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Cost of Increased Energy Efficiency for Residential Water Heaters

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ABSTRACT

The goal of this analysis was to estimate the energy savings potential and associated costs of individual design options or combinations of design options. Design options added to baseline residential water heaters reduce water heater energy consumption and can save United States consumers billions of dollars a year.

To determine the energy saving viability of particular design option combinations, both the energy savings potential and the estimated costs were calculated. Energy use for design options for each of the three classes of water heaters were modeled either with computer simulation programs or a simplified calculation method. Water heater manufacturers, distributors and industry experts provided the cost data. The analysis then developed a price relationship to show the manufacturer and consumer cost to achieve increased efficiency.

The results show that energy efficiency measurements can be increased by 4% for electric water heaters; 9% for gas-fired water heaters and 2% for oil-fired water heaters. A significantly higher efficiency level with an acceptable payback can be achieved for electric and gas-fired water heaters. This information serves as the basis for making improvements in energy efficiency of U.S. residential storage-type water heaters.

KEYWORDS

Consumption, Efficiency, Energy Analysis, Energy Estimating, Heat Loss, Hot Water, Residential, Service Water Heating, Water Heater

INTRODUCTION

Water heaters consume 17% of U.S. residential home total energy. Energy-efficient water heaters reduce energy consumption and can save U.S. consumers billions of dollars a year. The work presented in this paper follows from the National Appliance Energy Conservation Act (NAECA or the Act) of 1987 which requires consideration of amending the energy conservation standards for residential water heaters in order to make them more efficient. The Act initiates a rulemaking process and specifies consideration of a standard that "achieves the maximum improvement in energy efficiency which is technologically feasible and economically justified."

The costs of increased energy efficiency for residential water heaters were determined by developing efficiency and price data for design options and combinations of design options for electric, gas, and oil water heaters. The efficiency data is based on DOE test procedure for residential water heaters (FR 1998) and the application of computer simulations and other analytical methods to investigate the efficiency improvements resulting from design options and their interactions when multiple design options are used. The total installed cost for water heaters was developed by building on factory costs to include sales tax and manufacturer, distributor, and installer markups. Additional installation costs, which are required for certain design options are also included in the consumer price for water heaters with those options. The energy prices used for this ranking are current national average energy prices from Annual Energy Outlook 1998 (EIA 1998).

The results of the analysis show a price relationship between manufacturer and consumer costs and increased efficiency. The cost-efficiency charts show the increased cost and efficiency resulting from the considered design option combinations for each water heater type.

ANALYSIS TOOLS AND ASSUMPTIONS

In this first section, the sources of information that provided data for the analysis are given. Impending regulations outside of NAECA that will impact the manufacture and installation of water heaters are discussed next in the Technological Issues. In Baseline Models, the basic water heater models used are described. Energy Calculation Methodology discusses the methods used to calculate energy consumption for each type of water heater - electric, gas-fired, and oil-fired.

The scope of the study is limited to the following:

- product classes of electric, gas-, and oil-fired water heaters.
- tank volumes of 50-gal (190-l) electric, 40-gal (150-l) gas-fired, and 32-gal (190-l) oil-fired.
- DOE 24-hour test procedure test conditions for residential water heaters for calculation of energy consumption and energy parameters (FR 1998)

Assumptions used in the analysis include:

- average energy prices. Payback calculations use a natural gas price of $6.42/MMBtu and electricity price of $0.0788/kWh. and the currency values are in 1998$.

Information Sources

The primary source of both manufacturer costs and efficiency data for this analysis is an industry association. It collected cost and efficiency data from water heater manufacturers. These data were aggregated to protect the confidentiality of the individual manufacturers. Data for four of the design options being considered (2.5- and 3-inch insulation, plastic tank & side arm heater) were obtained from industry consultants (Minniear1997) (West 1998). Manufacturer cost data were reconfirmed for certain design options by direct contact with component manufacturers. The costs to the consumer for water heater equipment and installation are taken from the Water Heater Price Database (DOE 1999). This database contains information from more than 130 retail stores, wholesale distributors, and plumbing contractors throughout the United States.

Technological Issues

Most residential water heaters are insulated with polyurethane. Currently, manufacturers use HCFC-141b, an ozone-depleting substance, as a blowing agent for the insulation. As a result of the Montreal Protocol, HCFC-141b is scheduled for phaseout by January 1, 2003. This requirement will affect the efficiency of water heaters. Two alternative blowing agents, water and hydrofluorocarbon 245fa (HFC-245fa), are considered in this analysis. Published laboratory measurements (see Table 1) were used to determine the properties of water heater insulation blown with water or HFC-245fa in this analysis (Fanney 1999). As can be seen in this table the current blowing agent has the greatest insulating capabilities and water has the least.

Table 1
Water Heater Insulation Characteristics w/ Different Blowing Agents

	w/ HFC-141b	**w/ HFC-245fa**	**w/ Water/CO_2**
Insulation conductivity	0.000233 Btu/ft·min·°F (0.02420 W/m·K)	0.000240 Btu/ft·min·°F (0.024922 W/m·K)	0.000331 Btu/ft·min·°F (0.034327 W/m·K)

Another regulatory change, originating from the Consumer Product Safety Commission (CPSC), requires future gas-fired water heaters to be resistant to ignition of flammable vapors (Topping 1996). In this study, this requirement is acknowledged by adding a cost to the manufacturer cost of all design options for gas-fired water heaters, including the baseline design. This design is assumed to have no impact on efficiency.

Baseline Models

The baseline models are defined as the most common size water heater with the minimum efficiency allowed by existing energy-efficiency standards. The general characteristics of the baseline model for each of the three primary product classes (i.e., electric storage, gas-fired storage, and oil-fired storage) are shown in Table 2.

Table 2
General Characteristics of the Baseline Models

Characteristics	Electric	Gas	Oil
Rated Volume	50-gallon (190-l)	40-gallon (150- l)	32 gallon (120-l)
Insulation Blowing Agent	HCFC-141b	HCFC-141b	HCFC-141b
Insulation Thickness (nom.)	1.5 in. (3.8 cm)	1 in. (2.5 cm)	1 in. (2.5 cm)
Rated Input	4,500 W	40,000 Btu/hr (11,700 W)	90,000 Btu/hr (26,000 W)
Ignition System	N/A	Pilot at 450 Btu/hr (120W)	Electronic Ignition, IID
Burner Motor	N/A	N/A	⅛ hp (282 W)
Energy Factor (EF)	0.86	0.54	0.53
Recovery Efficiency (RE)	98%	76%	75%

The energy performance of the baseline units is mandated by the NAECA minimum efficiency standards (see Table 3).

Table 3
NAECA Minimum Efficiency Standards

Product Class	Minimum Allowable Energy Factor (EF)
Electric Water Heater	0.93 - (.00132 x Rated Storage Volume in gallons)
Gas-Fired Water Heater	0.62 - (.0019 x Rated Storage Volume in gallons)
Oil-Fired Water Heater	0.59 - (.0019 x Rated Storage Volume in gallons)

Energy Calculation Methodology

Design options for each of the three classes of water heaters were modeled with either a computer simulation program or a simplified calculation method. For the analysis of the electric and gas-fired water heaters, a customized tool was developed which integrates a library of inputs, automates the development of input files, executes the simulation programs, processes the results, performs diagnostics and develops cost-efficiency tables. The flow of the analysis is shown in Fig. 1.

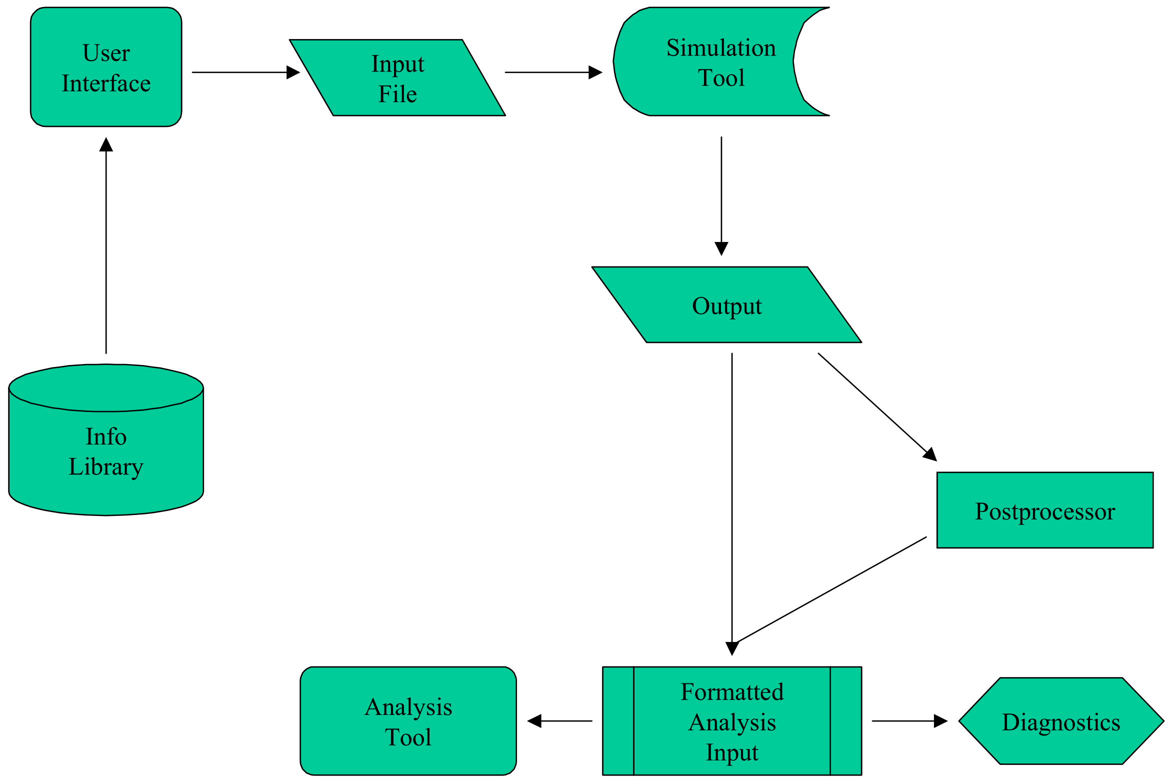

Figure 1. Water heater energy calculation flow

Outputs from the computer simulations were used to determine the energy-efficiency characteristics of the water heater (e.g., Energy Factor (EF), Recovery Efficiency (RE), and standby heat loss coefficient, (UA)), based on the DOE test procedure (FR 1998). This work included an assessment of the economic impacts of trial energy-efficiency standards for electric, gas-, and oil-fired water heaters according to the criteria in the Energy Policy and Conservation Act (EPACT). The simulation models and energy calculation methods are discussed briefly below.

For the electric water heater analysis, the procedure uses a detailed electric water heater simulation program (Hiller 1992). The output does not directly include the EF, RE, and UA calculations from the DOE test procedure. However, it does provide detailed temperature profiles of the water inside the water heater tank during the simulation. These temperature profiles are used to determine the EF and other parameters of the water heater using the test procedure calculations. A spreadsheet tool (DOE 1999-2), which is included in the postprocessing module of the integrated procedure, has been developed to calculate the efficiency characteristics according to the specifications of the DOE test procedure using the output of the simulation program.

For the gas-fired water heater analysis, the procedure uses a detailed gas-fired storage water heater program (Paul 1993). It calculates energy flows throughout a water heater including water draws, flue heat losses, jacket heat losses, fittings heat losses, and combustion chamber heat losses. The program outputs include the EF, RE, and UA from the DOE test procedure. Therefore, additional calculations are not necessary for determining a gas-fired water heater's energy-efficiency characteristics under the DOE test procedure.

A simplified water heater analysis model (WHAM), which is publicly available, was used for the analysis for oil-fired water heaters (Lutz 1999). WHAM bases its calculation on the 24-hour simulated use test portion of the DOE test procedure. The model calculates energy consumption from a water heater's RE, UA, and rated input (P_{on}). WHAM energy calculations have been checked against both the detailed simulation calculations. WHAM is a good predictor of daily energy use for oil-fired water heaters because one of the simplifying assumptions is that all the water drawn from the tank is at the setpoint temperature. For a given draw volume (such as the separate 10.7 gallon (40.5 liter) draws of the DOE test procedure), an oil-fired water heater will fire at approximately the same time as will a gas-fired water heater of similar volume. However, because the recovery rate of oil-fired water heaters is typically more than twice that of gas-fired water heaters, the temperature of the water being drawn from the heater will be closer to the water heater setpoint temperature.

OVERALL ANALYTICAL APPROACH

For this study, a distinction is made between baseline models containing current technologies and future baseline models that are expected to incorporate new mandated features. The current technologies are referred to as "existing" baseline models and the future technologies as "2003" baseline models (for the year 2003, when new efficiency standards are proposed to take effect). The next sections, Exiting Baseline Models and 2003 Baseline Models, summarize the primary characteristics of water heaters for the three fuel types. Design Option Selection and Design Option Modeling describe the design options and the fuels for which they are appropriate. The next two sections, Manufacturing Costs, and Retail Prices, Installation, and Maintenance Costs, describe the cost data assumptions. The final section, Cost-Efficiency Data, utilizes this information to estimate the energy savings potential of individual design options.

Existing Baseline Models

Computer simulations of existing baseline models for all three fuel types use the characteristics of water heaters recently available on the market and include specifications described for baseline models (Baseline Models section of the previous part).

Table 4 summarizes the primary characteristics of the typical existing electric baseline water heater. For electric water heaters, the typical existing baseline model was simulated with the characteristics of a 50-gallon (190-liter) baseline water heater with an EF of 0.86. It was determined that only by using 1.5 in. (3.8 cm) of foam insulation was possible to achieve the minimum allowable NAECA efficiency of 0.86 EF.

Table 4
Electric Water Heater Baseline Characteristics

Tank Rated Capacity	50 gal (190 l)
Tank Diameter	15.84 in. (40.23 cm)
Tank Length	54.48 in. (138.38 cm)
Insulation Thermal Conductivity	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)
Conductivity of Feed-Throughs	0.40 Btu/ft·min·°F (41.54 W/m·K)
Natural Convection UA for Feed-Through calcs	0.185 Btu/hr·°F

Table 5 summarizes the primary characteristics of the typical existing gas-fired baseline water heater. The simulated gas-fired baseline model is a 40-gallon (150-liter) gas-fired water heater with an EF of 0.54 and an RE of 76%.

Table 5
Gas-Fired Water Heater Baseline Model Characteristics

Descriptive parameter	Value
Input Rating	40000 Btu/hr (11723 W)
Pilot Input	450 Btu/hr (117 W)
Excess Combustion Air	40.9 (%)
Off-cycle pressure loss coefficient	12.5800
Flue baffle effectiveness multiplier	2.000
Inside Diameter	15.84 in. (40.23 cm)
Steel Wall Thickness	0.054 in. (0.1372 cm)
Height	47.6 in. (120.9 cm)
Volume	38.0 gallons (143.8 liter)
Foam insulation thickness	0.981 in. (2.492 cm)
Sheet metal thickness	0.019 in. (0.0483 cm)
Insulation Thermal Conductivity	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)
Flue Internal Diameter	3.84 in. (9.75 cm)
Volume to Thermostat Ratio	4.05 gallons (15.33 liter)

Table 6 summarizes characteristics of the baseline oil-fired water heater. The existing oil-fired water heater, modeled with WHAM equation, is a 32-gal unit with an EF of 0.529 and a RE of 75%.

Table 6
Oil-Fired Water Heater Baseline Model Characteristics

Descriptive parameter	Value
Input Rating	90,000 Btu/hr (26,377 W)
On-cycle electric consumption	282 W
Off-cycle electric consumption	0.0 W
Inside Diameter	17.892 in. (40.366 cm)
Steel Wall Thickness	0.054 in. (0.1372 cm)
Height	32.7 in. (83.1 cm)
Volume	32.0 gallons (120 liter)
Sheet metal thickness	0.019 in. (0.0483 cm)
Insulation Thermal Conductivity	0.0140 Btu/hr·ft·°F (0.0242 W/m·K)
Flue Internal Diameter	6.00 in. (15.24 cm)

2003 Baseline Models

It is expected that new energy-efficiency standards will take effect near year 2003. The 2003 baseline models developed for this analysis use foam insulation blown with water or hydrofluorocarbon 245fa (HFC-245fa). Although the cost of water-blown insulation is lower than the cost of HFC-245fa, it is also 42% less effective as an insulation compared to HCFC-141b as a blowing agent. By comparison, HFC-245fa is projected to be 2½ times more costly than HCFC-141b, but it is only 3% less effective as an insulation than HCFC-141b.

To model the 2003 baseline electric water heater with the alternative blowing agents, the foam insulation thickness was increased to 2.12 in. for water and 1.55 in. for HFC-245fa. In order to keep the energy characteristics of the new baselines equivalent to the HCFC-141b baseline, the foam insulation thickness was increased from 0.981 in. to 1.31 in. for water and 1.0 in. for HFC-245fa. For the oil-fired water heater baseline for the alternative blowing agents, the foam insulation thickness was increased from 0.981 in. to 1.41 in. for water and 1.01 in. for HFC-245fa.

Design Option Selection

Design options that improve the efficiency of water heaters were grouped into two categories: 1) designs that reduce standby losses and 2) designs that improve combustion efficiency. Only design options already in use or that have been tested as a research prototype are analyzed .

Designs that reduce standby losses—heat traps and increased jacket insulation—are frequently applicable to all fuel types. Manufacturers insulate water heaters by filling the cavity between the jacket and the tank with polyurethane foam insulation. Most water heaters on the market today have at least 1-inch thick foam insulation, while some models have 2- or 3-inch thick insulation. An alternate way to reduce jacket losses is to use advanced insulation materials such as evacuated panels.

Other design options reduce also standby losses, but usually are restricted to one type of fuel. Plastic water heater tanks reduce conducted heat. The bottom of the tank can be insulated but only in electric or indirect water heaters. A damper installed on the flue of gas-fired water heaters minimizes off-cycle heat losses. The side arm heater design avoids flue losses on gas-fired water heaters by using a separate heat exchanger to heat water and a small circulation pump. An electronic ignition device can replace a standing pilot ignition system in gas-fired water heaters.

Two design options were considered that improve combustion efficiency. The first is increased heat exchange from a flue baffle. A flue baffle is a twisted strip of metal inserted into the flue of a gas or oil water heater that improves heat transfer to the flue wall. The second, increased heat exchanger surface area, usually from multiple flues, improves the heat transfer from the flue gas to the water. Table 7 lists the design options and their applicability by their fuel types.

Table 7
Water Heater Design Options: Modeling

Design Option	Electric	Gas	Oil
Simulation Model	WATSIM	TANK	WHAM
Heat Trap	Yes	Yes	Yes
Insulation Thickness	2", 2.5", 3"	2", 2.5", 3"	2", 2.5", 3"
Insulated Tank Bottom	Foamed disk/bottom	N/A	N/A
Plastic Tank	Steel Shell & Plastic Liner	Only with Side-Arm Heater	N/A
Improved Flue Baffle	N/A	78% RE & 80% RE	78% RE
Electromechanical Flue Damper	N/A	Yes	N/A
Electronic Ignition, IID	N/A	Yes	N/A
Side Arm Heater	N/A	Yes	N/A
Interrupted Ignition	N/A	N/A	Yes
Increased Heat Exchange Area	N/A	N/A	82% RE

Design Option Modeling

Heat Traps. A heat trap prevents losses associated with the circulation of hot water into the water heater plumbing when hot water is not being drawn. It keeps the buoyant hot water from circulating out into the piping distribution system because of natural convection. Heat traps, in this context, refer to the configuration which includes the heat trap cartridge assembly, the deep tube, and the attachment to the water heater. The cold water inlet line heat trap is generally mounted in the cold water supply pipe (the dip tube assembly); the heat trap mechanism resides near the top of the water heater within the tank. The hot water outlet line heat trap is mounted at the top of the water heater; the heat trap mechanism is part of a plastic cartridge enclosed within the steel pipe that houses the entire heat trap/anode device. By containing hot water in the storage tank, the heat trap minimizes standby heat loss. Different means were used to model the heat traps impacts for the three fuel types: for electric water heaters the natural convection heat transfer losses at the supply and draw lines were reduced, the gas-fired water heater model offers a direct modeling option and oil-fired water heaters were modeled by matching the energy factor impact reported by the industry.

Increased Jacket Insulation. Most electric water heaters on the market today have jacket (sides and top) insulation that is at least 1-in. (2.5-cm) thick. Some manufacturers provide 2- to 3-in. (5.1- to 7.6-cm) thick insulation. Although increasing the insulation thickness reduces standby heat loss, the increased overall diameter of the water heater may pose installation problems. Shipping costs also increase because fewer water heaters can fit in a container space. Insulation thicknesses greater than 3 in. (7.6 cm) were not considered in this analysis.

Table 8 summarizes the changes made to the HFC-245fa 2003 baseline model to simulate the performance of the water heaters insulated with 2-, 2.5, and 3-in. (5.1-cm, 6.4-cm, and 7.6-cm) foam insulation. Because of the higher conductivity of water-blown insulation, its baseline insulation is thicker than 2 in., so 2-in. insulation is not one of design options.

Table 8
Water Heater Modeling with 2-, 2.5, & 3-in. Foam Insulation

Descriptive Parameter		with 2-in. insulation	with 2.5-in. insulation	with 3-in. insulation
insulation	top:	2.00 in. (5.08 cm)	2.50 in. (6.35 cm)	3.00 in. (7.62 cm)
thickness	side:	2.00 in. (5.08 cm)	2.50 in. (6.35 cm)	3.00 in. (7.62 cm)

Insulating the Tank Bottom. Insulating the bottom of electric water heater tanks reduces standby loss. A foamed "disk/bottom insulation" assembly is used for the tank bottom insulation. The bottom insulation portion of the disk/bottom insulation assembly reduces the heat losses from the bottom of the tank, and the disk portion reduces conduction heat losses through the perimeter. Table 9 summarizes the changes made to the 2003 baseline model to simulate the performance of electric water heaters with bottom insulation.

Table 9
Electric Water Heater Modeling with Foamed Bottom Insulation

Descriptive Parameter	2003 Baseline	Bottom Insulation
support ring conductivity	0.40 Btu/ft·min·°F (41.54 W/m·K)	0.000472 Btu/ft·min·°F (0.0490 W/m·K)
bottom thickness insulation	0.75 in. (1.91 cm)	1.5 in. (3.8 cm)
bottom insul. conductivity -245fa	0.000333 Btu/ft·min·°F (0.0346 W/m·K)	0.000240 Btu/ft·min·°F (0.0249 W/m·K)
- water-blown	0.000333 Btu/ft·min·°F (0.0346 W/m·K)	0.000331 Btu/ft·min·°F (0.034327 W/m·K)

Plastic Tank. There are several methods for constructing plastic water heater tanks. This analysis used steel shell/plastic interior style tanks constructed of a thin steel shell with an internal plastic tank. The steel exterior serves as the primary structural support for the tank. The lower heat conductivity of the plastic compared to steel reduces the heat conducted through the tank wall to the insulation. Plastic tanks cannot be used with center-flue gas-fired water heaters because plastic cannot withstand the high temperatures produced by the flames. For gas-fired water heaters, this option was considered only with indirect water heating techniques (e.g., the side arm water heater). Table 10 summarizes the changes made to the 2003 baseline model to simulate the performance of a plastic tank.

Table 10
Water Heater Modeling with Plastic Tank

Descriptive Parameter	2003 Baselines	2003 Baselines w/ Plastic Tank
tank wall thickness	0.063 in. (0.16 cm)	steel 0.0853 in. (0.16 cm) plastic 0.126 in. (0.32 cm)
wall conductivity	0.40 Btu/ft·min·°F (41.54 W/m·K)	0.0018 Btu/ft·min·°F (0.1869 W/m·K)
insulation conduct. - 245fa	0.000333 Btu/ft·min·°F (0.0346 W/m·K)	0.000240 Btu/ft·min·°F (0.0249 W/m·K)
- water-blown	0.000333 Btu/ft·min·°F (0.0346 W/m·K)	0.000331 Btu/ft·min·°F (0.034327 W/m·K)

Improved Flue Baffle. Flue, in this context, refers to the "internal gas passageway" inside gas-fired water heaters. The standard flue baffle is a twisted strip of metal inserted into the flue. It increases the turbulence of flue gases and improves heat transfer to the flue walls. A flue baffle with optimized geometry can increase recovery efficiency (RE) from 76% to as much as 85%, depending on the specific geometry. At REs above 80%, flue gas condensation may occur in the flue, which can lead to corrosion and a shortened water heater life. This analysis considers REs of 78% and 80%. Table 11 summarizes the changes made to the 2003 baseline model for gas-fired water heaters to simulate the performance of an improved flue baffle. In order to model a water heater with an RE of 78% or 80%, the excess combustion air was decreased and the flue baffle heat exchanger multiplier was increased accordingly.

Table 11
2003 Baseline Models vs. Gas Fires Water Heater with Improved Flue Baffle

Descriptive Parameter	2003 Baselines	RE = 78%	RE = 80%
Excess Combustion Air (%)	40.9	34.0	27.0
Flue baffle effectiveness multiplier	2.0	2.2	2.7

In the case of oil-fired water heaters the flue losses are reduced during on-time only. The references for existing oil-fired water heaters report REs range from 75% to 83% (Bock 1998).

Electronic Ignition. Unlike standing pilots that consume gas continuously, electric ignition devices operate only at the beginning of each “on”-cycle. Although there is no increase in steady-state efficiency with use of electronic ignition devices, overall fuel consumption may be reduced. Burner “on”-time may increase to make up for the heat the standing pilot would have supplied during standby periods.

For this analysis, the gas-fired water heaters were analyzed with an intermittent pilot ignition system. Table 12 summarizes the changes made to the 2003 baseline models to simulate the performance of an intermittent pilot ignition system. Total “on”-cycle power consumption includes the power draw of the gas valve, the control module, and the electronic thermostat. The total “off”-cycle power consumption is only the electronic thermostat.

Table 12
2003 Baseline Gas-Fired Water Heater vs. Model with Electronic Ignition

Descriptive Parameter	2003 Baselines	with Electronic Ignition
Pilot Input	450 Btu/hr (154 W)	0 Btu/hr (0 W)
“On”-cycle power consumption	0.0 W	15.7 W
“Off”-cycle power consumption	0.0 W	0.4 W

Electromechanical Flue Damper. Gas-fired storage water heaters are equipped with a draft hood connecting the flue to a vent pipe or chimney. During “off”-cycles, a water heater loses heat by natural convection up the flue. A damper can minimize “off”-cycle heat losses. Flue dampers are assumed to have no effect on water heater RE. For this analysis, electromechanical flue dampers are considered only in conjunction with electronic ignition systems. The flue damper is modeled by adjusting the “off”-cycle pressure loss coefficient. Table 13 summarizes the changes made to the 2003 baseline model to simulate the performance of an electromechanical flue damper.

Table 13
2003 Baseline Model vs. Gas-Fired Water Heater with Electromechanical Flue Damper

Descriptive parameter	2003 Baselines	with Electromechanical Flue Damper
"Off"-cycle pressure loss coefficient	12.58	168
"Off"-cycle power consumption	0.0 W	5.0 W

Side Arm Heater. The side arm heater design avoids large flue losses by removing the flue from the center of the tank. Water is withdrawn from the bottom of the tank, heated by a burner in a small, separate heat exchanger, and returned to the top of the tank. A small circulation pump moves water through the heat exchanger when the burner is on. The basic designs incorporate an intermittent pilot ignition device and 1 in. (2.56 cm) of HFC-245fa or 1.31 in (3.33 cm) of water-blown insulation and were analyzed with three REs: 76%, 78%, and 80%. The calculation is based on the WHAM energy calculation method. Table 14 provides EF estimates for side arm designs utilizing metal or plastic tanks at the three RE levels.

Table 14
Energy Factor Estimates for Side Arm Gas-Fired Water Heater

Side Arm Water Heater Design	Energy Factors (w/ metal tank)	Energy Factors (w/ plastic tank)
with 76% RE	0.620	0.620
with 78% RE	0.633	0.633
with 80% RE	0.646	0.646

Increased Heat Exchanger Surface Area. This design option is applied to oil-fired water heaters only. It is based on a design which uses small projections on the inner flue surface to increase the heat-transfer area and turbulence. Energy performance of the increased heat exchanger surface area design option is modeled by increasing the RE of the 2003 baseline model from 0.75 to 0.82.

Interrupted Ignition. Interrupted ignition turns off the ignition spark after a flame has been established. This saves electrical energy because the spark operates less often. This feature saves 131 Wh/day and in addition increases the RE to 0.825 (DOE 1999-3).

Manufacturer Costs

Manufacturer cost estimates are for a 50-gallon electric water heater, a 40-gallon gas-fired water heater and a 32-gal for oil-fired water heater and are disaggregated into variable (material, labor, transportation, overhead) and fixed (capital, product design) costs. Variable and fixed costs are expressed on a per-unit basis as an incremental increase cost over the existing baseline design. The industry association provided most of the manufacturer costs with the exception of oil-fired water heaters, plastic tanks and side-arm heaters, which were provided by industry consultants.

Existing Baseline Model. Cost estimates for the existing baseline model—an electric water heater with 1.5 in. (3.8 cm) of jacket insulation, a gas-fired and an oil-fired water heater with 1 in. (2.5 cm) of jacket insulation using HCFC-141b as a blowing agent—were supplied by the industry association. The amount and cost of materials associated with other thicknesses of HCFC-141b insulation were calculated. The material costs for the HCFC-141b foam insulation ($1/lb or $2.2/kg) and sheet metal ($0.30/lb or $0.66/kg) are based on estimates by an independent consultant. No fixed costs were assumed for any of the baseline model. The total manufacturing cost for the oil-fired water heater does not include the burner. The manufacturer cost estimates for the existing baseline water heaters is presented are Table 15.

2003 Baseline Model. To convert the baseline manufacturer costs associated with foam insulation blown with HCFC-141b to insulation blown with HFC245fa and water, the amount and cost of materials associated with varying thicknesses of insulation were estimated. It was assumed manufacturers will maintain the thermal resistance of their baseline model when switching from HCFC-141b to an alternative insulation. Therefore, in Table 14, the actual thickness level for 1.5 in. or 1 in. of HFC-245fa and water-blown insulation is assumed to be greater than for HCFC-141b, because of the higher conductivity.

Table 15 presents manufacturer cost estimates for the existing baseline water heaters with HCFC-141b, HFC-245fa and water-blown insulation. The material costs for the 2003 baseline models include the difference in material costs between HCFC-141b and HFC-245fa and between HCFC-141b and water-blown models. In addition, in the case of gas-fired and oil-fired water heaters, in order to estimate the cost of the significantly thicker water-blown insulation, the labor, transportation, and overhead costs as well as the fixed costs were increased by an adjustment ratio. This ratio was calculated from the available data for upgrading from 1" to 2" insulation.

To resist the ignition of flammable vapors, gas-fired water heaters need to be redesigned. A value of $35 is added to the total manufacturing cost ($15 variable costs & $20 fixed cost) for product redesign.

Table 15
Baseline Model Manufacturer Costs

	Variable Costs					Fixed Cost	Total Mfg
	Material	**Labor**	**Transp**	**Overhd**	**Total**	**Total**	**Cost**
Design	***($)***	***($)***	***($)***	***($)***	***($)***	***($)***	***($)***
Electric Water Heater							
Baseline w/ 141b - 1.5 in (3.81 cm)	62.16	10.57	10.11	38.89	121.73	0.00	121.73
Baseline w/ 245fa - 1.55 in (3.94 cm)	10.57	10.11	10.11	38.89	123.87	0.00	123.87
Baseline w/ water - 2.12 in (5.38 cm)	71.97	10.57	10.11	38.89	131.54	0.00	131.54
Gas-fired Water Heater							
Baseline w/ 141b - 0.981 in (2.49 cm)	75.02	10.74	9.67	38.35	133.78	0.00	133.78
Baseline w/ 245fa - 1.00 in (2.54 cm)	91.13	10.74	9.67	38.35	149.89	0.00	169.89
Baseline w/ water - 1.31 in (3.33 cm)	92.06	10.92	10.46	39.10	152.54	0.44	172.98
Oil-fired Water Heater							
Baseline w/ 141b - 0.981 in (2.49 cm)	85.00	18.25	-	36.00	139.25	0.00	139.25
Baseline w/ 245fa - 1.01 in (2.57 cm)	86.02	18.25	-	36.00	140.27	0.00	140.27
Baseline w/ water - 1.41 in (3.54 cm)	87.01	18.38	-	37.41	142.80	1.36	144.16

Design Option. Tables 16 and 17 summarize incremental manufacturer costs for incorporating different design options into an water heater.

Two heat trap designs were considered: 1) a ¾-in. (1.9-cm) by 3-in. (7.6-cm) metal pipe nipple with an inserted plastic heat trap. This assembly is used for both supply and draw lines, and 2) a plastic drop-in-tube design for the supply line and a plastic cartridge heat trap design within a combined outlet and anode rod assembly for the draw line. Manufacturer costs for heat traps for electric and gas-fired water heaters differ slightly in the data provided by the industry association. The costs reflect the addition of heat traps on both the supply and draw lines.

The variable and fixed cost data provided for jacket insulation include increases from a baseline level to a thickness of 2.0 in. only. The costs for upgrading to 2.0-in. (5.1-cm) insulation, modified for both HFC-245fa and water-blown foam, were multiplied by adjusting ratios to approximate the variable and fixed costs for 2.5-in. (6.4-cm) and 3-in. (7.6-cm) of insulation.

Manufacturer costs for insulating the tank bottom and plastic tank electric water heater design are based on data provided by an independent consultant. The plastic tank design fixed costs reflects the amount required to convert baseline production to the new design and is based on an assumed baseline model production volume of 40,000 units per year.

Manufacturer costs for the improved flue baffle design for gas-fired water heaters is for a design that increased the RE to 78%. The manufacturing cost to increase the RE from the baseline to 80% is the same as the manufacturing cost to increase RE to 78%. The largest component of the manufacturing cost increase is product design.

Manufacturer costs for electronic ignition were based on replacing a standing pilot with an intermittent pilot ignition device. The cost of the electronic ignition system was based entirely on data from the industry association. The electromechanical flue dampers were only analyzed with electronic ignition systems. The incremental manufacturer costs for both design options is used in the analysis.

The manufacturer costs for six types of side arm heater designs are summarizes in Table 17; 76%, 78 % and 80 % RE designs that use a metal tank and 76%, 78 % and 80 % RE designs using a plastic tank. It is assumed that the cost difference between the 76% and 78% RE designs and between the 76% and 80% RE designs equal the cost of the improved flue baffle design. This assumption means heat exchanger costs for a 78% RE design would be higher than those for a 76% RE design. It was also assumed that the cost to switch from a 76% RE design to an 80% RE design is equivalent. Because side arm heaters were analyzed only with electronic ignition systems, the incremental manufacturer costs associated with all six design options include electronic ignition.

Table 16
Incremental Manufacturer Costs for Electric Water Heater Design Options

Design	Incremental Variable Costs (per unit)					Incremental Fixed Costs			Total Incremental Mfg Cost
	Material ($)	Labor ($)	Transp ($)	Overhead ($)	Total ($)	Capital ($)	Product Design ($)	Total ($)	($)
Heat Traps	2.59	0.20	0.00	0.83	3.62	0.00	0.00	0.39	4.01
HFC-245fa									
Incr. Insulation - 2.0 in	8.59	0.50	1.44	2.26	12.79	-	-	4.61	17.40
Incr. Insulation - 2.5 in	14.41	1.00	2.88	4.52	22.81	-	-	6.92	29.73
Incr. Insulation - 3.0 in	21.60	1.50	5.40	6.78	35.28	-	-	9.22	44.50
Water-blown									
Incr. Insulation - 2.5 in	3.49	0.38	1.09	1.72	6.68	-	-	6.92	13.60
Incr. Insulation - 3.0 in	9.90	0.88	3.17	3.98	17.93	-	-	9.22	27.15
Insulated Tank Bottom	2.28	0.12	0.00	0.36	2.76	-	-	1.15	3.91
Plastic Tank	5.25	0.80	0.00	3.20	9.25	15.00	3.00	18.00	27.25

Table 17
Incremental Manufacturer Costs for Gas-Fired Water Heater Design Options

Design	Variable Costs					Fixed Costs			Total
	Material ($)	Labor ($)	Transp ($)	Overhead ($)	Total ($)	Capital ($)	Product Design ($)	Total ($)	Mfg Cost ($)
Heat Traps	2.75	0.16	0.00	0.21	3.12	0.07	0.13	0.20	3.32
HFC-245fa									
Incr. Insulation - 2.0 in	9.61	0.59	2.56	2.40	15.16	0.84	0.59	1.43	16.59
Incr. Insulation - 2.5 in	14.55	1.18	5.12	4.80	25.65	1.26	1.18	2.44	28.09
Incr. Insulation - 3.0 in	20.61	1.77	9.60	7.20	39.18	1.68	1.77	3.45	42.63
Water-blown									
Incr. Insulation - 2.0 in	6.46	0.41	1.77	1.660	10.29	0.84	0.59	1.43	11.72
Incr. Insulation - 2.5 in	10.76	1.18	5.12	4.80	21.86	1.26	1.18	2.44	24.33
Incr. Insulation - 3.0 in	16.12	1.77	9.60	7.20	34.69	1.68	1.77	3.45	38.14
Improved Flue Baffle	0.97	1.25	0.00	1.38	3.60	1.14	1.70	2.84	6.44
Electronic Ignition (IID)	43.78	2.60	4.84	7.55	58.77	2.05	1.44	3.49	62.26
Metal Tank									
76% RE Side Arm Heater	68.28	3.87	7.34	19.35	98.84	2.85	3.44	6.29	105.13
78% RE Side Arm Heater	69.25	5.12	7.34	20.73	102.44	3.99	5.14	9.13	111.57
80% RE Side Arm Heater	69.25	5.12	7.34	20.73	102.44	3.99	5.14	9.13	111.57
Plastic Tank									
76% RE Side Arm Heater	73.53	4.67	9.74	21.15	109.09	5.85	4.04	9.89	118.98
78% RE Side Arm Heater	74.50	5.92	9.74	30.22	112.69	6.99	5.74	12.73	125.42
80% RE Side Arm Heater	74.50	5.92	9.74	30.22	112.69	6.99	5.74	12.73	125.42

Retail Prices, Installation, and Maintenance Costs

All consumer price data come from the Water Heater Price Database (DOE 1998). The Database contains information on more than 1100 water heater models, including retail prices, fees (installation, delivery, etc.), and warranties. (DOE 1999-1) Retail price is the cost to the consumer of the water heating equipment only. The retail price of a baseline water heater is a function of the length of the manufacturer's warranty. The baseline models chosen for this analysis have up to six-year warranties. The six-year warranty is the shortest warranty period offered by water heater manufacturers and is typically reserved for models produced in large volume.

The median retail price for a baseline 50-gallon (190-liter) electric storage water heater is $181.58. The manufacturer cost of an existing electric baseline water heater is $121.73. Dividing the median retail price ($181.58) by the manufacturer cost ($121.73) yields a manufacturer cost-to-retail price markup of 1.49. The median retail price for a baseline 40 gallon (150 liter) gas-fired storage water heater is $163.00. The manufacturer cost of an existing gas-fired baseline water heater is $133.78. Dividing the median retail price ($163.00) by the manufacturer cost ($133.78) yields a manufacturer cost-to-retail price markup of 1.22. The estimated consumer cost for a baseline 32-gal (120-l) oil-fired water heater, without a burner, is $446. The estimated manufacturing cost is $139.25. The typical manufacturer-to-retail markup is 3.2.

The baseline manufacturer cost-to-retail price markup is assumed to be constant for all of the design options considered here. Thus, the retail price for any modified design is simply determined by multiplying the manufacturer cost by the derived markup and adding a 5.00% sales tax.

The installation and maintenance costs are part of the total installed cost. The median installation cost for the 50-gallon baseline electric water heater is $155.00, for the 40-gallon baseline gas-fired water heater, $159.00 and for 32-gallon oil-fired water heater, $491.00. There are no maintenance costs associated with baseline electric and gas-fired water heaters. Typical annual maintenance cost for a baseline oil-fired water heater is $97.14.

Cost-Efficiency Data

The goal of this analysis was to estimate the energy savings potential of individual design options and combinations of design options. The approach added individual design options or combinations of design options to the baseline unit. First, set of design combinations considered for all three fuel types and for the two "2003" insulations was established. A full list of the selected design combinations is presented in Appendix A. The analysis then developed a price relationship to show the manufacturer and consumer cost to achieve increased efficiency. The results from the simulation models and calculations were used to determine the efficiency levels corresponding to various design option combinations.

The results of the design option combination analysis for the two 2003 baselines for 50-gallon electric water heaters are presented in Table 18a,b, for 40-gallon gas-fired water heaters in Table 19a,b, and for 32-gallon oil-fired water heaters in Table 20a,b. Included in the cost-efficiency tables are the total water heater installed cost, EF, energy use, and payback period. Design options were added incrementally to the baseline model in order of shortest payback period. The payback period for each set of design options was calculated relative to the baseline design according to the following relationship:

$$PAYBACK = \frac{\Delta CC}{\Delta OC} = \frac{\Delta RC + \Delta IC}{\Delta EC + \Delta MC}$$

where;

PAYBACK	= payback period (years),
ΔCC	= change in consumer cost relative to baseline,
ΔOC	= change in operating cost relative to baseline,
ΔRC	= change in retail cost relative to baseline,
ΔIC	= change in installation cost relative to baseline,
ΔEC	= change in energy cost relative to baseline, and
ΔMC	= change in annualized maintenance cost relative to baseline.

The existing baseline design with HCFC-141b foam insulation is also presented in the three tables to show the manufacturer cost and retail price differences. Cost effectiveness of all design options are relative to the 2003 baseline designs.

For electric water heaters using HFC-245fa as the blowing agent, the highest EF attainable is 0.912, achieved by using heat traps, 3-in. (7.6-cm) jacket insulation, an insulated tank bottom, and a plastic tank. The payback period for this design is 8.21 years. Energy savings are 250 kWh/yr. Models incorporating heat traps, 2.5 in. insulation, and an insulated tank bottom have an EF of 0.901 and a payback of 3.69 years. This design saves 203 kWh/yr in electricity. For water-blown insulation, the highest EF attainable is 0.894, achieved with heat traps, 3-in. (7.6-cm) jacket insulation, an insulated tank bottom, and a plastic tank. The payback period for this design is 9.86 years and energy savings are173 kWh/yr. Models incorporating heat traps, 2.5-in. insulation, and an insulated tank bottom have an EF of 0.883 and a payback of 3.67 years. This design saves 117 kWh/yr.

For gas-fired water-heaters using HFC-245fa as the blowing agent, the highest EF attainable is 0.715 achieved by using a side arm design, electronic ignition, an improved flue baffle (78% RE), a plastic tank, 3-in. (7.6-cm) jacket insulation, and heat traps. The payback period for this design is 10.3 years. Energy savings are 7.70 million Btu/year. Models incorporating heat traps, 2 in. insulation, and 78% RE have an EF of 0.592 and a payback of 3.27 years. This design saves 1.93 million Btu/year. For water-blown insulation, the highest EF attainable is 0.706 achieved with side arm design, electronic ignition, 78% RE, a plastic tank, 3-in. (7.6-cm) jacket insulation and heat traps. The payback period for this design is 10.7 years and energy savings are 7.42 million Btu/year. Models incorporating heat traps, 2 in. insulation, and 78% RE have an EF of 0.583 and a payback of 3.26 years. This design saves 1.63 million Btu/year.

For oil-fired water heaters using HFC-245fa as the blowing agent, the highest EF attainable is 0.614 achieved by using intermittent ignition, 82% RE, 3-in. (7.6-cm) jacket insulation, and heat traps. The payback period for this design is 15.5 years. Energy savings are 3.6 million Btu/year. Models using heat traps, have the shortest payback period of 6.1 years and an EF of 0.535. This design saves 0.31 million Btu/year. For water-blown insulation, the highest EF attainable is 0.6058 achieved with an intermittent ignition, 82% RE, 3-in. (7.6-cm) jacket insulation, and heat traps. The payback period for this design is 15.1 years. Energy savings are 3.4 million Btu/year. The design option using 2 in. insulation has an EF of 0.537 and a payback of 4.62 years. This design saves 0.43 million Btu/year.

The results show that energy efficiency measurements can be increased by 4% for electric water heaters; 9% for gas-fired water heaters and 2% for oil-fired water heaters. Figures 2, 3, and 4 depict a simple payback period and EF for the selected design options.

Figure 2 Payback vs. Energy Factor: Electric Water Heaters, 50-gal (190 l)

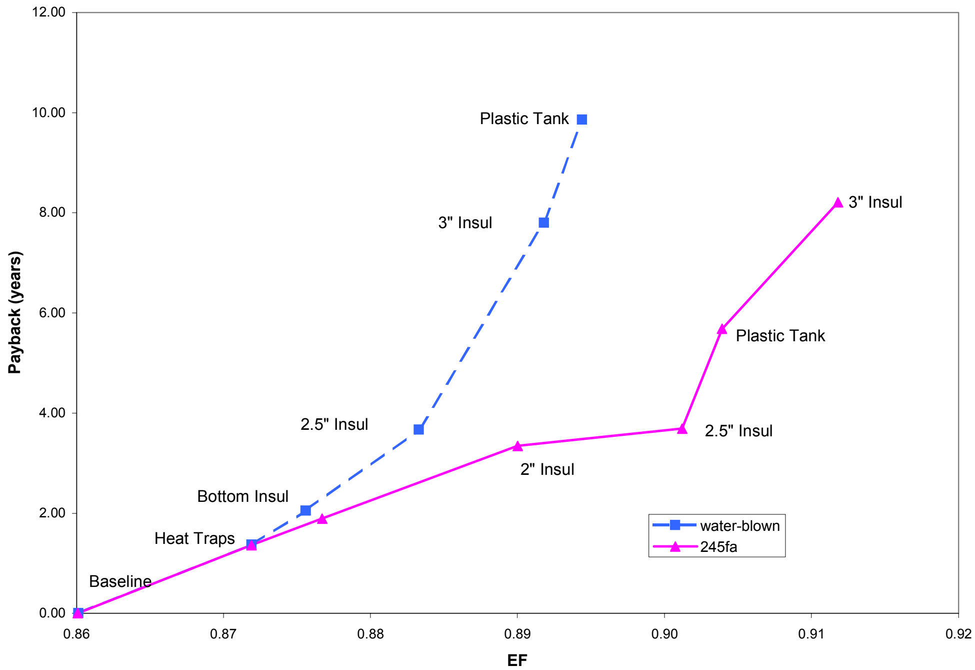

Figure 3 Payback vs. Energy Factor: Gas-Fired Water Heaters, 40-gal (150l)

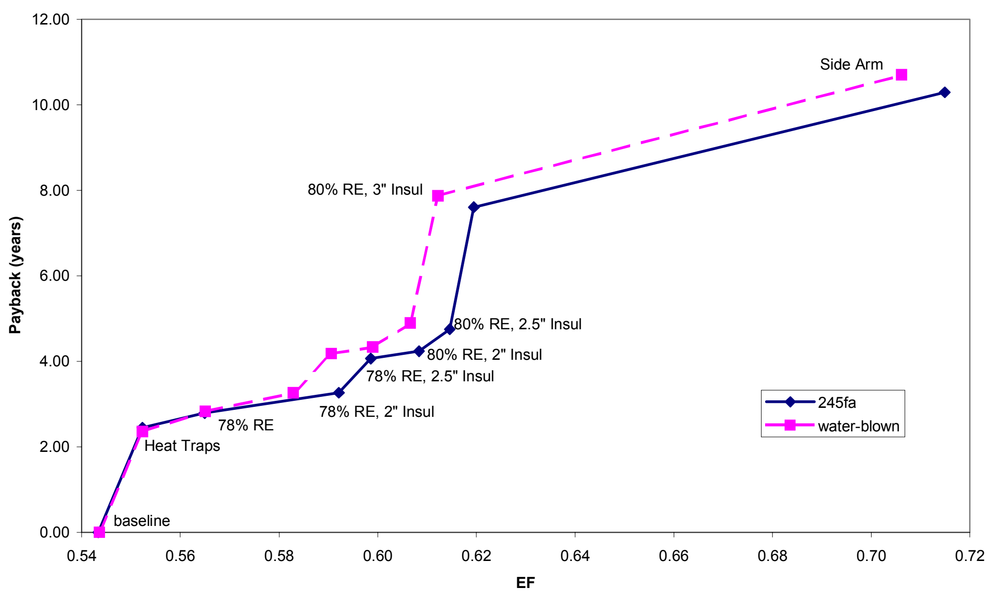

Figure 4 Payback vs. Energy Factor: Oil-Fired Water Heaters, 32-gal (120 l)

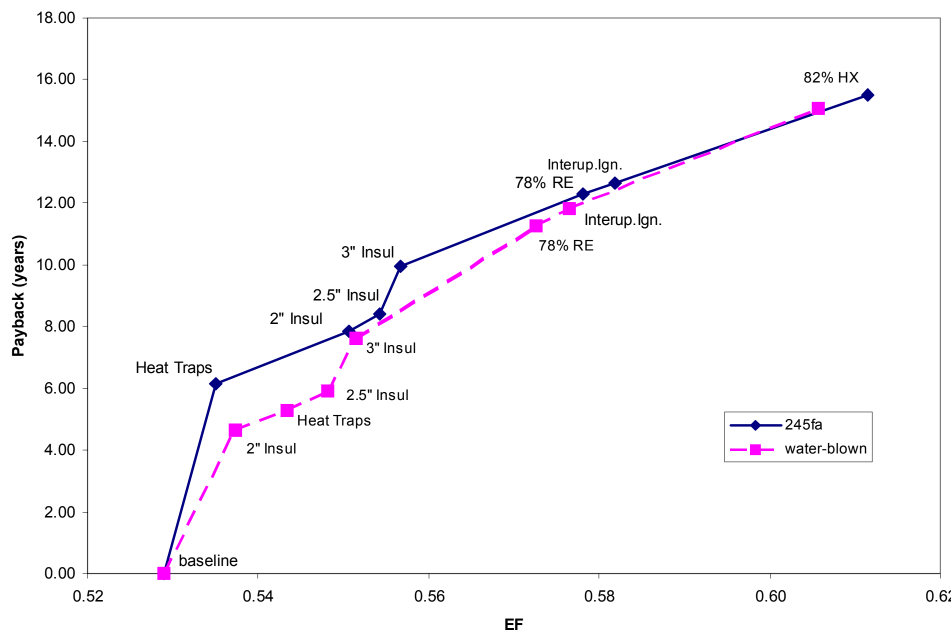

Table 18a
Cost-Efficiency Table for 50-gal (190 l) Electric Water Heater
HFC-245fa 2003 Baseline

Design No.	Design Options	Total Mfg Cost *($)*	Retail Price *($)*	Install. Cost *($)*	Maint. Cost *($)*	Energy Factor	Energy Use Daily *kWh/day*	Energy Use Yearly *kWh/yr*	Payback Period *years*
00	Existing Baseline	121.73	190.66	155.00	0.00	0.8600	13.583	4958	NA
0	2003 Baseline	123.87	194.01	155.00	0.00	0.8601	13.582	4958	NA
1	Heat Traps	127.86	200.26	155.00	0.00	0.8719	13.422	4899	1.36
2	Tank Bottom Insul.	131.77	206.39	155.00	0.00	0.8767	13.355	4875	1.89
3	2" Insulation	149.25	233.77	155.00	0.00	0.8900	13.168	4807	3.34
4	2.5" Insulation	161.58	253.07	155.00	0.00	0.9012	13.025	4754	3.69
5	Plastic Tank	184.84	289.50	155.00	0.00	0.9039	12.998	4744	5.68
6	3" Insulation	199.61	312.64	198.19	0.00	0.9118	12.897	4708	8.21

Table 18b
Cost-Efficiency Table for 50-gal (190 l) Electric Water Heater
Water-Blown 2003 Baseline

Design No.	Design Options	Total Mfg Cost ($)	Retail Price ($)	Install. Cost ($)	Maint. Cost ($)	Energy Factor	Energy Use Daily *kWh/day*	Energy Use Yearly *kWh/yr*	Payback Period *years*
00	Existing Baseline	121.73	190.66	155.00	0.00	0.8600	13.583	4958	NA
0	2003 Baseline	131.54	206.02	155.00	0.00	0.8601	13.581	4957	NA
1	Heat Traps	135.53	212.27	155.00	0.00	0.8719	13.422	4899	1.37
2	Tank Bottom Insul.	139.44	218.40	155.00	0.00	0.8756	13.371	4881	2.05
3	2.5" Insulation	153.12	239.82	155.00	0.00	0.8833	13.261	4840	3.67
4	3" Insulation	166.67	261.04	198.19	0.00	0.8918	13.144	4798	7.80
5	Plastic Tank	189.93	297.47	198.19	0.00	0.8944	13.102	4784	9.86

Table 19a
Cost-Efficiency Table for 40-gal (150 l) Gas-Fired Water Heater: HFC-245fa 2003 Baseline

Design No.	Design Options	Total Mfg. Cost ($)	Retail Price[1] ($)	Install. Cost ($)	Maint. Cost ($)	Energy Factor	Fuel Use Daily Btu/day	Fuel Use Yearly MMBtu/year	Payback years
00	**Existing Baseline**	**133.78**	**171.15**	**159.00**	**0.00**	**0.544**	**78558**	**28.67**	**NA.**
0	**2003 Baseline**	**169.89**	**217.35**	**159.00**	**0.00**	**0.5434**	**78579**	**28.68**	**NA.**
1	**Heat Traps**	**173.19**	**221.57**	**159.00**	**0.00**	**0.5523**	**77843**	**28.41**	**2.45**
2	**78% RE**	**179.63**	**229.81**	**165.73**	**0.00**	**0.5649**	**75644**	**27.61**	**2.79**
3	**78% RE, 2"**	**196.22**	**251.03**	**165.73**	**0.00**	**0.5921**	**73297**	**26.75**	**3.27**
4	**78% RE, 2.5"**	**207.72**	**265.74**	**165.73**	**0.00**	**0.5986**	**72787**	**26.57**	**4.06**
5	**80% RE, 2"**	**196.22**	**251.03**	**202.51**	**0.00**	**0.6084**	**70809**	**25.85**	**4.24**
6	**80% RE, 2.5"**	**207.72**	**265.74**	**202.51**	**0.00**	**0.6146**	**70320**	**25.67**	**4.75**
7	**80% RE, 3"**	**222.26**	**284.35**	**245.70**	**0.00**	**0.6195**	**69956**	**25.53**	**7.61**
8	Side Arm	**341.24**	**436.56**	**279.83**	**14.73**	**0.7149**	**57210**	**20.88**	**10.30**

Table 19b

Cost-Efficiency Table for 40-gal (150-liter) Gas-Fired Water Heater: Water-Blown 2003 Baseline

Design No.	Design Options	Total Mfg Cost ($)	Retail Price ($)	Install. Cost ($)	Maint. Cost ($)	Energy Factor	Fuel Energy Use Daily Btu/day	Fuel Energy Use Yearly MMBtu/ye	Payback Period years
00	Existing Baseline	133.78	171.15	159.00	0.00	0.554	78558	28.67	NA
0	2003 Baseline	172.98	221.3	159.00	0.00	0.5436	78522	28.66	NA
1	Heat Traps	176.28	225.53	159.00	0.00	0.5523	77756	28.38	2.35
2	78% RE	182.72	233.77	165.73	0.00	0.5651	75625	27.60	2.83
3	78%RE, 2" Insulation	194.44	248.76	165.73	0.00	0.5829	74045	27.03	3.26
4	78% RE, 2.5" Insulation	207.02	264.85	165.73	0.00	0.5906	73384	26.79	4.18
5	80% RE, 2" Insulation	194.44	248.76	202.51	0.00	0.599	71533	26.11	4.33
6	80% RE, 2.5" Insulation	207.02	264.85	202.51	0.00	0.6066	70926	25.89	4.89
7	80% RE, 3" Insulation	220.86	282.56	245.70	0.00	0.6122	704967	25.73	7.87
8	Side Arm	339.84	434.78	279.83	14.73	0.7062	57916	21.14	10.70

Table 20a

Cost-Efficiency Table for 32-gal (120 l) Oil-Fired Water Heater: HFC-245fa 2003 Baseline

Design No.	Design Options	Total Mfr Cost ($)	Retail Price ($)	Install Cost ($)	Maint. Cost ($)	Energy Factor	Fuel Use Daily Btu	Fuel Use Yearly MMBtu	Electrical Use Daily Wh	Electrical Use Yearly kWh	Paybac year
00	**Existing Baseline**	**139.25**	**445.60**	**491.00**	**97.14**	**0.529**	**76860**	**28.05**	**240.8**	**217.94**	**NA**
0	**“2003" Baseline**	**140.27**	**448.86**	**491.00**	**97.14**	**0.529**	**76860**	**28.05**	**240.8**	**217.94**	**NA**
1	**Heat Traps**	**144.94**	**463.81**	**491.00**	**97.14**	**0.535**	**76001**	**27.74**	**238.1**	**215.50**	**6.14**
2	**2" Insulation**	**155.58**	**497.86**	**509.25**	**97.14**	**0.551**	**73844**	**26.95**	**231.4**	**209.39**	**7.86**
3	**2.5" Insulation**	**160.65**	**514.08**	**509.25**	**97.14**	**0.554**	**73358**	**26.78**	**229.9**	**208.01**	**8.40**
4	**3" Insulation**	**165.87**	**530.78**	**517.25**	**97.14**	**0.557**	**73028**	**26.66**	**228.8**	**207.07**	**9.96**
5	**78% RE**	**203.17**	**650.14**	**517.25**	**97.14**	**0.578**	**70340**	**25.67**	**220.4**	**199.45**	**12.31**
6	**Interrupted Ignition**	**220.67**	**706.14**	**517.25**	**97.14**	**0.582**	**70341**	**25.67**	**82.7**	**195.50**	**12.63**
7	**Increased HX Area**	**286.62**	**917.18**	**517.25**	**97.14**	**0.611**	**66939**	**24.43**	**79.1**	**186.06**	**15.51**

Table 20b

Cost-Efficiency Table for 32-gal (120 l) Oil-Fired Water Heater: Water-Blown 2003 Baseline

Design No.	Design Options	Total Mfr Cost ($)	Retail Price ($)	Install Cost ($)	Maint. Cost ($)	Energy Factor	Fuel Use Daily Btu	Fuel Use Yearly MMBtu	Electrical Use Daily Wh	Electrical Use Yearly kWh	Payback year
0	Existing Baseline	139.25	445.60	491.00	97.14	0.529	76860	28.05	240.8	217.94	NA
0a	“2003" Baseline	144.16	461.31	509.25	97.14	0.529	76860	28.05	240.8	217.94	NA
1	2" Insulation	149.01	476.83	509.25	97.14	0.537	75676	27.62	237.1	214.58	4.62
2	Heat Traps	153.51	491.23	509.25	97.14	0.544	74819	27.31	234.4	212.15	5.26
3a	2.5" Insulation	158.20	506.24	509.25	97.14	0.548	74174	27.07	232.4	210.32	5.90
3b	3" Insulation	162.87	521.18	517.25	97.14	0.552	73721	26.91	231.0	209.04	7.63
3c	78% RE	200.17	640.54	517.25	97.14	0.573	70999	25.91	222.5	201.32	11.27
3d	Interrupted Ignition	217.67	696.54	517.25	97.14	0.576	71000	25.92	83.4	197.33	11.80
5	Increased HX Area	283.62	907.58	517.25	97.14	0.606	67568	24.66	79.8	187.80	15.07

CONCLUSIONS

This study determined the costs of increased energy efficiency for residential water heaters by developing price and efficiency data for design options and combinations of design options for each type of water heater. It rank orders design options based on the shortest payback period.

The results show that:

1) For electric water heaters with HFC-245fa insulation, it is possible to achieve an energy factor of 0.90 with a payback of less than 4 years. For water-blown insulation, the energy factor can reach 0.88 with a similar 4 year or under payback.

2) For gas-fired water heaters with HFC-245fa insulation, it is possible to achieve an energy factor of 0.60, with a payback of about 4 years. For water blown insulation, the energy factor can reach 0.59 with a similar 4 year or under payback.

3) For oil-fired water heaters with HFC-245fa insulation, the efficiency level above the energy factor of EF=0.53 will have a payback of more than 6 years. For water blown insulation, an EF of 0.54 will have approximately 4.5 years payback.

From these results, we can conclude that a significantly higher efficiency level with an acceptable payback can be achieved for electric and gas-fired water heaters. This information, as well as full-scale life-cycle cost analysis, serves as the basis for improvements in energy efficiency of U.S. residential storage-type water heaters.

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Appendix A Definition of Design Option Combinations

Table A-1 Electric Water Heaters

	Short Name	Full Description
HFC-245fa		
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (245fa)
1	Heat Traps	2003 Baseline + Heat Traps
2	Tank Bottom Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation
3	2" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2" Insulation
4	2.5" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation +
5	Plastic Tank	2003 Baseline + Heat Traps + 2.5" Insulation + Plastic Tank
6	3" Insulation	2003 Baseline + Heat Traps + 3" Insulation + Plastic Tank
Water-Blown		
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (Water-Blown)
1	Heat Traps	2003 Baseline + Heat Traps
2	Tank Bottom Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation
3	2.5" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2.5" Insulation
4	3" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 3" Insulation
5	Plastic Tank	2003 Baseline + Heat Traps + 3" Insulation + Plastic Tank

Table A-2 Gas-Fired Water Heaters: HFC-245fa

	Short Name	Full Description
HFC-245fa		
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (245fa)
1	Heat Traps	2003 Baseline + Heat Traps
2	78% RE	2003 Baseline + Heat Traps + 78% RE
3	78% RE, 2" Insul	2003 Baseline + Heat Traps + 78% RE + 2" Insulation
4	78% RE, 2.5" Insul	2003 Baseline + Heat Traps + 78% RE + 2.5" Insulation
5	80% RE, 2" Insul	2003 Baseline + Heat Traps + 80% RE + 2" Insulation
6	80% RE, 2.5" Insul	2003 Baseline + Heat Traps + 80% RE + 2.5" Insulation
7	80% RE, 3" Insul	2003 Baseline + Heat Traps + 80% RE + 3" Insulation
8	Side Arm	2003 Baseline + Heat Traps + 80% RE + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank
Water-Blown		
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (Water-Blown)
1	Heat Traps	2003 Baseline + Heat Traps
2	78% RE	2003 Baseline + Heat Traps + 78% RE
3	78% RE, 2" Insul	2003 Baseline + Heat Traps + 78% RE + 2" Insulation
4	78% RE, 2.5" Insul	2003 Baseline + Heat Traps + 78% RE + 2.5" Insulation
5	80% RE, 2" Insul	2003 Baseline + Heat Traps + 80% RE + 2" Insulation
6	80% RE, 2.5" Insul	2003 Baseline + Heat Traps + 80% RE + 2.5" Insulation
7	80% RE, 3" Insul	2003 Baseline + Heat Traps + 80% RE + 3" Insulation
8	Side Arm	2003 Baseline + Heat Traps + 80% RE + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank

Table A-3 Oil-Fired Water Heaters

	Short Name	Full Description
HFC-245fa		
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (245fa)
1	Heat Traps	2003 Baseline + Heat Traps
2	2" Insulation	2003 Baseline + Heat Traps + 2" Insulation
3	2.5" Insulation	2003 Baseline + Heat Traps + 2.5" Insulation
4	3" Insulation	2003 Baseline + Heat Traps + 3" Insulation
5	78% RE	2003 Baseline + Heat Traps + 3" Insulation + 78% RE
6	Interrupted Ignition	2003 Baseline + Heat Traps + 3" Insulation + 78% RE + Interrupted Ignition
7	Increased HX Area	2003 Baseline + Heat Traps + 3" Insulation + Interrupted Ignition + Increased Heat Exchanger Area (82% RE)
Water-Blown		
00	Existing Baseline	Baseline (141b)
0	2003 Baseline	Baseline (Water-Blown)
1	2" Insulation	2003 Baseline + 2" Insulation
2	Heat Traps	2003 Baseline + 2" Insulation + Heat Traps
3	2.5" Insulation	2003 Baseline + 2.5" Insulation + Heat Traps
4	3" Insulation	2003 Baseline + 3" Insulation + Heat Traps
5	78% RE	2003 Baseline + 3" Insulation + Heat Traps + 78% RE
6	Interrupted Ignition	2003 Baseline + 3" Insulation + Heat Traps + 78% RE + Interrupted Ignition
7	Increased HX Area	2003 Baseline + 3" Insulation + Heat Traps + Interrupted Ignition + Increased Heat Exchanger Area (82% RE)