RESULTS AND METHODOLOGY OF THE LIFE-CYCLE COST ANALYSIS FOR RESIDENTIAL WATER HEATER EFFICIENCY STANDARDS

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List of Acronyms

AEO	Annual Energy Outlook
CEC	California Energy Commission
CPI	Consumer Price Index
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
GAMA	Gas Appliance Manufacturers Association
GRI	Gas Research Institute
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
LBNL	Lawrence Berkeley National Laboratory
LCC	Life-Cycle Cost
LPG	Liquefied Petroleum Gas
MCF	thousands of cubic feet
NES	National Energy Savings
NOAA	National Oceanic & Atmospheric Administration
RECS	Residential Energy Consumption Survey
WHAM	Water Heater Analysis Model

RESULTS AND METHODOLOGY OF THE LIFE-CYCLE COST ANALYSIS FOR RESIDENTIAL WATER HEATER EFFICIENCY STANDARDS

The Energy Policy and Conservation Act, as amended, provides energy conservation standards for water heaters among other products and authorizes the Secretary of Energy to prescribe amended or new energy standards for each type of covered product. This is a preliminary Life-Cycle Cost Analysis; it is part of the analyses the Department will conduct for the water heater rulemaking.

Request for Stakeholder Comments

The Department specifically requests comments from stakeholders and other interested parties regarding the following items:

- water heater lifetime data
- updated manufacturing costs, retail prices, and installation costs
- manufacturer cost-to-retail price markup values
- insulation components characteristics and costs
- fuel price scenarios
- uncertainty ranges on EF, RE, and UA values for different design options
- inlet water temperature assumptions
- relationship between the setpoint and inlet water temperatures
- hot water draw model

Note: This edition of the LCC Report, dated November 3, 1998, is the second edition to appear on this site. The first, dated October 1998, has been superceded to correct three errors. First, a correction in the value assigned to the maximum lifetime for electric water heaters produced a slight change in their life-cycle costs. Second, a correction in the ranges of uncertainty for the RE and UA energy parameters caused changes in energy consumption, operating costs, and life-cycle costs. Third, the Improved Flue Baffle design option for gas-fired water heaters was found to contain an erroneous component, which had a significant effect on the economic results for that design option.

1 Purpose of Life-Cycle Cost Analysis

This report describes the analysis of economic impacts on individual consumers from possible revisions to residential water heater energy efficiency standards. Recognizing that each household is unique, variability is explicitly accounted for by performing the calculation for a large sample of individual households. Variables within the household that cannot be characterized or are uncertain are represented by a range of values. The results are expressed as the fraction of households being impacted at particular magnitudes. Life-cycle cost (LCC) captures the total sum of purchase price and future operating expenses for water heaters. Another measure of economic impact, payback period, is also calculated.

2 Connection to Remainder of Water Heater Standards Analysis

The LCC Analysis is one step in the analysis of water heater efficiency standards. Much of the input for this analysis comes from the Engineering Analysis[1]. The other major input is from a database of water heater specifications and costs[2]. The results of the LCC Analysis will be used by the Department to select the trial standard levels used in the later stages of analysis and decision making. The outputs will also be used by the National Energy Savings forecast and the Utility and Environmental analyses.

2.1 From Engineering Analysis

2.1.1 Order and Combinations of Design Options

The combinations of design options are taken directly from the Engineering Analysis. They are presented in order of ascending cumulative payback period using the DOE test procedure conditions and the 1998 national average energy price.

2.1.2 Estimates of Factory Costs of Baseline Models and Design Options

The estimates of factory cost for the baseline models and the incremental cost of design options are from data supplied by the Gas Appliance Manufacturers Association (GAMA). For a few design options, GAMA was unable to supply estimates of manufacturer costs. In these cases, consultants familiar with the water heater industry were hired to supply this data.

2.1.3 Estimates of Factory Cost of All Standard Size Baseline Models and Design Options

GAMA supplied estimates of factory cost for the typical size tanks only. The range of factory costs were estimated for water heaters with different size tanks by adding or subtracting the material costs for different amounts of steel, for both jacket and tank, and of foam insulation.

2.1.4 Energy Parameters of Baseline Models and Design Options

The energy consumption in the LCC Analysis was calculated using the Water Heater Analysis Model (WHAM)[3]. The energy parameters used by WHAM--RE, UA, and rated input -- are based on the simulation models used in the Engineering Analysis. The temperatures and average daily hot water draw are selected for individual households in the analysis according to algorithms explained in later sections.

2.2 LBNL Water Heater Cost Database

LBNL has developed a database of specifications and retail prices for residential water heaters currently on the market. The specifications are from manufacturers' product literature. Efficiency ratings are taken mostly from directories of certified efficiency ratings. [4] Retail prices and installation costs for residential water heaters were collected through telephone calls and faxes to several dozen distributors and retail outlets throughout the United States.

2.2.1 Prices of Baseline Models

For this analysis, the price of baseline models was taken from the LBNL Water Heater Cost Database. The baseline models were defined as those with five year manufacturer warranties and having no special design features.

2.2.2 Installation Costs

Installation costs were also taken from the LBNL Water Heater Cost Database. In addition to the actual costs of installing water heaters, delivery, removal, and permit fees are also included. Typical costs for miscellaneous parts used in installing a water heater, such as pipe fittings, were also added.

2.3 Input to Selection of Trial Standard Levels

For the next steps in the analysis, the Department must select trial standard levels. The LCC Analysis includes all the design options that have not been screened out at this stage of the analysis and considers each fuel type separately. The trial standard levels will be a subset of the design options considered in the LCC Analysis and will cover all three fuel types simultaneously. The Department will consider the results presented here to help decide which design options to assign to trial standard levels.

2.4 Output to National Energy Savings Forecast

The National Energy Savings (NES) forecast was developed from a spreadsheet that projects energy savings at the national level for different trial standard levels. The calculations it performs are based on average annual energy consumption and average installed cost of water heaters. The LCC Analysis includes the range of energy consumption and installed cost of water heaters for all the design options. The average of these ranges will be used in the national energy savings calculations.

3 Summary of Results

This analysis estimates the portion of the population that will benefit from different design options in terms of reduced life-cycle cost. The average life-cycle cost reduction is also estimated. The results of this study are summarized in the following table.

Electric Water Heaters

Design Option		Fraction of Population Benefitting (%)	Average LCC Savings ($)
1	Heat Traps	94.9	54.11
2	1 + 2" Jacket Insulation	83.9	52.93
3	1 + 2.5" Jacket Insulation	79.9	58.67
4	3 + Plastic Tank	68.6	43.55
5	3 + Insulated Tank Bottom	59.3	22.51

Gas-fired Water Heaters

Design Option		Fraction of Population Benefitting (%)	Average LCC Savings ($)
1	Heat Traps	95.5	26.51
2	1 + 2" Jacket Insulation	97.9	60.56
3	1 + 2.5" Jacket Insulation	93.8	57.01
4	3 + Side Arm Heater	54.9	14.70
5	2 + Improved Flue Baffle	21.7	-31.27

Oil-fired Water Heaters

Design Option		Fraction of Population Benefitting (%)	Average LCC Savings ($)
1	Heat Traps	--	--
2	1 + 2" Jacket Insulation	--	--
3	2 + Improved Flue Baffle	--	--
4	3 + Interrupted Ignition	--	--

The results from the analysis of the oil-fired water heaters will be included in a later version of this report.

4 Methodology and Definitions

Analysis of an energy efficiency standard involves calculations of impacts; for example, the impact of a standard on consumer life-cycle cost. In order to perform the calculation, the analyst must first: 1) specify the equation or model that will be used; 2) define the quantities in the equation; and 3) provide numerical values for each quantity. In the simplest case, the equation is unambiguous (contains all relevant quantities and no others), each quantity has a single numerical value, and the calculation results in a single value. However, unambiguity and precision are rarely the case. In almost all cases, the model and/or the numerical values for each quantity in the model are not completely known (uncertainty) or the model and/or the numerical values for each quantity in the model depend upon other conditions (variability). Explicit analysis of uncertainty and variability is intended to provide more complete information to the decision-making process.

4.1 Uncertainty and Variability

To account for the uncertainty and variability, the LCC model was developed using Microsoft Excel combined with Crystal Ball (a commercially available add-on). The model uses Monte Carlo simulations to perform the analysis considering uncertainty and variability.

The analysis explicitly specifies both the uncertainty and variability in the model's inputs using probability distributions. The Monte Carlo simulation then takes thousands of random samples from the probability distribution for each input within the model to calculate the outputs. The distribution of the values calculated for the model outcome therefore reflects the probability of the values that would occur. This technique provides solutions to a broad range of questions and helps provide an insight into the likelihood of various possible outcomes.

An importance analysis is also produced which shows the relative contribution of each of the inputs to the total range of outputs.

A variety of graphic displays are used to illustrate the implications of the analysis results. These include: a) a cumulative probability distribution showing the percentage of US households which would have a net life-cycle saving by owning a more energy-efficient water heater or b) a chart that depicts variation of the life-cycle cost for each design option considered.

One major assumption has been made throughout the analysis. One of two probability distributions, Triangular or Normal, will be used where a specific form of uncertainty or variability is totally or partially unknown. The Triangular distribution is one of the simplest forms of probability distributions. It uses three simple parameters, minimum, most-likely, and maximum, to describe the probability distribution for a given set of data. It is commonly used in cases where the knowledge about the factor of interest is limited. Normal distribution, on the other hand, is based on an underlying assumption that the data follow a bell-shaped distribution. This is usually the case in which a variable is influenced by many factors but none of them is dominant. When nothing but a mean and variance about a random variable is known, the Department will use the Normal distribution to describe the variable.

4.1.1 Uncertainty

When making observations of past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy actually consumed by a particular appliance type (such as the average U.S. water heater) has not been directly recorded very often. Rather, energy consumption is usually estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

4.1.2 Variability

Variability means that different applications or situations produce different numerical values for a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, the amount of hot water used per day by a household depends upon the specific circumstances and behaviors of the occupants (e.g., number of persons, personal habits about hot water use, etc.). Variability makes specifying an appropriate value more difficult. One's personal experience may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., gallons of hot water use per day) to other variables that are better known or easier to forecast (e.g., persons per household).

4.1.3 Approaches

Two approaches to consider uncertainty and variability are described here:

Scenario analysis uses a single numerical value for a quantity in the calculation, then changes the numerical values and repeats the calculation. A number of calculations are done, which provide some indication of the extent to which the result depends upon the assumptions. For example, the life-cycle cost of an appliance could be calculated for electricity prices of 2, 8, and 14 cents per kWh.

The advantages of scenario analysis are that the calculation is simple; a range of estimates is used; and crossover points can be identified. When examining a given design option, a crossover point occurs when the energy price rises to a point at which the savings in operating cost compensate for the increased purchase expense of the design option. The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

In this analysis of water heaters, the only variables treated as scenarios are future energy prices. These prices are taken from forecasts by DOE's Energy Information Administration (EIA)[5] and the Gas Research Institute (GRI)[6].

Probability analysis considers the probabilities within a range of values. For quantities with variability (e.g., electricity prices in different households), surveys can be used to generate a frequency distribution of numerical values (e.g., the number of households with electricity prices at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures such as a triangular probability distribution can be used to provide probabilities (e.g., manufacturing cost to improve energy efficiency to some level may be estimated to be $10 +/- $3).

The advantage is that the probability approach provides the greatest information about the outcome of the calculations, that is, the probability that the outcome will be in any particular range is provided. The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

5 Details of LCC Uncertainty Analysis for Water Heaters

5.1 Overview

The LCC analysis is designed to determine the life-cycle cost and the cumulative payback for consumers for a variety of design options to improve the efficiency of residential water heaters. To account for all the variability and uncertainty among consumers, the analysis is done for thousands of households from a weighted sampling from DOE/EIA's 1993 Residential Energy Consumption Survey (RECS)[7]. In addition to the variety of consumers, wherever possible, other inputs for the analysis are also represented as samples drawn from a range of values. In this way, the analysis accounts for the full range of characteristics related to residential hot water use.

All design options for water heaters are analyzed as if they were in production levels equivalent to the typical existing baseline models, i.e., possessing similar economies of scale. The term "typical existing" baseline is used in this analysis to refer to current water heater models that use HCFC-141b as a blowing agent for foam insulation and are of the most common, or typical, tank size (50-gal for electric, 40-gal for gas-fired, and 32-gal for oil-fired). The criteria for the selection and an in-depth description of the baseline models is provided in the Engineering Report.

Manufacturers' data from GAMA's consumers directory revealed 25 different volume sizes for electric water heaters, 19 for gas, and 4 for oil. Within each volume size, there are varying numbers of models. Some sizes have over 1,000 different models. For the purposes of this study, the assumption was made that a size with more models indicated that more of that size was shipped and, therefore, purchased. The sizes with the greatest number of models were checked against GAMA shipment data for the years 1988 through 1995. GAMA shipment data is reported in ranges rather than exact size volumes. After comparing consumers directory data and shipment data, standard sizes were selected as representative of current market conditions. Table 5.1.1 presents a list of all of the standard-size water heaters (based on rated tank volume) considered in the LCC analysis.

Table 5.1.1 Water Heater Standard Sizes

Water Heater Fuel Type	Rated Volume (gal)	Rated Volume (liter)*
Electric	30	110
Electric	40	150
Electric (typical)	50	190
Electric	65	250
Electric	80	300
Gas-fired	30	110
Gas-fired (typical)	40	150
Gas-fired	50	190
Gas-fired	75	280
Oil-fired (typical)	32	120
Oil-fired	50	190

* rounded to the nearest 10 liters

The Montreal Protocol bans use of HCFC-141b as a blowing agent for polyurethane foam insulation after 2003. For this analysis, HFC-245fa is assumed to be the substitute blowing agent. Polyurethane foam made with HFC-245fa may be slightly less effective as an insulation. Costs may be slightly higher as well. Additionally, the U.S. Consumer Product Safety Commission, an independent Federal regulatory agency, is currently working with the water heater industry to design gas-fired water heaters that will not ignite flammable vapors. Both of these changes will be in effect by the time any new efficiency standard becomes effective. The future baseline models, which will incorporate these two changes, are referred to as the "analytic" baseline models in this analysis. These will be the baselines against which design options are compared.

5.1.1 Separate Analysis for Each Fuel (Product Class)

The LCC analysis is done separately for each energy source: electric, gas, and oil. This analysis does not address fuel choice or fuel switching. These issues are addressed in the National Energy Savings analysis.

5.1.2 Combinations of Design Options from Engineering Analysis

The design options used in this analysis are described in more detail in the Engineering Report. Design options are combined by order of cumulative payback as determined in the Engineering Analysis. Hot water use and energy costs in this analysis reflect the range of values among consumers, unlike the Engineering Analysis, which is based on the DOE Energy Factor test procedure and average national energy prices.

5.1.3 Five Major Modules

A spreadsheet model with five major modules is the basis of the LCC analysis. The major modules are LCC and Payback, Operating Cost, Equipment Cost, Energy Analysis, and Hot Water Draw. The individual modules are described in more detail later in this report. Several of these modules have accompanying data tables that are used for reference. Each module has its own inputs and outputs, with some modules using as inputs the outputs of other modules.

As a default, the spreadsheet opens to a main page that allows the user to select scenarios for future energy prices, and then initiates a Monte Carlo run by sampling all of the inputs 10,000 times. There is a separate spreadsheet available for each type of water heater being considered; electric, gas-fired, and oil-fired. The spreadsheets are written in Microsoft Excel 97. The Monte Carlo capabilities are enabled by Crystal Ball, an add-on program that helps analyze the risks and uncertainties associated with models. Crystal Ball is available from Decisioneering, Inc.

The LCC spreadsheets will be available later in November 1998 on the DOE, Office of Codes and Standards web site at <http://www.eren.doe.gov/buildings/codes_standards/reports/index.htm>. If you have any questions or are unable to access the web site, please contact Ms. Brenda Edwards-Jones at (202) 586-2945 or by fax at (202) 586-4617.

5.1.4 Flowchart

To provide a general overview, a flowchart showing the major sections of the spreadsheet and the data flow between the modules is shown in Figure 5.1.1.

5.1.5 Description of Outputs

The main outputs of each module are summarized as tables and charts in the individual sections. The summaries for each module give outputs by design option, except for the draw module. The draw module calculates hot water use for each household. The amount of hot water use is not affected by water heater efficiency, so it is not calculated separately for each design option.

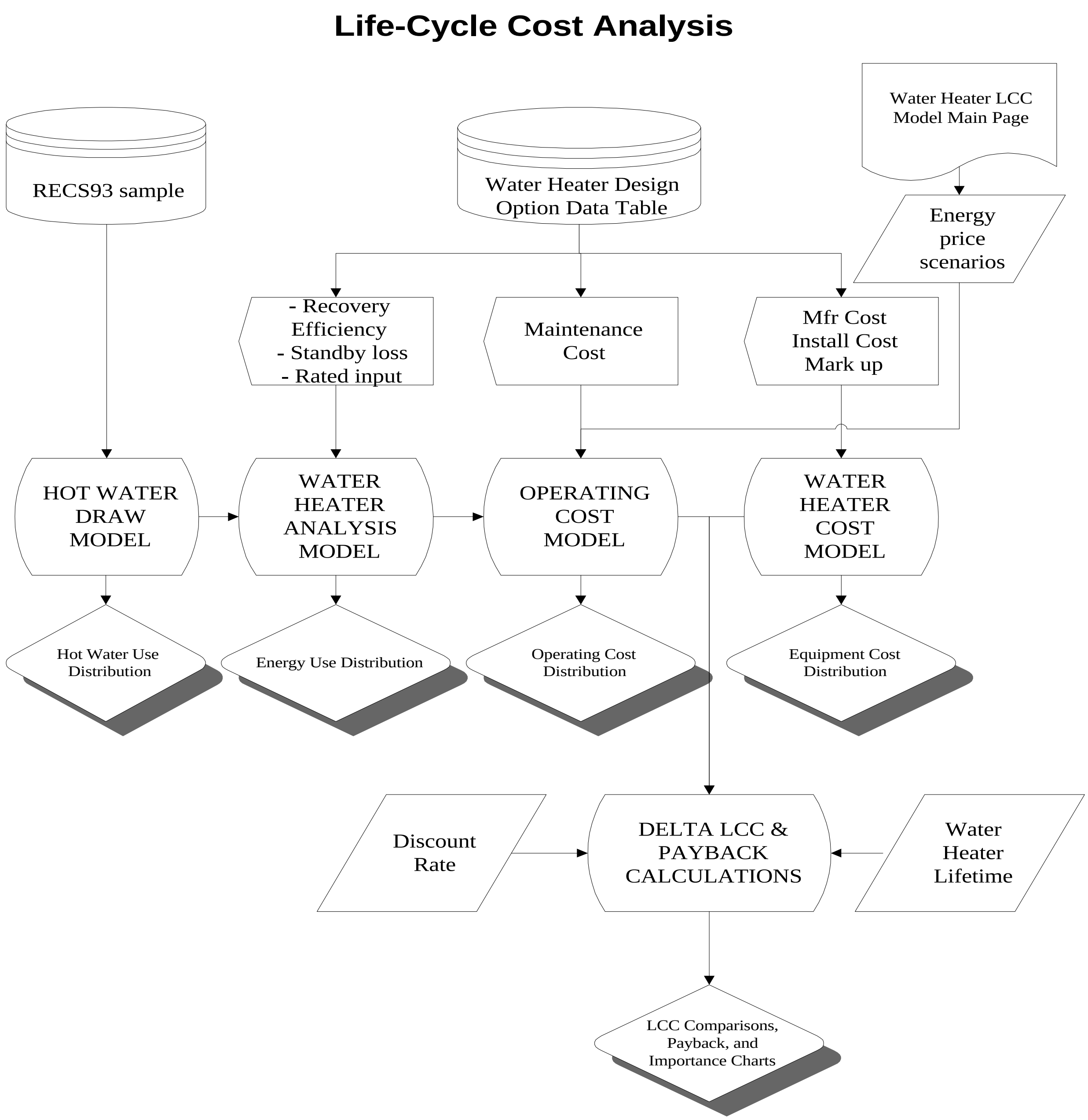

Figure 5.1.1 Flowchart of LCC Analysis Spreadsheet

The summary tables list the average value for each output and the percent of households that would benefit by using that design option. For example, in the LCC and Payback module, the values reported in the tables are LCC and Payback. In other modules, other outputs are reported as appropriate.

The impact of individual design options are shown in combined histogram and cumulative frequency charts. These charts show the output (LCC or payback) by percent of the population in order of ascending value. The bars of the histograms show the relative frequency of different results out of 10,000 samples from 5,788 RECS households (2,559 with electric water heaters, 2805 with gas-fired, 248 with LPG, and 176 with oil-fired). RECS household weightings were used to develop the samples. The lines show cumulative percentages of the results for each value. The higher the absolute value of the correlation, the more influence the input has on the output. A negative correlation indicates a decrease in output in response to an increase in the input. For example, in Figure 5.2.6, the higher the discount rate, the larger the difference in LCC.

The final type of chart is a tornado chart, which shows the impact of the inputs of each module on the output in question. The sensitivity is measured as the rank order correlation between each input and the output of interest. The higher the correlation the more influence that input has on the output.

5.2 Life-Cycle Cost Module

5.2.1 Introduction

The life-cycle cost is defined as the total consumer expense over the lifetime of a water heater, including purchase price and operating expenses (which includes energy expenditures). Future operating expenses are discounted to the time of purchase, and summed over the lifetime of the water heater.

5.2.2 Equations and General Descriptions for LCC and Payback

Life-cycle cost is defined by the following equation:

$$LCC_{option} = EquipCost_{option} + NPV(D_{rate}, OprCost_{option}, Lifetime)$$

where:

EquipCost	=	cost of buying and installing a water heater ($)
	=	(equipment cost) + (sales tax) + (installation cost)
options	=	one of 5 design options for electric, 5 for gas, and 4 for oil-fired
NPV	=	Net present value ($) is defined by the following equation:

$$NPV = \sum_{year=1}^{Lifetime} \frac{OprCost_{year}}{\left(1 + D_{rate}\right)^{year}}$$

D_{rate}	=	Discount rate (real) (%)
OprCost	=	cost of operating a water heater ($/year)
	=	(energy usage) x (energy rate) + (maintenance cost)
Lifetime	=	Lifetime of water heater (years)

EquipCost is defined as the costs associated with buying and installing a water heater. This includes the cost of a water heater plus sales tax, installation charges, and, if the water heater is being replaced, charges for the removal of the old water heater.

NPV (**Net Present Value)** is the present value today of a future stream of expenditures.

$\mathbf{D_{rate}}$ is defined as the rate at which future expenditures are discounted to establish their present value. A distribution of discount rates was derived to represent the variability in financing methods consumers use in purchasing appliances. The resulting distribution of discount rates will be used to calculate a distribution of life-cycle costs for water heaters.

Consumers purchase appliances in new homes and as retail purchases. The retail purchases are paid by cash, credit cards, or retailer loans. A comment[8] (Whirlpool, 1990) indicated that for white goods about 40% of retail purchases are paid in cash, 35% use credit cards, and 25% use retailer loans. The same comment indicates 25% of appliance purchases are for new homes. (For water heaters, it is estimated that purchases for new homes are now about 20%.) The method of purchase used by consumers is assumed to be indicative of the source of the funds and the type of financing used by these consumers.

A range of interest rates that may reasonably be expected to apply in the future to different types of consumer savings or financing were estimated.

For new housing, the estimated nominal mortgage rate ranges from 5-8%, the derived after-tax rate is based on a tax of 28%, and an inflation rate of 2% is subtracted from the total. The result is a range of real mortgage rates of 1.60-3.76%. (Example: 5% * (100%-28%) - 2% = 1.60%)

For cash, the minimum rate is 0%. This rate applies to purchasers making cash purchases without withdrawing from savings accounts. For the maximum, the opportunity cost is represented by the interest that could have been earned in a savings account. The historical nominal maximum savings rate ranged from 4.5-5.5% from 1970 to 1986 (real rates of -8.27 to +3.58%). A real rate of 3% was selected as indicative of the maximum.

The interest rates for retailer loans and credit cards are assumed to have the same range. The minimum credit card rate is taken as 6% real. Introductory rates on some credit cards today are 5.9% nominal, but after the introductory period (often 6 months), the rate becomes much higher. Maximum rates are over 20% nominal. However, if the purchase is paid for initially by a credit card and the consumer pays off the balance in less than the life of the water heater, then the effective interest rate is lower than the nominal credit card rate. The current assumption is a range of 6-15% real.

DOE recognizes that other factors might be considered in the estimation of real consumer discount rates, such as the actual impacts of appliance purchases on consumer savings, indebtedness or consumption, and expressed or imputed consumer preferences. While such data, if it were to become available, might provide a stronger analytical basis for DOE's choice of discount rates, it is considered unlikely that such data would have a significant effect on the range of values considered in the current analysis.

Figure 5.2.1 shows the distribution of real discount rates, ranging from 0 to 15%, with a mean of 6%.

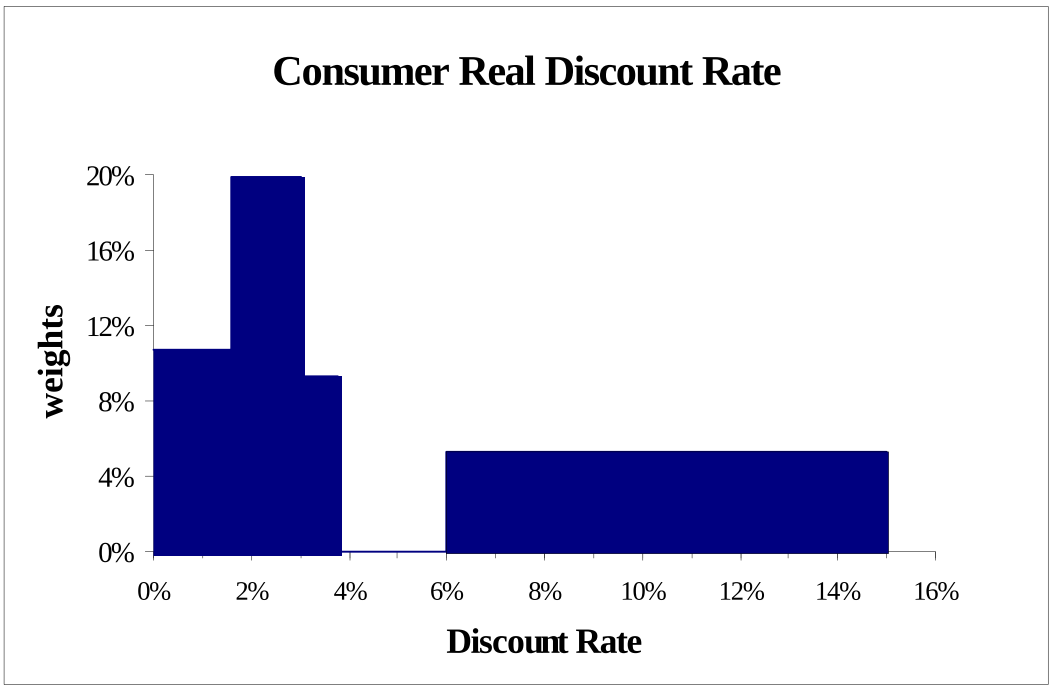

Figure 5.2.1 Distribution of Consumer Discount Rates

OprCost is defined as the expenditures necessary to keep the water heater operating. It has two parts, fuel and maintenance. Fuel costs are calculated by multiplying annual water heater energy use by the energy rate paid by the household. Maintenance costs are repair charges.

Lifetime is the period of time the water heater will provide service. Table 5.2.1 shows lifetimes for water heaters by fuel type. Oil-fired water heaters are assumed to have the same distribution of lifetimes as gas-fired water heaters.

Table 5.2.1 Water Heaters and Lifetime by Fuel Type[9]

Fuel	Lifetime (years)		
	Minimum	Average	Maximum
Electric	4	12	19
Gas and LPG	3	9	15
Fuel Oil	3	9	15

The simple payback period measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs.

The payback period equation can be expressed as:

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

where:

option = one of 5 design options for electric, 5 for gas-fired, and 4 for oil-fired water heaters

base = the typical analytic baseline design

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) from replacing the analytic baseline water heater with a water heater incorporating another design option. Payback periods are expressed in years. A payback period of three years means that the increased purchase price is equal to three times the value of reduced operating expenses in the year of purchase, or that the increased purchase price is recovered in approximately 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.

5.2.3 General Description of Sources of Data

Residential Energy Consumption Survey

The analysis uses as its underlying data source the 1993 RECS. RECS provides information concerning energy consumption in the residential sector and contains a more complete set of data for water heater analysis than any other survey reviewed for this study. The survey contains basic data concerning household characteristics from an interview questionnaire and annual fuel consumption and expenditures (excluding transportation fuel) derived from the records of fuel suppliers. Also included are weather data (in the form of heating and cooling degree days) and a weighting variable. The 1993 RECS survey consists of a total of 7,111 sample households from across the contiguous U.S.

Most, but not all, of RECS household records are used in the analysis and are assumed, with their weighted averages, to be representative of housing on a national scale. The households that are included in the analysis have three defining features:

1. Running hot water
2. An individual water heater
3. One of four fuels: electricity, oil, gas, or LPG

Households without these features are not used in the analysis.

RECS sometimes reports ranges, rather than precise numbers, for variables, and there are also certain omissions of crucial information for variables needed for this analysis. In order to correct for these missing or insufficient data, two methods were used: (1) when ranges were given, best point estimates were made within the range; and (2) when the RECS data did not cover particular areas of interest, other studies were used to develop the necessary information for each RECS housing unit.

National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, operates the National Climatic Data Center, which is the world's largest active archive of weather data. The analysis uses NOAA's 30-year (1961-1990) average air temperatures[10].

Gas Appliance Manufacturers Association

The Gas Appliance Manufacturers Association (GAMA) is a national trade organization which represents hot water heater manufacturers in the U.S. It collects and disseminates data on water heating equipment. This analysis uses GAMA's shipment data, consumers' directory, and manufacturer costs for most design options.

Manufacturer Product Literature

Most manufacturers of water heaters provide dealers (and consumers) with literature describing their models, including their efficiency ratings.

5.2.4 Life-Cycle Cost and Payback Results

Electric Water Heaters

Table 5.2.2 lists the portion of the population benefitting from each design option, in terms of reduced life-cycle cost. The average LCC savings and payback are also shown.

Table 5.2.2 Life-Cycle Cost and Payback for Electric Water Heaters

Design Option		Fraction of Population Benefitting (%)	Average LCC Savings ($)	Average* Payback (yrs)
1	Heat Traps	94.9	54.11	1.07
2	1 + 2" Jacket Insulation	83.9	52.93	3.49
3	1 + 2.5" Jacket Insulation	79.9	58.67	4.14
4	3 + Plastic Tank	68.6	43.55	5.76
5	3 + Insulated Tank Bottom	59.3	22.51	6.79

* median

Figure 5.2.2 shows the cumulative frequency of differences in LCC by design option for electric water heaters. The percent of the population benefitting and being disadvantaged are also shown on the graphs. Note that a negative difference in life-cycle cost for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread in the population.

Figure 5.2.3 shows cumulative frequency of payback period by design option. The percent of population which would have a payback of less than or equal to three years is indicated. A three-year payback period was chosen because it was assumed that design options which satisfy this criteria are most likely to be included in the proposed standard. In general, the design options with higher efficiencies tend to show a wider spread in the population.

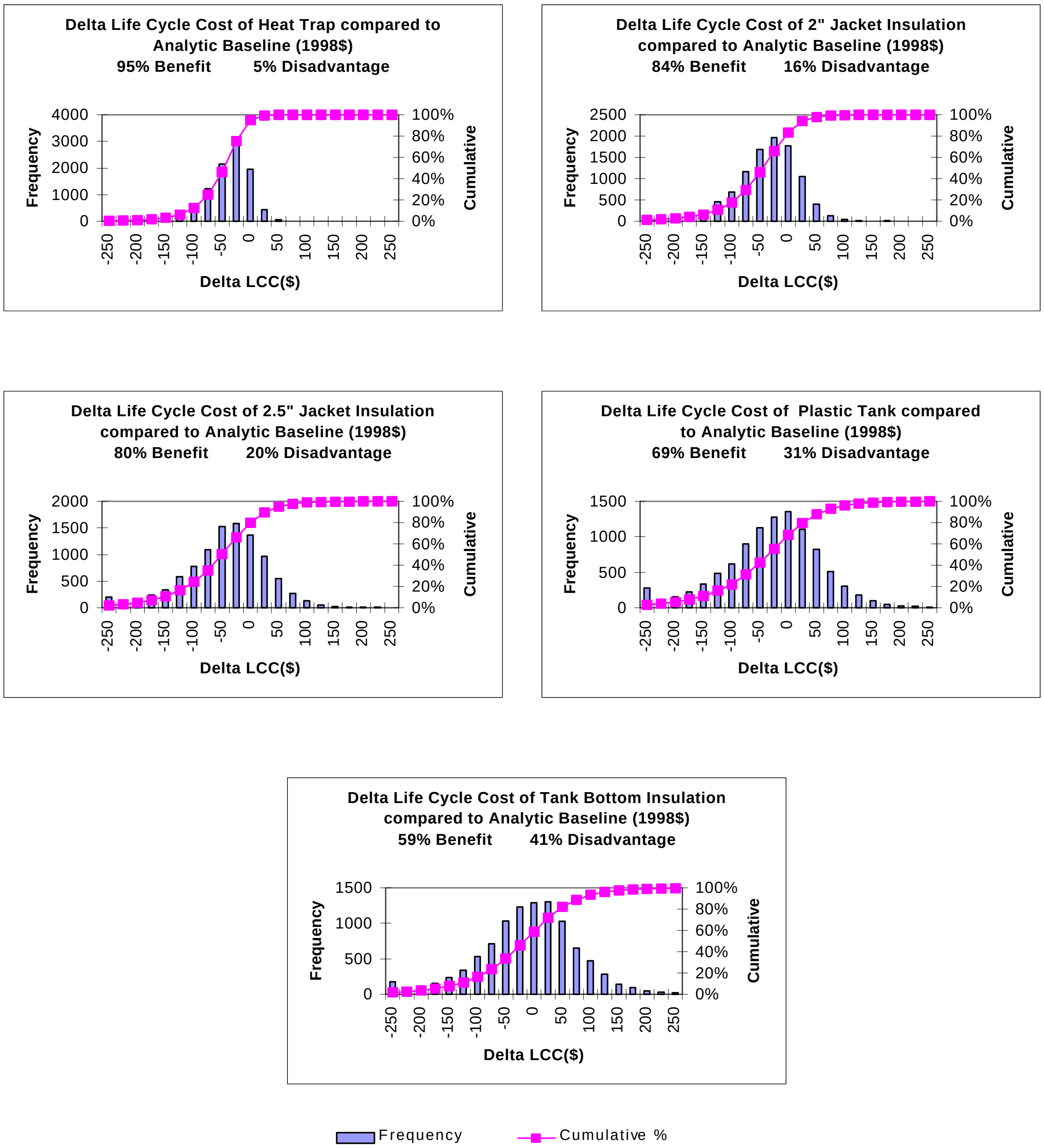

Figure 5.2.2 Difference in Life-Cycle Costs by Design Option for Electric Water Heaters

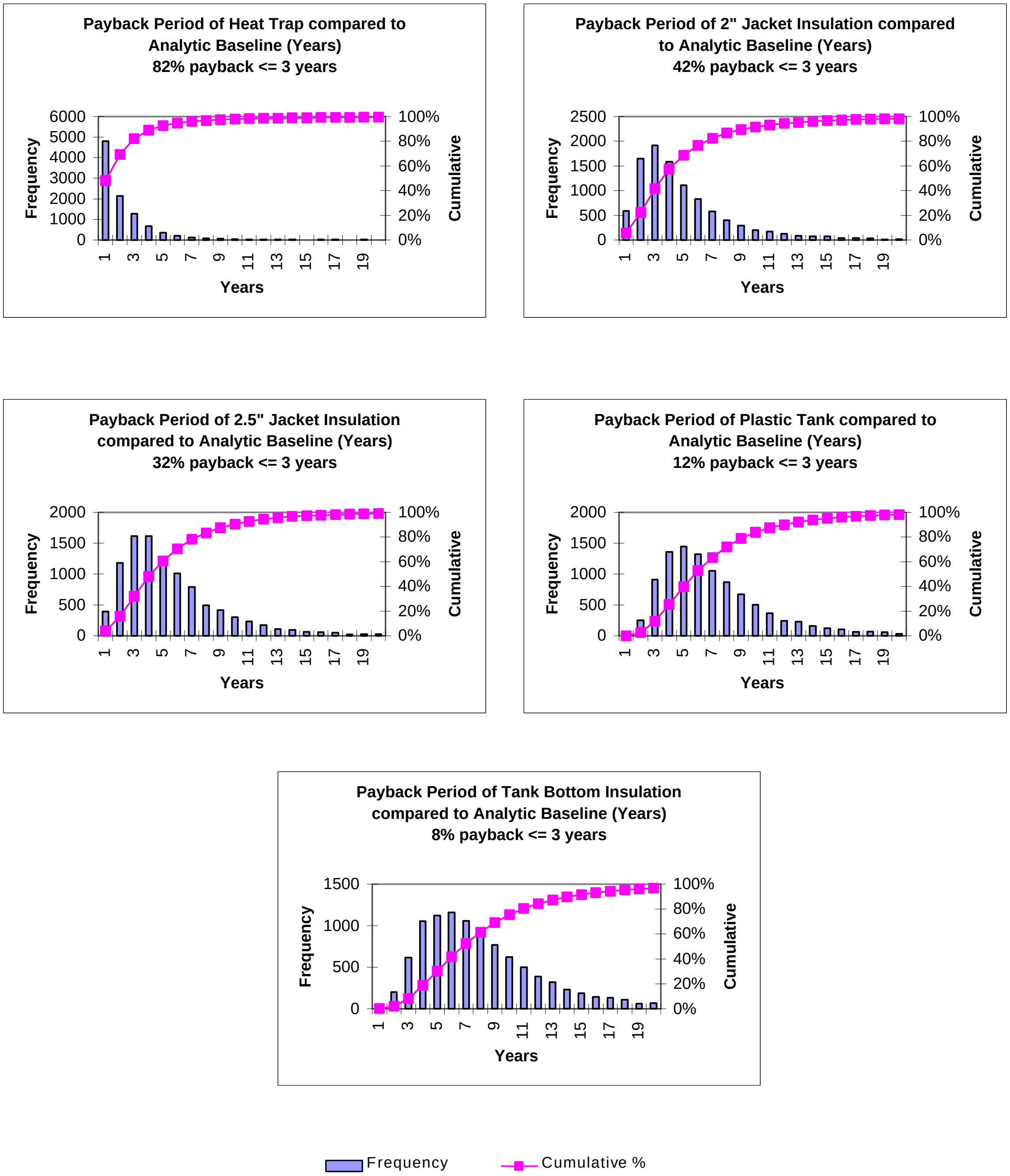

Figure 5.2.3 Payback Period by Design Option for Electric Water Heaters

Gas-fired Water Heaters

Table 5.2.3 lists the portion of the population benefitting from each design option, in terms of reduced life-cycle cost. The average LCC savings and average payback are also shown.

Table 5.2.3 Life-Cycle Cost and Payback for Gas-Fired Water Heaters

Design Option		Fraction of Population Benefitting (%)	Average LCC Savings ($)	Average* Payback (yrs)
1	Heat Traps	95.5	26.51	0.70
2	1 + 2" Jacket Insulation	97.9	60.56	1.87
3	1 + 2.5" Jacket Insulation	93.8	57.01	2.62
4	3 + Side Arm Heater	54.9	14.70	6.25
5	2 + Improved Flue Baffle	21.7	-31.27	9.35

*median

Figure 5.2.4 shows the cumulative frequency of differences in LCC by design option for gas-fired water heaters. The percent of the population benefitting and being disadvantaged are also show on the graphs. Figure 5.2.5 shows cumulative frequency of payback period by design option. The percent of population which would have a payback of less than or equal to three years is indicated.

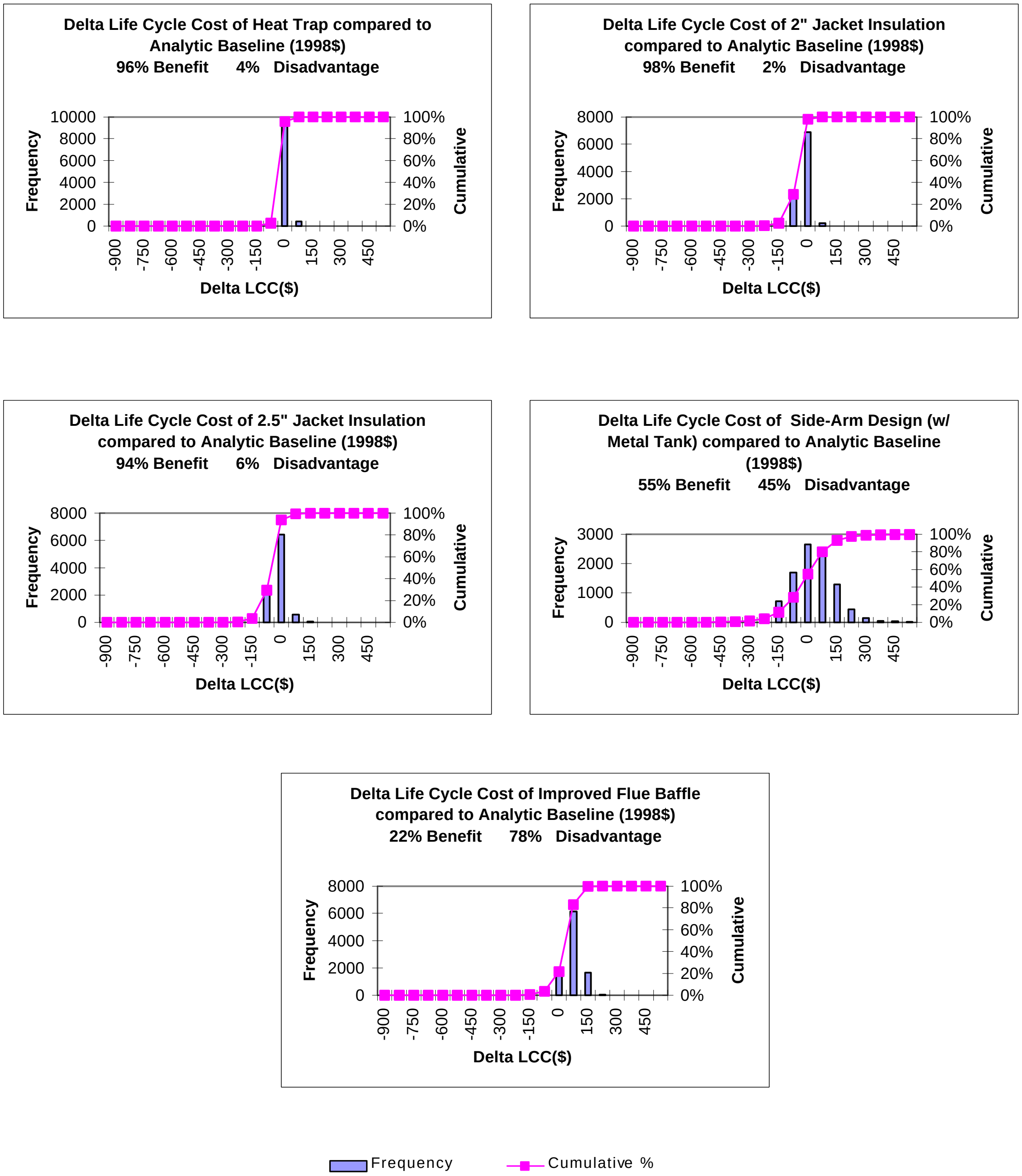

Figure 5.2.4 Difference in Life-Cycle Cost by Design Option for Gas-Fired Water Heaters

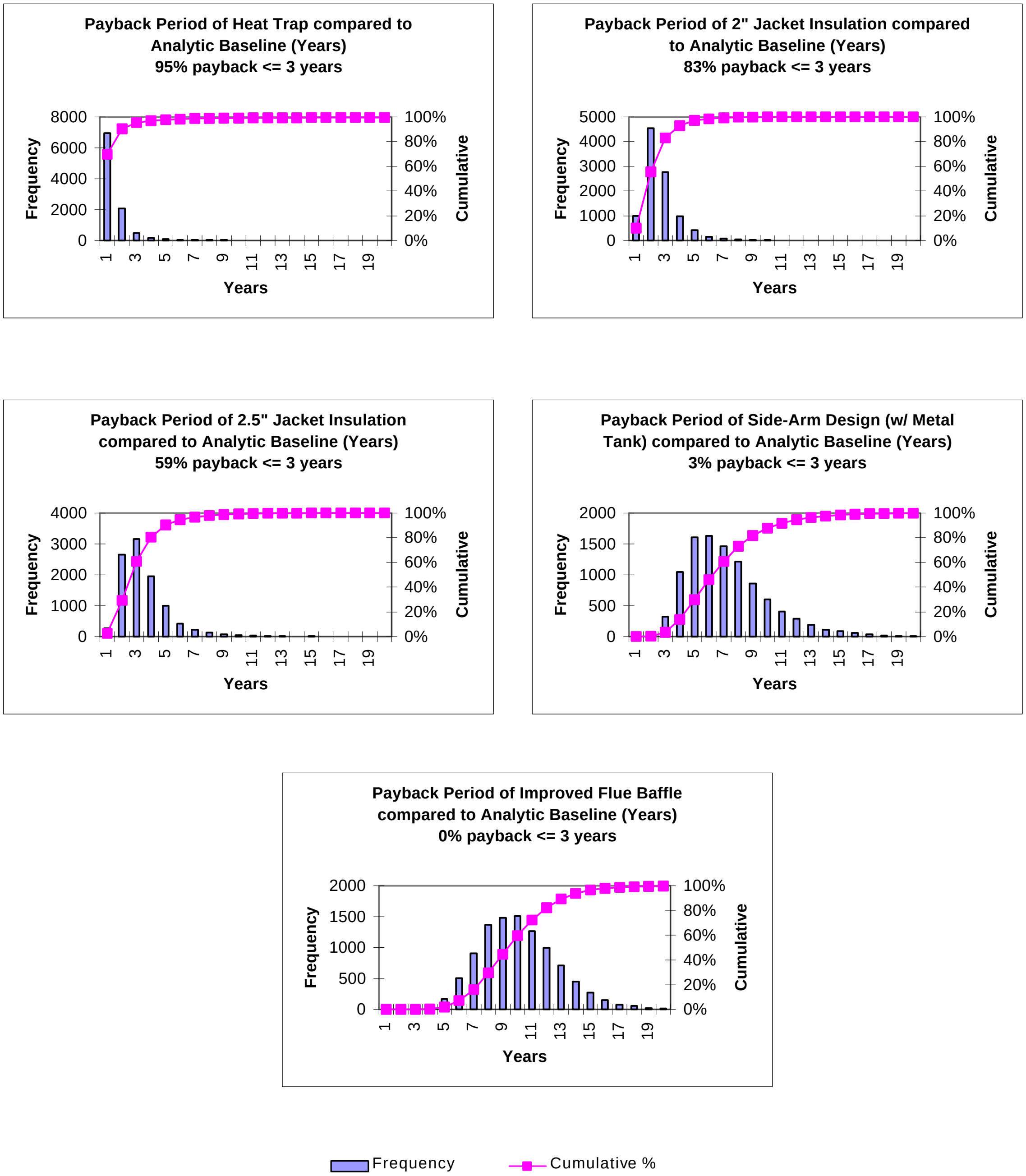

Figure 5.2.5 Payback Period by Design Option for Gas-Fired Water Heaters

The following two sensitivity charts (Figures 5.2.6 and 5.2.7) show the results of sensitivity analysis for differences in LCC for the design options with the highest average life-cycle cost savings for electric and gas-fired water heaters. Sensitivity charts for other design options are found in Appendix A. Figure 5.2.6 and Figure 5.2.7 show the rank order correlation of input variables with the incremental LCC for the 2.5" Jacket Insulation on electric water heaters and the 2" Jacket Insulation design option on gas-fired water heaters. Variables are ordered with maximum correlation (positive or negative) on top and minimum correlations on the bottom.

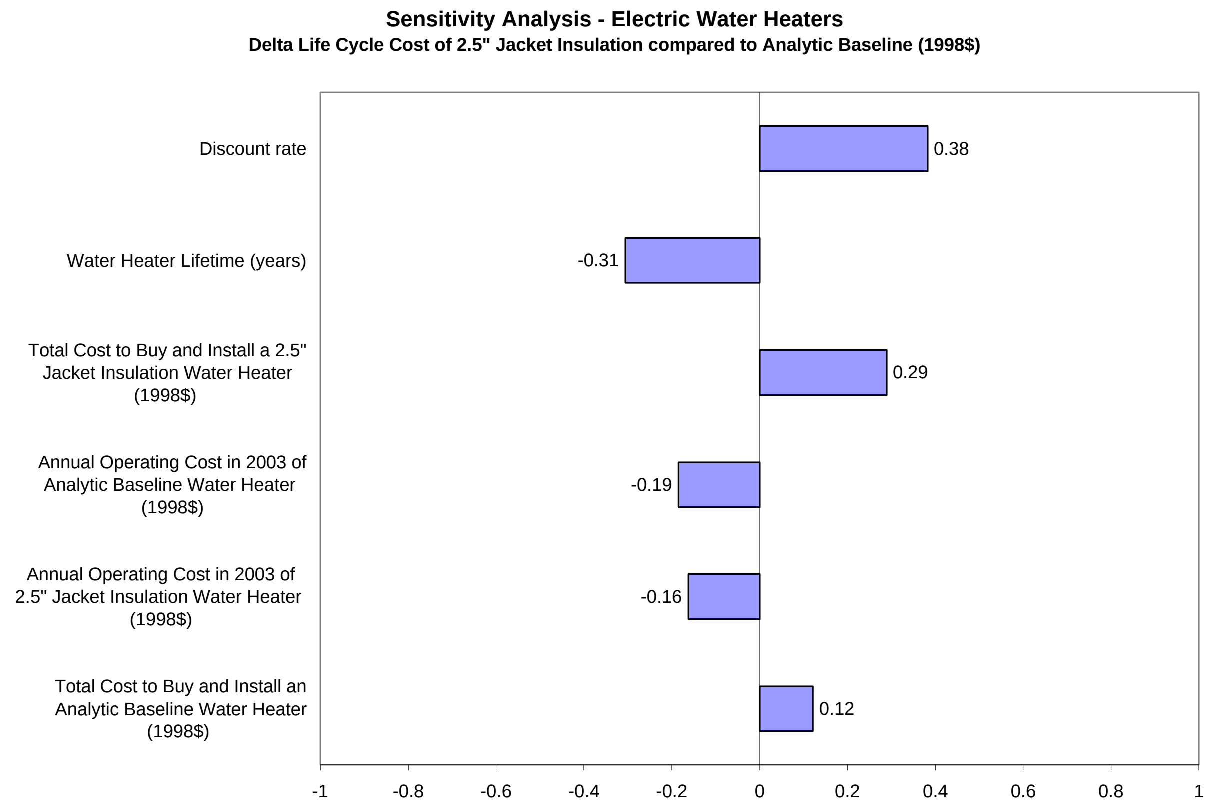

Figure 5.2.6 Sensitivity Analysis for Difference in Life-Cycle Cost of 2.5" Jacket Insulation on Electric Water Heater

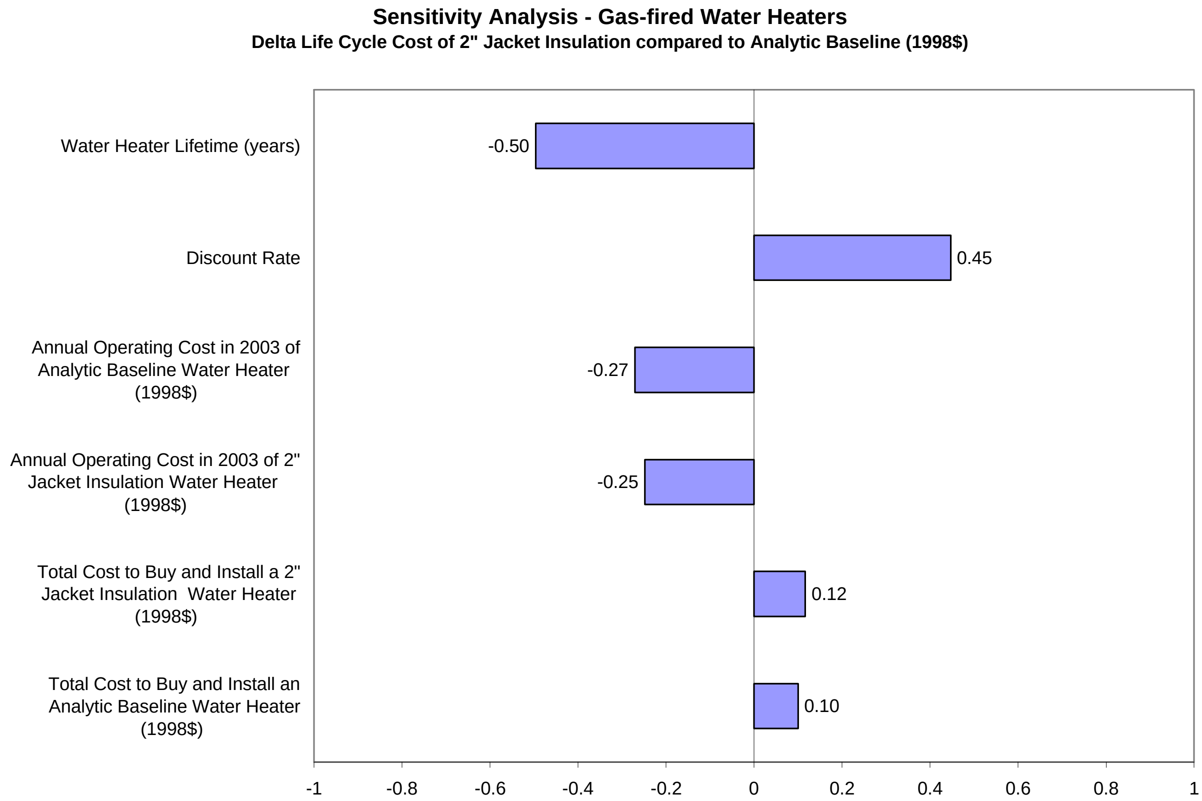

Figure 5.2.7 Sensitivity Analysis for Difference in Life-Cycle Cost of 2" Jacket Insulation on Gas-fired Water Heater

5.3 Equipment Cost Module

5.3.1 Introduction to Equipment Cost

The equipment cost represents the sum of the retail price, sales tax, and installation costs. The retail price is calculated from the manufacturer's cost multiplied by an overall markup.

The first half of this discussion addresses the typical existing baseline model; the analytic baseline model is the basis for the later description of the design options.

5.3.2 Equation for Equipment Cost

The water heater cost (equipment cost only) is calculated using the equation:

$$EquipCost_{option,\ size} = MfrCost_{option,\ size}\ x\ Markup_{size}\ x\ (1 + SalesTax) + TotlInstCost_{option}$$

where:

MfrCost	=	cost to manufacture water heater ($)
Markup	=	markup from manufacturer's cost to retail price
SalesTax	=	sales tax on water heater (%)
TotInstCost	=	total cost of installation of water heater ($)

The markup is calculated using the following ratio:

$$Markup_{size} = RetlPrice_{size} / MfrCost_{size}$$

where:

RetlPrice	=	water heater price at the retail outlet, all standard-size existing baseline models ($)

Total installation cost is based on:

$$TotInstCost_{option} = InstCost + AddInstCost_{option}$$

where:

InstCost	=	cost to install baseline water heater ($)

AddInstCost = additional cost(s) to install fuel-fired water heater with certain design options ($)

The additional installation cost is calculated as follows:

$$AddInstCost_{option} = AddElecCost_{option} + AddVentCost_{option} + AddTubeCost_{option}$$

where:

AddElecCost = additional cost of installing a new electric circuit for gas-fired water heaters with design options that require electricity ($)

AddVentCost = additional cost of upgrading the venting system for gas-fired water heaters with designs that increase recovery efficiency ($)

AddTubeCost = additional cost to install a burner tube extension for oil-fired water heaters with certain design options ($)

5.3.3 General Description of Key Variables

MfrCost is the manufacturing cost to produce a water heater. This cost is the sum of the variable and the fixed costs. The variable costs are composed of the direct costs to the manufacturer, which are defined as the sum of the material, labor, and overhead costs. The variable manufacturer cost is also called a full production cost. The fixed costs, the costs to convert to the production of a new water heater design, are the sum of the capital cost and the product design cost. The fixed manufacturer cost is sometimes called a conversion cost.

Markup is defined as the ratio between the retail price to the manufacturer's cost. This is an overall markup; it may include several intermediate markups applied by a wholesaler or other intermediate sellers.

SalesTax is the local, state or county tax applied to the water heater at the point of sale.

RetlPrice is defined as the retail outlet price of the water heater paid directly by the customer. This price does not include the installation cost or any other miscellaneous fees such as delivery fee, removal fee, permit fee, and parts fee.

TotInstCost is the total installation cost of the water heater. It is the price paid directly by the customer to have the water heater installed including the additional cost of adding a new electrical circuit and/or upgrading the venting system in the case of some gas-fired water heater design options.

InstCost is the installation cost of the baseline water heater. It is the price paid directly by the customer to have the water heater installed, including any miscellaneous fees such as delivery fee, removal fee, permit fee, and parts fee. It does not include the cost of adding a new electrical circuit and/or upgrading the venting system in the case of gas-fired water heaters with design options that may require these.

AddInstCost is the additional installation cost to install an electric circuit and/or to upgrade the venting system of a gas-fired water heater, or to install a burner tube extension for oil-fired water heater.

AddElecCost is the additional cost of installing an electric circuit for the gas-fired water heater when the design option includes an intermittent ignition device and/or an electromechanical flue damper and there is no pre-existing electrical outlet near the water heater.

AddVentCost is the additional cost to install an upgraded venting system or upgrade an existing venting system to eliminate condensate problems in gas-fired water heaters with design options that increase recovery efficiency. As discussed in the Engineering Report, the flue loss efficiency has been limited to 80.0%. Consequently the only upgrades considered are the installation of Type-B vent connectors between the water heater and the existing vent system.

AddTubeCost is the additional installation cost to install a burner tube extension for an oil-fired water heater with thicker insulation than the baseline unit.

5.3.4 General Description of Sources of Data

Introduction

To determine the equipment cost, manufacturing cost, retail price, installation cost, and sales tax information are needed. GAMA provided estimates of water heater manufacturing costs for typical existing baseline models[11]. LBNL contracted with a consultant[12] recommended by GAMA for additional data. (Fixed manufacturing costs, because they apply only to costs associated with converting to new water heater designs, are discussed later in this section in conjunction with the analytic baseline.)

The source of the retail price, the sales tax, and the installation cost is the LBNL Water Heater Cost Database which contains data collected from large retail chains and various wholesale distributors. The following variables from the database are used to identify the retail price data:

RatedVolume	Volume of the water heater tank
WHModel	Model name
YearsWarranty	Number of years covered in the model's warranty
WHFuel	Type of fuel used
RetailPrice	Retail price
DeliveryFee	Charge for transporting water heater to the customer’s house
InstallFee	Charge to install water heater
RemovalFee	Charge to remove old water heater from the customer’s house
PermitFee	Fee (where required) to install water heater
PartFee	Charge for (any) extra parts

Markup is based on manufacturing cost and retail price. The retail prices for all standard-size existing baseline models are drawn from the collected data. The criteria for the existing baseline models are a 5-year manufacturing warranty and no special design features. Manufacturing costs for other than typical existing baseline water heaters, i.e., all other standard sizes, are based on the manufacturing cost for the typical water heater plus (or minus) incremental costs for extra (or less) foam insulation and sheet metal.

Manufacturing Cost

Variable Manufacturing Cost. The variable component of the manufacturing cost for the typical existing model is the sum of direct material, direct labor, overhead, and transportation costs. The overhead cost includes the factory overhead cost only. The non-production costs, which include selling, general, and administrative costs, research and development costs, and interest costs, are considered a part of the fixed manufacturing cost and are not included in the variable manufacturing cost.

The typical existing baseline variable manufacturing cost data used in the analysis for electric, gas-fired, and oil-fired water heaters are presented in Table 5.3.1.

Table 5.3.1 Typical Existing Baseline Water Heaters - Variable Cost Data

Typical Existing Baseline	Average Variable Costs				Cost Uncertainty Range	
	Material ($)	Labor ($)	Overhead* ($)	Total ($)	Minimum	Maximum
Electric (50-gal)	62.16	12.41	50.99	125.56	84.96	171.92
Gas (40-gal)	75.02	12.49	50.10	137.61	104.31	174.40
Oil (32-gal)						

*includes transportation

As explained above, the manufacturing costs for other size water heaters are based on the manufacturing cost for the typical existing baseline water heater plus (or minus) incremental costs for extra (or less) materials, i.e., foam insulation and sheet metal. Table 5.3.2. presents the calculated incremental costs for all other standard-size existing baseline models.

Table 5.3.2 Other Standard-Size Existing Baseline Water Heaters -Variable Cost Data

Rated Volume	Incremental Material Cost ($)	Total Variable Cost ($)
Electric 30-gal	-7.78	117.78
Electric 40-gal	-2.83	122.73
Electric 65-gal	3.87	129.43
Electric 80-gal	7.39	132.95
Gas-fired 30-gal	-3.15	134.46
Gas-fired 50-gal	2.23	139.84
Gas-fired 75-gal	7.50	145.11
Oil-fired 50-gal		

Retail Price

The retail price is defined as the retail outlet price of the water heater equipment paid directly by the customer. This price does not include the installation cost nor any other miscellaneous fees such as delivery fee, removal fee, permit fee, or parts fee. The retail price analysis is based on the LBNL Water Heater Cost Database which contains data collected from retail chains and wholesale distributors.

The models selected for the analysis are baseline models with a 5-year manufacturing warranty and no special design features. Figure 5.3.1 presents the sample sizes for electric water heaters, showing the number of retailer responses on which the retail cost data is based. Figure

5.3.3 presents the sample sizes for gas-fired water heaters. For example, the retail price for the 50-gal electric water heater is based on a sample of 50 responses regarding the retail price of existing baseline water heaters and the retail price for the 40-gal gas-fired water heater is based on a sample of 52 responses. The size of the data samples generally reflects that of the 1996 GAMA-reported shipment share of each water heater size (rated volume)[13]. The comparisons of GAMA water heater shipments vs. water heater sample size by rated volume are shown in Figure 5.3.2 for electric water heaters and in Figure 5.3.4 for gas-fired water heaters. As can be seen in the figures, the fit is quite close, although much better for electric than gas-fired. This indicates that the samples generally reflect actual shipments.

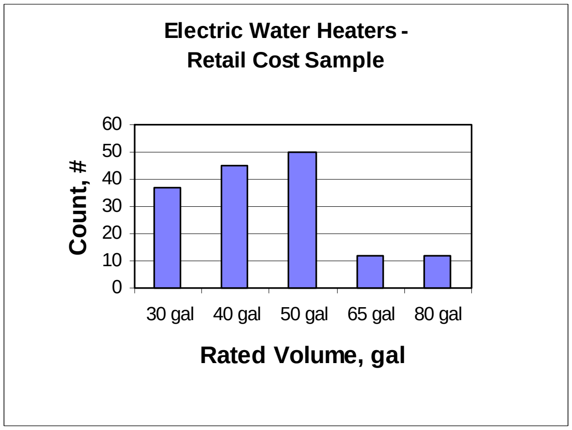

Figure 5.3.1 Electric Water Heaters Sample Sizes

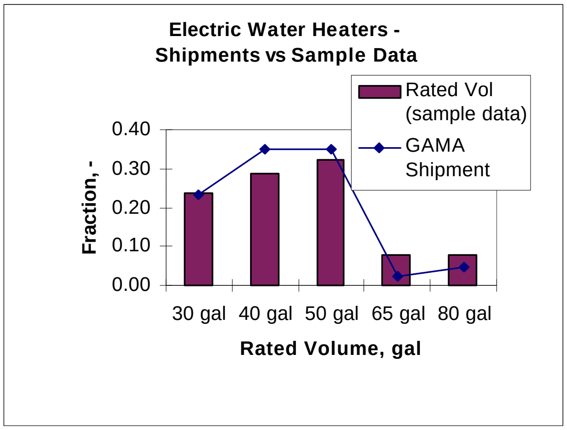

Figure 5.3.2 Electric Water Heaters - Shipments vs Sample Sizes

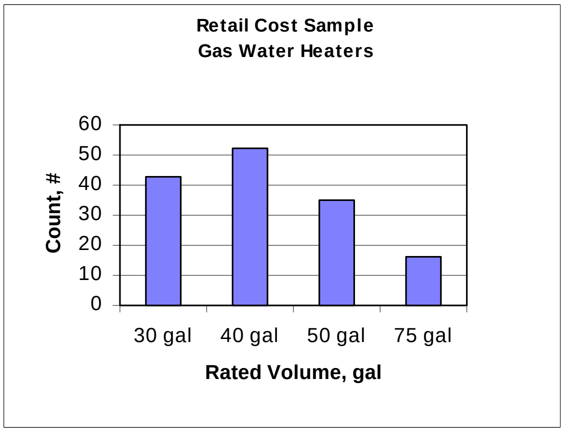

Figure 5.3.3 Gas-fired Water Heaters - Sample Sizes

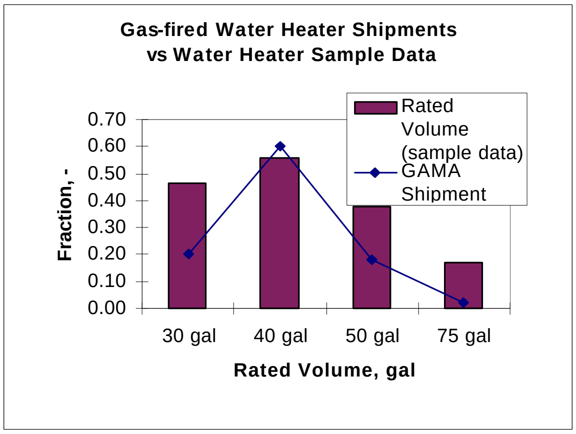

Figure 5.3.4 Gas-fired Water Heaters - Shipments vs Sample Sizes

The retail prices for all standard-size existing baseline water heaters are shown in Figure 5.3.5 for electric water heaters and in Figure 5.3.6 for gas-fired water heaters. The mean values represent the average reported retail price for each standard-size water heater. The figures also show the minimum and maximum values for the retail price ranges obtained through the survey. For example, the mean retail price for the 50-gal electric water heater is $178.88, with the minimum retail price reported to be $128.00 and the maximum as $297.00. In the case of gas-fired water heaters, the mean retail price for the 40-gal size water heater is $149.94, with the minimum of $115.00 and the maximum of $260.00. Note that these retail prices do not include sales tax.

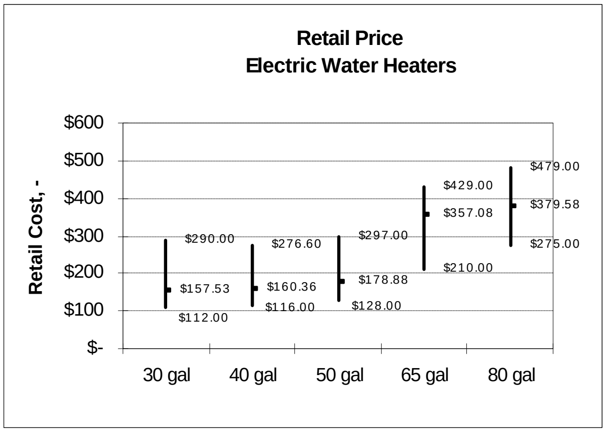

Figure 5.3.5 Retail Prices - Electric Water Heaters

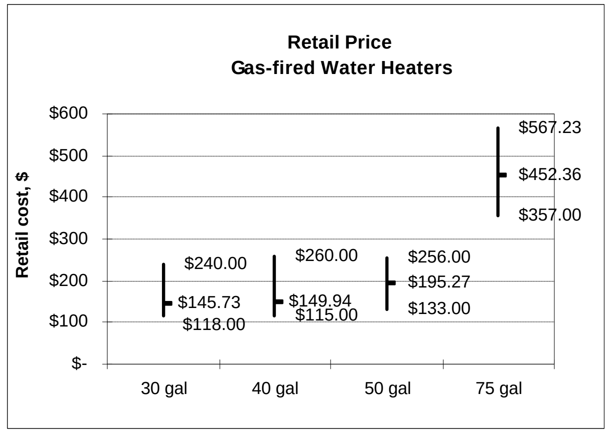

Figure 5.3.6 Retail Prices - Gas-fired Water Heaters

Installation Cost

The installation cost of the water heater is the price paid by the customer to have the water heater installed. This price does not include the retail price, but does include other miscellaneous fees such as delivery fee, removal fee, permit fee, and parts fee.

Installation costs are included in the LBNL Water Heater Cost Database used for the development of the water heater retail prices. The baseline models were selected using the same criteria used for the retail price determination: a 5-year manufacturing warranty and no special design features.

Figure 5.3.7 presents the sample sizes for electric water heaters, showing the number of retailer responses on which the installation cost data is based. Figure 5.3.8 presents the sample sizes for gas-fired water heaters. For example, the installation cost for the 50-gal electric water heater is based on a sample of 41 responses about installation costs for the existing baseline water heaters and the installation cost for the 40-gal gas-fired water heater is based on a sample of 48 responses.

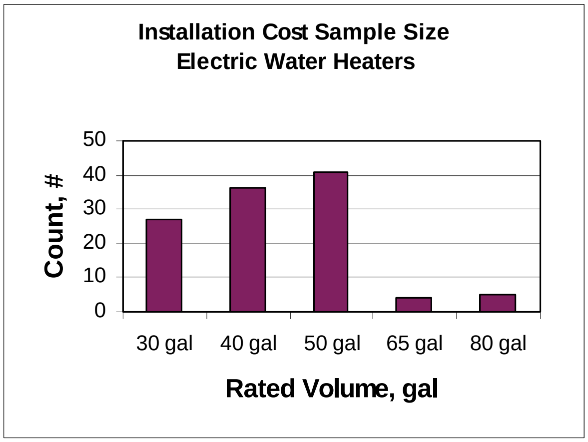

Figure 5.3.7 Installation Cost Sample Size - Electric Water Heaters

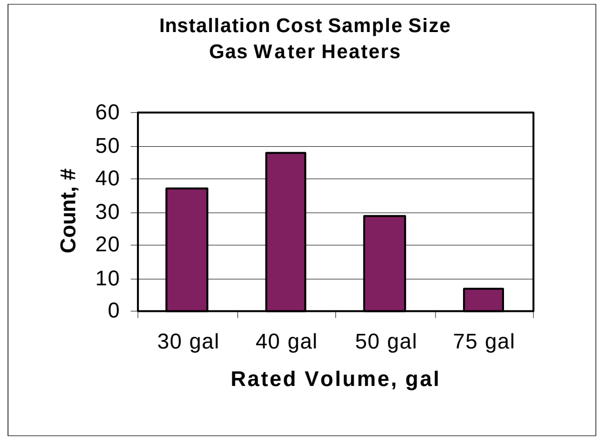

Figure 5.3.8 Installation Cost Sample Size - Gas-fired Water Heaters

The installation costs for all standard-size existing baseline water heaters are shown in Figure 5.3.9 for electric water heaters and in Figure 5.3.10 for gas-fired water heaters. The mean values represent the average reported installation cost for each water heater size. The figures also show the minimum and maximum values for installation costs obtained through the survey. For example, the mean installation cost for the 50-gal electric water heater is $160.73, with the minimum reported to be as little as $65.00 and the maximum as high as $258.00. The relatively narrow installation cost range for 65-gal electric water heaters is primarily due to the small installation cost sample size for this particular tank size (see Fig. 5.3.7). In the case of gas-fired water heaters, the average installation cost for the 40-gal size water heater is $159.52, with a minimum of $65.00 and a maximum of $258.00.

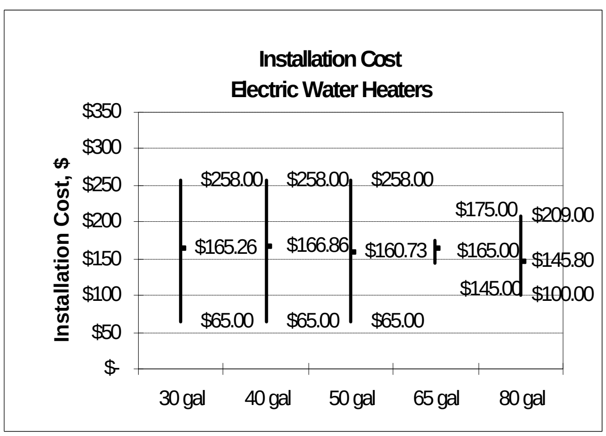

Figure 5.3.9 Installation Cost Ranges - Electric Water Heaters

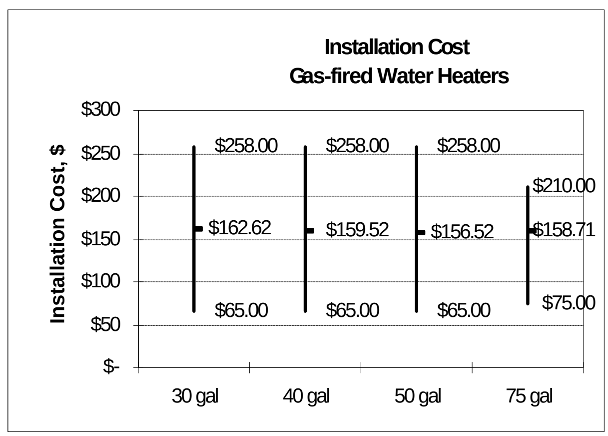

Figure 5.3.10 Installation Cost Ranges - Gas-fired Water Heaters

Manufacturer-to-Retail Markup

The manufacturer-to-retail markup is defined as the ratio of the retail price to the manufacturer cost. The retail prices reflect those of water heaters sold in 1998. Since the retail price and the estimated manufacturer cost differ for each fuel type and for each size (rated volume), the markup is different for each standard-size existing baseline model. Tables 5.3.3 and 5.3.4 show the average estimated markups for electric and gas-fired water heaters, respectively. The markup includes the average national value for taxes of 5.20% (A.D.L., 1998). Note that the retail prices are calculated using an exact value for the multipliers.

Table 5.3.3 Electric Water Heaters - Markup

Rated Volume	Manufacturer Cost ($)	Retail Price ($)	Markup
30-gal	117.78	165.72	1.41
40-gal	122.73	168.70	1.37
50-gal	125.56	188.18	1.50
65-gal	129.43	375.65	2.90
80-gal	132.95	399.32	3.00

Table 5.3.4 Gas-fired Water Heaters - Markup

Rated Volume	Manufacturer Cost ($)	Retail Price ($)	Markup
30-gal	134.46	153.31	1.14
40-gal	137.61	157.74	1.15
50-gal	139.84	205.42	1.47
75-gal	145.11	475.88	3.28

Analytic Baseline

As explained in the Engineering Report, the HCFC-141b blowing agent currently in use will be replaced by 2003. This report assumes that the new blowing agent will be HFC-245fa. The analytic baseline model developed for this analysis utilizes foam insulation blown with HFC-245fa. The assumed costs for the insulation components for both blowing agents are shown in Table 5.3.5. The total cost per pound of foam with the new blowing agent is $1.32 as compared to $1.00 for foam blown with HCFC-141b. Additionally, as also discussed in the Engineering Report, for health and safety reasons, future gas-fired water heaters must be able to resist ignition of flammable vapors. The new analytic baseline model for gas-fired water heaters includes the cost of design changes to prevent ignition of flammable vapors.

All of the following discussions are based on the analytic baseline models. The rated tank volumes of the analytic baseline models are the same as the tank volumes of the existing baseline models.

Table 5.3.5 Insulation Components Cost

Foam Components	Fraction (%)	Component Cost ($/lb)	Cost (141b) ($/lb)	Cost (245fa) ($/lb)
Blowing agent (141b)	13	1.50	0.20	--
Blowing agent (245fa)	13	4.00	--	0.52
Isocyanurate	51	0.75	0.38	0.38
Polyols	31	0.65	0.20	0.20
Catalysts, refractants, etc.	5	4.50	0.22	0.22
Total	100		1.00	1.32

Source: Williams, 1998[14].

Design Options

The incremental manufacturing costs for the design options were supplied primarily by GAMA. GAMA did not provide data for 2.5 " Jacket Insulation for electric water heaters, 2.5" Jacket Insulation, Plastic Tank, and Side Arm Heater for gas-fired, nor any of the design options for oil-fired water heaters. The missing data was supplemented by information obtained from consultants M. Minnear and E. West[15]. LBNL recalculated the costs of the insulation and the sheet metal to reflect the characteristics of the HFC-245fa blowing agent.

Design Option Combinations. As shown in Appendix F of the Engineering Report, many combinations of design options were initially analyzed. Most of the selected designs consist of combinations of basic design options. The Engineering Report gives a detailed explanation of the selection of design option combinations and the payback calculations. Energy costs for ordering and combining design options for all three fuel types were based on AEO's national average energy prices for the year 2003. A list of design option combinations is shown in Table 5.3.6 for electric water heaters and in Table 5.3.7 for gas-fired water heaters.

Table 5.3.6 Design Option Combinations for LCC Analysis - Electric Water Heaters

#	Design Option Combinations
0	Typical Analytic Baseline
1	0 + Heat Traps
2	1 + 2" Jacket Insulation
3	1 + 2.5" Jacket Insulation
4	3 + Plastic Tank
5	3 + Insulated Tank Bottom

Table 5.3.7 Design Option Combinations for LCC Analysis - Gas-fired Water Heaters

#	Design Option Combinations
0	Typical Analytic Baseline
1	Heat Traps
2	1 + 2" Jacket Insulation
3	2 + 2.5" Jacket Insulation
4	3 + Side Arm Heater
5	2 + Improved Flue Baffle

For each design option combination, the incremental variable and fixed costs were developed from the costs of each design component. The uncertainty ranges of the incremental total costs for most of the design options were provided by GAMA. Some of the variations (2.5" Jacket Insulation, Plastic Tank, and Side Arm Heaters) were developed using the ranges provided by M. Minniear and E. West. Since the uncertainty values were provided for the existing models, the next step was to recalculate the data to be applicable for the design options based on the analytical model.

Incremental Manufacturing Costs

The LCC analysis uses individual design options that are then grouped together in combinations of design options according to the results of the Engineering Analysis. This analytic procedure requires incremental manufacturing costs of individual design options.

The distributions of the manufacturing costs for most design options were provided by GAMA as cumulative frequency tables. GAMA data only applied to 50-gal electric water heaters and to 40-gal gas-fired water heaters. This data is used as a basis for the development of the incremental manufacturing costs. Table 5.3.8 for electric water heaters and Table 5.3.9 for gas-fired water heaters show a schematic view of the methodology used in the development. A detailed explanation of the procedure is presented in Appendix B of this report.

The general methodology is as follows: 1) GAMA distributions of the manufacturing cost for each design option (aside from the existing baseline) are adjusted for HFC-245fa foam by adding or subtracting the cost of the foam. 2) The GAMA distributions of the manufacturing cost for the other standard sizes are adjusted by adding or subtracting the cost of extra foam and extra sheet metal. No size adjustments for costs of the Plastic Tank or Insulated Tank Bottom design options were made. 3) The distributions of the manufacturing cost for the design options not provided by GAMA are based on distribution ranges provided by LBNL consultants.

Table 5.3.8 Electric Water Heaters - Incremental Manufacturing Costs for Separate Design Options and Standard Sizes

Design Option	30-gal	40-gal	50-gal	65-gal	80-gal
Existing Baseline	GAMA Level 1 - (change tank size)	GAMA Level 1 - (change tank size)	GAMA Level 1	GAMA Level 1 + (change tank size)	GAMA Level 1 + (change tank size)
Analytic Baseline	GAMA Level 1 - (change tank size) + (HFC-245fa)	GAMA Level 1 - (change tank size) + (HFC-245fa)	GAMA Level 1 + (HFC-245fa)	GAMA Level 1 + (change tank size) + (HFC-245fa)	GAMA Level 1 + (change tank size) + (HFC-245fa)
Heat Traps	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1
2" Jacket Insul	GAMA Level 3 - Level 1- (change tank size) + (HFC-245fa)	GAMA Level 3 - Level 1- (change tank size) + (HFC-245fa)	GAMA Level 3 - Level 1+ (HFC-245fa)	GAMA Level 3 - Level 1+ (change tank size) + (HFC-245fa)	GAMA Level 3 - Level 1 + (change tank size) + (HFC-245fa)
2.5" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul
Plastic Tank	Plastic Tank (from M. Minniear)	Plastic Tank (from M. Minniear)	Plastic Tank (from M. Minniear)	Plastic Tank (from M. Minniear)	Plastic Tank (from M. Minniear)
Insul Tank Bottom	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1

Note: GAMA levels for electric water heaters:

Level 1 - Baseline
Level 2 - Heat Traps
Level 3 - 2" Jacket Insulation
Level 6 - Insulated Tank Bottom

Table 5.3.9 Gas-Fired Water Heaters - Incremental Manufacturing Costs for Separate Design Options and Standard Sizes

Design Option	30-gal	40-gal	50-gal	75-gal
Existing Baseline	GAMA Level 1 - (change tank size)	GAMA Level 1	GAMA Level 1 + (change tank size)	GAMA Level 1 + (change tank size)
Analytic Baseline	GAMA Level 1 - (change tank size) + (HFC-245fa) + (flammable vapor)	GAMA Level 1 + (HFC-245fa) + (flammable vapor)	GAMA Level 1 + (change tank size) + (HFC-245fa) + (flammable vapor)	GAMA Level 1 + (change tank size) + (HFC-245fa) + (flammable vapor)
Heat Traps	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1	GAMA Level 2 - Level 1
2" Jacket Insul	GAMA Level 3 - Level 1 - (change tank size) + (HFC-245fa)	GAMA Level 3 - Level 1 + (HFC-245fa)	GAMA Level 3 - Level 1 + (change tank size) + (HFC-245fa)	GAMA Level 3 - Level 1 + (change tank size) + (HFC-245fa)
2.5" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul	scale 2" Jacket Insul
Side Arm Heater	Side Arm Heater (from M. Minniear)	Side Arm Heater (from M. Minniear)	Side Arm Heater (from M. Minniear)	Side Arm Heater (from M. Minniear)
Electronic Ignition (IID)*	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1	GAMA Level 6 - Level 1
Improved Flue Baffle	GAMA Level 5 - Level 1	GAMA Level 5 - Level 1	GAMA Level 5 - Level 1	GAMA Level 5 - Level 1

*Although IID is included as a separate design option in this table, it is only used in conjunction with a Side Arm Heater.

Note: GAMA levels for gas-fired water heaters:

Level 1 - Baseline
Level 2 - Heat Traps
Level 3 - 2" Jacket Insulation
Level 5 - Improved Flue Baffle
Level 6 - Electronic Ignition (IID)

Table 5.3.10 lists the incremental costs for the individual design options for the typical 50-gal electric water heater.

Table 5.3.10 Incremental Costs for Electric Water Heaters (50-gal)

Design Options	Average Incremental Manufacturing Cost ($)
Heat Traps	6.68
2" Jacket Insulation	24.41
2.5" Jacket Insulation	43.01
Plastic Tank	27.93
Insulated Tank Bottom	32.89

Figure 5.3.11 shows the distribution of the incremental manufacturing costs of separate design options for the 50-gal electric water heater.

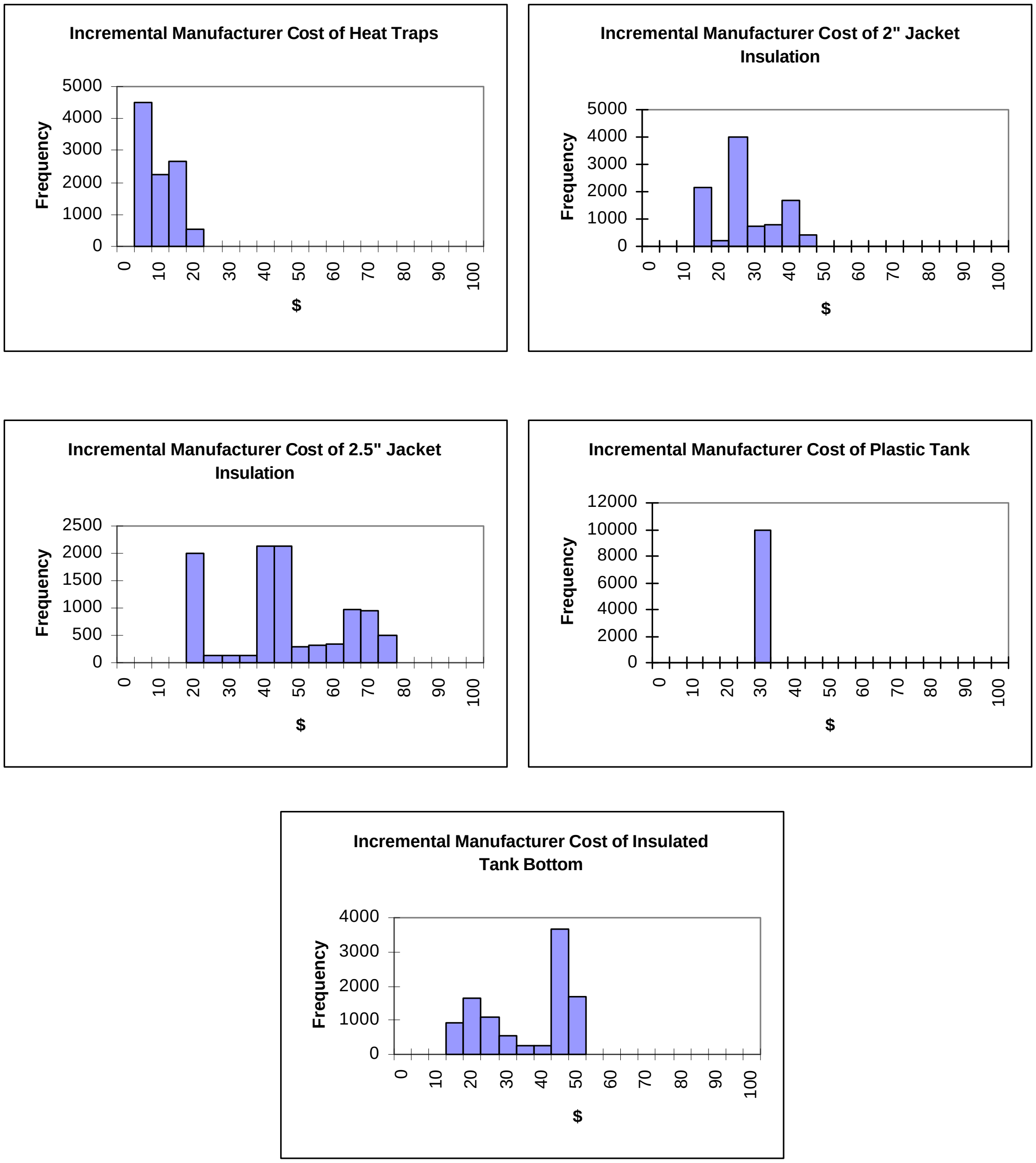

Figure 5.3.11 Distribution of Incremental Manufacturing Cost for Separate Design Options for Electric Water Heaters

Table 5.3.11 lists the incremental costs for the individual design options for the typical 40-gal gas-fired water heater.

Table 5.3.11 Incremental Costs for Gas-fired Water Heaters (40-gal)

Design Options	Average Incremental Manufacturing Cost ($)
Heat Traps	2.38
2" Jacket Insulation	16.41
2.5" Jacket Insulation	27.76
Side Arm Heater w/ IID	7.18
Improved Flue Baffle	108.11

Figure 5.3.12 shows the distribution of the incremental manufacturing cost of separate design options for the 40-gal gas-fired water heater.

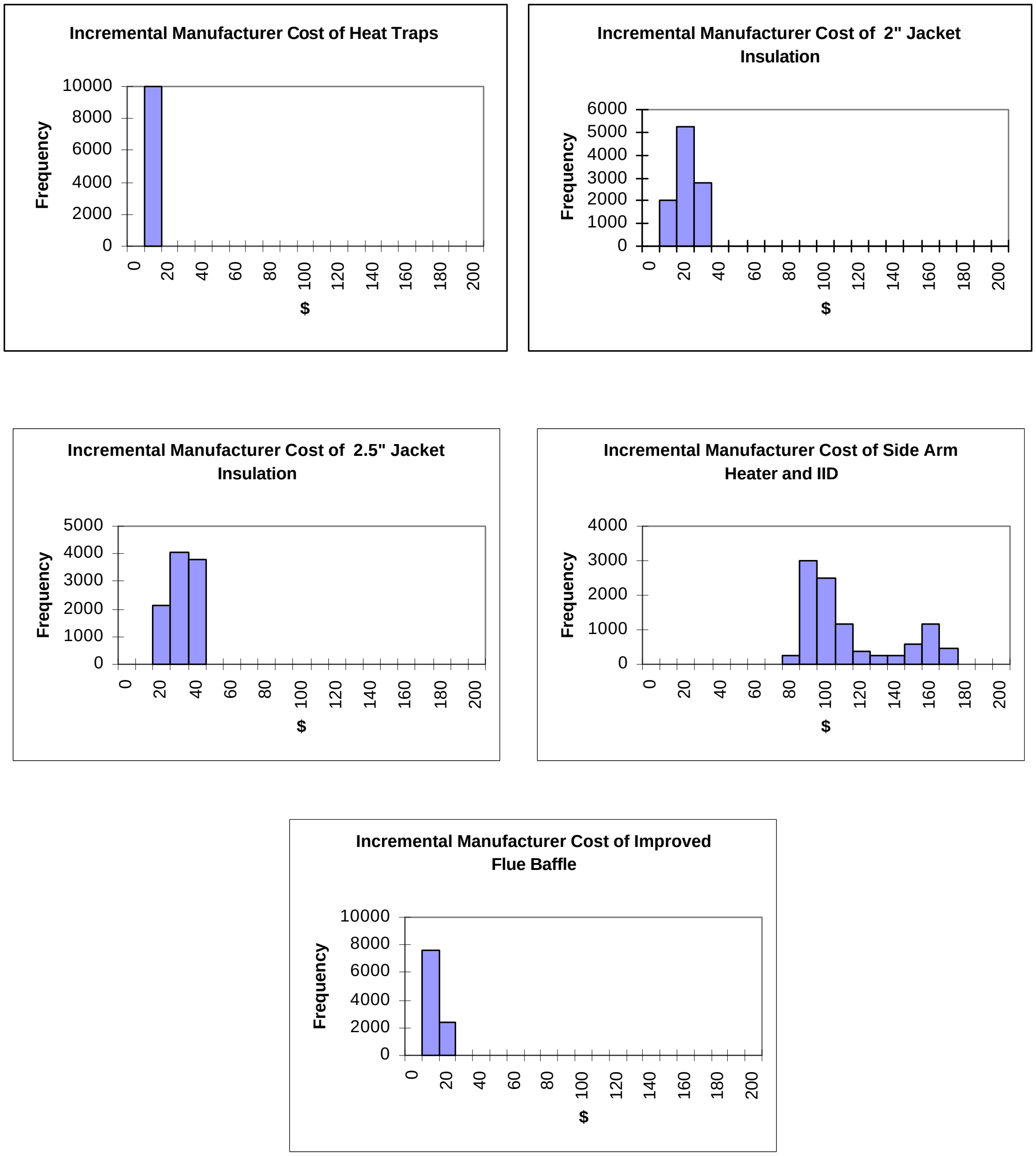

Figure 5.3.12 Distribution of Incremental Manufacturing Costs for Separate Design Options for Gas-Fired Water Heaters

Variable Manufacturing Cost. The variable manufacturing cost for each design option is calculated as the sum of the analytic baseline manufacturing cost plus the associated incremental variable manufacturing cost for that design option. The incremental variable manufacturing cost is the sum of the incremental material, labor, and overhead cost to produce the design option.

The typical analytic baseline variable manufacturing costs and the incremental variable costs for design options used in the analysis for electric water heaters are presented in Table 5.3.12 and for the gas-fired water heaters in Table 5.3.13. These costs come from the Engineering Report.

As mentioned earlier, for health and safety reasons, future gas-fired water heaters must resist flammable vapor ignition. Because of this, the variable manufacturing cost for the analytic baseline model includes a cost of $15 for a design to prevent ignition of flammable vapors. Since the added variable cost is included in the typical analytic baseline design, it does not impact the cost-effectiveness of any design improvement. Note that the incremental insulation costs for the baseline electric water heater tank (50-gal) are lower than for gas-fired (40-gal), because the insulation for the baseline electric water heater tank is 1.5 inches thick compared to1 inch for the baseline gas-fired tank.

Table 5.3.12 Electric Water Heater (50-gal) - Variable Cost Data

	Design Options	Average Variable Costs			
		Material ($)	Labor ($)	Overhead ($)	Total ($)
0	Analytic Baseline	64.30	12.41	50.99	127.70
1	0 + Heat Traps	2.59	0.20	0.83	3.62
2	1+ 2" Jacket Insulation	8.59	0.51	3.66	12.76
3	1 + 2.5" Jacket Insulation	14.41	1.02	7.32	22.75
4	3 + Plastic Tank	5.25	0.80	3.20	9.25
5	3 + Insulated Tank Bottom*	0.00	0.00	0.00	26.98

* GAMA provided only total incremental costs.

Table 5.3.13 Gas-fired Water Heater (40-gal) - Variable Cost Data

	Design Options	Average Variable Costs			
		Material ($)	Labor ($)	Overhead ($)	Total ($)
0	Analytic Baseline	91.13	12.49	50.10	153.72
1	0 + Heat Traps	2.75	0.16	0.21	3.12
2	1 + 2" Jacket Insulation	9.59	0.60	4.93	15.12
3	1 + 2.5" Jacket Insulation	14.49	1.20	9.86	25.55
4	3 + Side Arm Heater	68.28	5.38	26.02	99.68
5	2 + Improved Flue Baffle	0.97	1.29	1.32	3.58

Fixed Manufacturing Cost. The fixed component of the manufacturing cost is the cost to convert the production line to manufacture a new water heater design. Some of the fixed costs used in the analysis were submitted by GAMA; the consultants provided the rest of the fixed costs. The fixed cost is the sum of the capital cost and the product design cost. Production volume has a significant impact on the per unit conversion cost, particularly on the capital cost. GAMA did not provide the range of production volume used to calculate the fixed costs, because of the need to protect specific manufacturer responses.

The fixed manufacturing cost for each design option is the sum of the incremental capital cost and the incremental product design cost to produce the design option. The incremental fixed manufacturing cost data used in the analysis for electric water heaters is presented in Table 5.3.14 and for the gas-fired water heaters in Table 5.3.15.

The fixed manufacturing cost for the gas-fired analytic baseline model includes a capital cost for a design to prevent ignition of flammable vapors. Since the added fixed cost is included in the typical analytic baseline design, it does not impact the cost-effectiveness of any design improvement. The assumed fixed cost of $20.00 for the ignition prevention design for gas-fired water heaters is included in the data for the analytic baseline model in Table 5.3.15. No attempt was made to disagregate the $20.00 between capital and product design costs. Note that GAMA provided both capital and product design costs for 2" insulation for gas-fired water heaters, but only a total fixed cost for electric water heaters.

Table 5.3.14 Electric Water Heaters (50-gal) - Fixed Cost Data

Design Options		Average Fixed Costs		
		Capital Cost ($)	Product Design ($)	Total ($)
0	Analytic Baseline	0.00	0.00	0.00
1	0 + Heat Traps**	--	--	0.39
2	1 + 2" Jacket Insulation**	--	--	0.73
3	1 + 2.5" Jacket Insulation*	--	--	1.02
4	3 + Plastic Tank*	15.00	3.00	18.00
5	3 + Insulated Tank Bottom**	--	--	3.39

* design options 3 & 4 are adjusted based on data from M. Minniear
**GAMA provided only total incremental costs.

Table 5.3.15 Gas-fired Water Heaters (40-gal) - Fixed Cost Data

Design Options		Average Fixed Costs		
		Capital Cost ($)	Product Design ($)	Total ($)
0	Analytic Baseline*	20.00	0.00	20.00
1	0 + Heat Traps	0.07	0.13	0.20
2	1 + 2" Jacket Insulation	0.85	0.59	1.44
3	1 + 2.5" Jacket Insulation **	1.28	1.18	2.46
4	3 + Side Arm Heater**	6.34	3.49	9.83
5	2 + Improved Flue Baffle	1.17	1.72	2.89

*with flammable vapor resistant design
**design options 3 & 4 are adjusted based on data from M. Minniear

Other Standard Sizes - Manufacturing Cost. The typical analytic baseline models represent the common size water heaters with an efficiency equal to the minimum allowed by the existing energy efficiency standards. These units have the largest market share in their product class. Other standard water heater sizes are manufactured in addition to the typical size.

The methodology used to select water heaters with rated volumes other than the typical size is explained in Section 5.1 of this report. The manufacturing costs for all sizes were estimated from the variable manufacturing cost for the typical existing baseline water heaters by adding or subtracting the cost of incremental amounts of insulation and sheet metal. It was assumed that there would be no differences in the fixed manufacturing costs for other size water heaters. The variable manufacturing costs for Heat Traps, Plastic Tank, and Insulated Tank Bottom for electric water heaters, and Side Arm Heater and Improved Flue Baffle for gas-fired water heaters, were assumed to be the same for all sizes. The variable manufacturing cost data used in the analysis for electric water heaters are presented in Table 5.3.16 and for the gas-fired water heaters in Table 5.3.17.

Table 5.3.16 All Standard Sizes Variable Manufacturing Cost - Electric Water Heater

Design Options	30-gal ($)	40-gal ($)	50-gal (typical) ($)	65-gal ($)	80-gal ($)
Existing baseline	117.78	122.73	125.56	129.43	132.95
Analytic baseline	119.29	124.67	127.70	131.86	135.63
2" Jacket Insulation	11.96	12.53	12.76	13.09	13.38
2.5" Jacket Insulation	21.01	22.25	22.75	23.44	24.05

Note: Costs of increased jacket insulation are presented as incremental variable manufacturing costs and are based on the typical analytic baseline.

Table 5.3.17 All Standard Sizes Variable Manufacturing Cost - Gas-fired Water Heater

Design Options	30-gal ($)	40-gal (typical) ($)	50-gal ($)	75-gal ($)
Existing baseline	134.46	137.61	139.84	145.11
Analytic baseline	150.40	153.72	156.06	161.59
2" Jacket Insulation	14.41	15.12	15.55	16.62
2.5" Jacket Insulation	24.47	25.55	26.21	27.82

Note: Costs of increased jacket insulation are presented as incremental variable manufacturing costs and are based on the typical analytic baseline.

As explained in the Engineering Report, multiple design options were developed for each water heater fuel type.

Markup for Design Options

The manufacturer-to-retail markup was assumed to remain constant for all of the design options within a standard size model. Thus, the retail price for any design was determined simply by multiplying its manufacturer cost by the derived markup for the existing baseline water heater of that size.

5.3.5 Results

Electric Water Heater Equipment Costs

Table 5.3.18 lists the average manufacturing and total installed cost for the analytic baseline and the design option combinations for all sizes of electric water heaters, where total installed cost is the final total cost to the customer, i.e., the sum of the retail price, sales tax, and any installation cost.

Table 5.3.18 Equipment Costs for Electric Water Heaters (All Sizes)

Design Options		Average Manufacturing Costs ($)	Average Total Installed Costs ($)
0	Analytic Baseline	121.13	345.09
1	0 + Heat Traps	127.81	355.58
2	1 + 2" Jacket Insulation	148.43	388.35
3	1 + 2.5" Jacket Insulation*	163.97	413.08
4	3 + Plastic Tank	191.90	456.98
5	3 + Insulated Tank Bottom	196.86	464.68

Figure 5.3.13 shows, for each design option and for all standard sizes, the difference in total installed cost compared to the analytic baseline for electric water heaters. Variations in total installed cost include variations in manufacturing cost, mark-up, and installed cost. In general, design options with higher efficiencies have a wider spread in total incremental installed cost. Note that Table 5.3.18 shows average manufacturing cost and average total installed equipment cost, while Figure 5.3.13 shows the spread of the incremental total installed cost.

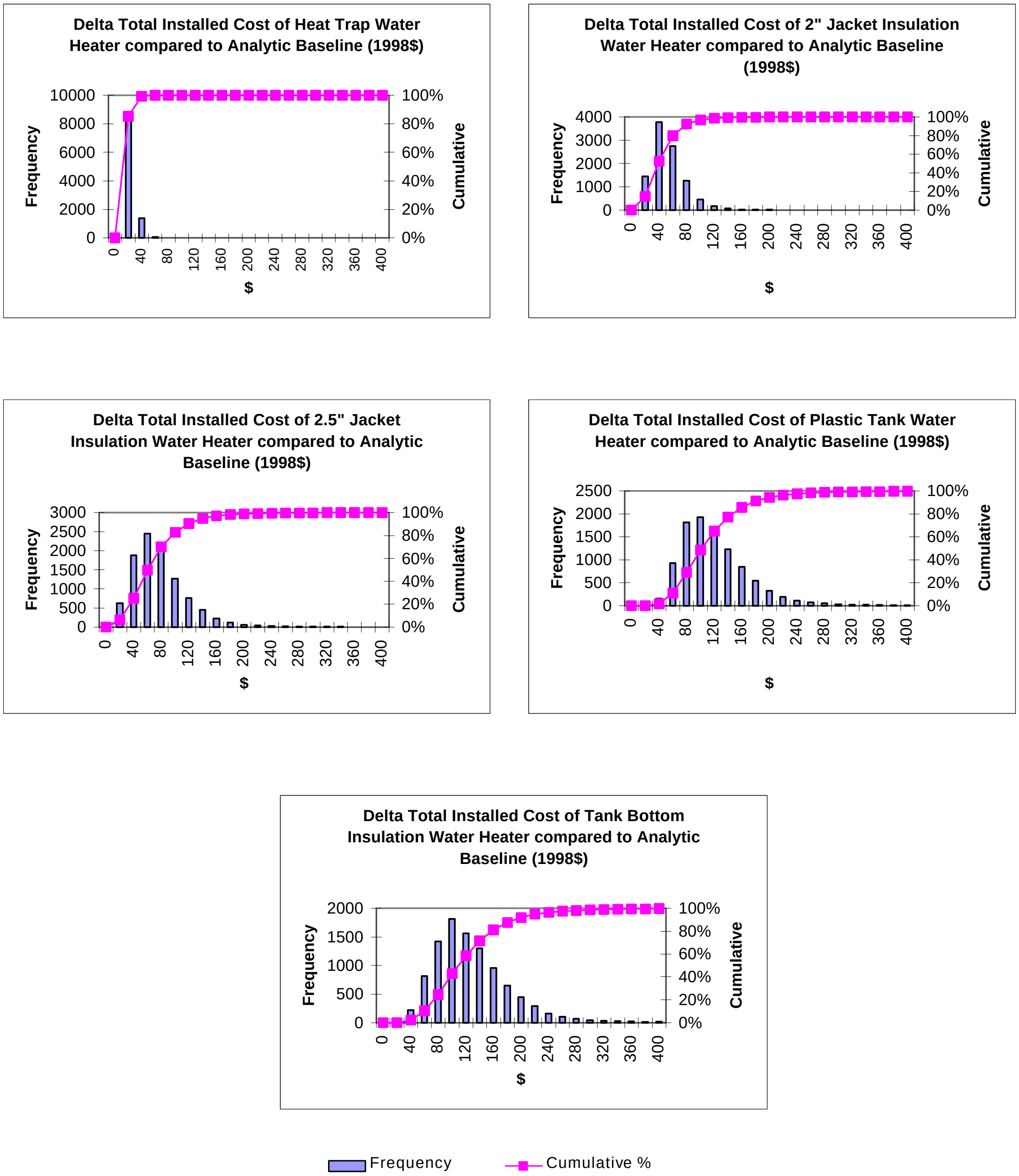

Figure 5.3.13 Difference in Total Installed Cost by Design Option for Electric Water Heaters

Gas-fired Water Heater Equipment Costs

Table 5.3.19 lists the average manufacturing and total installed cost for the analytic baseline and the design option combinations for all sizes of gas-fired water heaters, where total installed cost is the final total cost to the customer, i.e., retail price, sales tax, and any installation cost.

Table 5.3.19 Equipment Costs for Gas-fired Water Heaters (All Sizes)

Design Options		Average Manufacturing Costs ($)	Average Total Installed Costs ($)
0	Analytic Baseline	175.56	385.76
1	0 + Heat Traps	177.94	388.86
2	1 + 2" Jacket Insulation	194.50	411.47
3	1 + 2.5" Jacket Insulation	205.93	427.04
4	3 + Side Arm Heater w/ IID	314.05	602.15
5	2 + Improved Flue Baffle	201.67	530.50

Figure 5.3.14 shows, for each design option and all standard sizes, the difference in total installed costs compared to the analytic baseline for gas-fired water heaters. Variations in total installed cost include variations in manufacturing cost, mark-up, and installed cost. In general, design options with higher efficiencies have a wider spread in total incremental installed cost. Note that Table 5.3.19 shows average manufacturing cost and average total installed equipment cost, while Figure 5.3.14 shows the spread of the incremental total installed cost.

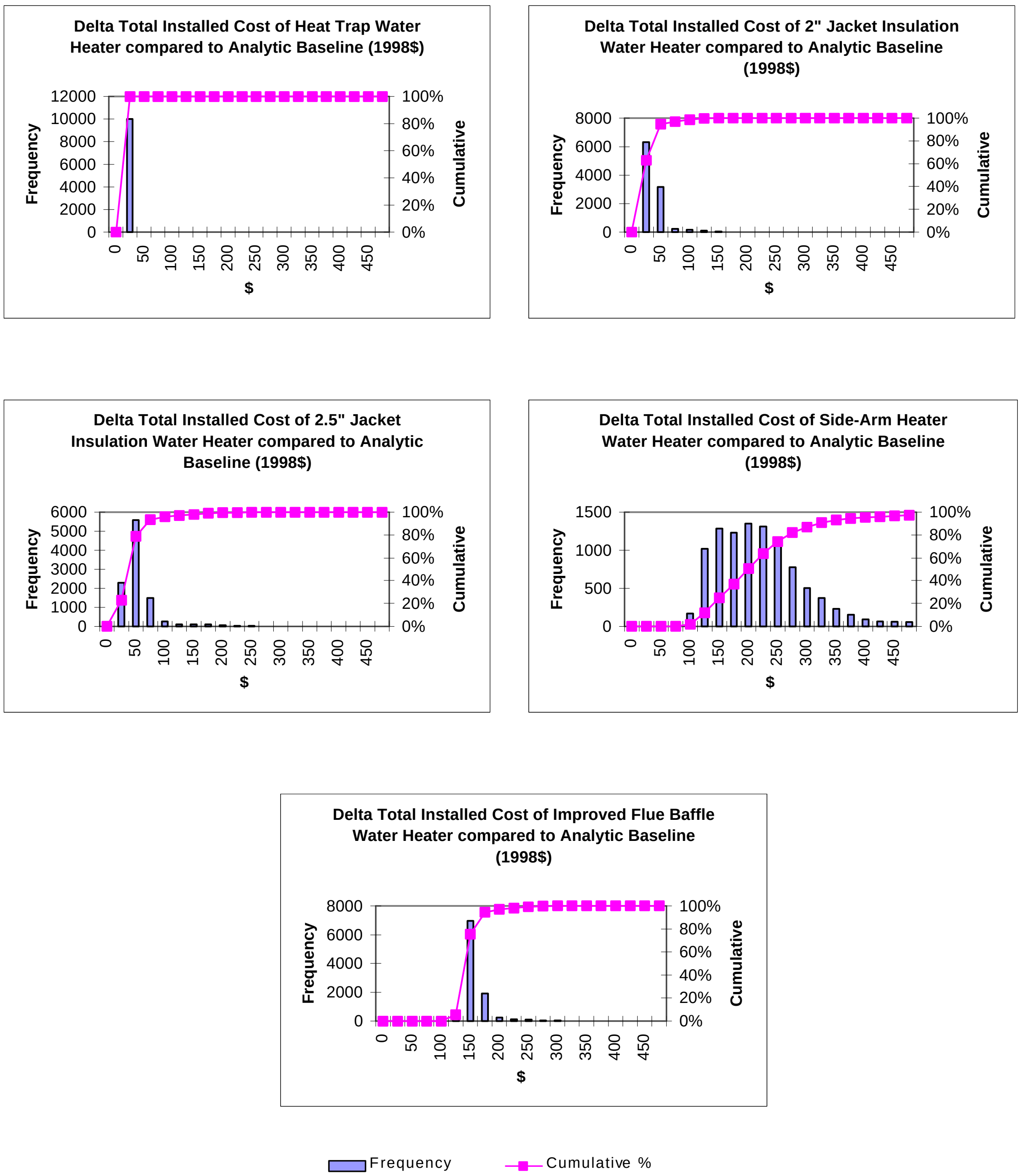

Figure 5.3.14 Difference in Total Installed Costs by Design Option for Gas-fired Water Heaters

5.4 Operating Cost Module

5.4.1 Introduction to Operating Cost Module.

Operating a water heater involves two costs. A residential consumer pays for fuel to operate the water heater and for maintenance to keep the water heater running properly. Fuel costs depend on the water heater energy usage and the per unit cost of fuel. Maintenance costs depend on water heater design.

There are four types of fuel commonly used in residential water heaters--electricity, gas, liquefied petroleum gas (LPG or propane), and distillate fuel (oil). Depending on the particular type of water heater, more than one type of fuel may be used in its operation. For instance, electric water heaters use only electricity, whereas gas-fired water heaters use gas (or LPG) plus electricity for some designs.

Future fuel costs will vary from house to house. There are two primary factors that contribute to this variation. One is the existing variability in energy price, which depends on the rate schedule charged by the utility and the consumption pattern of the particular household. The other is the uncertainty of future energy prices[16]. The uncertainty in the future trend of prices is further complicated by the current restructuring of the electricity supply industry.

To deal with the variations in energy prices, the fuel rates reported in energy bills of the sample in the 1993 RECS are used to represent the variability of energy price from house to house. To account for future uncertainties, various scenarios of projected future energy prices (trends by national average) are applied to each household's energy price. Four possible fuel price scenarios are built into the LCC calculations. They are:

EIA Annual Energy Outlook 1998, High Economic Growth
EIA Annual Energy Outlook 1998, Reference Case
EIA Annual Energy Outlook 1998, Low Economic Growth
GRI 1998 Baseline Projection

Other scenarios will be considered in the analysis as they become available. Figures 5.4.1, 5.4.2, 5.4.3, and 5.4.4 show the trends for the projected future prices for each of the four fuel prices, namely, electricity, gas, LPG, and oil, respectively.

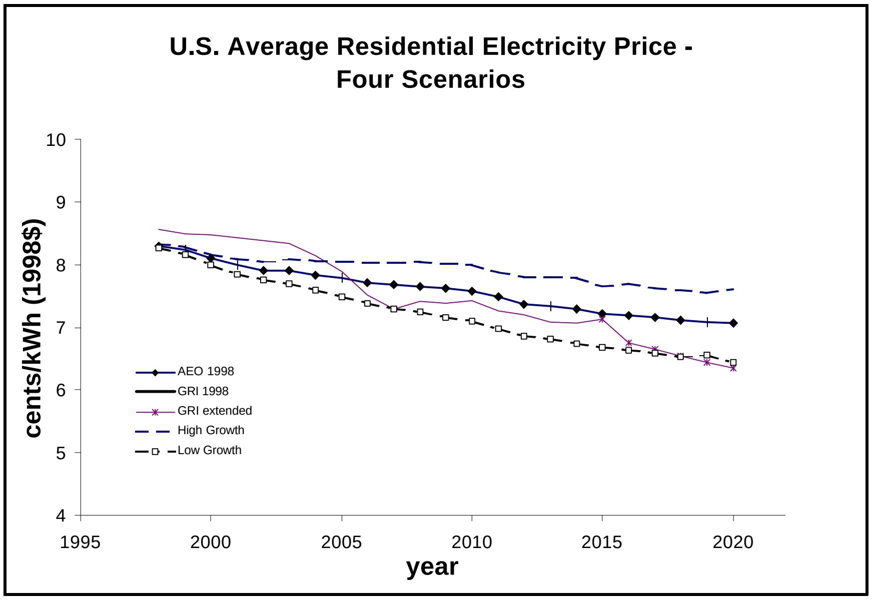

Figure 5.4.1 Electricity Price Scenarios

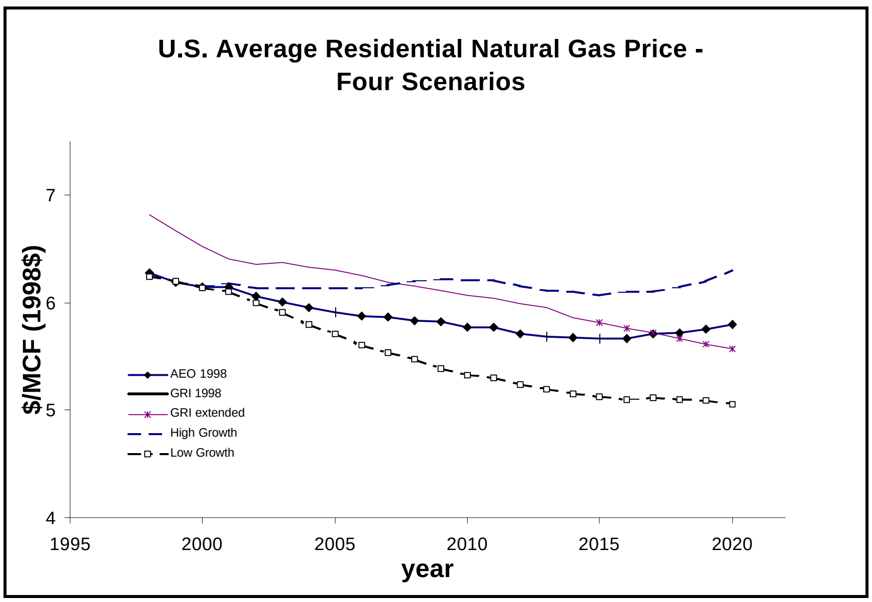

Figure 5.4.2 Gas Price Scenarios

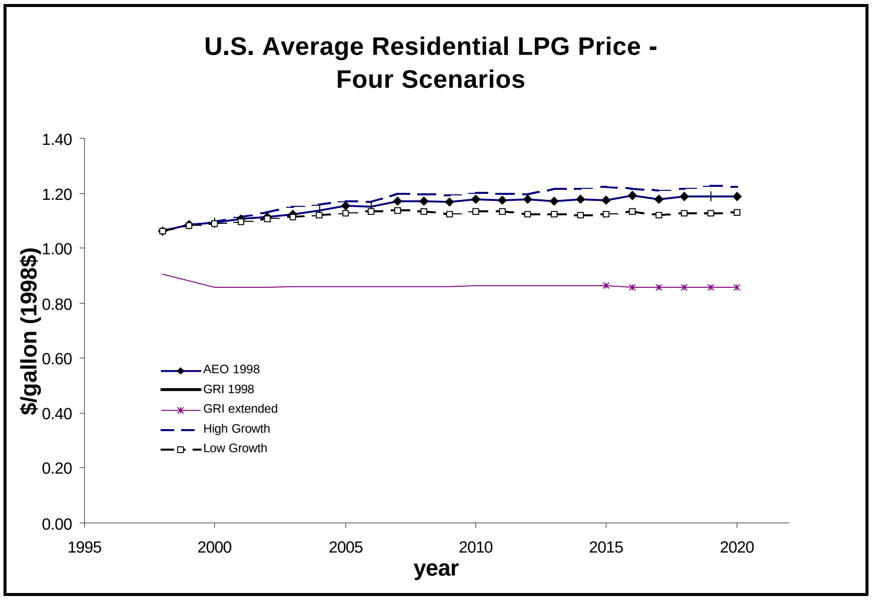

Figure 5.4.3 LPG Price Scenarios

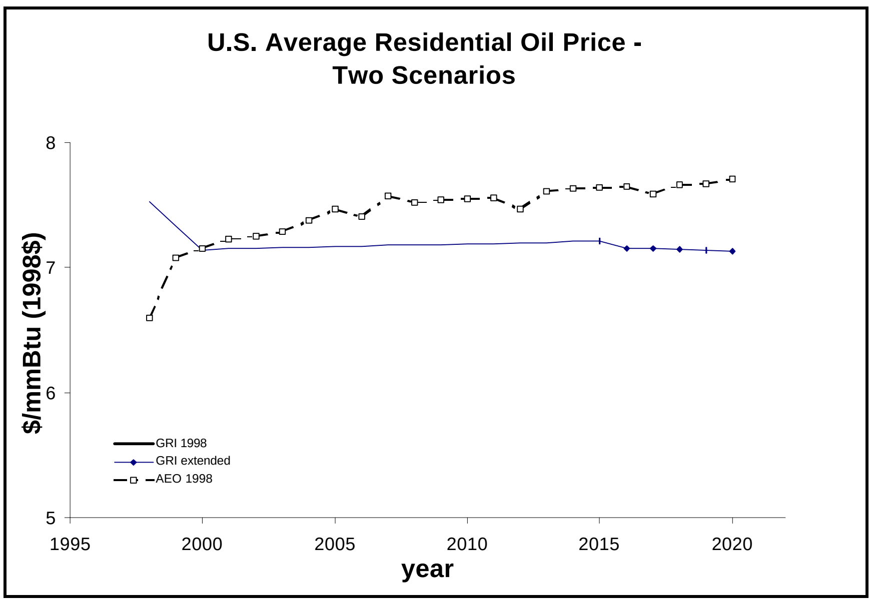

Figure 5.4.4 Oil Price Scenarios

The figures show that all electricity price projections share a declining pattern, while the price projections for gas and LPG are more varied. Oil prices remain relatively flat.

After adjusting for inflation and energy price changes, energy prices for the RECS households are scaled from the starting year by the projected average future energy prices. Thus each sampled house from RECS has four different future annual energy price series associated with it. Future annual operating costs are estimated as annual energy use multiplied by the annual energy price series for each of the four scenarios. Section 5.4.4 gives a detailed description of how the calculation is implemented in the spreadsheet models.

When a consumer saves electricity, the bill savings depend upon the marginal energy charge as reflected in the utility rate schedule (cents per kilowatt-hour), which may be higher or lower than the average rate. An exact accounting would require knowing for each household: the quantity and timing of energy used with and without the saved energy, and the rate schedule (rate per kilowatt-hour as a function of the quantity of kilowatt-hours used, including seasonal and/or time-of-day pricing). In general, such detailed information is not known.

Three approaches are considered: 1) average rates, calculated as the ratio of household expenditures for electricity (including fixed charges) to kWh consumed; 2) partial adjustment of known inaccuracies by subtracting the average fraction corresponding to fixed charges from average rates; and 3) estimating the actual consumer marginal energy rate. We review the advantages and disadvantages of each of these approaches below:

a) Average rates.
Advantage: Simple. Available in published historical data and forecasts.
Disadvantage: May over- or under-estimate the consumer marginal energy rate.

b) Subtract average fixed charge everywhere.
Advantage: Approximately accounts for fixed charges. Edison Electric Institute (EEI) has assembled information on fixed charges for average general service residential rates for a large number of utilities that show fixed charges on average represent about 7.5% of average rates).[17]
Disadvantage: By reducing the value of energy savings in all cases, including those where the marginal rate is higher than the average price including fixed charges, this method under-estimates the actual consumer marginal energy rate in some cases.

c) Estimate distribution of consumer marginal energy rates.
Advantage: Theoretically most accurate.
Disadvantage: Practical difficulties: The rate schedules for households in the RECS survey are not known. Assignment to utility service territories and to rate schedules would need to be imputed. Month by month electrical consumption would be needed to determine the monthly marginal rate. Rate schedule data does not exist for all utilities and, when available, is usually limited to general service residential customers.

Average rates are assumed in this analysis even though it is recognized that the use of marginal energy rates would improve the accuracy of the analysis. At this time, however, the data needed to determine marginal rates is not readily available. Moreover, inasmuch as it is unknown at this point if removing fixed costs is more or less reflective of marginal rates, this intermediate step is not taken in this analysis.

In order to develop consumer marginal energy rates, the Department proposes to collect data on current rate schedules and energy consumption. Those rates will be assigned to a national sample of buildings and households, weighted to represent the total U.S. population of buildings and households. The result will be a weighted distribution of consumption by marginal rates. This approach will be applied to residential and commercial customers.

DOE proposes to obtain a sample of residential buildings from existing surveys, such as the RECS or from a commercially available database. RECS data has the advantage of being in the public domain. In contrast, a commercially available database is likely to be more expensive, but may have significant added value in terms of assigning the buildings to states or to utilities, including a broader sample of the population, and permitting stratification of this larger sample to distinguish among some sub-populations. Each building will be assigned to a geographic region (e.g., state or utility service territory). Energy consumption by month will be included in the database for each building, in order to treat seasonal changes in consumption and rates. Peak demand will be included for commercial buildings.

Recent Federal surveys (RECS, Commercial Building Energy Consumption Survey (CBECS)) gather information by fuel on annual energy consumption and total expenditures. Total expenditures included customer and other fixed charges, energy rates, demand charges, taxes, etc., but these were not tabulated separately from each other. These surveys gathered customer bills but did not extract information on rate schedules, fixed charges, or marginal rates. The Department proposes to explore the feasibility of extracting historical information on rate schedules, including the relationship between fixed charges and marginal rates to average prices. This effort, if successful, will provide information about the extent to which marginal rates differ from average prices, or from average prices less fixed charges.

Given restructuring of parts of the energy supply sector, customers may have more than one bill (e.g., one from the distribution company, and one or more from generators or suppliers). To capture complete information, future surveys are expected to gather energy-pricing information directly from customers, rather than from utilities or local distribution companies. The most efficient means to collect energy-pricing information in the future involves changing the current processing of the billing information so as to gather more detail from the bills, to include consumption by month and pricing information. The pricing information would include for each customer, the rate schedule, marginal rates, fixed charges, demand charges for commercial and industrial customers, or time-of-use rates where applicable. The Department will express the need for these data in discussions with EIA about the design of future surveys.

Residential electricity rate schedules will be collected from Federal databases where available, state regulatory agencies or directly from utilities. The information obtained for each rate schedule will include any fixed charges (customer charges, etc.), block structure, and rate per kilowatt-hour by block. Information from utilities or local distribution companies will be examined to determine: confirmation of the set of rate schedules, the number of customers by state using each rate schedule, the total electricity sales by state by rate schedule, and (if possible) monthly electricity sales by state by rate schedule.

In the database of buildings, such characteristics as energy consumption and expenditures and number of customers by state or utility will be used to map a rate schedule onto each of the buildings in the national sample. The marginal rate for each building will be the block from the rate schedule corresponding to that building's monthly energy consumption.

For life-cycle savings calculations, the monthly energy savings will be estimated for each building. Those monthly energy savings for each building will then be evaluated for each building at the monthly marginal rate, using the rate schedule assigned to each building.

5.4.2 Equations for Operating Cost Module

A generalized equation that describes the operating costs of all three types of water heaters-- electric, gas-fired, and oil-fired -- can be expressed as follows:

$$OprCost_{year,\ options} = \sum_{EnergyType=elec,gas,oil} AnnualQ_{EnergyType,option} \times FutrPrice_{EnergyType,year} + MaintCost$$

For each particular type of water heater, the generic formula shows different specific forms.

A. Equations for Electric Water Heater Operating Cost Module

$$OprCost_{\text{[illegible]}} = AnnualQin_{\text{[illegible]}} \times FutrElecPrice_{\text{[illegible]}}$$

and

$$FutrElecPrice_{\text{[illegible]}} = ElecPrice_{\text{[illegible]}} \times ElecIncrRatio_{\text{[illegible]}}$$

and

$$ElecPrice_{\text{[illegible]}} = ElecRate \times Inflator93 \times ElecScaler$$

where:

AnnualQin	=	average annual electricity consumption (kWh/year)
FutrElecPrice	=	future price of electricity in 1998$ (¢/kWh)
$ElecPrice_{98}$	=	revised RECS house electricity price in 1998$ (¢/kWh)
ElecIncrRatio	=	ratio of future electricity price to 1998 price
ElecRate	=	RECS-reported electricity price in 1993$ (¢/kWh)
Inflator93	=	an inflation factor to convert 1993$ to 1998$
ElecScaler	=	a conversion factor for electricity price change that is different from inflation. It is the ratio of the average real electricity price in 1998 to that in 1993 in constant dollars.

B. Equations for Gas and LPG Water Heater Operating Cost Module.

$$OprCost_{year,\,option} =$$
$$AnnualQelec_{option} \times FutureElecPrice_{year} + AnnualQgas_{option} \times FutrFuelPrice_{EnergyType,\,year} + MaintCost_{option}$$

and

$$FutrElecPrice_{year} = ElecPrice_{98} \times ElecIncrRatio_{year}$$

$$FutrFuelPrice_{EnergyType,\,year} = FuelPrice_{98} \times FuelIncrRatio_{EnergyType,\,year}$$

and

$$FuelPrice_{98} = FuelRate \times Inflator93 \times GasScaler$$

and

$$ElecPrice_{98} = FuelRate \times Inflator93 \times ElecScaler$$

and, if EnergyType = LPG, then

$$FuelPrice\{\{ \; = FuelRate \times Inflator93 \times LPGScaler$$

where additionally:

AnnualQelec	=	annual electricity consumption (kWh/year)
AnnualQgas	=	annual gas consumption (MCF/year*)
FutrFuelPrice	=	future price of water heating fuel($/MCF)
$FuelPrice_{98}$	=	revised water heating fuel price ($/MCF)
FuelIncrRatio	=	ratio of future water heating fuel price to 1998 price
FuelRate	=	RECS house water heating fuel rate in 1993$ ($/MCF)
Inflator96	=	an inflation factor to convert AEO and GRI energy prices to 1998$
Inflator93	=	an inflation factor to convert RECS house energy price to 1998$
ElecScaler	=	a conversion factor for real electricity price change
GasScaler	=	a conversion factor for real gas price change
LPGScaler	=	a conversion factor for real LPG price change

5.4.3 General Description of Key Variables

AnnualQin is the average annual energy consumption, i.e., the total amount of energy consumed by the water heater during the process of heating water and keeping it hot. For electric water heaters this is in kWh/yr. For fuel fired water heaters this is in Btu/yr.

* Note: MCF denotes thousands of cubic feet. Wherever LPG is also applicable, the corresponding unit is gal/year.

AnnualQelec is the annual electricity consumption used by the electronic ignition system and/or the electromechanical flue damper in a gas-fired water heater.

AnnualQgas is the annual gas or LPG consumption of the water heater (MCF/year)

FuelRate is the price of water heating fuel for the household as reported in RECS (in 1993$). The fuel price is defined as the average price per unit fuel (MCF) recorded. In the electric water heater spreadsheet model, **FuelRate** is **ElecRate**.

ElecRate is the price of electricity for the household as reported in RECS (in 1993$). The electricity price is defined as the average price per unit electricity (kWh) consumed. The analysis averages any seasonal fluctuations in the price of electricity.

Inflator93 adjusts the RECS household energy price (1993$) to reflect 1998 dollars, using the Consumer Price Index (CPI). The analysis assumes that the average annual rate of inflation for 1998 will equal the average rate during the first quarter of 1998.

$$= \frac{CPI_{1998}}{CPI_{1993}} = 1.1251$$

Inflator96 is an inflation factor to convert AEO and GRI energy prices to 1998$

$$= \frac{CPI_{1998}}{CPI_{1996}} = 1.0362$$

FuelIncrRatio is the ratio of future national average water heating fuel price to the 1998 price for the selected scenario. The year 1998 serves as the base year.

FutrFuelPrice is the price of water heating fuel ($/MCF) in each future year. It is calculated as a product of **FuelPrice** and **FuelIncrRatio** for a particular fuel type.

ElecIncrRatio is the ratio of national average electricity price between some future year and 1998 for the selected scenario. The year 1998 serves as the base year.

FutrElecPrice is the projected household electricity price at a particular sampled house from RECS for the specified scenario in 1998$.

ElecScaler is a conversion factor for real electricity price change, represented by the ratio of electricity prices in 1998 to the electricity prices in 1993 in constant dollars.

$$= \frac{National Average Price_{1998}}{National Average Price_{1993}} = 0.9820$$

GasScaler is a conversion factor for real gas price change in constant dollars

$$= \frac{National Average Price_{1998}}{National Average Price_{1993}} = 1.0601$$

LPGScaler is a conversion factor for real LPG price change in constant dollars

$$= \frac{National\ Average\ Price_{1998}}{National\ Average\ Price_{1993}} = 0.6166$$

FuelPrice$_{98}$ is the revised gas-fired water heating fuel price ($/MCF) in 1998. It takes the RECS household energy price (**FuelRate**) and multiplies it by **Inflator93** and the corresponding scaler for gas or LPG, respectively.

ElecPrice$_{98}$ is the revised electricity price. It takes the RECS household electricity price (**ElecRate**) and multiplies it by the **Inflator93** and the **ElecScaler** to change 1993 dollars to 1998 dollars to account for inflation and electricity price change.

MaintCost is the price to repair the water heater when it fails ($/year). In reality, if any electric or the baseline gas-fired water heater fails, residential consumers tend to replace the entire water heater rather than having the water heater serviced. Therefore, the electric and baseline gas-fired water heaters have no associated maintenance costs. Oil-fired water heaters and burners are cleaned and maintained more regularly and therefore do have maintenance costs. The mean value for the maintenance costs associated with all sizes of baseline oil-fired models is $97.14 per year. This mean value comes from prices for annual maintenance contracts gathered from telephone conversations with seven oil-fired equipment suppliers in the eastern U.S[**] . Note that the costs are for a separate contract for a water heater only. Costs may go down significantly if multiple oil-fired appliances are on the same contract in a household.

5.4.4 General Description of Data Sources and Calculations in Spreadsheets

[**] The data from the seven oil-fired equipment suppliers can be found in Appendix G of the Engineering Report.

The average annual energy consumption is calculated with the Water Heater Analysis Model (see Section 5.5 for a full discussion of WHAM) and is an input to the operating cost module. In the electric water heater model, it represents the annual electricity use of a water heater (**AnnualQin**). For water heaters that use more than one type of fuel, the annual usage of each type of fuel is calculated separately. For instance, in some designs of gas-fired water heaters, **AnnualQin** is a sum of the annual gas (or LPG) (**AnnualQgas**) and the electricity consumption (**AnnualQelec**).

Fuel rates as reported in the 1993 RECS are used as a base to capture the variability of fuel prices across the nation. Consumer Price Indexes (CPI) from the U. S. Bureau of Labor Statistics are used to calculate **Inflator93** that accounts for inflation over the period of 1993 to 1998.

Similarly, national average energy prices reported in DOE's Energy Information Administration (EIA) *Annual Energy Review*[18] are used to compute scalers (**ElecScaler**, **GasScaler**, and **LPGScaler**) to take into account real energy price changes since the 1993 RECS survey. Multiplying **FuelRate** by **Inflator93** and then by the corresponding scaler yields the 1998 value of unit fuel price (**FuelPrice**) in 1998 dollars for each RECS household.

DOE/EIA publishes projections of future energy prices in its *Annual Energy Outlook 1998* (AEO). The projections include three cases: reference, high economic growth, and low growth. The Gas Research Institute also publishes a forecast for future fuel rates (electricity, gas, and oil) in its *1998 Edition of the GRI Baseline Projection.* These projections show a similar pattern (see Figures 5.4.1, 5.4.2, 5.4.3, and 5.4.4), but vary in magnitude. The four scenarios are used in the analysis to help demonstrate how future energy price trends affect the outcome of the analysis. Since the four fuel price projections are reported as 1996 dollars per million Btu, they are converted into appropriate units (cent/kWh for electricity, $/MCF for gas, and $/gal for LPG and oil) and into 1998 dollars (multiplied by **Inflator96**).

The incremental ratios of the energy price scenarios are derived by dividing each year's projected price by the 1998 price (**ElecIncrRatio** for electricity and **FuelIncrRatio** otherwise) and applied to the **FuelPrice** of each RECS sample house to represent its future energy prices (**FutrElecPrice** for electricity and **FutrFuelPrice** for other fuels) for the selected scenario. The annual operating costs of the water heater are then computed based on the equations described in Section 5.4.2.

Two implementation details need to be noted here. One, GRI only projects to the year 2015; in this analysis GRI projections (for all fuels) are extended to the subsequent years (2016 - 2020) by extrapolations based on a linear fit to the available time series data of each fuel. Two, GRI did not have a projection for LPG future prices in time to be included in this analysis. It was therefore estimated using the average ratio of historical LPG to oil prices.

5.4.5 Operating Cost Results

Electric Water Heater Operating Cost

Table 5.4.1 lists the average annual operating cost for the analytic baseline and design options for all sizes of electric water heaters, based on 1993 RECS. The average operating cost savings from the baseline are listed for each design option.

Table 5.4.1 Operating Costs for Electric Water Heaters

Design Option		Average Annual Operating Cost ($)	Average Savings from Baseline ($)
0	Analytic Baseline	292.93	
1	0 + Heat Traps	285.05	7.88
2	1 + 2" Jacket Insulation	281.22	11.71
3	1 + 2.5" Jacket Insulation	277.55	15.38
4	3 + Plastic Tank	274.01	18.92
5	3 + Insulated Tank Bottom	275.66	17.27

Figure 5.4.5 presents for each design option, the difference in operating cost compared to baseline.

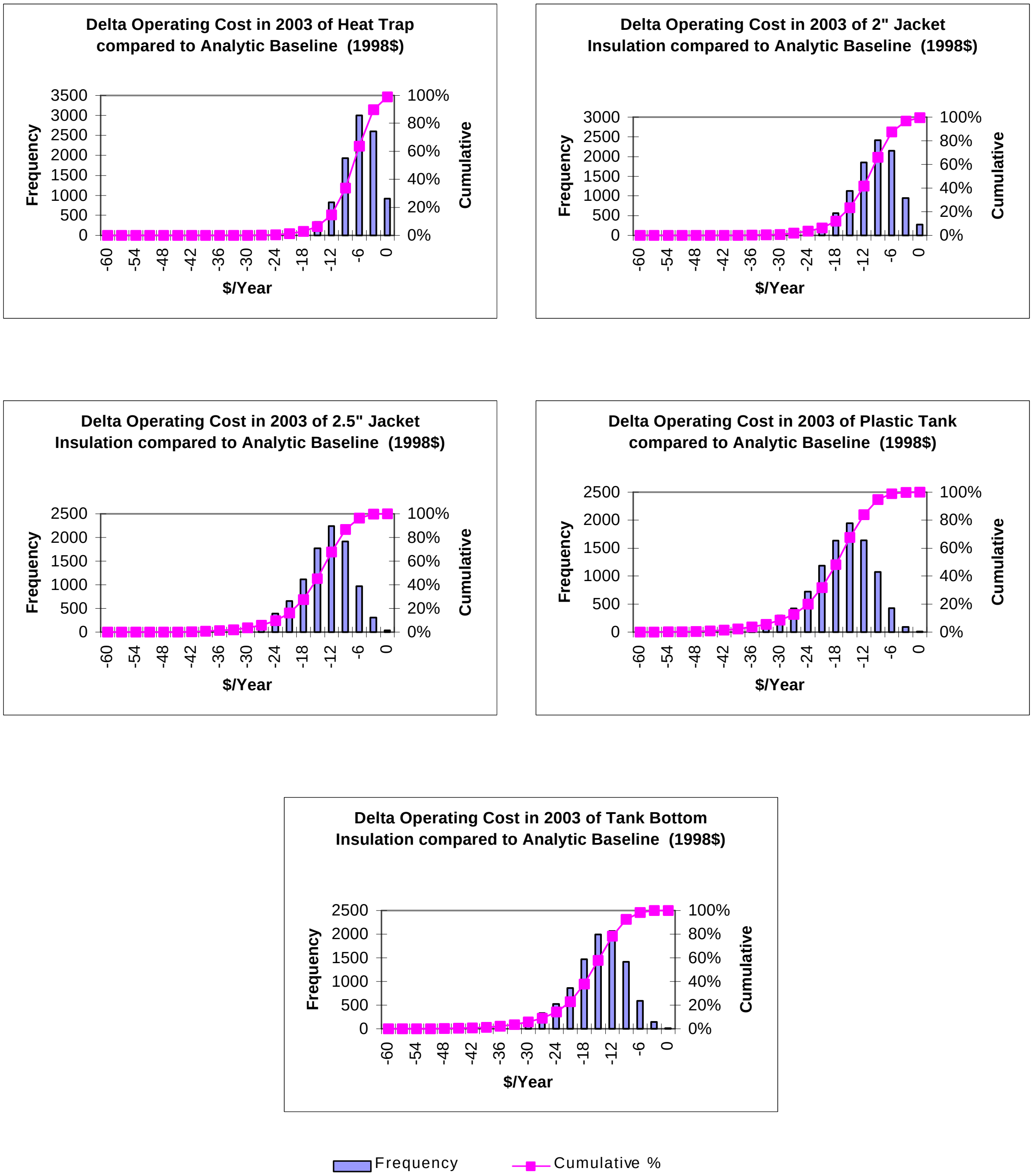

Figure 5.4.5 Difference in Operating Costs by Design Options for Electric Water Heaters

Gas-fired Water Heater Operating Costs

Table 5.4.2 lists the average annual operating cost for the analytic baseline and for design options of all standard sizes of gas-fired water heaters, based on 1993 RECS data. The average operating cost savings from the baseline are listed for each design option.

Table 5.4.2 Operating Costs for Gas-Fired Water Heaters

Design Option		Average Annual Operating Cost ($)	Average Annual Savings from Baseline ($)
0	Analytic Baseline	159.36	
1	0 + Heat Traps	155.12	4.24
2	1 + 2" Jacket Insulation	147.00	12.36
3	1 + 2.5" Jacket Insulation	145.28	14.08
4	3 + Side Arm Heater	126.25	33.11
5	2 + Improved Flue Baffle	143.10	16.26

Figure 5.4.6 shows a cumulative frequency plot of the difference in operating cost compared to baseline for gas-fired water heaters.

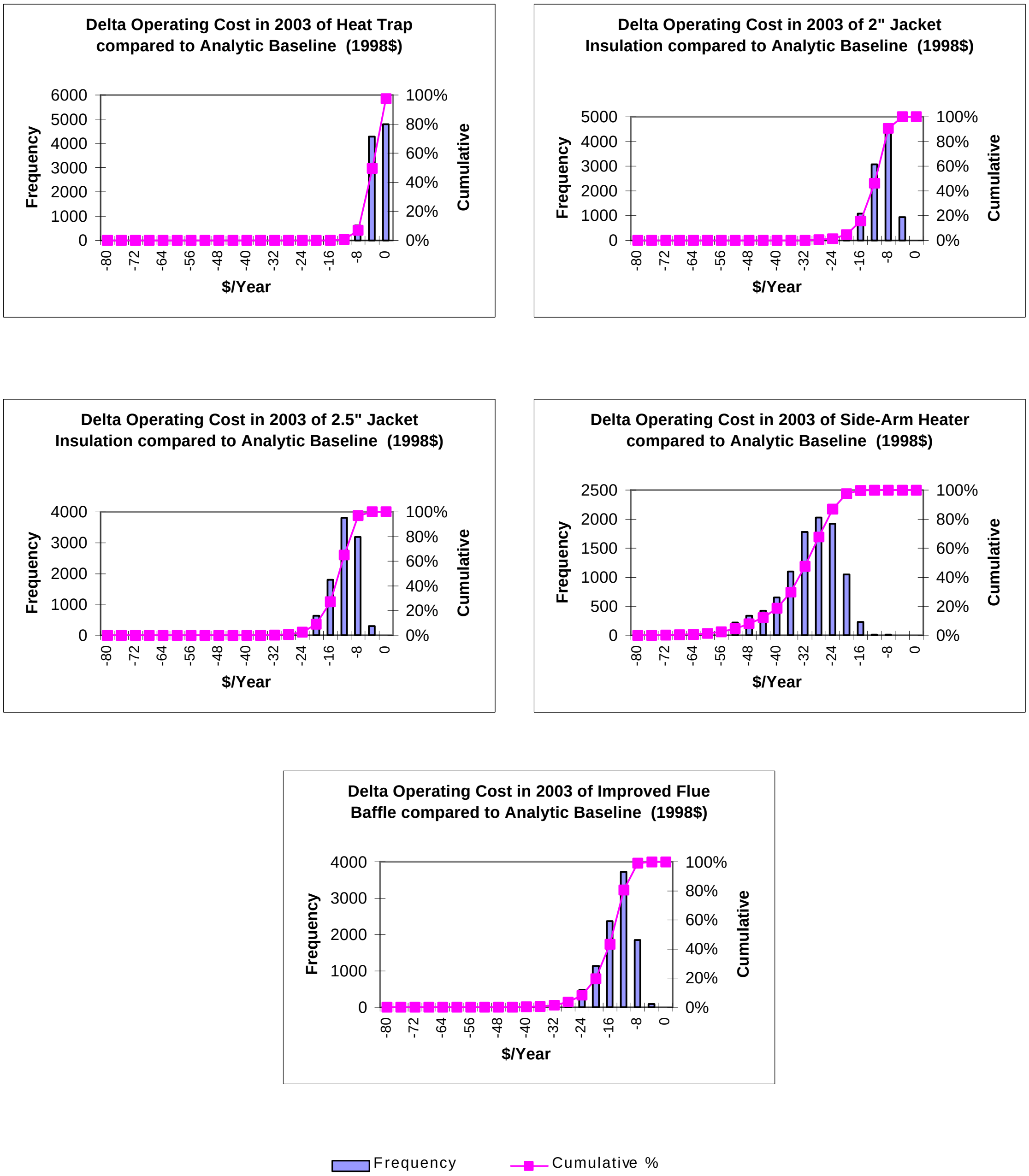

Figure 5.4.6 Difference in Operating Costs by Design Options for Gas-Fired Water Heaters

5.5 Energy Analysis Module

5.5.1 Introduction to Energy Use

Residential water heater energy usage can be accurately estimated using a simplified energy equation, the Water Heater Analysis Model. WHAM is a simple energy equation that accounts for a variety of operating conditions and water heater characteristics when calculating energy consumption. Three parameters – recovery efficiency (RE), standby heat loss coefficient (UA), and rated input power (Pon) – are used to describe the efficiency characteristics of the water heater. The operating conditions of the water heater are indicated by average daily hot water draw volume, inlet water temperature, thermostat setting, and air temperature around the water heater.

WHAM was developed as a method to quickly and reliably estimate residential water heater energy consumption. Because it is written as an equation, it can be implemented in spreadsheets. It does not require the detailed inputs that other water heater simulation models demand. In each of the LCC analysis spreadsheets, water heater energy consumption is calculated for 10,000 different households for both baseline water heaters and all design options being considered.

The energy analysis module uses the average daily hot water consumption for each household calculated by the Hot Water Draw Module. Other key characteristics, such as water temperature for each household, are from the RECS database. The LCC analysis uses RE and UA values from computer simulations developed for the Engineering Analysis and Pon from manufacturers' product literature to describe the energy performance of water heaters.

5.5.2 Equations for Energy Use

The WHAM equation, which solves for average daily water heater energy consumption (Q_{in}), is expressed as follows:

$$Q_{in} = \frac{vol \cdot den \cdot Cp \cdot (T_{tank} - T_{in})}{RE} \cdot \left(1 - \frac{UA \cdot (T_{tank} - T_{amb})}{Pon}\right) + 24 \cdot UA \cdot (T_{tank} - T_{amb})$$

where:

Q_{in} = total water heater energy consumption (Btu/day)

RE = recovery efficiency

Pon =	rated input power (Btu/hr)
UA =	standby heat loss coefficient (Btu/hr-^{o}F)
T_{tank} =	thermostat setpoint temperature (^{o}F)
T_{in} =	inlet water temperature (^{o}F)
T_{amb} =	temperature of the air surrounding the water heater (^{o}F)
vol =	volume of hot water drawn in 24 hours (gal/day)
den =	density of stored water at the average of the setpoint and inlet temperature (lb/gal)
Cp =	specific heat of stored water at the setpoint temperature (Btu/lb-^{o}F)

5.5.3 General Description of Key Variables

Recovery Efficiency (RE). The recovery efficiency (RE) is the ratio of energy added to the water compared to the energy input to the water heater. It represents how efficiently energy is transferred to the water when the heating element is on or the burner is firing. RE covers the steady-state efficiency only. It accounts for the amount of energy lost through the water heater jacket and the flue and fittings while the heater is firing.

Rated Input Power (Pon). Rated input power is the nominal power rating the manufacturer assigns to a particular design of water heater expressed in kW for electric water heaters or Btu/hr for gas-fired or oil-fired water heaters. For gas-fired water heaters this includes the pilot light.

Standby Heat Loss Coefficient (UA). The standby heat loss coefficient (UA) indicates the water heater hourly standby energy losses expressed in Btu/hr-^{o}F. It is reported in terms of energy input required to maintain the water at the setpoint temperature. This represents the rate at which energy must be added to the water heater when it is not heating water for delivery.

Thermostat Setpoint Temperature (T_{tank}). The thermostat setpoint temperature is the desired delivery temperature of the hot water.

Inlet Water Temperature (T_{in}). The inlet water temperature is the temperature of the water supplied to the water heater.

Temperature of the Air Surrounding the Water Heater (T_{amb}). The temperature surrounding the water heater is the ambient air temperature of the space in which the water heater is located.

Volume of Hot Water Drawn in 24-Hour Period (vol). This is the estimated daily household use of hot water.

Density of Water (den). The density of hot water at the average of the setpoint and inlet temperatures. This is mass per unit volume, expressed as lb/gal (kg/l).

Specific Heat of Water (C_p). The specific heat of water at the average of the setpoint and inlet temperatures. This is the amount of heat needed to increase or decrease the temperature of 1 pound of water by 1 °F (1 kg/K).

5.5.4 General Description of Sources of Data

Derivations of Energy Parameters

Introduction

The total water heater energy consumption (Q_{in}) is calculated using water heater energy parameters such as the recovery efficiency (RE), the standby heat loss coefficient (UA), and the rated input power (Pon) and the estimated hot water use. The definitions for the water heater energy parameters are provided by the U.S. DOE EF test procedure for water heaters[19]. The energy parameters were developed from simulation models, water heater manufacturer and retail contacts, independent sources, and customized calculation tools developed at LBNL.

Determining RE, UA, and Pon

The LCC analysis uses RE and UA values from computer simulations developed for the Engineering Analysis. Two detailed water heating simulation programs — WATSIM for electric water heaters and TANK for gas-fired water heaters — were used to perform the simulations. The WHAM water heater simulation tool was used for oil-fired water heaters.

WATSIM is a detailed electric water heater simulation program developed by the Electric Power Research Institute (EPRI)[20]. The use of WATSIM is explained in the Engineering Report. The output of WATSIM does not directly provide values for RE and UA. It does, however, provide detailed temperature profiles of the water inside the tank during the simulation run. These temperature readings can be used to determine the energy parameters of the electric water heater using the standard test procedure calculations. A spreadsheet tool, described in Appendix A of the Engineering Report, was developed to calculate RE and UA.

TANK is a detailed gas-fired storage water heater simulation program developed by Battelle for the Gas Research Institute[21]. TANK is explained in the Engineering Report. The outputs of TANK include RE and UA.

The simplified water heater analysis model (WHAM) was used for the analysis of oil-fired water heaters. In the case of the oil-fired water heaters, the total daily energy consumption was calculated based on the estimated burner operating hours. Then, a rearranged WHAM equation was used to estimate UA. The use of the WHAM model for the calculation of the energy parameters for oil-fired water heaters is explained in the Engineering Report.

The primary source of data for rated input power (Pon) is the water heater manufacturers' product literature. In order to generate values for Pon, a large sample of water heaters was examined and typical values for each standard size were assigned.

Table 5.5.1 is a summary of all standard water heater sizes studied in this analysis with corresponding values for UA, RE, and Pon for the three fuel types.

Table 5.5.1 Water Heater Design Characteristic Values

	Rated Volume (gal) (liter)	UA (Btu/hr-°F)	RE	Pon (Btu/hr)
Electric	30 (110)	2.92	.972	15354
	40 (150)	3.40	.968	15354
	50 (190)	3.64	.967	15354
	65 (250)	3.98	.966	15354
	80 (300)	4.42	.965	15354
Gas	30 (110)	11.56	.758	30000
	40 (150)	13.86	.756	40000
	50 (190)	16.14	.723	50000
	75 (280)	21.80	.672	75000
Oil	32 (120)	14.93	.760	90000
	50 (190)	18.26	.760	104000

Other Standard-Size Water Heaters

The typical analytic baseline models represent the most common size water heater with an EF at the minimum allowed by current energy efficiency standards. These units have the largest market share in their product class (50-gal/190 liter for electric, 40-gal/150 liter for gas-fired, and 32-gal/120 liter for oil-fired). Other standard-size water heaters that were also considered in the LCC analysis are listed in Table 5.1.1.

All standard-size analytic baseline models were modeled by adjusting the typical analytic baseline models in the WATSIM and TANK simulation tools. Table 5.5.2 shows the values of the electric water heater parameters which have been adjusted in WATSIM in order to model the standard tank sizes. The typical tank diameter for each standard size is determined from a large sample of water heaters selected from the product literature. The actual tank volume of the electric water heater is 10% less than the rated volume. The values for the tank diameter and actual tank volume were used to calculate the tank height. The rest of the geometry parameters, such as the locations of the hot water and cold water outlets, the electric heater elements, the thermostats, and the miscellaneous feed through fittings, were determined by scaling them relative to the length of the baseline model. In WATSIM all heights are referenced from the bottom of the tank support skirt (top of the base pad).

Table 5.5.2 Electric Water Heater Modeling Parameter Variations

	30-gal	40-gal	50-gal	65-gal	80-gal
Tank Diameter (ft)	1.17	1.17	1.32	1.50	1.67
Tank Height (ft)	3.48	4.60	4.54	4.55	4.52
Location of H.W. Inlet (ft)	3.48	4.60	4.54	4.55	4.52
Height of Heater Element 1 (ft)	0.48	0.63	0.62	0.62	0.60
Height of Heater Element 2 (ft)	2.48	3.28	3.24	3.25	3.23
Height of Thermostat 1 (ft)	0.70	1.01	1.00	1.00	1.00
Height of Thermostat 2 (ft)	2.79	3.69	3.64	3.65	3.62
Height of Feed-Through 1 (ft)	3.48	4.60	4.54	4.55	4.52
Height of Feed-Through 2 (ft)	3.48	4.60	4.54	4.55	4.52
Height of Feed-Through 3 (ft)	0.13	0.13	0.13	0.13	0.13
Height of Feed-Through 4 (ft)	3.48	4.60	4.54	4.55	4.52

Table 5.5.3 shows the values of the gas-fired water heater parameters which have been adjusted in TANK in order to model all the standard tank sizes. All the required TANK input parameters, such as the tank diameter, the internal flue diameter, and the firing rate for each standard size, are determined from a large sample of water heaters selected from product literature. The actual tank volume of the gas-fired water heater is 5% less than the rated volume. The TANK simulation program calculates most of the geometry parameters based on the values for the tank diameter and volume. The location (elevation) of the thermostat does not change from size to size and the thermostat is fixed at a height of 0.39 feet (11.9 cm). TANK requires an input for the 'Volume to Thermostat (gal)' parameter, which is determined as the amount of water that would need to be added to an empty water heater tank to raise the level of the water to the thermostat location. This parameter is determined using the specific tank diameter and the thermostat elevation.

Table 5.5.3 Gas-fired Water Heater Modeling Parameter Variations

	30-gal	40-gal	50-gal	75-gal
Tank Volume (gal)	28.5	38.	47.5	71.25
Firing Rate (Btu/hr)	30000	40000	50000	75000
Tank Diameter (in)	13.84	15.84	17.84	21.84
Internal Flue Diameter (in)	2.84	3.84	3.84	3.84
Volume to Thermostat (gal)	3.1	4.05	6.36	7.70

Detailed computer simulations were performed for each design option and all combinations of design options as they applied to all of the standard-size baseline models.

Determination of the Uncertainty Ranges for EF, RE, UA, and Pon

The energy factor (EF) is the ratio of output energy in the form of hot water to the input energy at the standard test conditions. The WHAM equation is used in the LCC analysis to calculate EF values for all the design options as a function of RE, UA, and Pon, which are calculated as explained above.

The following procedure was developed to calculate the uncertainty ranges for all the energy parameters. An estimate of the EF values and the associated uncertainty ranges for all the design options added separately to typical existing baseline electric and gas water heaters were provided by M. Minniear, a consultant.

The EF uncertainty range data for the typical tank size was used to develop ratios to represent the variations of the EF values for all the standard tank sizes.

The range of uncertainty for RE and UA was developed from the range of uncertainty for EF. This is done by calculating the variations in RE and UA that would independently cause the desired variation of EF. The range on the RE and UA terms is reduced by $1/\sqrt{2}$. This assumes that the RE and UA distributions have approximately equal impacts on EF. A detailed explanation of the entire procedure to develop the uncertainties for the water heater energy parameters is found in Appendix C. Variations in Pon have a much smaller impact on EF within the operating limits of actual water heaters. Values for the variations in Pon were developed by determining the Pon range for each standard size of water heaters listed in the GAMA directory.

The impact on EF for variations in RE, UA, and Pon are shown in Table 5.5.4 for electric water heaters and in Table 5.5.5 for gas water heaters. Figure 5.5.1 shows the variation of EF for electric water heaters caused by deviations of RE, UA, and Pon from typical values of RE = 98%, UA = 3.3 Btu/hr-^{o}F, and Pon = 4.5 kW. Figure 5.5.2 shows same for a gas-fired water heater for deviations from typical values of RE = 78%, UA = 14.4 Btu/hr-^{o}F, and Pon = 40,000 Btu/hr.

Table 5.5.4 Energy Efficiency Characteristics - Electric Water Heaters (50-gal)

	Design Options	EFwham	EFmin	EFmax	RE	REmin	REmax	UA	UAmin (Btu/hr-°F)	UAmax	PON	PONmin (Btu/hr)	PONmax
	Existing Baseline (141b)	0.861	0.837	0.863	0.967	0.945	0.969	3.64	3.59	4.31	15354	12966	18766
0	Analytic Baseline (245fa)	0.861	0.837	0.863	0.967	0.945	0.969	3.64	3.59	4.31	15354	12966	18766
1	0 + Heat Traps	0.879	0.865	0.881	0.970	0.958	0.972	3.06	3.01	3.45	15354	12966	18766
2	1 + 2" Jacket Insul	0.892	0.859	0.894	0.972	0.943	0.973	2.62	2.57	3.50	15354	12966	18766
3	1 + 2.5" Jacket Insul	0.903	0.869	0.905	0.973	0.945	0.974	2.29	2.24	3.16	15354	12966	18766
4	3 + Plastic Tank	0.907	0.897	0.917	0.970	0.962	0.978	2.06	1.82	2.31	15354	12966	18766
5	3 + Insul Tank Bottom	0.907	0.873	0.909	0.972	0.944	0.973	2.13	2.08	2.99	15354	12966	18766

Table 5.5.5 Energy Efficiency Characteristics - Gas-fired Water Heaters (40-gal)

	Design Options	EFwham	EFmin	EFmax	RE	REmin	REmax	UA	UAmin (Btu/hr-°F)	UAmax	PON	PONmin (Btu/hr)	PONmax
	Existing Baseline (141b)	0.544	0.529	0.549	0.755	0.735	0.762	13.82	13.51	14.78	40000	28000	60000
0	Analytic Baseline (245fa)	0.544	0.529	0.549	0.756	0.735	0.762	13.86	13.55	14.82	40000	28000	60000
1	0 + Heat Traps	0.554	0.549	0.564	0.756	0.749	0.769	12.96	12.37	13.27	40000	28000	60000
2	1 + 2" Jacket Insul	0.580	0.564	0.584	0.762	0.742	0.767	11.04	10.82	11.98	40000	28000	60000
3	1 + 2.5" Jacket Insul	0.599	0.583	0.604	0.780	0.760	0.785	10.37	10.16	11.27	40000	28000	60000
4	3 + Side Arm Heater	0.662	0.644	0.673	0.764	0.743	0.771	5.24	4.75	6.06	40000	28000	60000
5	2 + Impr Flue Baffle	0.675	0.656	0.687	0.784	0.762	0.791	5.36	4.87	6.16	40000	28000	60000

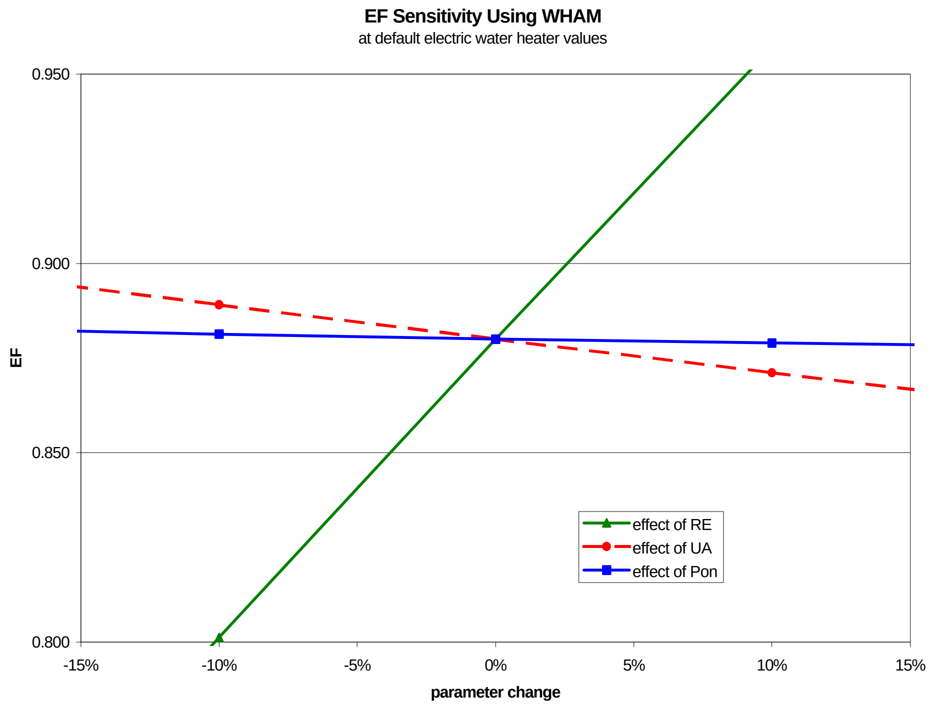

Figure 5.5.1 Variations of EF for Electric Water Heaters

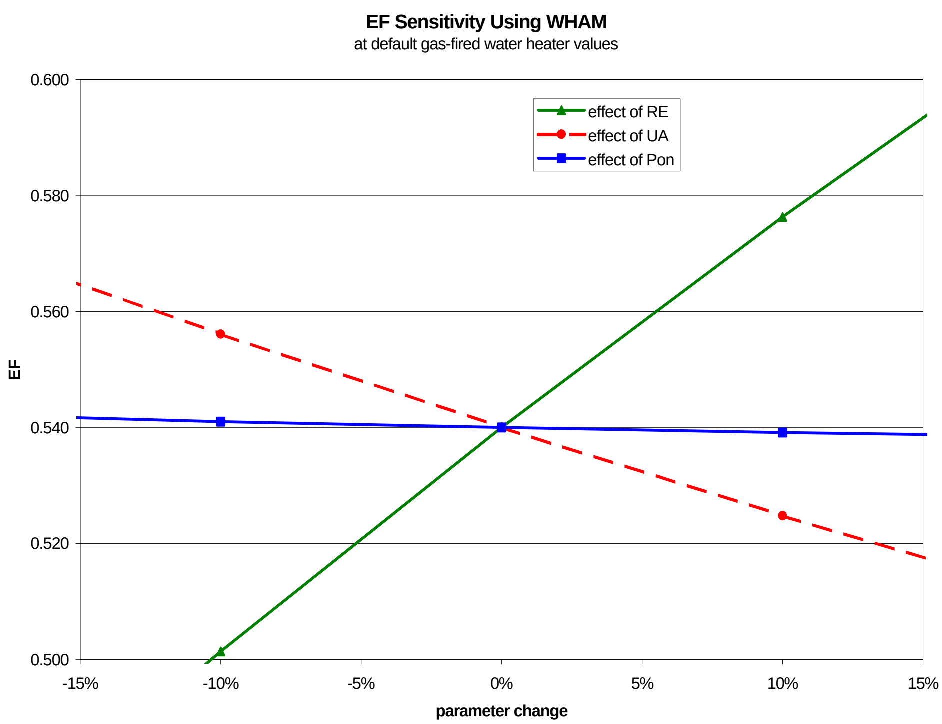

Figure 5.5.2 Variations of EF for Gas-fired Water Heaters

Temperature Derivations

The temperatures for water heater thermostat setpoint, inlet water temperature, and temperature of the air surrounding the water heater are based on the outdoor air temperature.

RECS provides data on heating and cooling degree days, but not air temperatures, for each household in the sample. To assign a physical location to each RECS household from which outdoor air temperatures could be derived, three steps were taken:

1. The continental United States was divided into 42 different climate zones. Each zone is associated with a particular city.[22] Figure 5.5.3 shows the 42 climate zones. The cities are listed below.

Birmingham, AL
Phoenix, AZ
Fresno, CA
Los Angeles, CA
San Diego, CA
San Francisco, CA
Denver, CO
Miami, FL
Jacksonville, FL
Atlanta, GA
Boise, ID
Chicago, IL
Lake Charles, LA
Boston, MA
Portland, ME
Minneapolis, MN
St. Louis, MO
Great Falls, MT
Raleigh, NC
Bismarck, ND
Omaha, NE
Albuquerque, NM
Las Vegas, NV
Reno, NV
Buffalo, NY
New York, NY
Cincinnati, OH
Oklahoma City, OK
Portland, OR
Philadelphia, PA
Pittsburgh, PA
Charleston, SC
Memphis, TN
Nashville, TN
El Paso, TX
Ft. Worth, TX
San Antonio, TX
Salt Lake City, UT
Burlington VT
Seattle-Tacoma, WA
Cheyenne, WY
Washington DC

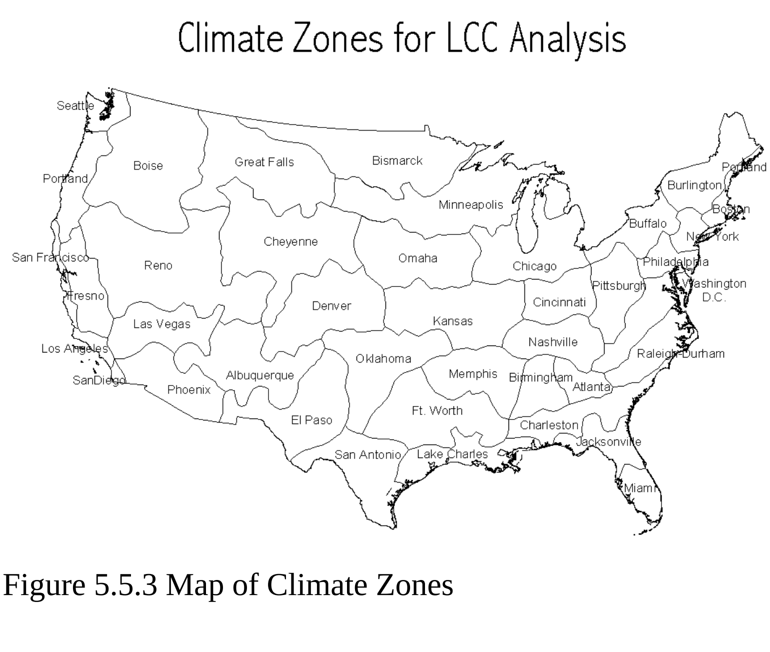

Figure 5.5.3 Map of Climate Zones

2. NOAA provides daily outdoor air temperatures and cooling and heating degree days for each of the 42 cities. Cooling degree days are the number of degrees the average temperature is above a base temperature. Heating degree days are the number of degrees the average temperature is below a base temperature. The base temperature used in this study is 65°F.

3. RECS reports heating and cooling degree days for each housing record. Every RECS household was assigned to the climate zone within its reported census region with the closest number of heating and cooling degree days for 1993.

Once each RECS household is associated with a climate zone, other temperature assignments are made from the 30 year average annual temperatures from NOAA.

To assign thermostat setpoints for RECS households, an equation was derived from a California Energy Commission (CEC) study that measured hot and cold water temperatures.[23]

The CEC study examined single-family houses built between 1984 and 1988 to assess the accuracy of the California Title 24 Energy Efficiency Standards modeling assumptions. As a part of the study, hot and cold water temperatures were measured. The CEC assumed that hot water temperatures were equal to the water heater thermostat setpoint and the cold water temperatures were equal to the inlet water temperatures.

The graph of the CEC data displayed in Figure 5.5.4 shows the correlation between the thermostat setpoint and the inlet water temperature. The data show that people with colder inlet water tend to set their water heaters to higher setpoint temperatures to avoid using a greater proportion of hot water to cold to get their desired water temperature. Often what motivates people to increase the setpoint is frequently running out of hot water.

The equation that was derived from the CEC data is shown below. If the inlet water temperature for the household is 58°F, then the water heater's setpoint temperature is 134.1°F. As the inlet water temperature gets warmer, the setpoint temperature decreases.

$$T_{tank} = 134.1 + 0.55 * (58 - T_{in})$$

RECS households were given setpoint temperatures based on their inlet water temperatures using this equation. Since individual households maintain a wide range of thermostat settings, a random error with a mean of 0°F and a standard deviation of 13°F was added to account for this variability.

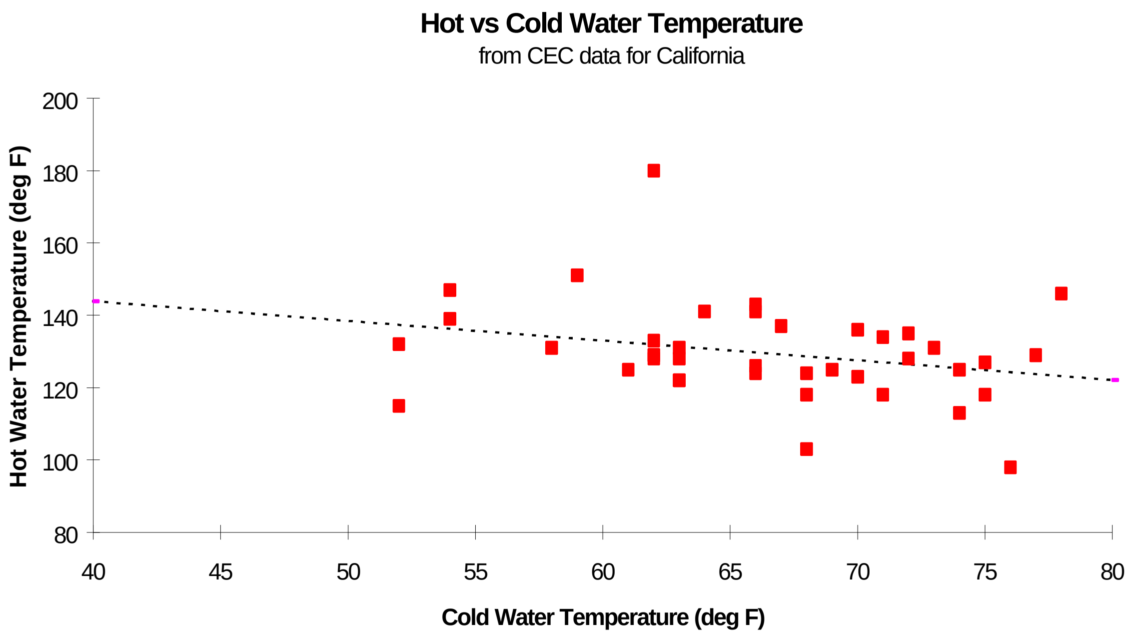

Figure 5.5.4 Comparison of Setpoint and Inlet Water Temperatures

Inlet water temperature was assumed to equal the ground water temperature, which varies according to geographic region. Ground water temperatures are assumed to be slightly warmer than air temperatures. Two degrees were added to the NOAA average annual outdoor air temperature data[24]. The estimates were compared to the National Well Water Association's published annual average ground water temperatures for various regions in the country[25]. The comparison shows that, in the majority of cases, the difference between the two estimates is less than 2°F.

A set of assumptions to determine air temperature around the water heater was developed based on calls to fifty water heater installers from around the country regarding the typical locations for water heater installation.

1. RECS reports the presence or absence of basements and, if there is a basement, whether or not it is heated. If the house had a basement, it was assumed the water heater was located in the basement. For unheated basements, the assigned temperature was the average between the outdoor air temperature for that climate zone and a house air temperature of 72°F (22.2°C).

2. If the basement is reported as a heated space, then the temperature of the air around the water heater is assumed to be the temperature of the house: 72°F (22.2°C).

3. If the house had no basement but did have a garage or carport, it was assumed that the water heater was in the garage or carport. The temperature assigned was 5°F (2.8°C) higher than the outside air temperature for that house.

4. In the absence of a basement, garage, or carport, it was assumed that the water heater was in the house (in the kitchen or a utility closet) and a temperature of 72°F (22.2°C) was assigned.

Table 5.5.6 shows the percentages of assigned water heater locations.

Table 5.5.6 Water Heater Location Percentages

Water Heater Location	Percentage (%)
unheated basement	20.9
heated basement	26.0
garage	24.7
house	28.3

The volume of hot water drawn in 24 hours is calculated using the Hot Water Draw Model discussion in Section 5.6.

5.5.5 Energy Analysis Results

Electric Water Heater Energy Use

Table 5.5.7 lists the average annual energy use for electric water heaters and the average daily energy savings for each design option.

Table 5.5.7 Energy Consumption for Electric Water Heaters

Design Option		Average Electricity Use (kWh/yr)	Average Energy Savings (Btu/day)
0	Analytic Baseline	3503	
1	0 + Heat Traps	3408	884
2	1 + 2" Jacket Insulation	3362	1312
3	1 + 2.5" Jacket Insulation	3318	1726
4	3 + Plastic Tank	3276	2121
5	3 + Insulated Tank Bottom	3296	1936

Figure 5.5.5 shows, for each design option, the cumulative frequency of the difference of energy consumption compared to analytic baseline electric water heaters.

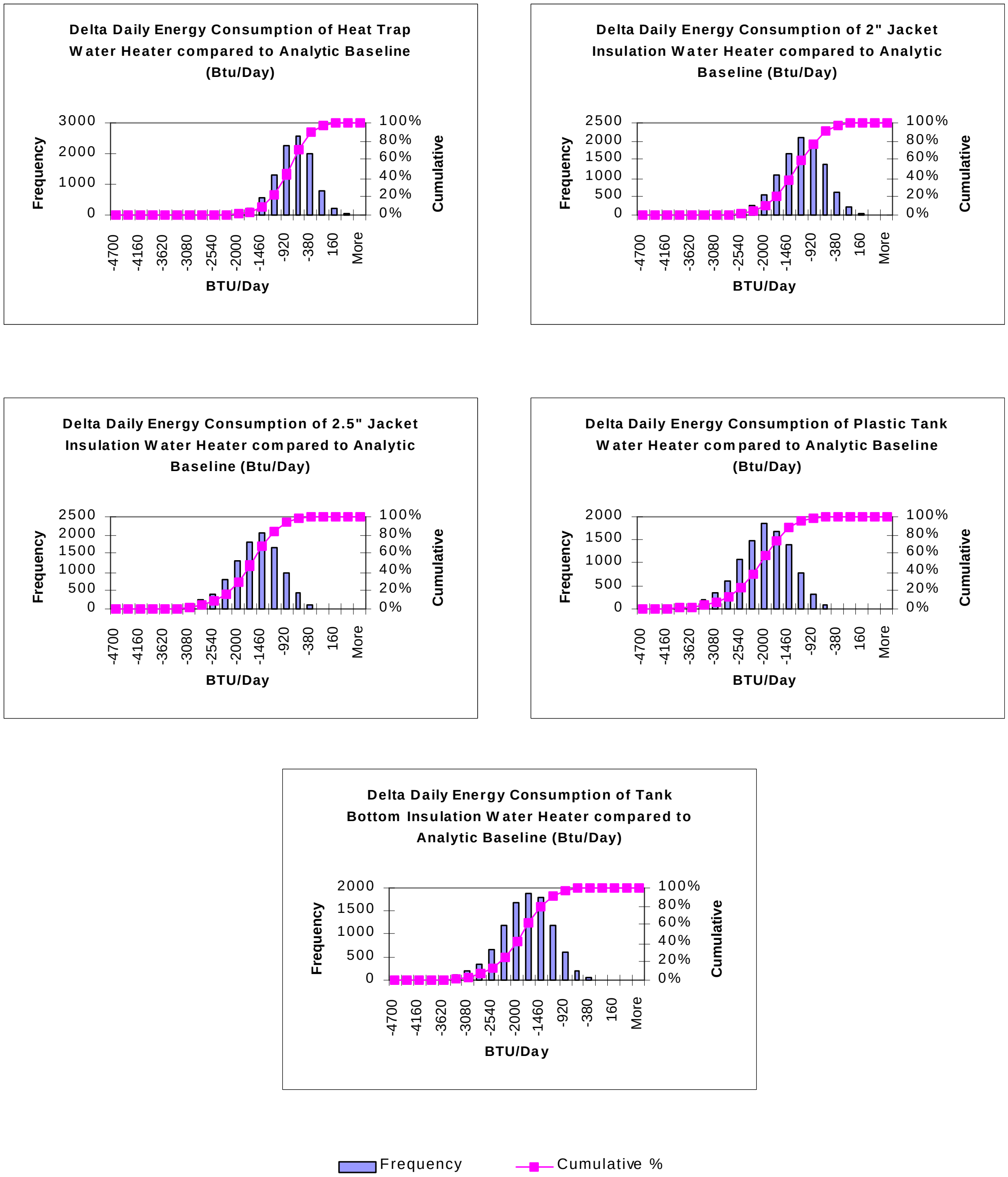

Figure 5.5.5 Differences in Energy Consumption by Design Option - Electric Water Heaters

Gas-fired Water Heater Energy Use

Table 5.5.8 lists the average annual energy use for gas-fired water heaters and the average daily energy savings for each design option.

Table 5.5.8 Energy Consumption for Gas-Fired Water Heaters

Design Option		Average Energy Use		Average Energy Savings
		(MCF/yr)	(kWh/yr)	(Btu/day)
0	Analytic Baseline	22.32	0	
1	0 + Heat Traps	21.72	0	1671
2	1 + 2" Jacket Insulation	20.58	0	4886
3	1 + 2.5" Jacket Insulation	20.34	0	5567
4	3 + Side Arm Heater	17.37	23	13719
5	2 + Improved Flue Baffle	20.04	0	6422

Figure 5.5.6 shows, for each design option, the cumulative frequency of the difference of energy consumption compared to analytic baseline gas-fired water heaters.

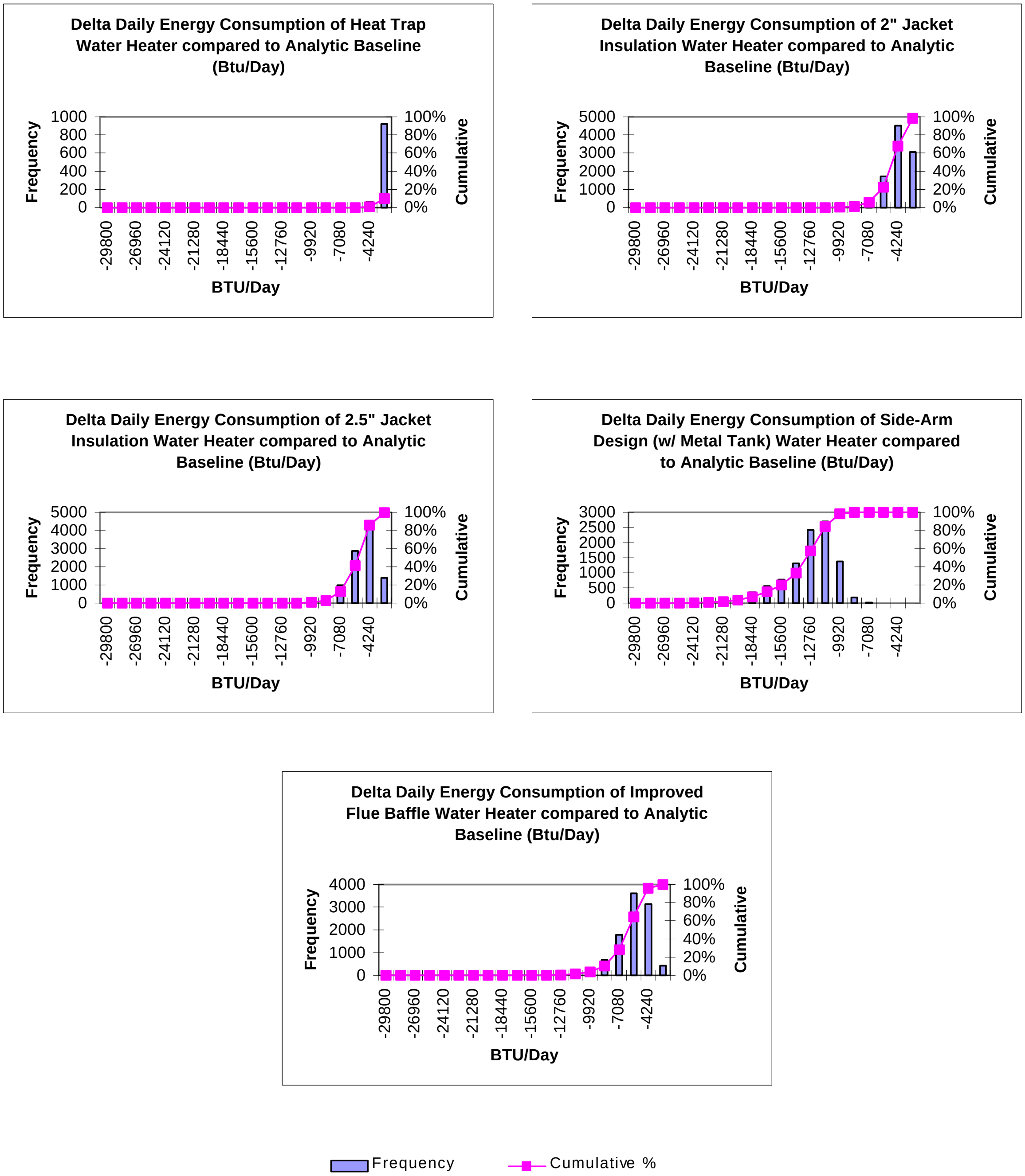

Figure 5.5.6 Differences in Energy Consumption by Design Option - Gas-fired Water Heaters

5.6 Hot Water Draw Module

5.6.1 Introduction to Hot Water Use

Hot water use varies widely between households because it is dependent on the household and water heater characteristics including: the number and age of the people who live in the home, the presence of hot water-using appliances, the tank size and thermostat setpoint of the water heater, and the climate in which the home is situated. By accounting for these five types of characteristics, the draw model estimates average daily hot water draw volume[26].

There is a degree of uncertainty in this estimation of hot water use. Uncertainty is caused not only by variability in the demographic and climatic inputs but also by uncertainties attached to the weighting factors, i.e., the estimated coefficients in the equation. The uncertainties in the coefficients are defined using normal distributions with the parameters provided in the original regression analysis[27].

5.6.2 Equation for Hot Water Use

The Hot Water Draw Model equation is expressed as follows:

$$vol = \{ sea\_coef + (per\_coef * per) + (age1\_coef * age1) + (age2\_coef * age2) + [age34\_coef * (age3 + age4)] + (T_{tank}\_coef * (T_{tank} + T_{tank}\_err)) + (Tanksz\_coef * Tanksz) + T_{in}\_coef * T_{in}) + (T_{air}\_coef * T_{air}) + (home\_coef * athome) - [(0.692 * per + 1.335 * \sqrt{(per)} * no\_dw] - [(1.1688 * per + 4.7737 * \sqrt{(per)}) * no\_cw] \} * (senior\_mf * no\_pay)$$

where:

vol = hot water consumption, gal (L)/day

per = total number of persons in household

age1 = number preschool children, age 0-5 yrs

age2 = number of school age children, age 6-13 yrs

age3 = number of adults, age 14-64 yrs

age4 = number of adults, age 65 yrs and over

T_{tank} = water heater thermostat setting, ºF (ºC)

*Tank*sz = water heater nominal tank size, gal (L)

T_{in} = water heater inlet water temperature, ºF (ºC)

T_{air} = outdoor air temperature, ºF (ºC)

athome = presence of adults at home during day

no_dw = absence of a dishwasher

no_cw = absence of a clothes washer

senior_mf = senior-only household in a multi-family building

no_pay = household does not pay for hot water

.

T_{tank}*_err* = estimation error for the thermostat setpoint (normal distribution)

sea_coef = coefficient for seasonal effects (normal distribution)

per_coef = coefficient for total number of persons in household (normal distribution)

age1_coef = coefficient for "age1" (normal distribution)

age2_coef = coefficient for "age2" (normal distribution)

age34_coef = coefficient for "age3" + "age4" (normal distribution)

home_coef = coefficient for "athome" (normal distribution)

Tanksz_coef = coefficient for water heater tank size (normal distribution)

T_{tank}*_coef* = coefficient for water heater setpoint (normal distribution)

T_{inlet}*_coef* = coefficient for water heater inlet temperature (normal distribution)

T_{air}*_coef* = coefficient for average outdoor temperature (normal distribution)

5.6.3 General Description of Key Variables

Number of People in Household (per). The total number of household members.

Number of Preschool Children (age1). The number of infants and young children up through age 5.

Number of School-Age Children (age2). The number of children age 6 through 13.

Number of Adults 14-64 (age3). The number of adults age 14 to 64.

Number of Adults 65+ (age4). The number of adults age 65 or more.

Thermostat Setpoint (T_{tank}). The thermostat setting of the heating element of the water heater.

Water Heater Tank Size (Tanksz). The nominal size of the water heater tank.

Outside Air Temperature (T_{air}). The average annual outdoor air temperature.

Inlet Water Temperature (T_{in}). The temperature of the water entering the water heater.

Unemployed Household Member (athome). The presence of a household member at home during the day.

Dishwasher (no_dw). Absence of a dishwasher in the household.

Clothes Washer (no_cw). Absence of a clothes washer in the household.

Senior Only (senior_mf). A senior-only (age 65 or more) household in a multi-family building.

No-Pay Household (no_pay). A household that does not pay to heat water.

5.6.4 General Description of Sources of Data

RECS provides data on the number, age, and employment status of household occupants, presence of a clothes washer or dishwasher, and form of payment to fuel utilities.

The derivations of the three temperature variables are discussed in Section 5.5.4.

RECS reports three ranges of water heater tank size -- small, medium, and large; for this analysis however, specific sizes are needed. By matching the three RECS ranges with the standard sizes, an exact water heater size was assigned to each RECS house.

Table 5.6.1 shows, by fuel type, the RECS water heater volumes and the corresponding selections for this analysis.

Table 5.6.1 Water Heater Volumes Selected for LCC Analysis

	RECS	Selection for LCC Analysis (gal) (liters)
Electric	Small	30 (110)
	Medium	40 (150)
	Large	50 (190)
		65 (250)
		80 (300)
Gas	Small	30 (110)
	Medium	40 (150)
	Large	50 (190)
		75 (280)
Oil	Small	
	Medium	32 (120)
	Large	50 (190)

Terms and values for no_dw, no_cw, senior_mf, and no_pay were developed by LBNL for the draw model.

Standard errors for the coefficients used in the equation were reported in the original hot water consumption model. These values were used to develop the normal distributions for the coefficients.

5.6.5 Results of Hot Water Use Calculations

Figure 5.6.1 shows estimated daily hot water use for households with electric water heaters as a histogram. For these households average daily use is 44.3 gallons. Figure 5.6.2 shows the equivalent chart for households with gas-fired water heaters. For those households the average daily use is 48.9 gallons of hot water.

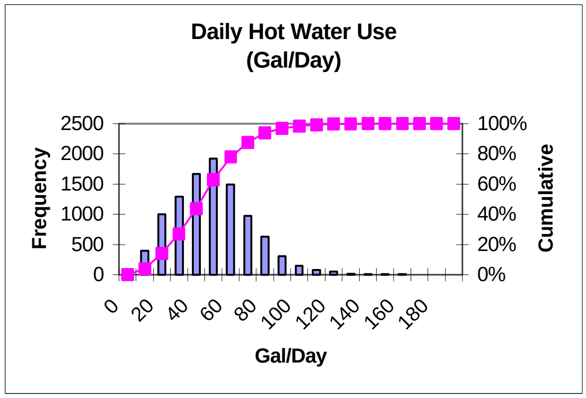

Figure 5.6.1 Frequency Chart of Hot Water Use - Households with Electric Water Heaters

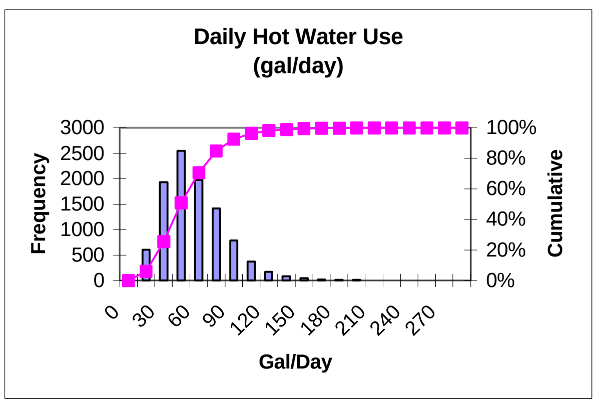

Figure 5.6.2 Frequency Chart for Hot Water Use - Households with Gas-Fired Water Heaters

References

1. Lawrence Berkeley National Laboratory (LBNL), 1998. *Engineering Analysis Methodology and Results for Residential Water Heater Efficiency Standards,* 1998. Intermediate report to U.S. DOE, Berkeley, CA. October 1.

2. LBNL, 1998. *LBNL Water Heater Cost Database*. [Microsoft Excel spreadsheet.] Berkeley, CA. August.

3. Lutz, J.D., C.D. Whitehead, A. Lekov, D. Winiarski, G.J. Rosenquist, 1998. "WHAM: A Simplified Energy Consumption Equation for Water Heaters." In: *Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings, August 23-28, 1998.* American Council for an Energy-Efficient Economy, Washington, DC.

4. Gas Appliance Manufacturers Association (GAMA), 1998. *Consumers' Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment.* Prepared for GAMA by Intertek Testing Services, Cortland, NY. April.

5. U.S. DOE, Energy Information Administration, 1997. *Annual Energy Outlook 1998.* DOE/EIA-0383(98). Washington, DC. December.

6. Gas Research Institute (GRI), 1998. *1998 Edition of the GRI Baseline Projection.* Arlington, VA.

7. U.S. DOE, Energy Information Administration, 1995. *Household Energy Consumption and Expenditures 1993*. DOE/EIA-0321(93), Washington, DC. October.

8. Whirlpool Corporation comments to the Department of Energy, December 12, 1990, Docket No. CE-RM-90-201, p. 1&2, Attachment #1.

9. "The Life Expectancy/Replacement Picture." 1998. *Appliance Magazine*. **55**:9, 71. September.

10. National Oceanic and Atmospheric Administration (NOAA), 1998. <http://www.ncdc.noaa.gov/ol/climate/online/ccd/meantemp.html > (last accessed: July 17, 1998).

11. Stanonik, F., 1998. Manufacturing Cost Data for Residential Gas and Electric Storage Water Heaters. GAMA, Arlington, VA. Letters to DOE, June 19 and July 17.

12. Minniear, M., 1997. *Residential Water Heaters: Initial Estimates of Manufacturing Costs and Energy Consumption*, Task 1 of LBNL Subcontract No. 6466797, p.3, Minniear Corporation, Panama City, FL, November 12.

13. Gas Appliance Manufacturers Association (GAMA), 1996. *GAMA Statistical Release*. Arlington, VA.

14. Williams, D., 1998. AlliedSignal, Morristown, NJ. Personal communication, March 17.

15. West, E., 1998. *Oil-Fired Water Heaters, Improvement to the Energy Use Attribute.* Work performed under Pacific Northwest National Laboratory Subcontract No. 323519, August 14.

16. McMahon, J., 1998. *Quantities and Current Assumptions for Calculating Life Cycle Costs of Clothes Washers*, p. 6 - 12, Research Memo to U.S. DOE, LBNL, Berkeley. CA. March 11.

17. Electric Edison Institute. 1997. Binder and spreadsheet by S. Rosenstock, presented to DOE Advisory Committee on Appliance Standards, Subcommittee on Economic Analysis, September 26, and subsequent updates.

18. U.S. DOE, Energy Information Administration, 1998. *Annual Energy Review Interactive Data Query System* <http://tonto.eia.doe.gov/aer> (last accessed: 10/7/98).

19. *Title 10, Code of Federal Regulations, Part 430 - Energy Conservation Program for Consumer Products, Appendix E to Subpart B - Uniform Test Method for Measuring the Energy Consumption of Water Heaters*. January 1, 1998.

20. Hiller, C. C., A. I. Lowenstein, R. L Merriam, 1992. *WATSIM User's Manual, Version 1.0: EPRI Detailed Water Heating Simulation Model User's Manual*, Electric Power Research Institute, TR-101702, Palo Alto, CA, October.

21. Paul, D.D., G.R. Whitacre, J.J. Crisafulli, R.D. Fischer, A.L. Rutz, J.G. Murray, G.S. Holderbaum, 1993. *TANK Computer Program User's Manual with Diskettes: An Interactive Personal Computer Program to Aid in the Design and Analysis of Storage-Type Water Heaters*. Prepared for Gas Research Institute, GRI-93/0186, Battelle Memorial Institute, Columbus, OH, July.

22. Huang, Y.J., R. Ritschard, J. Bull, S. Byrne, I. Turiel, D. Wilson, C. Hsui, D. Foley, 1987. *Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-Family Residential Buildings*. Technical Support Document for the PEAR Microcomputer Program. Lawrence Berkeley Laboratory, LBL-19128, Berkeley, CA.

23. California Energy Commission (CEC), 1990. *Occupancy Patterns & Energy Consumption in New California Houses (1984-1988)*. P400-90-009. Sacramento, CA.

24. Labs, K., 1979. "Underground Building Climate." *Solar Age*. October 1979. **4**:10, 44-50.

25. Abrams, D.W. and A.C. Shedd, 1992. *Commercial Water Heating Applications Handbook.* Prepared for Electric Power Research Institute. EPRI TR-100212, Research Project 3169-01, Final Report. Palo Alto, CA.

26. Lutz, J.D., X. Liu, J.E. McMahon, C. Dunham-Whitehead, L.J. Shown, Q.T. McGrue, 1996. *Modeling Patterns of Hot Water Use in Households*. Lawrence Berkeley National Laboratory. LBNL-37805. Berkeley, CA.

27. Ladd, G.O. and J.L. Harrison. Gilbert Associates, Inc. 1985. *Electric Water Heating for Single-Family Residences: Group Load Research and Analysis*. Prepared for Electric Power Research Institute. EPRI EA-4006. Palo Alto, CA.