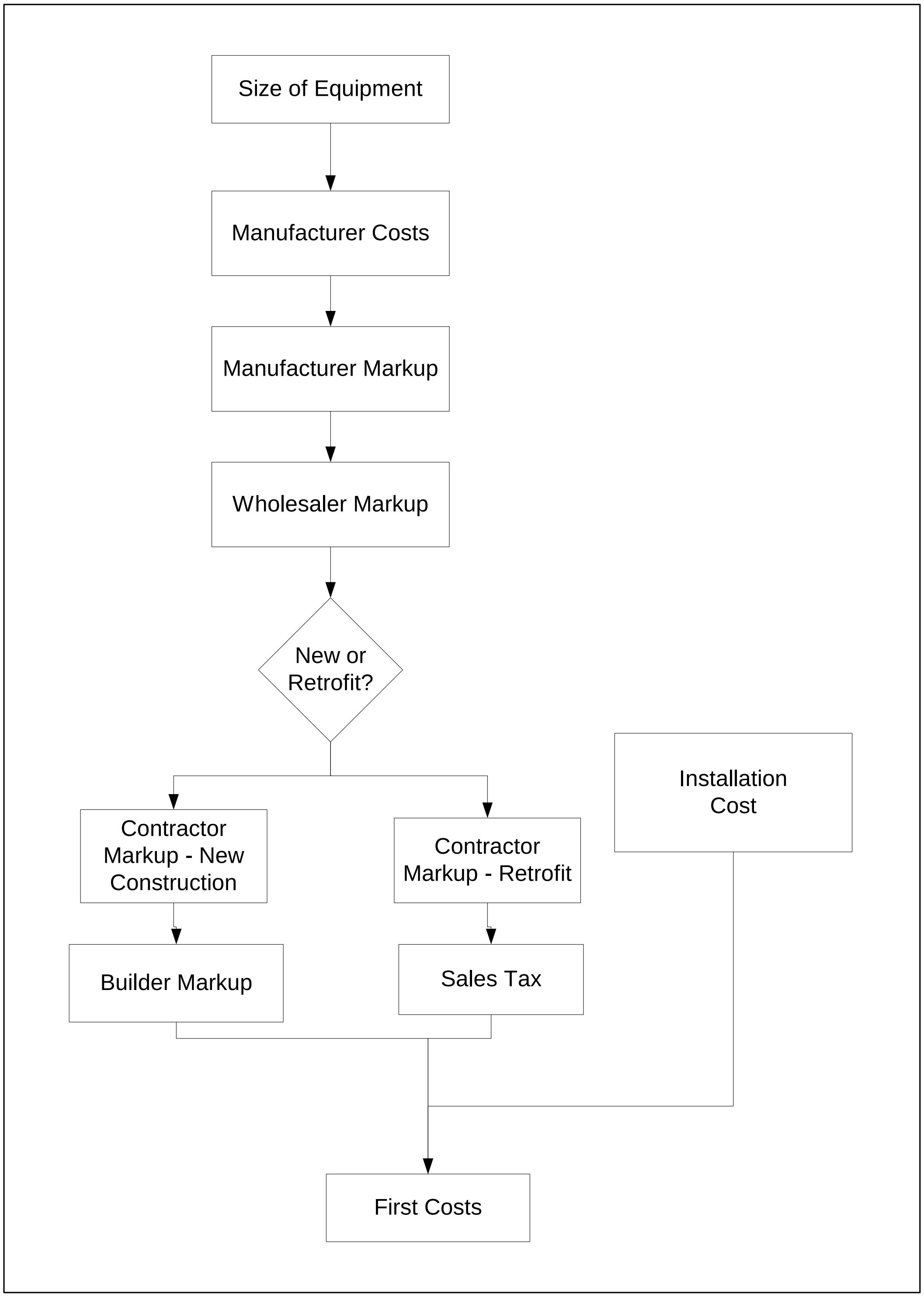

Figure 8.3.1 First Cost for Non-Weatherized Gas Furnaces

8.3.1.1 Manufacturing Cost

The Department determined manufacturing costs using a reverse-engineering cost analysis for one size of equipment for each product class. To derive the manufacturing costs for other sizes of furnaces and boilers, DOE scaled the reverse-engineered model costs. See Chapter 6, Engineering Analysis, for a description of the reverse-engineering cost analysis.

Non-Weatherized Gas Furnace. To represent the majority of combinations of input capacity and nominal maximum airflow, the Department chose virtual models to represent 26 different combinations of those two variables. Each virtual model had its own cost and energy characteristics. (See Chapter 7, Energy Consumption of Furnaces and Boilers, for more details about virtual models.) To develop the cost for each virtual model, DOE reverse-engineered one model size (input capacity = 75kBTU/h and airflow capacity = 3 tons) and assigned costs for the different components. The Department scaled the cost for other input capacities from the basic model cost for both non-condensing and condensing models. A cost adder included adjusted costs for furnaces of different maximum nominal airflow capacity. The virtual models include models with the most commonly occurring input capacities (*Qin*), with corresponding maximum nominal airflow rates at 0.5 inches water gauge. Figure 8.3.2 shows manufacturing costs by input capacity and airflow capacity for baseline model non-weatherized gas furnaces. The scalars that DOE used to adjust the cost from 75kBTU/h are found in the bottom row. Airflow capacity adders are in the left column.

	Input Capacity (kBTU/h)											
	45	50	60	70	75	80	90	100	115	120	125	140
800 CFM (2 tons) (-$9.79)	307.65	311.06	319.59									
1200 CFM (3 tons) ($0.00)	317.44	320.85	329.38	337.92	341.33	346.45	356.69	366.93				
1600 CFM (4 tons) ($5.79)				343.71	347.12	352.24	362.48	372.72	388.08	393.20	398.32	
2000 CFM (5 tons) ($14.82)						361.27	371.51	381.75	397.11	402.23	407.35	422.71
Cost Scalars	0.93	0.94	0.965	0.99	1	1.015	1.045	1.075	1.12	1.135	1.15	1.195

Figure 8.3.2 Manufacturing Costs ($) for Baseline Model Non-Weatherized Furnaces by Input Capacity and Airflow Capacity

Other Product Classes. In its analysis of weatherized gas furnaces, DOE used the same virtual models as it used in the analysis of non-weatherized gas furnaces. For mobile home furnaces and oil-fired furnaces, the Department used a subset of the 25 virtual furnace models, because the market in those product classes is limited to a smaller number of sizes of furnaces. The Department used the sizes of the generic models for non-weatherized gas furnaces, weighted to match the boiler sizes in the shipments data from Gas Appliance Manufacturers Association (GAMA).[6]

For weatherized gas furnaces, mobile home furnaces, and oil-fired furnaces, DOE scaled the cost for input sizes from the basic model cost for both non-condensing and condensing models. Table 8.3.1 shows the cost scalars that DOE used. The Department developed these scalars as part of the manufacturing cost estimates. It used the same cost scalers for boilers.

Table 8.3.1 Manufacturing Cost Scalars for Furnaces

Input Capacity (kBtu)	AFUE < 90%	AFUE ≥ 90%
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

8.3.1.2 Installation Cost

The installation cost is the cost to the consumer of installing a furnace or a boiler; in this analysis it is not considered part of the retail price. The cost of installation covers all labor associated with the installation of a new unit or the replacement of an existing one. This includes costs of changes to the house, such as venting modifications, that would be required for the correct installation of the equipment.

Chapter 6, Engineering Analysis, describes the approach for estimating installation costs. For the LCC analysis, DOE assigned each household an installation cost from a distribution of weighted average values. For non-weatherized gas furnaces, oil-fired furnaces, and gas and oil boilers, the distribution was calculated with the Installation Model. For weatherized gas furnaces, DOE used calculations based on the RS Means approach to calculate a mean value, and assigned a triangular distribution of ±15 percent around the mean. For mobile home furnaces, because they are installed at the mobile home factory, the installation cost is included in the markup.

For non-weatherized gas furnaces, DOE calculated LCCs using each of the three sets of installation cost data described in Chapter 6: the Installation Model, Gas Research Institute (GRI), and Natural Resources Canada (NRCan). For gas boilers, DOE calculated LCCs using the Installation Model and GRI costs. In both cases, DOE considered the costs from the Installation Model as default values, and the LCC results calculated with these costs are presented in section 8.4 below. Alternative installation costs were not available for the other product classes.

The GRI costs are generally higher than the Installation Model costs, while the NRCan costs are lower. They represent alternative costs that bound the potential range of installation costs. Appendix 8.3 presents the LCC results for non-weatherized gas furnaces and gas boilers using the alternative installation costs. For the GRI data set, DOE used the distribution of values provided in the GRI report. For the NRCan data set, which provided mean values, DOE assigned a triangular distribution of ±15 percent around the mean.

8.3.1.3 Finance Costs

Many consumers purchase heating equipment with some type of financing. Calculations of the value of payments made over time should be discounted. The present value of the payments for consumers purchasing equipment over time is exactly the value of the equipment payments as if paid all at once. The discount rate section (8.3.4) discusses the assumptions regarding selection of methods of financing for furnaces and boilers. Because of this, DOE sampled discount rates from various types of financing methods available to consumers for furnaces and boilers.

8.3.2 Operating-Cost Inputs

Operating cost consists of energy and maintenance costs. The energy cost consists of separate costs for natural gas or oil, and electricity. Electricity is used for blower fans shared by furnaces and air conditioners, and by other electrical components in fossil-fueled furnaces and boilers. The Department's energy consumption calculations and results are presented in Chapter 7, Energy Consumption of Furnaces and Boilers.

8.3.2.1 Energy Prices

For all classes of gas equipment, the Department used the average energy price for each house to calculate the energy costs of base case equipment. It used marginal energy prices determined for each house 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. 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.

For oil-fired furnaces and boilers, the Department used the average oil prices for each house for both base case forecast equipment and higher-efficiency equipment, as the data necessary for estimating marginal prices were not available. The Department used the same method for LPG-fired equipment.

The LCC analysis requires information on the price of natural gas or heating oil during the winter, as well as the price of electricity used by electrical components. A furnace fan operates during the heating season and the cooling season. Since electricity prices vary by season in much of the country, DOE used different winter and summer electricity prices. Boilers generally are not operated during the summer months and, therefore, do not use electricity in the summer.

Calculating Energy Prices for RECS Households in 1998. The Department calculated average and marginal energy prices for each sample house in 1998 using RECS data. Along with RECS household data, EIA collects billing data (for up to 16 billing cycles) for a subset of households in the total RECS sample (see Figure 8.3.3). 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.

The Department estimated marginal energy prices from the RECS monthly billing data by calculating linear regression of monthly customer bills to monthly customer energy consumption for each household for which billing data were available (see Figure 8.3.4). The Department interpreted the slope of the regression line for each household as the marginal energy price for that household for the season in question.[7]

To derive seasonal electricity prices, DOE divided the electricity billing data into summer and the rest of the year (non-summer). The Department considered a bill to be a summer bill if the midpoint of its billing period was in the four-month period from June 1 to September 30. The

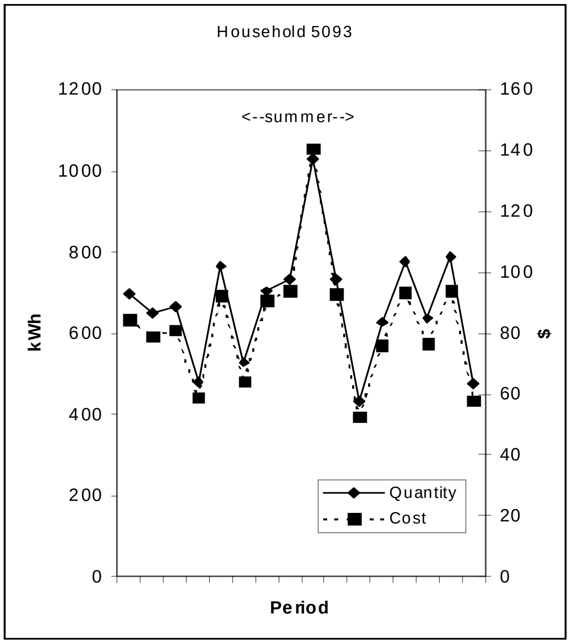

Figure 8.3.3 Example RECS97 Household: Billing Data

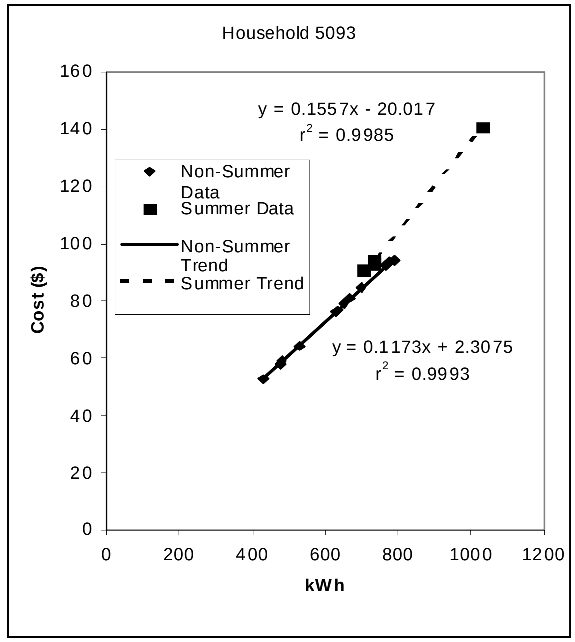

Figure 8.3.4 Example RECS97 Household: Regression Lines, Slopes

Department estimated the marginal electricity price for each season to be equal to the slope of the regression line for the billing data for that season.[a]

The Department divided the natural gas billing data into two seasons: winter and the rest of the year. The Department considered a bill to be a winter bill if the midpoint of its billing period was in the four-month period from November 1 to February 28. Using the same r^2 cutoffs for the seasonal gas price regressions as for the electricity price regressions, the Department rejected 10 percent of the household gas billing data. Using these criteria, 2317 households with gas billing data had acceptable marginal price slopes; 66 percent of those households had acceptable seasonal data. The Department estimated annual marginal gas prices for the other 34 percent of the households in the same manner as it had for electricity prices.

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[a] While the "r^2" values for the regressions of RECS electricity bills were generally very high, DOE eliminated some outliers by rejecting slopes (marginal prices) where the linear regression had an r^2 value less than 0.90 for either the summer or the non-summer. When acceptable slopes were not available for either season, DOE used the slope for the regression of all of the available billing cycles (unless the r^2 value of the annualized slope was also less than 0.90). Based on this methodology, DOE rejected 8 percent of the household electricity billing data. Using these criteria, 4396 households with electricity billing data had acceptable marginal price slopes; 79 percent of those households had acceptable seasonal data. For the remaining 21 percent of the households where both seasons did not have regression-line slopes with r^2 values greater than 0.90, DOE used all of the monthly billing periods in combined form to estimate an annual marginal price.

For each household sampled from the RECS database, DOE identified the average electricity and gas prices—either from that household's data, if available, or from another nearby household. For the RECS subset used in this LCC analysis, DOE used 1740 housing records (of the 2317 housing records with natural gas price data and 2269 housing records with electricity price data).

The Department calculated annual average LPG prices with data for RECS97 houses with LPG-fired equipment. Monthly data necessary to calculate marginal prices were not available for households using LPG heating. The same method was used for houses with oil-fired equipment.

Projecting 1998 Prices to 2012 and Beyond. As in past rulemakings, the Department used price forecasts by the EIA to estimate the trend in natural gas, oil, and electricity prices. It multiplied the average and marginal prices for 1998 of each sampled house by the forecast annual price changes in EIA's *Annual Energy Outlook 2003* (*AEO 2003*)[8] to arrive at prices in 2012 and beyond. The Department calculated LCC and PBP using three separate projections from *AEO2003*: 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. Appendix 8.4 presents the LCC results for High Growth and Low Growth price projections for residential natural gas, fuel oil, and electricity. The Department used the same method to forecast LPG prices.

8.3.2.2 Maintenance 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. As discussed there, DOE developed several groups of maintenance costs, according to the Annual Fuel Utilization Efficiency (AFUE), for most of the product classes.

For the LCC analysis, DOE assumed a triangular distribution for maintenance costs to capture the variability of these costs. The Department was not aware of any reliable data that provide a distribution of maintenance costs. It assumed a minimum and maximum of 15 percent of the average cost.

8.3.3 Lifetime

The lifetime is the age at which furnaces or boilers are retired from service. Table 8.3.2 shows the lifetime range for the six product classes.

Table 8.3.2 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‡	13	17	22
Hot-Water Oil-Fired Boiler‡	12	15	19

* Appliance Magazine[9]
† Mobile Home Technical Support Document, 1993[10]
‡ GRI, 1990

8.3.4 Discount Rates

8.3.4.1 Approach for Estimating Discount Rates

The Department derived the discount rates for the LCC analysis from estimates of the interest or "finance cost" to purchase furnaces or boilers. Following financial theory, the finance cost of raising funds to purchase furnaces or boilers can be interpreted as: (1) the financial cost of any debt incurred to purchase equipment, principally interest charges on debt, or (2) the opportunity cost of any equity used to purchase equipment, principally interest earnings on household equity.

The purchase of equipment for new homes entails different finance costs for consumers than does purchase of replacement equipment. Thus, the Department used different discount rates corresponding to the finance cost of new construction and replacement installations.

8.3.4.2 Discount Rate Applied to New Housing Equipment

The Department estimated discount rates for new-housing equipment based on mortgage interest rate data provided in the Federal Reserve Boards' *Survey of Consumer Finances (SCF).* This survey indicates that mortgage rates carried by homeowners in 1998 averaged 7.9 percent.[11] After adjusting for inflation and interest tax deduction, real after-tax interest rates on mortgages averaged 4.2 percent and ranged from -1.6 percent to 12.8 percent. The Department used a 28 percent marginal income tax rate and 1.56 percent price inflation. (The median U.S. household income in 2000 was $43,162.[12] The marginal income tax of heads of households with this income is 27.5 percent.[13] The Department rounded 27.5 percent to 28 percent for this analysis. Price inflation reflects the change in the consumer price index (CPI) in 1998.)

8.3.4.3 Discount Rate Applied to Replacement Equipment

For equipment purchased to replace old or failed equipment where cash or some form of credit is used to finance the acquisition, it is appropriate to establish how the purchase affects a consumer's overall household financial situation. For example, even though the purchase might be financed through a dealer loan or some other short-term financing vehicle, the more probable effect of the purchase is to cause the consumer either to incur additional credit card debt or to forego investment in some type of savings-related asset. Cash that was once available to either pay for household expenses or to invest in an asset like the stock market or a savings account now must be earmarked to pay off the equipment purchase, thus causing the consumer to incur additional credit card debt or to lose the opportunity to earn income from assets.

The Department estimated the average household equity and debt portfolio from 1995 and 1998 SCF data. The Department estimated interest or return rates associated with each type of equity and debt from a variety of sources. Rates for second mortgages and credit cards are from 1998 SCF data. The Department estimated interest rates associated with household certificates of deposit (CDs), treasury bills (T-bills), and corporate bonds as an average of the Federal Reserve Board time-series data covering 1977–2001.[14] Based on relative returns to less-liquid assets, the Department assumed that the interest rate on transactions (checking) accounts averages 2 percent real. The midpoint of the transactions account distribution is 2 percent. The 2 percent figure is based on an analysis of returns to money-market accounts and savings accounts, and returns to CD and bond holdings. The Department estimated annual return associated with household stock holdings as an average of data published by the Stern Business School covering the 1977–2001 period.[15] The Department estimated mutual fund rates as an average of the Standard and Poor's (S&P) 500 stock rate (67 percent) and the T-bill rate (33 percent).

Table 8.3.3 summarizes the average shares of household equity and debt based on the above sources and the real, after-tax interest rates associated with each type of equity or debt. The Department assumed a marginal tax rate of 28 percent and CPI inflation to derive real from nominal values. The weighted-average real, after-tax interest rate across all types of household debt and equity used to purchase replacement furnaces or boilers is 6.7 percent.

Table 8.3.3 After-Tax Real Interest or Return Rates for Household Debt and Equity Types

Type	Average Share of Household Debt plus Equity (%)	Rate Mean (%)
Second mortgage	3.0	5.9
Credit card and installment	9.1	12.0
Transaction (checking) accounts	20.0	2.0
CD (6-month)	7.9	2.8
Savings bonds (Treasury)	1.6	3.7
Bonds (Corporate AAA)	8.3	4.4
Stocks (S&P500)	30.2	9.6
Mutual funds	19.8	7.6
Total/Weighted-average discount rate	100	6.7

8.3.4.4 Accounting for Variation in Discount Rates

To account for variation in discount rates among consumers, DOE used a distribution of rates of interest or return on debt and equity among households. The data used to construct these distributions are provided in Appendix 8.2, where the figures show the distribution of nominal rates obtained from the data sources previously mentioned. The Department calculated the real, after-tax rates as described in sections 8.3.4.2 and 8.3.4.3. The interest-rate distribution for transactions accounts is assumed to be triangular and to range from 0 percent to 4 percent.

8.3.5 Payback Period Inputs

The data inputs to the PBP calculation are the 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 2012. The energy prices that DOE used in the PBP calculation were the prices projected for that year.

The payback period equation can be expressed as:

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

where *base* is the base case design, 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). The Department made the comparisons based on replacing the base case forecast 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.

8.3.6 Summary of Inputs

Table 8.3.4 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.
Installation Cost	Uses a distribution of weighted-average installation costs from the “Installation Model.” Installation configurations are weight-averaged by frequency of occurrence in the field, and vary by installation size. The Installation Model is RS Means-based, and comparable to available known data.
Maintenance Costs	Uses 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.
Annual Heating and Cooling Load	Heating and cooling loads calculated using 1997 RECS data. The furnace input capacity versus airflow capacity is assumed based on the vintage of the equipment and characteristics of each house.
Annual Energy Use	26 virtual models based on actual furnace characteristics capture the range of common furnace sizes. Energy calculations reflect actual house characteristics.
Energy Prices	1997 average and marginal energy prices are calculated for each house. AEO 2003 forecasts are used to estimate future average and marginal energy prices.
Lifetime	Uses Appliance Magazine survey results.
Discount Rate	Data from Survey of Consumer Finance and other sources were applied to estimate a discount rate for each house.

8.4 RESULTS

For each set of sample houses using equipment in a given product class, DOE calculated the average LCC savings and the median and average payback period for each of the design options and efficiency levels. The Department calculated LCC savings and payback period relative to the base case forecast equipment in each house. As mentioned above, the base case forecast (no new standards) assumes purchase of equipment reflecting current patterns with respect to efficiency. The Department sampled the efficiency (AFUE) of the base case forecast equipment assigned to each house from a distribution of AFUEs that is representative of shipments for the year 2000, and is correlated with climate. Therefore, the base case equipment is not limited to the baseline model. (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 some houses, the Department assigned furnaces that are more efficient than some of the design options. The Department assumed that a household would not replace higher-efficiency equipment with lower-efficiency equipment, and thus considered these as “no impact” cases, since they would not be affected.

The tables below present LCC and PBP results using the energy price forecast in the Reference case from *AEO2003*. Appendix 8.4 presents results using the energy price forecasts in the Low and High Economic Growth cases from *AEO2003*.

8.4.1 Non-Weatherized Gas Furnaces

Table 8.4.1 shows the LCC and payback results for non-weatherized gas furnaces. The 81 percent AFUE level using single-stage (8 percent of installations use Category III venting system) shows basically no change (-$3) in LCC impact. The 81 percent AFUE level using two-stage modulation (no Category III venting systems required) has a positive LCC savings of $72. The positive LCC savings for the 81 percent two-stage modulation design are due, in part, to it having lower energy consumption than the single-stage furnace of the same AFUE. To estimate the energy use of this furnace under field conditions, DOE adopted the assumptions for two-stage modulation that appear in the DOE test procedure (see Appendix 6.3 for discussion of the issues concerning use of these assumptions). The 90 percent AFUE condensing level has a negative LCC impact (-$154). The LCC and PBP results calculated using GRI and NRCan installation costs are presented in Appendix 8.3.

Table 8.4.1 LCC and PBP Results for Non-Weatherized Gas Furnaces Using Installation Model Costs

Design Option: AFUE	LCC					Payback	
	Average	**Average Savings**	**Net Cost**	**No Impact***	**Net Benefit**	**Median**	**Average****
	$	$	%	%	%	years	years
78%	$9,966						
80%	$9,795	$0	0%	99%	1%	2.1	37.8
80% 2-stage mod.	$9,718	$41	33%	27%	40%	8.6	13.5
81% single stage, 8% Cat. III	$9,789	-$3	32%	27%	41%	8.8	27.8
81% 2-stage Mod, no Cat. III	$9,680	$63	29%	26%	45%	7.6	17.0
82%	$10,170	-$292	70%	26%	4%	28.7	84.6
82% 2-stage Mod	$10,103	-$256	65%	26%	9%	18.5	60.2
83%	$10,400	-$468	73%	26%	1%	63.3	121.3
90%	$9,917	-$154	56%	26%	18%	17.9	42.5
92%Incr. HX Area	$9,924	-$166	60%	15%	25%	16.1	41.7
96% Step Mod ECM	$10,724	-$954	89%	2%	9%	32.3	88.9

* "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.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.4.1 shows the range of LCC savings for non-weatherized gas furnaces, using the Installation Model cost data. 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.

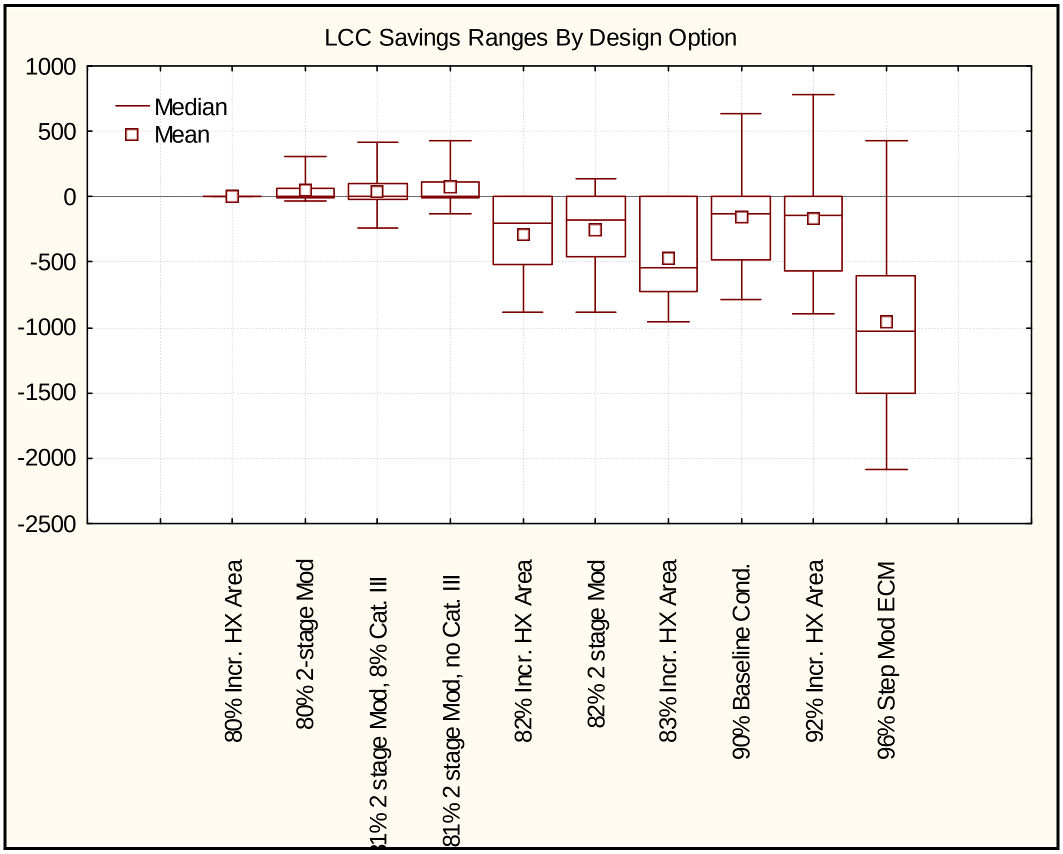

Figure 8.4.1 Range of LCC Savings for Non-Weatherized Gas Furnaces

Figure 8.4.2 shows the range of LCC savings for each census division for the 90 percent AFUE condensing furnace. Most regions show negative mean savings.

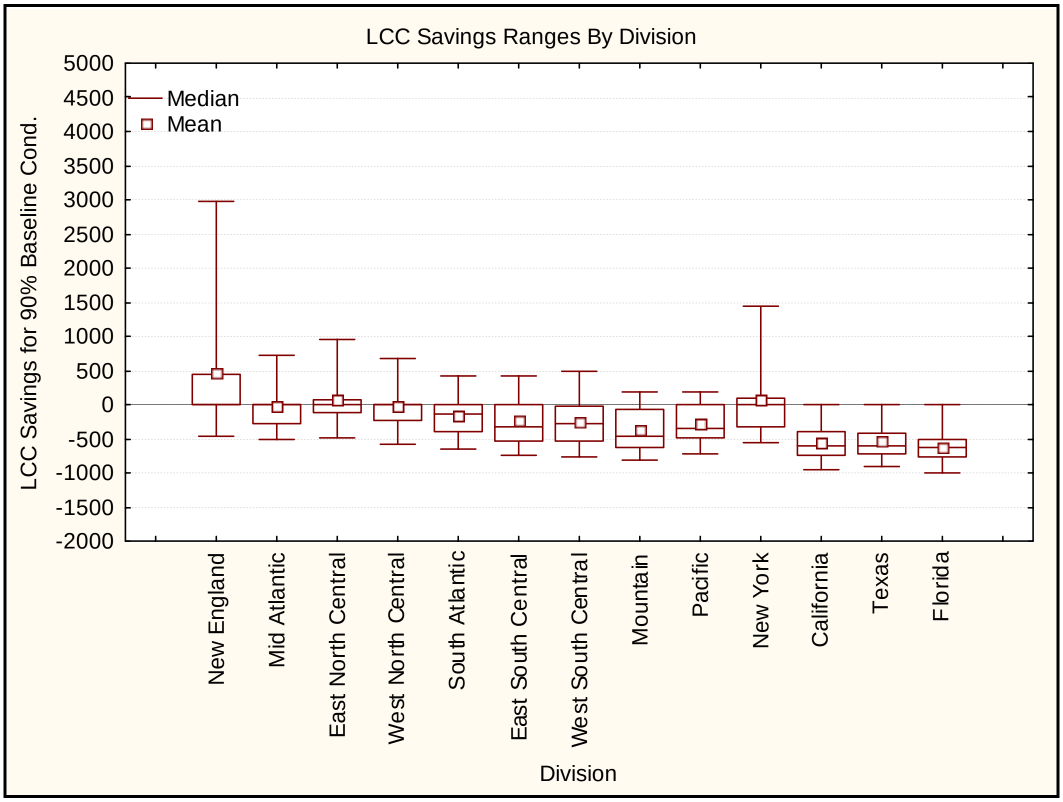

Figure 8.4.2 LCC Savings for Each Census Division for the 90 percent AFUE Condensing Furnace

8.4.2 Other Product Classes

For weatherized gas furnaces (Table 8.4.2), the results show positive average LCC savings for AFUE levels through 82.5 percent.

Table 8.4.2 LCC and PBP Results for Weatherized Gas Furnaces

Design Option: AFUE	LCC					Payback	
	Average	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average**
78% Baseline Model	$8,545						
80% Incr. HX Area	$8,457	$2	0%	98%	2%	1.1	1.5
80% Improved Insulation	$8,454	$4	26%	46%	28%	9.0	8.2
80% Improved Heat Xfer	$8,467	-$4	52%	46%	2%	2.8	3.7
81% Incr. HX Area	$8,418	$23	2%	46%	52%	2.0	2.6
81% Improved Insulation	$8,415	$25	20%	20%	60%	5.2	6.4
81% Improved Heat Xfer	$8,424	$18	32%	20%	48%	3.8	5.1
82% Incr. HX Area	$8,380	$53	3%	20%	77%	2.1	2.9
82% Improved Insulation	$8,377	$56	18%	0%	82%	4.3	5.6
82% Improved Heat Xfer	$8,382	$51	24%	0%	76%	2.5	3.4
82.5% Incr. HX Area	$8,347	$86	6%	0%	94%	2.9	3.9
82.5% Improved Insulation	$8,345	$88	11%	0%	89%	3.9	5.5
82.5% Improved Heat Xfer	$8,345	$89	4%	0%	96%	2.4	3.3

* "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.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.4.3 shows the range of LCC savings by design option for weatherized gas furnaces.

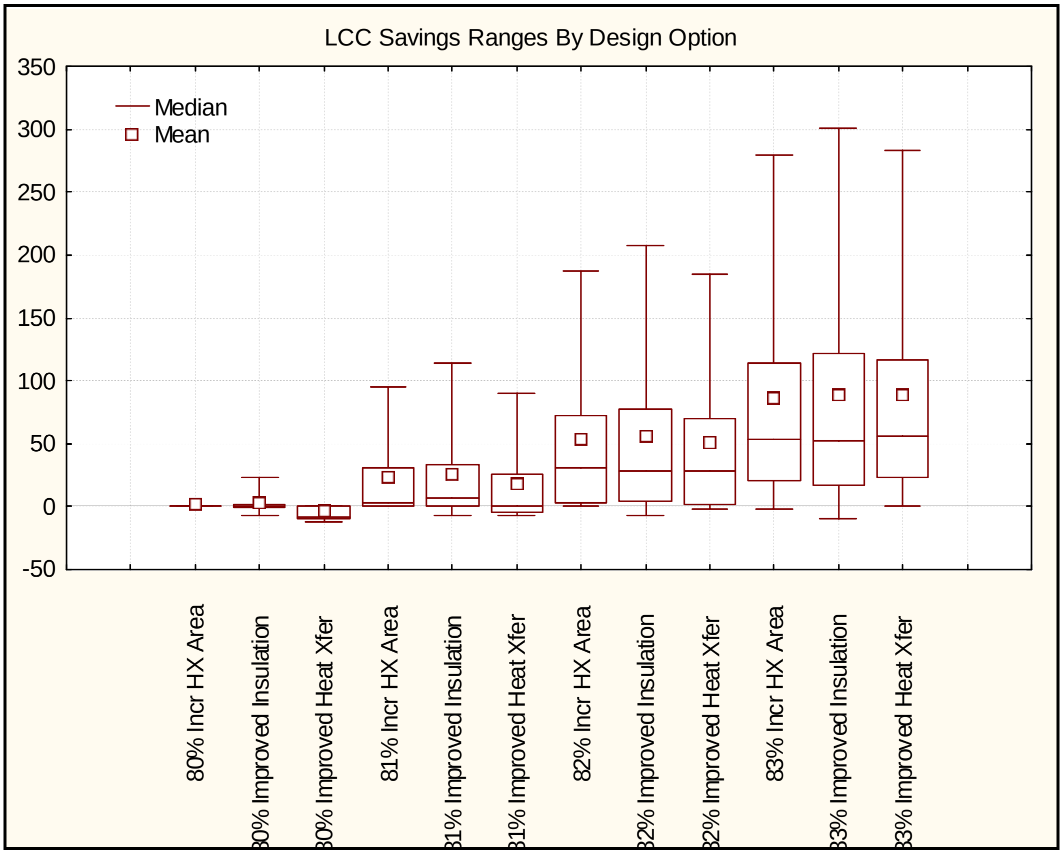

Figure 8.4.3 LCC Savings Ranges by Design Option for Weatherized Gas Furnaces

For mobile home gas furnaces (Table 8.4.3), the results show positive average LCC savings for the 80-82 percent AFUE levels using single-stage technology. The 90 percent AFUE condensing level shows an average LCC savings of $192, but 45 percent of the households have a negative impact.

Table 8.4.3 LCC and PBP Results for Mobile Home Gas Furnaces

Design Option: AFUE	LCC					Payback	
	Average LCC	**Average Savings**	**Net Cost**	**No Impact***	**Net Benefit**	**Median**	**Average****
75% Baseline Model	$7,904						
80%	$7,480	$64	1%	85%	14%	2.4	4.7
80% 2-stage modulation	$7,718	-$163	80%	5%	15%	26.0	60.5
81%	$7,428	$112	10%	5%	85%	4.4	6.3
81% 2-stage modulation	$7,670	-$117	75%	5%	20%	24.9	60.3
82%	$7,385	$153	14%	5%	81%	5.1	7.5
82% 2-stage modulation	$7,630	-$80	70%	5%	25%	22.9	56.3
90%	$7,352	$184	46%	5%	49%	12.5	22.7

* "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.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.4.4 shows the range of LCC savings by design option for mobile home gas furnaces.

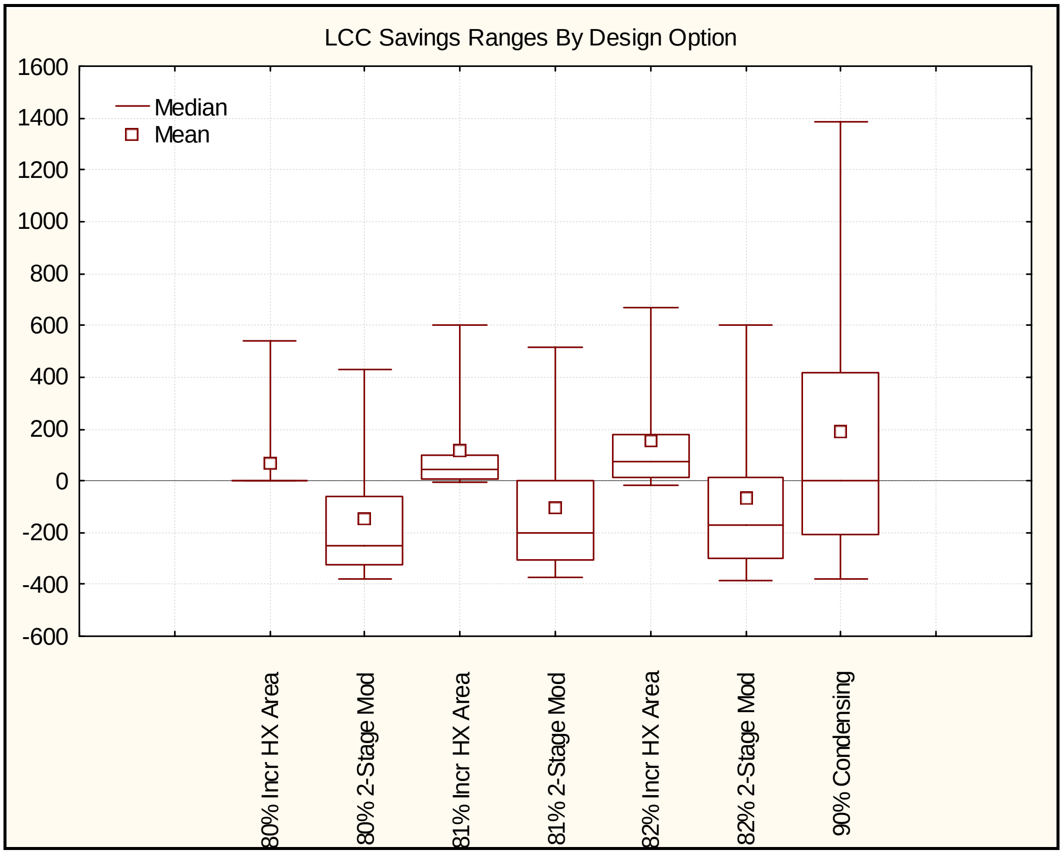

Figure 8.4.4 LCC Savings Ranges by Design Option for Mobile Home Furnace

For oil-fired furnaces (Table 8.4.4), the results show positive average LCC savings for AFUE levels from 80 percent through 83 percent.

Table 8.4.4 LCC and PBP Results for Oil-Fired Furnaces

Design Option: AFUE	LCC					Payback	
	Average	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average**
78% AFUE - Baseline Model	$16,194						
80% AFUE- Incr. HX Area	$15,900	$11	0%	96%	4%	0.2	0.2
81% AFUE- Incr. HX Area	$15,762	$95	2%	39%	59%	0.4	0.5
81% AFUE Atom Burner 2-stage Mod.	$15,885	$8	42%	30%	28%	11.7	19.4
82% AFUE- Incr. HX Area	$15,625	$190	2%	30%	68%	0.3	0.4
82% AFUE Atom Burner 2-stage Mod.	$15,753	$89	35%	22%	42%	8.5	13.8
83% AFUE- Incr. HX Area	$15,492	$293	3%	22%	75%	0.3	0.4
83% AFUE Atom Burner 2-stage Mod.	$15,626	$178	31%	15%	54%	6.8	11.2
84% AFUE- Incr. HX Area	$15,967	-$111	58%	15%	27%	13.7	20.8
84% AFUE Atom Burner 2-stage Mod.	$16,106	-$240	71%	7%	22%	16.3	25.1
85% AFUE- Incr. HX Area	$15,845	$1	49%	7%	44%	10.0	13.8
85% AFUE Atom Burner 2-stage Mod.	$15,989	-$143	69%	0%	31%	13.7	20.1

* "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.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.4.5 shows the range of LCC savings by design option for oil-fired furnaces.

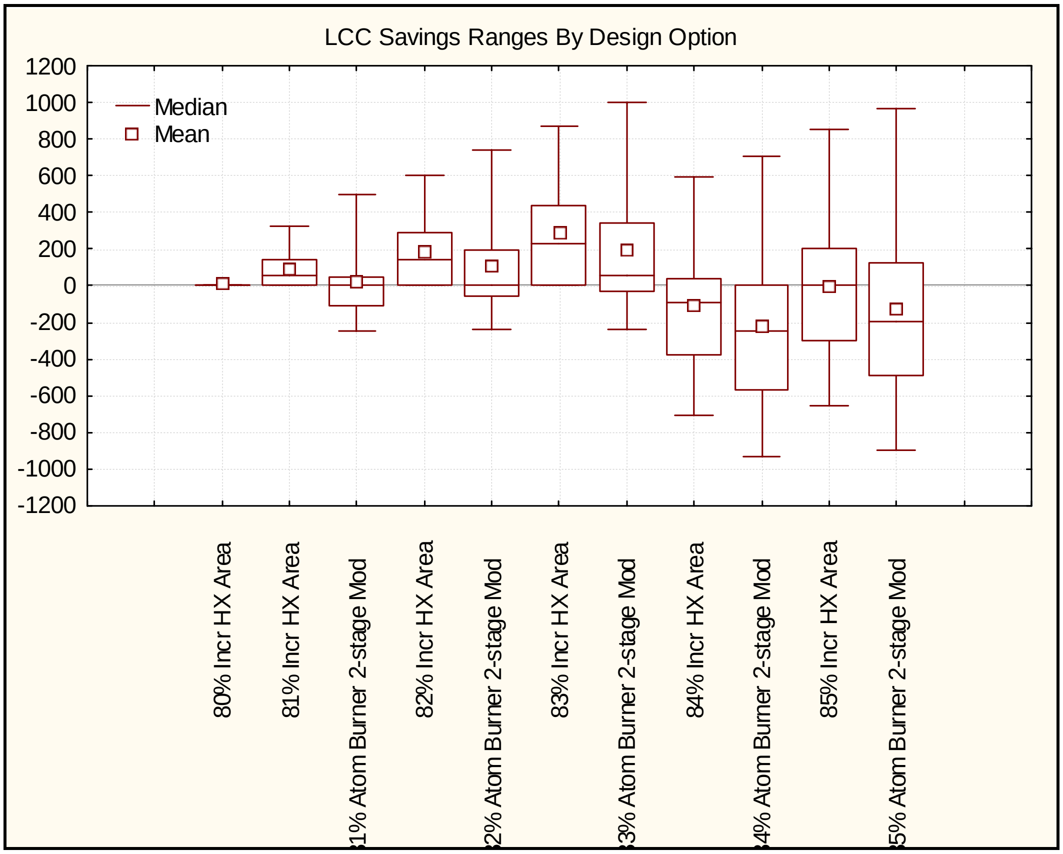

Figure 8.4.5 LCC Savings Ranges by Design Option for Oil-Fired Furnaces

For hot-water gas boilers (Table 8.4.5), the results show positive average LCC savings for the AFUE levels from 81 percent through 84 percent using single-stage technology.

Table 8.4.5 LCC and PBP Results for Hot-Water Gas Boilers

Design Option: AFUE	LCC					Payback	
	Average LCC	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average**
80% Baseline Model	$10,635						
81%	$10,371	$93	0%	65%	35%	2.1	2.4
81% 2-stage modulation	$10,599	-$36	38%	44%	18%	9.9	14.8
82%	$10,314	$125	3%	44%	53%	2.5	3.3
82% 2-stage modulation	$10,542	-$36	48%	30%	22%	9.3	19.6
83%	$10,256	$166	5%	30%	66%	2.5	3.3
83% 2-stage modulation	$10,483	-$29	59%	15%	27%	9.9	23.3
84%	$10,199	$215	6%	15%	79%	2.5	3.4
84% 2-stage modulation	$10,426	$0	62%	6%	32%	10.5	22.7
88%	$10,741	-$294	67%	6%	27%	17.5	29.8
91%	$10,823	-$372	75%	3%	22%	19.3	43.0
99%	$11,304	-$853	85%	0%	15%	21.7	46.1

* "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.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.4.6 shows the range of LCC savings by design option for hot-water gas boilers.

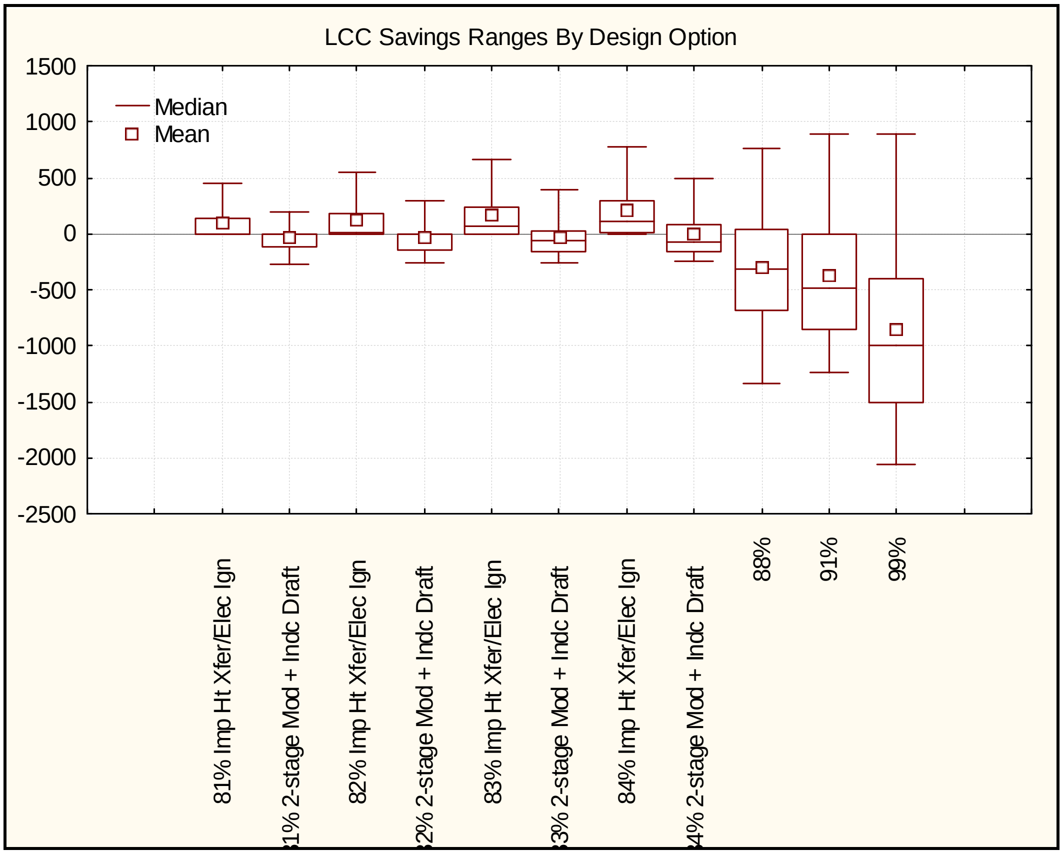

Figure 8.4.6 LCC Savings Ranges by Design Option for Hot-Water Gas Boilers

For hot-water oil-fired boilers (Table 8.4.6), the AFUE levels through 84 percent (without use of atomized burner) have positive average LCC savings.

Table 8.4.6 LCC and PBP Results for Hot-Water Oil-fired Boilers

Design Option: AFUE	Average	Average Savings	Net Cost	No Impact*	Net Benefit	Median	Average**
80%	$14,890						
81%	$14,772	$6	0%	95%	5%	0.6	0.8
81% Atomized Burner	$15,166	-$36	11%	89%	0%	70.4	104.9
82%	$14,657	$18	0%	89%	11%	0.7	0.8
82% Atomized Burner	$15,051	-$45	16%	84%	0%	35.0	64.3
83%	$14,545	$36	0%	84%	16%	0.7	0.8
83% Atomized Burner	$14,939	-$119	37%	61%	2%	23.0	45.0
84%	$14,435	$79	0%	61%	39%	0.7	0.8
84% Atomized Burner	$14,830	-$169	58%	37%	5%	26.7	57.6
86%	$14,943	-$234	52%	37%	11%	23.0	31.6
86% Atomized Burner	$15,338	-$602	91%	7%	2%	53.0	98.1
90%	$15,260	-$527	81%	7%	12%	19.6	23.8
95%	$15,561	-$829	88%	0%	12%	19.1	23.0

* "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.

** From the form of the payback calculation, a very small change in operating cost can result in extremely large paybacks. These extremely large paybacks will skew the average payback. In these cases, median is probably a better indicator.

Figure 8.4.7 shows the range of LCC savings by design option for hot-water oil-fired boilers.

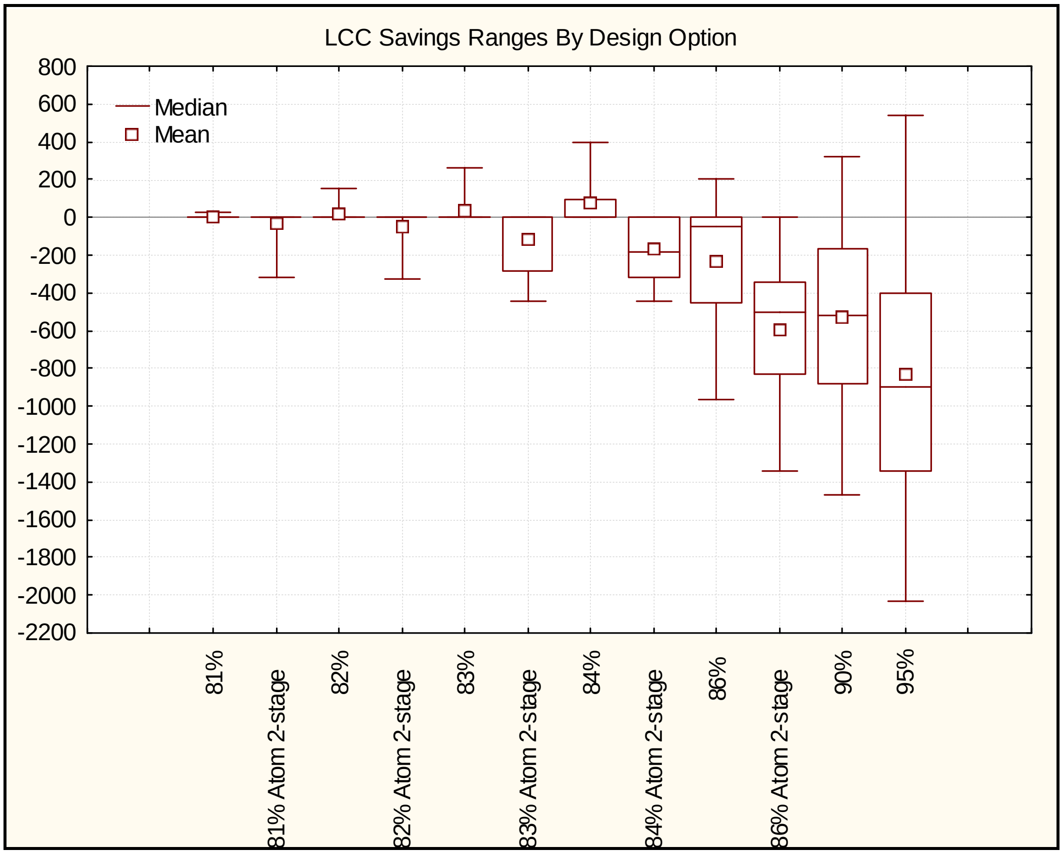

Figure 8.4.7 LCC Savings Ranges by Design Options for Hot-Water Oil-Fired Boilers

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