AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY STANDARDS FOR CONSUMER PRODUCTS:

**ROOM AIR CONDITIONERS, WATER HEATERS, DIRECT HEATING
EQUIPMENT, MOBILE HOME FURNACES, KITCHEN RANGES AND OVENS,
POOL HEATERS, FLUORESCENT LAMP BALLASTS & TELEVISION SETS.**

**VOLUME 3: WATER HEATERS, POOL HEATERS, DIRECT HEATING EQUIPMENT,
& MOBILE HOME FURNACES**

November 1993

**U.S. Department of Energy
Assistant Secretary,
Energy Efficiency & Renewable Energy.
Office of Codes and Standards
Washington, DC 20585**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER
HH

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

ACKNOWLEDGEMENT

This document was prepared for the Department by staff members of the Energy Analysis Program at Lawrence Berkeley Laboratory.

Volume F

Table of Contents

CHAPTER 1. ENGINEERING ANALYSIS	1-1
1.1 INTRODUCTION	1-1
1.2 PRODUCT CLASSES	1-3
1.3 GAS-FIRED STORAGE WATER HEATERS	1-3
1.3.1 Design Options for Gas-Fired Storage Water Heaters	1-5
1.3.2 Energy Calculations for Gas-Fired Storage Water Heaters.	1-11
1.3.3 Cost and Efficiency Data for Gas-Fired Storage Water Heaters	1-15
1.3.4 Maximum Technologically Feasible Design for Gas-Fired Storage Water Heaters	1-24
1.4 ELECTRIC STORAGE WATER HEATERS	1-25
1.4.1 Design Options for Electric Storage Water Heaters	1-26
1.4.2 Energy Calculations for Electric Storage Water Heaters	1-29
1.4.3 Cost and Efficiency Data for Electric Storage Water Heaters	1-31
1.4.4 Maximum Technologically Feasible Design for Electric Storage Water Heaters	1-34
1.5 OIL-FIRED STORAGE WATER HEATERS	1-35
1.5.1 Design Options for Oil-Fired Storage Water Heaters	1-35
1.5.2 Energy Calculations for Oil-Fired Storage Water Heaters	1-37
1.5.3 Cost Data for Oil-Fired Storage Water Heaters	1-40
1.5.4 Maximum Technologically Feasible Design for Oil-Fired Storage Water Heaters	1-43
1.6 GAS-FIRED INSTANTANEOUS WATER HEATERS	1-43
1.6.1 Design Options for Gas-Fired Instantaneous Water Heaters	1-43
1.6.2 Energy Calculations for Gas-Fired Instantaneous Water Heaters	1-45
1.6.3 Cost Data for Gas-Fired Instantaneous Water Heaters	1-49
1.6.4 Maximum Technologically Feasible Design for Gas-Fired Instantaneous Water Heaters	1-50
CHAPTER 2. BASE CASE FORECASTS: WATER HEATERS	2-1
2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS	2-1
2.2 AVERAGE EQUIPMENT LIFETIME	2-1
2.2 BASE CASE PROJECTIONS	2-1
2.2.1 New Appliance Unit Energy Consumptions	2-2
2.2.1.1 Efficiency Distributions	2-2
2.2.1.2 Usage	2-2
2.2.2 Annual U.S. Appliance Installations	2-2
2.2.3 U.S. Residential Energy Consumption	2-3
2.2.4 Price of Purchased Appliances	2-4
2.3 SENSITIVITY ANALYSIS OF THE BASE CASE	2-4

CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS:WATER	
HEATERS	3-1
3.1 STANDARDS LEVELS	3-1
3.2 ENERGY CONSUMPTION	3-2
3.3 ANNUAL INSTALLATIONS	3-5
3.4 APPLIANCE PRICES	3-6
3.5 NET PRESENT VALUE (NPV)	3-8
3.6 SENSITIVITY ANALYSIS	3-8
CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS	
4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS	4-1
4.1.1 LCC Data Inputs	4-2
4.1.2 LCC Results	4-2
4.2 PAYBACK PERIODS BY STANDARD LEVEL	4-8
4.2.1 PBP Data Inputs	4-8
4.2.2 PBP Results	4-8
4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS	4-9
4.3.1 Data Inputs for Change in LCC	4-9
4.3.2 Results for Change in LCC	4-9
4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS	4-10
4.4.1 CCE Data Inputs	4-10
4.4.2 CCE Results	4-10
4.5 LCC SENSITIVITY ANALYSIS	4-15
CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF WATER HEATERS	
5.1 LONG-RUN IMPACTS	5-1
5.1.1 Qualitative Analysis	5-1
5.1.2 Quantitative Analysis	5-2
5.2 SHORT-RUN IMPACTS	5-2
5.3 IMPACT AS A FUNCTION OF FIRM SIZE	5-3
5.4 SENSITIVITY ANALYSIS FOR WATER HEATERS	5-4
5.4.1 Sensitivity Charts	5-5
5.4.2 Alternative Scenarios	5-5
5.4.3 Monte Carlo Analysis	5-6
CHAPTER 6. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES: WATER	
HEATERS	6-1
6.1 INTRODUCTION	6-1
6.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS	6-1
6.3 PEAK LOAD AND CAPACITY REDUCTIONS	6-1
6.4 REVENUE LOSSES	6-5
6.5 SENSITIVITY ANALYSIS	6-8

CHAPTER 7. ENVIRONMENTAL EFFECT	7-1
7.1 INTRODUCTION	7-1
7.2 RESULTS	7-1
7.2.1 Sulfur and Nitrogen Oxide Emissions	7-2
7.2.2 Carbon Dioxide Emissions	7-2
APPENDIX A. ENERGY USE AND COST DATA	A-1
A.1 ENERGY CALCULATIONS FOR GAS-FIRED STORAGE WATER HEATERS	A-1
A.2 DISAGGREGATED MANUFACTURER COSTS FOR GAS-FIRED STORAGE WATER HEATERS	A-13
A.3 ENERGY CALCULATIONS FOR ELECTRIC STORAGE WATER HEATERS	A-15
A.4 DISSAGGREGATED MANUFACTURER COSTS FOR ELECTRIC STORAGE WATER HEATERS	A-18
A.5 DISAGGREGATED MANUFACTURER COSTS FOR OIL-FIRED STORAGE WATER HEATERS	A-20
APPENDIX B. LBL-REM INPUT DATA: WATER HEATERS	B-1
APPENDIX C. LBL MANUFACTURER IMPACT MODEL:WATER HEATERS	C-1
C.1 INTRODUCTION	C-1
C.1.1 Engineering Cost Data	C-1
C.1.2 Industry Market Data	C-2
C.1.3 Financial Input Data	C-3
C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO	C-5

CHAPTER 7. ENVIRONMENTAL EFFECT	7-1
7.1 INTRODUCTION	7-1
7.2 RESULTS	7-1
7.2.1 Sulfur and Nitrogen Oxide Emissions	7-2
7.2.2 Carbon Dioxide Emissions	7-2
APPENDIX A. ENERGY USE AND COST DATA	A-1
A.1 ENERGY CALCULATIONS FOR GAS-FIRED STORAGE WATER HEATERS	A-1
A.2 DISAGGREGATED MANUFACTURER COSTS FOR GAS-FIRED STORAGE WATER HEATERS	A-13
A.3 ENERGY CALCULATIONS FOR ELECTRIC STORAGE WATER HEATERS	A-15
A.4 DISSAGGREGATED MANUFACTURER COSTS FOR ELECTRIC STORAGE WATER HEATERS	A-18
A.5 DISAGGREGATED MANUFACTURER COSTS FOR OIL-FIRED STORAGE WATER HEATERS	A-20
APPENDIX B. LBL-REM INPUT DATA: WATER HEATERS	B-1
APPENDIX C. LBL MANUFACTURER IMPACT MODEL:WATER HEATERS	C-1
C.1 INTRODUCTION	C-1
C.1.1 Engineering Cost Data	C-1
C.1.2 Industry Market Data	C-2
C.1.3 Financial Input Data	C-3
C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO	C-5

Table 1.1	Product Classes for Water Heaters	1-3
Table 1.2	Design Options for Gas-Fired Storage Water Heaters	1-6
Table 1.3	Energy Calculations for Gas-Fired Storage Water Heaters	1-13
Table 1.4	Energy Factor as Function of Volume for Gas-Fired Storage Water Heaters	1-15
Table 1.5	Cost Data for Gas-Fired Storage Water Heaters	1-17
Table 1.6	Design Options for Electric Storage Water Heaters	1-27
Table 1.7	Energy Calculations for Electric Storage Water Heaters	1-30
Table 1.8	Energy Factor as Function of Volume for Electric Storage Water Heaters	1-31
Table 1.9	Cost Data for Electric Storage Water Heaters	1-32
Table 1.10	Design Options for Oil-Fired Water Heaters	1-35
Table 1.11	Energy Calculations for Oil-Fired Water Heaters	1-39
Table 1.12	Energy Factor as Function of Volume for Oil-Fired Storage Water Heaters	1-40
Table 1.13	Cost Data for Oil-Fired Storage Water Heaters	1-41
Table 1.14	Design Options for Gas-Fired Instantaneous Water Heaters	1-44
Table 1.15	Energy Calculations for Gas-Fired Instantaneous Water Heaters	1-48
Table 1.16	Cost Data for Gas-Fired Instantaneous Water Heaters	1-50
Table 2.1	Average Equipment Lifetime (Years) of Water Heaters	2-1
Table 2.2	Base Case Projection of Unit Energy Consumption for New Water Heaters	2-2
Table 2.3	Annual Installations of New Water Heaters in U.S. Households (Thousands)	2-3
Table 2.4	Percent of Occupied U.S. Housing Units Having Water Heaters	2-3
Table 2.5	U.S. Residential Energy Consumption for Water Heaters (Quadrillion Btu, Primary Energy)	2-4
Table 2.6	Average Price of New Water Heaters in U.S. Households (1990 Dollars)	2-4
Table 2.7a	Average Purchase Price of New Electric Water Heaters (1990 Dollars)	2-6
Table 2.7b	Average Purchase Price of New Gas Water Heaters (Weighted-Average in 1990 Dollars)	2-6
Table 2.7c	Average Purchase Price of New Oil Water Heaters (1990 Dollars)	2-6
Table 2.8a	Average Unit Consumption of New Electric Water Heaters (kWh/Year)	2-7
Table 2.8b	Average Unit Consumption of New Gas Water Heaters (Weighted-Average in MMBtu/Year)	2-7
Table 2.8c	Average Unit Consumption of New Oil Water Heaters (MMBtu/Year)	2-7
Table 3.1	Trial Standards Levels for Water Heaters	3-2
Table 3.2a	Unit Energy Consumption for New Electric Storage Water Heater (kWh/Year)	3-2
Table 3.2b	Unit Energy Consumption for New Gas-Fired Storage Water Heater (Million Btu/Year)	3-3
Table 3.2c	Unit Energy Consumption for New Instantaneous Gas-Fired Water Heater (Million Btu/Year)	3-3
Table 3.2d	Unit Energy Consumption for New Oil-Fired Water Heater (kWh/Year)	3-3

Table 3.3a	U.S. Electricity Consumption for Water Heaters (Quadrillion Btu, Primary)	3-4
Table 3.3b	U.S. Gas Consumption for Water Heaters (Quadrillion Btu, Primary)	3-4
Table 3.3c	U.S. Oil Consumption for Water Heaters (Quadrillion Btu, Primary) (Includes Individual Units)	3-4
Table 3.3d	U.S. Energy Consumption for Electric + Gas + Oil Water Heaters (Quadrillion Btu, Primary) (Includes Individual and Common Units)	3-5
Table 3.4	Cumulative Installations of Water Heaters (Millions)	3-6
Table 3.5a	Average Purchase Price for New Electric Water Heater (1990 Dollars Per Unit)	3-7
Table 3.5b	Average Purchase Price for New Gas Water Heater (1990 Dollars Per Unit)	3-7
Table 3.5c	Average Purchase Price for New Instantaneous Gas Water Heater (1990 Dollars Per Unit)	3-7
Table 3.5d	Average Purchase Price for New Oil Water Heater (1990 Dollars Per Unit)	3-8
Table 3.6	Net Present Value for Water Heaters Purchased from 1996-2030 (Billion 1990\$ Discounted at 7.0%)	3-9
Table 3.7	Sensitivity Analysis Cases	3-9
Table 3.8a	Cumulative Energy Consumption of Electric Water Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)	3-10
Table 3.8b	Cumulative Energy Consumption of Gas Water Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)	3-10
Table 3.8c	Cumulative Energy Consumption of Oil Water Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)	3-10
Table 3.9a	Cumulative Shipments of Electric Water Heaters During the Period 1996-2030 (Millions)	3-11
Table 3.9b	Cumulative Shipments of Gas Water Heaters During the Period 1996-2030 (Millions)	3-11
Table 3.9c	Cumulative Shipments of Oil Water Heaters During the Period 1996-2030 (Millions)	3-11
Table 3.10	Total Net Present Value to Consumers for Units Sold During the Period 1996-2030 (Discounted to 1990 at 7% Real)	3-12
Table 4.1	Life-Cycle Costs of Electric Storage Water Heaters	4-3
Table 4.2	Life-Cycle Costs for Gas-Fired Storage Water Heaters	4-5
Table 4.3	Life-Cycle Costs for an Oil Storage Water Heater	4-6
Table 4.4	Life-Cycle Costs for Instantaneous Gas-Fired Water Heaters	4-7
Table 4.5.a	Cost and Energy-Use Summary Electric Storage Water Heaters	4-11
Table 4.5.b	Distribution of Units Sold Below Standards, Electric Storage Water Heaters	4-11
Table 4.5.c	Weighted-Averages of Units Sold Below Standards, Electric Storage Water Heaters	4-11
Table 4.5.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Electric Storage Water Heaters	4-11

Table 4.6.a	Cost and Energy-Use Summary, Gas-Fired Storage Water Heaters	4-12
Table 4.6.b	Distribution of Units Sold Below Standards, Gas-Fired Storage Water Heaters	4-12
Table 4.6.c	Weighted-Averages of Units Sold Below Standards, Gas-Fired Storage Water Heaters	4-12
Table 4.6.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gas-Fired Storage Water Heaters . . .	4-12
Table 4.7.a	Cost and Energy-Use Summary, Instantaneous Gas-Fired Water Heaters .	4-13
Table 4.7.b	Distribution of Units Sold Below Standards, Instantaneous Gas-Fired Water Heaters	4-13
Table 4.7.c	Weighted-Averages of Units Sold Below Standards, Instantaneous Gas-Fired Water Heaters	4-13
Table 4.7.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Instantaneous Gas-Fired Water Heaters	4-14
Table 4.8.a	Cost and Energy-Use Summary, Oil-Fired Storage Water Heaters	4-14
Table 4.8.b	Distribution of Units Sold Below Standards, Oil-Fired Storage Water Heaters	4-14
Table 4.8.c	Weighted-Averages of Units Sold Below Standards, Oil-Fired Storage Water Heaters	4-14
Table 4.8.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Oil-Fired Storage Water Heaters . . .	4-15
Table 4.9	Sensitivity Summary of Life-Cycle Costs of Electric Water Heaters . . .	4-17
Table 4.10	Sensitivity Summary of Life-Cycle Costs of Gas Water Heaters	4-18
Table 5.1	Water Heater Output Table: Primary Scenario - Long Run	5-2
Table 5.2	Water Heater Output Table: Primary Scenario - Short Run	5-3
Table 5.3	Water Heaters Sensitivity Chart: Primary Scenario (Sensitivity of ROE to 1 S.E. Change in Control Variable)	5-5
Table 5.4	Water Heater Output Table, Low Industry Price Elasticity Scenario	5-7
Table 5.5	Water Heater Output Table, High Industry Price Elasticity Scenario	5-7
Table 5.6	Water Heater Output Table, Constant Shipments Scenario	5-8
Table 5.7	Water Heater Output Table, High Discount Rate Scenario	5-8
Table 5.8	Water Heater Output Table, High Discount Rate Scenario	5-9
Table 5.9	Water Heater Output Table, Low Discount Rate & High Price	
Table 5.10	Water Heater Monte Carlo Runs: Searching for Low ROE	5-10
Table 6.1	Peak Demand Reductions (GW) - Water Heaters	6-3
Table 6.2	Capacity Savings (GW) - Water Heaters	6-4
Table 6.3	Net Revenue Losses - Water Heaters (Million 1990 Dollars)	6-7
Table 6.4	Present Value of Revenue Losses - Water Heaters (Million 1990 Dollars)	6-8
Table 6.5	Peak Demand Reductions (GW) - Water Heaters (Sensitivity Cases)	6-8
Table 6.6	Capacity Savings (GW) - Water Heaters (Sensitivity Cases)	6-9

Table 6.7	Present Value of Net Lost Revenues (Million 1990 \$) - Water Heaters (Sensitivity Cases)	6-9
Table A.1	Disaggregated Manufacturer Costs for Gas-Fired Storage Water Heaters .	A-14
Table A.2	Manufacturer Costs for Electric Storage Water Heaters	A-19
Table A.3	Manufacturer Costs for Oil-Fired Storage Water Heaters	A-20
Table C.1	Rates of Financial Costs	C-3
Table C.2	Other Financial Inputs	C-3
Table C.3	Fixed, Variable, and Revenue-Related Cost Split	C-3
Table C.4	One-Time Costs	C-4
Table C.5	Water Heaters Version of MIM - Control Panel	C-5
Table C.6	Water Heaters Version of MIM - Monte Carlo Module	C-6
Table C.7	Water Heaters Version of MIM - Accounting Module	C-7
Table C.8	Water Heaters Version of MIM - Engineering Inputs Module	C-8
Table C.9	Water Heaters Version of MIM - Standards Level Module	C-10
Table C.10	Water Heaters Version of MIM - Costs, Sales and Revenue Module	C-11
Table C.11	Water Heaters Version of MIM - Financial Module	C-13
Table C.12	Water Heaters Version of MIM - One-Time Cost Amortization Module . .	C-14
Table C.13	Water Heaters Version of MIM - Long-Run Model Module	C-15
Table C.14	Water Heaters Version of MIM - Short-Run Model Module	C-16
Table C.15	Water Heaters Version of MIM - Charts Module	C-17

CHAPTER 1. ENGINEERING ANALYSIS

1.1 INTRODUCTION

Water heaters are defined by NAECA as products that utilize oil, gas, or electricity to heat potable water for use outside the heater upon demand. These are major appliances, which use a large portion (18% on average) of total energy consumed per household (1). They differ from most other appliances in that they are usually installed in obscure locations as part of the plumbing and are ignored until they fail. Residential water heaters are capable of heating water up to 180° F, although the setpoints are usually set lower.

Most water heaters sold in the U.S. are storage water heaters, which continuously maintain a volume of water at a thermostatically controlled temperature. These are available in models using gas, electric, or oil for energy sources. The major manufacturers all make both electric and gas-fired storage water heaters. These two types account for over 99% of the market. Manufacturers of oil-fired water heaters typically do not make other types of water heaters, although they may private-label some gas and electric models. There are some smaller manufacturers that only make electric resistance or heat-pump water heaters.

The most common storage water heaters consist of a cylindrical steel tank that is glass-lined to limit corrosion. The tank is surrounded with polyurethane foam insulation and clad on the outside with a steel jacket. Both the inlet and outlet pipes most often enter the tank on the top. In addition, water heaters are required to have a temperature and relief valve for safety. This outlet is also installed on or near the top of the tank. A drain is installed at the bottom of the tank.

A typical production line begins with rolls of steel being fabricated into tank shells and bottoms. Fabrication and painting of the jackets, tops, and bottoms occur as a separate process. The flues are welded to the bottoms for the gas-fired models. After cleaning, a glass coating is applied to the inside surface of the shells and bottoms. The glass coating is baked on at high temperature. The bottom is inserted into the shell and they are welded together at the rim and around the flue for gas-fired models. Some of the components, such as anode rods, heating elements, and thermostats, may be installed at this point. The tank is then placed inside the jackets and foam insulation is injected. The remaining components, labels, instructions, and decoration are applied. Packaging is done near the end of the production line, with a complete package including instructions and labels coming off the line. The unit can either be stored in inventory or shipped directly (2). A general flow diagram of the production process is shown in Figure 1.1.

Figure 1.1 Manufacturing Flow Diagram for Water Heaters

Instantaneous water heaters do not store any water at a controlled temperature, instead they heat water only as it is being drawn through the water heater. Gas-fired instantaneous water heaters are available, but not very popular in the U.S. There are no domestic manufacturers of this type of water heater.

Water heater efficiency is rated by an energy factor (EF). This is the fraction of heat energy input as fuel or electricity that is converted to usable hot water. The method of determining EF is prescribed in a DOE test procedure. A new DOE test procedure for water heaters was adopted in October 1990, but did not become mandatory until October 1991 (3). The new test procedure uses a 24-hour simulated draw pattern to calculate EF, recovery efficiency, and standby loss. The previous DOE test procedure used a cold-start test to determine recovery efficiency, and a 48-hour standby test to determine standby loss (4). No draws were made during the test. The EF was calculated from the recovery efficiency and the standby loss. Also, the temperatures specified during the test were changed. The old test procedure used an inlet temperature of 70 °F, a setpoint temperature of 160 °F, and an ambient air temperature of 70 °F. The new test procedure specifies an inlet temperature of 58 °F, a setpoint temperature of 135 °F, and an ambient temperature of 67.5 °F. Standby losses in the old test procedure were in units of percent of heat content of tank lost per hour. The new test procedure yields a standby loss in units of Btu/hr-degF. In addition, the new test procedure puts narrower limits on allowed temperatures and includes procedures in the calculations to correct for variations from these temperatures. Because the new test procedure was not in effect at the time of this analysis, data from the old test procedure were used.

As part of this rulemaking, DOE has proposed a new procedure to calculate EF for fossil-fuel-fired water heaters that also use electricity. For these water heaters, the electric energy consumed during the test is converted to source Btus. The conversion factor from site to source energy used in this analysis was 3.37. This accounts for losses in generating and transmitting electricity from the generating station to the water heater.

1.2 PRODUCT CLASSES

The DOE has adopted the product classes listed in the Advanced Notice of Proposed Rulemaking (ANOPR) for this appliance with the exception of electric heat-pump water heaters (5). Electric heat-pump water heaters were included as a design option for electric storage water heaters. Electric instantaneous and small storage water heaters were not analyzed. Table 1.1 shows the list of product classes and current market shares.

Table 1.1 Product Classes for Water Heaters

	Product Class	Market Share	Year
1.	Gas-fired Storage	54.4% (6)	1990
2.	Electric Storage	44.9% (7)	1990
3.	Oil-fired Storage	0.5% (8)	1986
4.	Gas-fired Instantaneous	0.1% (9)	1990
5.	Electric Instantaneous	(not analyzed)	

Electric instantaneous water heaters typically do not have the capacity to supply an entire residence. A 20-amp (220 volt) circuit will supply only enough energy to heat a 3.0 gallon per minute flow by 10.3°F. This is not sufficient to supply enough water at the 120 to 140 °F range expected in most residences. Electric instantaneous water heaters are often installed as booster heaters or to supply a single lavatory in commercial buildings such as small offices. These heaters are essentially resistance heating elements installed in a pipe. No design options were found that would improve the efficiency of these heaters. For this reason and because so few are installed for residential use, electric instantaneous water heaters were not included in this analysis.

1.3 GAS-FIRED STORAGE WATER HEATERS

Gas-fired water heaters usually have a burner below the storage tank. The flue extends up through the center of the tank, through a draft hood, and connects to the venting system. A baffle is inserted in the flue to increase heat transfer from the hot combustion products to the flue wall. The main burner is controlled by a mechanical thermostat and is ignited by a standing pilot. See Figure 1.2.

Figure 1.2 Gas-Fired Storage Water Heater

Most water heaters on the market are low-efficiency models with an EF of 0.54, recovery efficiencies of 76%, and standby losses of 3 to 4% per hour. There are a limited number of mid-efficiency gas-fired water heaters with EFs over 0.60 and recovery efficiencies above 80%. These water heaters should not be vented to masonry chimneys or single-wall metal vents. The flue gases are cool enough that condensation is likely to occur. There is one condensing water heater currently on the market with an EF of .86 and a recovery efficiency of 94%. The unit is

intended for combination water and space heating. This high efficiency is achieved by intentionally condensing the combustion products and thereby recovering additional heat. A special venting system and a condensate drain are required for this water heater.

1.3.1 Design Options for Gas-Fired Storage Water Heaters

The design options analyzed are listed in Table 1.2. They are changes that can be incorporated into the design of a gas-fired storage water heater to improve its EF. The first design option is the baseline. This represents the typical gas-fired storage water heater that meets the minimal current efficiency standards for water heaters.

Table 1.2 Design Options for Gas-Fired Storage Water Heaters

0	Baseline
1	Heat Traps
2	Reduce Heat Leaks
3	R-16 Insulation
4	Improve Flue Baffle
5	Electronic Ignition with Flue Damper
6	Submerged Combustion Chamber
7	Electronic Ignition
8	Indirect Heating with Electronic Ignition
9	Multiple Flues
10	R-25 Insulation
11	Increased Flue Baffling and Forced Draft
12	Electronic Ignition and Power Vent
13	Vacuum Insulation
14	Tempering Tank
15	Submerged Combustion
16	Indirect Heating with Electronic Ignition and Plastic Tank
17	Directly Fired
18	Thermophotovoltaic Generator
19	Condensed Flue Gases
20	Condensing Pulse Combustion

Baseline

The baseline model gas-fired storage water heater chosen for this analysis was a bottom-fired, 40-gallon, glass-lined steel tank with a 3-inch center flue. The input rate was 34 kBtu/hr, with a pilot rated at 400 Btu/hr. The tank was insulated with one inch of polyurethane foam.

Heat Traps

Heat traps are small anti-convection devices that are put on the inlet and outlet connections to the water heater. They are modified check valves that use a small plastic ball to prevent convection-induced backflow. The physical appearance is of a short pipe nipple that can

be screwed directly into the tank. The ball in the hot water outlet pipe is slightly heavier than water and settles down on the outlet hole when no draws are being made. This prevents water in the hot water outlet line from sinking back into the tank as it cools off. The ball in the heat trap on the inlet line is slightly lighter than water. When water is not being drawn into the tank it floats up and seals the inlet hole. This prevents hot water from circulating back into the cold water inlet line. A small bypass is left open to allow water to leave the tank during the expansion of water following a cold start or a long draw.

All manufacturers who make water heaters that could benefit from this design option offer energy-saving models that incorporate heat traps. They can either be inserted at the factory or shipped in the box to be installed on site.

Reduce Heat Leaks

Reduced heat leaks were included as one of the design options in the analysis of water heaters. The actual features of this design option were not specified. Measures that could be included in this design option were to eliminate thermal bridges from jacket to feedthroughs, to eliminate voids and imperfections in jacket insulation, to insulate the pressure relief valve, to install plastic drain pipes, and to reduce the number of feedthrough by combining functions. These measures were not modeled separately.

R-16 Insulation

The jacket insulation on the baseline was one inch of foam insulation. This design option used two inches of foam insulation around the sides and top of the tank.

Improve Flue Baffle

The standard flue baffle is a twisted strip of metal inserted into the flue that increases the turbulence of flue gases and improves heat transfer. One manufacturer uses a flue with many small rectangular fins attached on the inside surface in their mid-efficiency model. The arrangement and size of these fins increases the recovery efficiency of the water heater.

When water heaters with this design option are installed on venting systems with masonry chimneys, the chimneys must be relined to prevent problems from condensation of flue gases. To avoid problems from condensation it is also possible to use sidewall venting.

Electronic Ignition with Flue Damper

A large portion of the standby losses of gas-fired storage water heaters are from losses from the flue. As the air inside is heated by the hot surface of the flue, it becomes more buoyant and rises. This draws in cooler air which in turn extracts more heat from the surface of the flue and the water surrounding it. Some of the heat from the standing pilot is also lost up the flue.

Electronic ignition can be used in place of the standing pilot. These devices use a spark or an electrically heated surface to ignite either a pilot or the main burner. A flue damper is an electrically activated damper in the flue that restricts the air flow when the main burner is off. These systems are available on commercial water heaters but are not yet used on residential water heaters.

Submerged Combustion Chamber

The combustion chamber in a standard gas-fired storage water heater is below the water tank. The bottom of the tank is suspended directly above the burner. The sides and bottom of the combustion chamber are not surrounded by water. By inserting the combustion chamber into the storage tank, more of the combustion energy can be recovered. Standby losses are reduced somewhat because of restrictions on the air flow through the combustion chamber and flue.

This design option increases recovery efficiency sufficiently so that condensation is likely to occur in venting systems that are not double-walled sheet metal. To avoid problems caused by condensation on other venting systems, masonry chimneys must be relined or sidewall venting must be used.

Electronic Ignition

Intermittent or electronic ignition systems can be installed to replace the standing pilot. It should be noted that a large portion of the heat from the pilot light is used to maintain water temperature in the tank. Not only is the pilot light replaced with new equipment, but so are all the required burner control and safety devices. This design option requires electricity at the water heater. There are three different technologies available to electronically ignite the burner. These are hot-surface ignition, spark-to-pilot ignition, and direct-spark ignition. The hot-surface ignition heats a ceramic oxide element to ignition temperature using line voltage. Both spark-to-pilot and direct-spark ignition use a spark to ignite the gas. The spark-to-pilot ignites a pilot which in turn ignites the burner. The direct-spark ignition uses a spark to directly ignite the main burner. Both of these designs can be built to use low voltage supplied by a 24 volt transformer. Low-voltage electricity can be supplied by a 24 volt plug-in transformer. This analysis was based on a spark-to-pilot ignition system using a plug-in transformer to reduce wiring and other installation costs.

Indirect Heating with Electronic Ignition

This design option avoids the large flue losses by removing the flue from the center of the tank. The water is withdrawn from the bottom of the tank and heated in a small heat exchanger over a burner. The tank for this design option would be very similar to the tanks in electric water heaters, without the electric resistance heating elements. Water is returned to the top of the tank. A small circulation pump moves water through the heat exchanger when the burner is on. The burner has electronic ignition. Auxiliary power is supplied by a low-voltage plug-in transformer.

Multiple Flues

This design option uses three smaller flues in place of one large central flue in the middle of the storage tank. The greater surface area of the flues produces an increase in recovery efficiency. It does this by increasing the surface area for heat exchange between the flue gases and the water in the tank. One manufacturer is currently offering this design option in a residential gas-fired water heater.

R-25 Insulation

This design option used three inches of foam insulation around the sides and top of the tank. The costs and energy savings were calculated as incremental changes from the R-16 (two inches of foam insulation) design option. This design option increased the diameter of water heaters four inches above the baseline. Additional installation costs were added to account for those cases where water heaters were installed in tight locations that required modification.

Increased Flue Baffling and Forced Draft

Increasing the flue baffling and forcing the flue gases through the baffle with either an induced-draft blower (downstream of the water heater) or a forced-draft blower (upstream of the water heater) can increase the recovery efficiency and reduce the standby flue losses. The off-cycle flue losses are reduced by the additional restrictions to air flow from both the blower and the increased baffling. The increased recovery efficiency from this design option necessitated relining vent systems that were not Type-B (double-wall) or used sidewall venting.

Several manufacturers are currently making water heaters with forced-draft or induced-draft blowers. However, this feature is included to allow sidewall venting and is not accompanied by any increase in flue baffling.

Electronic Ignition and Power Vent

Another way to reduce off-cycle flue losses when using an electronic ignition is to use power venting. The additional resistance to air flow through the flue caused by the fan without additional baffling was examined in the analysis of this design option. A spark-to-pilot ignition system was assumed to allow the use of a low-voltage plug-in transformer to avoid excessive electrical installation costs.

Vacuum Insulation

This was a generic design option used to examine the most promising of the advanced insulation techniques currently under development. These included aerogel insulation and powder insulation in a vacuum. The common element of these emerging insulation technologies is a much higher R-value in less thickness than is available from fiberglass or polyurethane foam. This design option was applied as a replacement for two inches of foam insulation. The

thickness of the insulation was decreased to one inch. The conductivity of the insulation was assumed to be one-third the value for foam insulation.

Tempering Tank

A tempering tank is an uninsulated storage tank plumbed in the water line before the water heater. When it is installed in a conditioned, or semi-conditioned space, it will raise the water heater inlet temperature to the ambient temperature. Under the new test procedure, this is equivalent to raising the input temperature 9.5 °F.

Submerged Combustion

In this design option the flue products are bubbled through a small volume of water by the pressure from the blower burner. This small volume is heated by direct contact with the flue products. The heated water is repressurized by a circulating pump and returned to the storage tank. A potential problem is the contamination of domestic water by the flue products. This design may conflict with plumbing codes (10).

Indirect Heating with Electronic Ignition and Plastic Tank

This design option is the same as Indirect Heating with Electronic Ignition, but substitutes a plastic tank instead of a glass-lined metal tank. It is based on a water heater that is currently on the market. It uses a blow-molded polybutylene tank which is wrapped in fiberglass to withstand the pressure from the supply line. The plastic tank is more resistant to corrosion, which gives a longer lifetime, and allows less heat conduction than a metal tank. The manufacturer of this water heater applies pre-shaped shells of rigid polyurethane foam to the tank.

Directly Fired

In this design option, water is sprayed through a series of baffles above the burner. Flue products are in direct contact with the water, which is repressurized by a circulating pump and returned to the storage tank. A potential problem is the contamination of domestic water by the flue products. This design may conflict with plumbing codes (11).

Thermophotovoltaic Generator

A thermophotovoltaic water heater uses a special light-emitting burner coupled with silicon photovoltaic cells to generate auxiliary power to run a fan, electronic ignition, controls, and charge a battery. This avoids the requirement of auxiliary electrical supply, while offering the efficiency advantages of electronic ignition and forced-draft combustion.

Condensed Flue Gases

To extract the maximum heat out of the fuel of a gas-fired appliance, the combustion products in the flue gases must be condensed. To do this in a storage water heater, the flue must be lengthened by coiling it around inside the tank. The flue exit must be low where it can contact the coolest water in the tank. The flue gases must be pushed through the water heater. One manufacturer currently makes a water heater using this technology. It is designed to provide both domestic hot water and space heating.

The condensate in flue gases is acidic. Special venting systems must be installed that can handle this condensate, and the condensate must also be drained safely. The installation cost in this analysis included the cost for adding electric service, installing conduit, reventing, and adding a condensate drain.

Condensing Pulse Combustion

Pulse combustion burners operate on self-sustaining resonating pressure waves that alternately rarify the combustion chamber (drawing a fresh fuel/air mixture into the chamber) and pressurize it (causing ignition by compression of the mixture to its flash point). This process is initiated by a blower that supplies an initial fuel and air mixture, which is ignited with a spark ignitor, to the chamber. Once resonance is produced, the process becomes self-sustaining; pulse frequencies are on the order of 100 cycles per second (12). Pulse combustion systems feature high heat transfer rates, are capable of self-venting, and can draw outside air for combustion even when installed inside. American Gas Association Laboratories (AGA Labs) built several prototype pulse combustion water heaters as part of a study of pulse combustion residential water heaters (13).

1.3.2 Energy Calculations for Gas-Fired Storage Water Heaters.

Annual gas and electricity consumption for each of the design options were calculated from the gas and electricity input rates and the number of hours the main burner was firing. The number of hours the main burner was firing was determined from the average daily energy consumption (ADEC) and the input rates. The calculations of ADEC, EF, recovery efficiency, and standby loss were based on the old DOE test procedure (14). The new test DOE test procedure had not become effective at the time this analysis was done; therefore most of the available data were from the old test procedure. Also the old test procedure allows the ADEC and EF to be calculated from the recovery efficiency and standby losses. The new test procedure determines EF in a much more direct manner. It can no longer be calculated from the recovery efficiency and standby losses. The EF for most of the design options listed here was calculated by combining the recovery efficiency and standby losses.

Recovery efficiencies were taken from either the California Energy Commission (CEC) or Gas Appliance Manufacturers Association (GAMA) water heater directories for existing models already containing the design option (15) (16).

When possible, the standby losses were converted to heat flows. These heat flows were apportioned among the fittings, the flue, and the jacket. Reductions in the apportioned heat flows were estimated for each of the design options. These reduced heat flows were then combined into a revised total standby loss. The recovery efficiency and revised total standby loss were used to calculate the EF and ADEC.

Table 1.3 summarizes the energy calculations for gas-fired storage water heaters. The EF(old) was calculated according to the old test procedures. Electricity is converted to Btus at the site. A new source EF was also calculated the same way, except that electricity was converted to Btus at the source. A multiplier of 3.37 was used to account for transmission losses and electricity-generation inefficiencies. The energy calculations, sources of data, and explanation of assumptions used for each design option are described in further detail in section A.1 of Appendix A in this volume.

Table 1.3 Energy Calculations for Gas-Fired Storage Water Heaters

Standard Level Number	Design Option Number	Description	EF	EF(old)	RE	S %/hr	Standby Losses				Burner On		Burner Off		ADEC kBtu	BOH hours/day	Energy Use	
							Total	Fittings	Flue	Jacket	Elec	Gas	Elec	Gas			Gas	Elec
							Btu/hr	Btu/hr	Btu/hr	Btu/hr	Watts	Btu/hr	Watts	Btu/hr			(MMBtu/yr)	(kWh/yr)
1	0	Baseline	0.544	0.544	0.76	3.79%	1125	90	751	284	0	34400	0	400	75.48	1.94	27.5	0.0
	1	0 + Heat Traps	0.550	0.550	0.76	3.63%	1078	43	751	284	0	34400	0	400	74.58	1.91	27.2	0.0
2	2	1 + Reduce Heat Leaks	0.554	0.554	0.76	3.56%	1057	22	751	284	0	34400	0	400	74.17	1.90	27.1	0.0
3,4	3	2 + R-16 Insulation	0.570	0.570	0.76	3.19%	947	22	751	175	0	34400	0	400	72.09	1.84	26.3	0.0
	4	3 + Improve Flue Baffle,std	0.662	0.662	0.85	2.40%	711	22	515	175	0	34400	0	400	61.99	1.54	22.6	0.0
	5	4 + IID w/ Flue Damper	0.681	0.711	0.85	1.45%	432	22	236	175	25	34000	15	0	57.71	1.66	20.6	137.2
	6	3 + Submerged Combustion Chamber,std	0.635	0.635	0.85	2.86%	849	22	652	175	0	34400	0	400	64.63	1.62	23.6	0.0
	7	6 + IID w/ Flue Damper	0.667	0.697	0.85	1.67%	495	22	298	175	25	34000	15	0	58.92	1.70	21.0	137.3
	8	3 + Improve Flue Baffle,side	0.627	0.652	0.85	2.40%	711	22	515	175	77	34400	10	400	63.02	1.54	22.6	125.2
	9	8 + IID	0.645	0.671	0.85	2.07%	615	22	419	175	80	34000	10	0	61.17	1.76	21.9	132.3
	10	3 + Indirect Heating w/IID	0.651	0.673	0.81	1.65%	490	315	0	175	50	34000	10	0	60.97	1.76	21.9	113.0
	11	3 + Multiple Flues	0.591	0.591	0.80	3.19%	947	22	751	175	0	34400	0	400	69.46	1.76	25.4	0.0
7	12	3 + IID w/ Flue Damper	0.603	0.628	0.76	1.82%	540	22	344	175	25	34000	15	0	65.42	1.89	23.4	137.9
	13	3 + Submerged Combustion Chamber,side	0.603	0.625	0.85	2.86%	849	22	652	175	77	34400	10	400	65.65	1.61	23.5	127.1
5,6	14	3 + R-25 insulation	0.576	0.576	0.76	3.05%	906	22	751	133	0	34400	0	400	71.30	1.81	26.0	0.0
	15	3 + Increase Baffling & Forced Draft,side	0.657	0.663	0.84	2.24%	666	22	469	175	55	34400	0	400	61.89	1.53	22.5	30.7
	16	3 + Increase Baffling & Forced Draft,std	0.657	0.663	0.84	2.24%	666	22	469	175	55	34400	0	400	61.89	1.53	22.5	30.7
	17	3 + IID & Power Vent	0.587	0.610	0.76	2.16%	642	22	445	175	80	34000	10	0	67.33	1.94	24.1	136.9

Standard Level Number	Design Option Number	Description	EF	EF(old)	RE	S	Standby Losses				Burner On		Burner Off		ADEC	BOH	Energy Use	
							Total	Fittings	Flue	Jacket	Elec.	Gas	Elec.	Gas			Gas	Elec
							%/hr	Btu/hr	Btu/hr	Btu/hr	Watts	Btu/hr	Watts	Btu/hr			kBtu	hours/day (MMBtu/yr) (kWh/yr)
	18	3 + Vacuum Insulation	0.573	0.573	0.76	3.11%	923	22	751	151	0	34400	0	400	71.63	1.82	26.1	0.0
	19	0 + Tempering Tank	0.587	0.587	0.85	3.79%	1125	90	751	284	0	34400	0	400	69.96	1.78	25.5	0.0
	20	0 + Submerged Combustion	0.704	0.809	0.97	0.90%					600	34000	10	0	50.72	1.39	17.2	386.0
	21	0 + Indirect w/IID & Plastic Tank	0.712	0.740	0.81	0.68%					50	34000	10	0	55.48	1.60	19.9	110.7
	22	0 + Directly Fired	0.704	0.809	0.97	0.90%					600	34000	10	0	50.72	1.39	17.2	386.0
	23	0 + TPV Generator	0.640	0.640	0.8	2.26%					0	34000	0	0	64.15	1.89	23.4	0.0
8	24	0 + Condense Flue Gases	0.819	0.860	0.94	0.53%					80	34000	10	0	47.74	1.37	17.0	122.4
	25	0 + Condensing Pulse	0.786	0.815	0.906	0.75%					27	34000	10	0	50.37	1.45	18.1	96.6

IID = Intermittent Ignition Device

RE = Recovery Efficiency

S = Standby Losses

BOH = Burner Operating Hours

Energy Factor as a Function of Volume

For a fixed level of insulation, a relationship exists between the volume of a water heater and its EF (17). The EF decreases with increasing tank volume because the test procedure assumes a constant usage per day. Since a large tank has greater standby losses, it requires more energy input to provide the same amount of hot water. The slope for these equations was found by fitting data from models listed in the October 1990 GAMA Directory (18). Only unique series of models with identical model numbers except for volume were chosen. Twenty-five unique series were identified for gas-fired storage water heaters. The slope used here was the average of the slope for each series of models. The intercept was chosen so that the linear equation yielded the EF from the analysis at the baseline volume.

The derivation of these equations was based on the old EF. The EF now contains a factor for converting electric energy consumption to source energy consumption. The relation of EF to volume was assumed to remain unchanged when the conversion factor was applied to electricity use.

Table 1.4 Energy Factor as Function of Volume for Gas-Fired Storage Water Heaters

Trial Standard Level	Design Option Number	EF at Baseline Volume	Energy Factor Equation
1	0	0.544	= 0.612 - (0.001707 * Volume)
2	2	0.554	= 0.622 - (0.001707 * Volume)
3	3	0.570	= 0.638 - (0.001707 * Volume)
4	3	0.570	= 0.638 - (0.001707 * Volume)
5	14	0.576	= 0.644 - (0.001707 * Volume)
6	14	0.576	= 0.644 - (0.001707 * Volume)
7	12	0.603	= 0.672 - (0.001707 * Volume)
8	24	0.819	= 0.887 - (0.001707 * Volume)

1.3.3 Cost and Efficiency Data for Gas-Fired Storage Water Heaters

This section presents manufacturer cost at large-scale production and costs to install water heaters with each of the design options included in this analysis. The manufacturer's cost is the cost to the manufacturer of making water heaters with the design options shown and does not include any markups to wholesalers or retailers.

Cost data for the more common design options were mostly from information supplied by manufacturers to GAMA and a report prepared by ADM Associates, Inc. (19) (20).

For many design options it was not possible to get manufacturing costs. For some of these design options, factory costs were estimated from current retail prices, then reduced to reflect cost decreases due to increased production levels. For other design options, costs were obtained from suppliers to manufacturers.

The average incremental cost of any extra installation or modification procedures necessary to install a water heater with that design option was added to the installation cost of the previous design option. This included costs of items such as supplying electricity to the water heater, relining the vent system for mid-efficiency water heaters using vent systems that were not Type-B, adding a condensate drain for high-efficiency water heaters, etc. The baseline installation costs were from a report by Lerman and were adjusted for inflation since 1987 using Means Historical Cost Indices (21) (22). No maintenance costs were included because of the relatively short life of water heaters.

The manufacturer and installation costs are listed in Table 1.5. The details and sources of the costs in this table are explained in Section A.2 of Appendix A of this volume. The EFs for the design options were from Table 1.3 in the "Energy Calculations," Section 1.3.2.

Table 1.5 Cost Data for Gas-Fired Storage Water Heaters

Standard Level Number	Design Option Number	Description	EF	Costs	
				Manufacturer 1990\$	Install 1990\$
1	0	Baseline	0.544	95.63	126.12
	1	0 + Heat Traps	0.550	99.20	126.12
2	2	1 + Reduce Heat Leaks	0.554	101.10	126.12
3,4	3	2 + R-16 Insulation	0.570	113.82	126.12
	4	3 + Improve Flue Baffle,std	0.662	133.82	363.49
	5	4 + IID w/ Flue Damper	0.681	187.77	374.69
	6	3 + Submerged Combustion Chamber,std	0.635	113.82	363.49
	7	6 + IID w/ Flue Damper	0.667	167.77	374.69
	8	3 + Improve Flue Baffle,side	0.627	173.82	206.72
	9	8 + IID	0.645	182.67	206.72
	10	3 + Indirect Heating w/IID	0.651	267.93	137.32
	11	3 + Multiple Flues	0.591	165.30	126.12
7	12	3 + IID w/ Flue Damper	0.603	167.77	137.32
	13	3 + Submerged Combustion Chamber,side	0.603	153.82	206.72
5,6	14	3 + R-25 Insulation	0.576	124.20	148.65
	15	3 + Increase Baffling & Forced Draft,side	0.657	426.32	206.72
	16	3 + Increase Baffling & Forced Draft,std	0.657	426.32	363.49
	17	3 + IID & Power Vent	0.587	158.77	206.72
	18	3 + Vacuum Insulation	0.573	162.98	126.12
	19	0 + Tempering Tank	0.587	145.63	176.12
	20	0 + Submerged Combustion	0.704	293.33	280.37
	21	0 + Indirect w/IID & Plastic Tank	0.712	344.41	137.32
	22	0 + Directly Fired	0.704	329.27	280.37
	23	0 + TPV Generator	0.640	295.63	126.12
8	24	0 + Condense Flu Gases	0.819	453.86	380.37
	25	0 + Condensing Pulse	0.786	484.36	380.37

IID = Intermittent Ignition Device

Baseline (Design Option #0)

Disaggregated manufacturing data for the baseline model were from manufacturers. GAMA collected the data from manufacturers and de-identified them to preserve the confidentiality of the sources (23). Installation costs were from a report prepared for Bonneville Power Administration and Pacific Power and Light (24). This was adjusted for inflation since 1987 using the Historical Cost Indexes from Means (25).

Heat Traps (Design Option #1)

The incremental cost data for heat traps were the average obtained from the GAMA data request and the ADM report (26) (27). The cost of parts and materials from the ADM report were combined before averaging with the GAMA data. ADM costs were adjusted for inflation from 1987 to 1990 using a multiplier of 1.127 (28). There was no additional installation cost for water heaters with heat traps.

Reduce Heat Leaks (Design Option #2)

Disaggregated manufacturing data for the reduced heat leaks design option were from the GAMA data request (29). No additional installation costs were associated with this design option.

R-16 insulation (Design Option #3)

The incremental cost data for R-16 foam insulation was the average of costs from the GAMA data request and ADM cost study (30) (31). ADM costs were adjusted for inflation as above. No additional installation costs were associated with this design option.

Improve Flue Baffle with Standard Venting (Design Option #4)

The cost of the flue with the improved baffling was \$20. This was provided by the supplier of the pre-assembled flue (32). The recovery efficiency is so high for this design option that modifications are required for venting systems other than Type-B to prevent condensation damage. The \$237.38 incremental installation cost used here represents the weighted-average cost for relining chimneys and replacing vent connectors where necessary.

The cost for relining or replacing either masonry chimney, single-wall or other than Type-B was \$408. Sixty percent of the replacement market water heater vents would need replacing. Single-wall vent connectors would also need to be replaced at a cost of \$85. Seventy-four percent of the replacement market water heaters use single-wall vent connectors. It was estimated that 75% of these would need replacement (33). The replacement market comprises 81.3% of total gas water heater shipments according to LBL-REM (34).

Electronic Ignition with Flue Damper (Design Option #5)

The material costs were for the incremental cost of a spark ignition system, a flue damper, a 24-volt plug-in transformer with low-voltage wire between the outlet and the water heater, and a control relay (35). The costs for the other portions of the manufacturers cost were from the GAMA data request (36). The incremental installation cost of \$11.20 was to install the low-voltage electrical supply for the electronic ignition and flue damper (37).

Submerged Combustion Chamber with Standard Venting (Design Option #6)

Manufacturing cost for the submerged combustion chamber will be no more than, and may even be less than, the cost of the baseline unit. This information was from studies done by a manufacturer on projected costs of submerged combustion water heaters in large volume production (38). The bottom end of a submerged combustion chamber water heater is much simpler to construct. There are no legs, skirt ring, or reflective liner. This results in lower materials costs. Tooling costs would increase. The incremental tooling and materials costs were estimated. The \$237.38 incremental installation cost used here represents the weighted-average cost for relining chimneys and replacing vent connectors where necessary as explained for design option #4.

Electronic Ignition with Flue Damper (Design Option #7)

This design option is the same as design option #5, except that it has been applied after submerged combustion, instead of after improved flue baffle. The manufacturers cost and installation costs are the same.

Improve Flue Baffle with Sidewall Venting (Design Option #8)

This design option is the same as design option #4, except instead of relining chimneys where necessary, sidewall power venting was used. The incremental manufacturer cost of \$60 included an improved flue, power venting, electronic ignition, and a 24 volt plug-in transformer. The improved flue cost \$20 (39). The power vent added approximately \$25 (40) (41). These were original equipment manufacturer (OEM) prices for large-volume purchases. The \$7.50 material cost for adding electronic ignition was taken as the difference between the cost of the electronic ignition with a flue damper and the cost of a flue damper in the GAMA data request (42). The \$7.50 material cost for a 24 volt transformer was estimated.

The \$80.60 installation cost was for adding low-voltage power and reventing. The cost of installing a plug-in transformer and running low-voltage wiring was \$5.60 (43). Adding a sidewall vent system was estimated to cost \$75 (44).

Electronic Ignition (Design Option #9)

Disaggregated factory costs were taken as the differences between the cost of the electronic ignition with flue damper design option and the cost of the flue damper design option in the GAMA data request (45). No additional installation costs were associated with this design option because 24 volt power was already supplied to the water heater.

Indirect Heating with Electronic Ignition (Design Option #10)

The factory cost of indirect heating with electronic ignition was estimated from the list price difference between gas (list \$779) and electric (list \$449) plastic tank water heaters.¹ The list prices were reduced 47%. This reduction was based on an assumed 27% markup from factory to retail cost at current production levels and a 60% reduction in factory costs if production were increased to 100,000 units per year. The differential manufacturer cost was reduced to capture the savings of not installing a flue or burner on the water heater. The reduction was estimated as the difference between the baseline gas (\$95.63) and electric (\$89.68) water heaters. The estimated incremental price of heat traps (\$8.8) was subtracted from the price of the electric unit because they were apparently not included in the gas unit. This was a total incremental factory cost of \$154.11. The incremental installation cost of \$11.20 was to install a plug-in transformer and the low-voltage wiring (46).

Multiple Flues (Design Option #11)

The cost data were from the ADM cost study and an estimate in the GRI report that incremental retail cost differences at large production volumes would be \$100 (47). This value was divided by two to get an estimate of factory cost. No additional installation cost was included.

Electronic Ignition with Flue Damper (Design Option #12)

The materials costs were for the incremental cost of a spark-ignition system, a flue damper, a 24-volt plug-in transformer with low-voltage wire between the outlet and the water heater, and a control relay (48). The other factory costs were from the GAMA data request (49). The installation cost was \$11.20 (50).

Submerged Combustion Chamber with Sidewall Venting (Design Option #13)

This design option is the same as design option #6, except instead of relining chimneys where necessary, sidewall power venting was used. The incremental manufacturer cost of \$35 included power venting, electronic ignition, a 24 volt plug-in transformer, and a savings on material cost from submerged combustion chamber. The power vent added approximately \$25

¹These were the Marathon models #MG40345 and #MP40238 produced by Water Heater Innovations. Kenmore Survivor Electric and Gas Models, "Catalog," Sears, Spring/Summer 1991, p. 1078.

(51) (52). These were OEM prices for large volume purchases. The \$7.50 material cost for adding electronic ignition was taken as the difference between the cost of the electronic ignition with a flue damper and the cost of a flue damper in the GAMA data request (53). The \$7.50 material cost for a 24 volt transformer was estimated. The \$80.60 installation cost was for adding low-voltage power and reventing. The cost of installing a plug-in transformer and running low-voltage wiring was \$5.60 (54). Adding a sidewall vent system was estimated to cost \$75 (55).

R-25 Insulation (Design Option #14)

The incremental cost for R-25 foam insulation was the average obtained from the GAMA data request and the ADM report (56) (57). The costs for this design option were from data for electric water heaters. The costs of parts and materials from the ADM report were combined before averaging with the GAMA data. ADM costs were adjusted for inflation from 1987 to 1990 using a multiplier of 1.127 (58). The incremental installation cost was \$22.54. It was estimated that 50% of water heaters were installed through doors 24" or less wide and would need additional installation work to accommodate the increased diameter of R-25 insulation. The additional installation cost to remove and replace a door frame was from the ADM cost study, updated for inflation from 1987 to 1990 using a multiplier of 1.127 (59).

Increased Baffling and Forced Draft with Sidewall Venting (Design Option #15)

Disaggregated factory costs were from the GAMA data request. The installation cost of \$80.60 was for adding low-voltage power and reventing. The cost of installing a plug-in transformer and running low-voltage wiring was \$5.60 (60.) Adding a sidewall vent system was estimated to cost \$75 (61).

Increased Baffling and Forced Draft with Standard Venting (Design Option #16)

The manufacturers cost was the same as the previous design option. The incremental installation cost of \$237.38 is the same as for design option #4.

Electronic Ignition & Power Vent (Design Option #17)

The \$40 incremental material scost covered the power vent, electronic ignition, and low-voltage plug-in transformer. The power vent added approximately \$25 (62) (63). These were OEM prices for large volume purchases. The \$7.50 material cost for adding electronic ignition was taken as the difference between the cost of the electronic ignition with a flue damper and the cost of a flue damper in the GAMA data request (64). The \$7.50 material cost for a 24 volt transformer was estimated. Labor, tooling, shipping, and overhead costs of power vent with an electronic ignition were estimated to be the same as for a flue damper with an electronic ignition as reported in the GAMA data request. The installation cost of \$80.60 was for adding low-voltage power and power venting. This was the same as design option #8.

Vacuum Insulation (Design Option #18)

The incremental cost to replace two inches of foam insulation with either vacuum/powder or aerogel insulation with an R-value of 25 was estimated at \$2.43/sq ft (65). The total incremental manufacturers cost was \$49.16. No additional installation cost was added.

Tempering Tank (Design Option #19)

The manufacturers cost of an un-insulated tank was assumed to be \$50. The installation cost for a tempering tank was estimated to be \$50.

Submerged Combustion (Design Option #20)

The total incremental manufacturer cost was estimated at \$197.70 (66). Prices were increased from 1981 to 1990\$ using a multiplier of 1.438 from the Consumer's Price Index and then reduced by a factor of 50% to eliminate factory-to-retail markups. The installation cost was for adding electric service, installing conduit, and reventing and was estimated at \$154.25. Forty-eight percent of water heaters are without an existing electrical outlet in the same room (67). The cost of adding electrical service was \$100 and a new vent was \$125 (68). The estimated incremental cost to install a hard-wired (or conduited) electrical service from an existing outlet to the water heater was \$75. A new vent system was added to the estimated 25% of units not already serviced by a Type-B vent.

Indirect Heating with Electronic Ignition and a Plastic Tank (Design Option #21)

The incremental manufacturer cost of \$248.78 was estimated as 47% of the current list price minus the cost of the baseline unit (69). This estimate was based on an assumed 16% reduction in manufacturer cost if production were increased to 100,000 units per year. The incremental installation cost was \$11.20 (70).

Directly Fired (Design Option #22)

The incremental factory cost was estimated at \$233.65 (71). Prices from 1981 were increased to 1990\$ using a multiplier of 1.438 from the Consumer's Price Index and then reduced by a factor of 50% to eliminate factory to retail markups. Installation work and costs were the same as for design option #20.

Thermophotovoltaic Generator (Design Option #23)

The incremental manufacturer cost was estimated at \$200 (72) (73). There was no additional installation cost for this design option because it does not need auxiliary power.

Condense Flue Gases (Design Option #24)

The incremental manufacturer cost of \$358.23 was derived from nationwide distributor prices. Current distributor price² was assumed to be based on a 40% markup from factory cost at current production levels and then reduced to 60% to account for savings if production were increased to 100,000 units per year.

The incremental installation cost of \$254.25 was for adding electric service, installing conduit, reventing, and adding a condensate drain. Forty-eight percent of water heaters are without an existing electrical outlet in the same room (74). The cost of adding electrical service was \$100 and a new vent was \$125 (75). The estimated incremental cost to install a hard-wired (or conduited) electrical service from an existing outlet to the water heater was \$75. A new vent system was added to the estimated 25% of units not already serviced by a Type-B vent. Installation cost for adding a new condensate drain to a condensing water heater was estimated at \$100.

Condensing Pulse (Design Option #25)

The disaggregated factory costs were from the ADM study (76). These costs were adjusted for inflation from 1987 to 1990 using a multiplier of 1.127 (77). Installation costs were the same as for design option #24.

1.3.4 Maximum Technologically Feasible Design for Gas-Fired Storage Water Heaters

The most efficient design option analysed for gas-fired storage water heaters was to condense the flue gases. One manufacturer currently makes a water heater using this technology. It is designed to provide both domestic hot water and space heating. The EF for this model, including the site to source conversion for electricity consumption, was calculated to be 0.819.

All of the efficiency values in Table 1.3 have some uncertainty associated with them. A 95% confidence interval was calculated for the maximum technologically feasible design. The low end of the interval was an EF of 0.773. The high end of the interval was 0.823. Volume A of this Technical Support Document provides a general discussion of how the 95% confidence interval is established for "max tech" designs.

²Polaris condensing direct vent water heater, Model #DVPB-35, Mor-Flo/American Comfort Systems, Nationwide Distributor Price Sheet, April 1, 1990, included in Comments on the Advanced Notice Of Proposed Rulemaking Regarding Energy Conservation Standards for 9 Types of Consumer Products (FR Vol. 55, No. 189, pg. 39624, 9/28/90) by the Southern Gas Association. Docket Number CE-RM-90-201, Comment Number 4, 12/5/90.

1.4 ELECTRIC STORAGE WATER HEATERS

Typical electric storage water heaters usually have two resistance heating elements inserted from the side of the tank. One element is close to the top of the tank. The other heating element is mounted much lower in the tank. These elements are each typically rated at 4,500 watts. They are controlled so that only one element can be on at a time. This keeps the water heater from drawing more than 20 amps at any time. Residential electric storage water heaters must be installed on a dedicated circuit. Electric storage water heaters are usually sized larger than gas-fired storage water heaters because the rate of recovery is lower. The heat input rate of 4,500-watt electric resistance heating element is about 60% of the heat input rate of a 34,000 Btuh burner with a 76% recovery efficiency. The input rate is limited to 4,500 watts by the capacity of the residential circuits. See Figure 1.3.

Because the resistance heating elements are immersed in the water that is being heated, the efficiency is very high. The standby loss for electric storage water heaters is much lower than for gas-fired storage water heaters. The entire tank is surrounded by insulation. There is no center flue or exposed bottom surface on an electric water heater. Typical values for standby loss are around 1%.

Figure 1.3 Electric Storage Water Heater

1.4.1 Design Options for Electric Storage Water Heaters

The design options considered in the engineering analysis of electric storage water heaters are listed in Table 1.6. They are changes that can be incorporated into the design of an electric storage water heater to improve its EF. The first design option is the baseline. This is not a change, but rather represents the typical electric storage water heater that just meets the current efficiency standards for water heaters.

Table 1.6 Design Options for Electric Storage Water Heaters

0	Baseline
1	Reduce Heat Leaks
2	Heat Traps
3	Add-On Heat Pump
4	Third-Generation Heat Pump
5	Integral Heat Pump
6	Heat Pump (GAMA data)
7	R-25 Insulation
8	Vacuum Insulation
9	Off Peak
10	Solar Pre-Heat
11	Tempering Tank

Baseline

The baseline model for this analysis was from the GAMA data request (78). It was a 52-gallon glass-lined steel tank. The tank was insulated with two inches of polyurethane foam. The heater had two elements each with an input of 4,500 watts. The elements were interlocked so only one could be energized at a time. The baseline EF of .86 was calculated according to the new test procedure for a 52-gallon electric storage water heater (79).

Reduce Heat Leaks

This design option is described for gas-fired storage water heaters.

Heat Traps

This design option is described for gas-fired storage water heaters.

Add-On Heat Pump

This design option was a separate heat pump that could be attached to an existing water heater. A small pump circulates water from the tank, through the heat pump. This design option was based on an existing water heater.³ The heat pump is designed to be installed on top of the water heater.

³Heat pump water heater model # B108 manufactured by E-tech, Atlanta, GA.

Third-Generation Heat Pump

The third-generation heat pump water heater is currently under development by Electric Power Research Institute (EPRI). The heat pump water heater has an 80-gallon storage tank with a downsized heat pump to reduce costs. The smaller unit will operate more continuously, which improves efficiency and lifetime. EPRI plans to have the unit on the market by 1992.

Integral Heat Pump

The integral heat pump uses a heat exchanger that is built into the inner wall of the tank as the condenser. This design increases the efficiency of the condenser and eliminates the need for a pump to circulate the water. This design option is based on a water heater currently on the market.⁴

Heat Pump (GAMA data)

The cost and efficiency data for this design option were taken from the GAMA data request. No description of the type of unit was given.

R-25 Insulation

This design option replaces two inches of polyurethane foam insulation around the tank with three inches of polyurethane foam insulation. It is described for gas-fired storage water heaters.

Vacuum Insulation

This design option replaces two inches of polyurethane foam insulation with either vacuum powder insulation or aerogel insulation with an R-value of 25. It is described for gas-fired storage water heaters.

Off Peak

Off-peak water heaters control the elements so no heating can occur for most of the day, often 7 AM to 11 PM. Usually this is encouraged by electric utilities that are trying to reduce their peak load. However this design option also reduces energy consumption. When draws are made during the time the elements are prevented from heating water, the mean tank temperature will decline. Lower mean tank temperature would reduce standby loss. The new DOE water heater test corrects for deviations from the specified tank temperature and therefore would not show any savings from this design option. Tank size must be increased to provide sufficient hot water during the day without reheating.

⁴Water heater model #TS-HP-52 HR, manufactured by DEC International, Therma-Stor Products Group.

Solar Pre-Heat

This design option uses solar collectors as pre-heaters to a standard electric storage water heater. The cost and efficiency data were the average of data for three different types of systems. The systems were a drainback system with low-cost plastic collectors using tap water as the working fluid,⁵ a self-pumping system using methyl alcohol and water as the working fluid,⁶ and a more traditional collector system using an anti-freeze working fluid.⁷

Tempering Tank

This design option is described for gas-fired storage water heaters.

1.4.2 Energy Calculations for Electric Storage Water Heaters

Both the EF and annual energy consumption were based on the average daily energy consumption (ADEC), which was calculated for all the design options analyzed for electric storage water heaters. The EF was calculated as the daily load divided by the ADEC. The daily load, 41,059 Btu, was calculated from the new DOE test procedure (80). The annual energy consumption was calculated as 365 times ADEC.

The reduction in ADEC was calculated for each design option. The EF of many design options is listed in water heater directories. These EFs were converted to ADECs and subtracted from the ADEC of the baseline model to determine the reduction in ADEC that could be attributable to the design option. These savings were subtracted from the previous design option in the table to determine the new ADEC. Because EF contains the inverse of the fuel consumption, it was not combined directly.

Table 1.7 summarizes the energy calculations for electric storage water heaters. The sources of data and explanation of assumptions used in the energy calculations for each design option are described in further detail in Section A.3 of Appendix A of this volume.

⁵The ASN II SKYLIGHT by American Solar Network is a drainback system using 2.5 gallons of tap water with a EDPM rubber absorber behind Lexan glazing. It uses "Qest" polybutylene connecting lines with copper fittings to reduce installation and materials costs. The working fluid is circulated with a 1/40 hp pump.

⁶The Copper Cricket by Sage Advance Corporation is a self-pumping double tank (solar plus auxiliary) system using a copper absorber with black chrome coating. The working fluid is 15% methyl alcohol in water.

⁷The SB56-225 Solar Boiler Solar System by Thermo Dynamics Ltd. is a two-solar-panel system using propylene glycol and water as a working fluid with a 80-gallon glass-lined storage tank.

Table 1.7 Energy Calculations for Electric Storage Water Heaters

Standard Level Number	Design Option Number	Design Options	ADEC <i>kBTU/day</i>	EF	Elec <i>kWh/yr</i>
	0	Baseline	47.67	.86	5096.2
	1	0 + Reduce Ht Leaks	46.99	.87	5024.3
1	2	1 + Heat Traps	45.83	.90	4899.5
3	3	2 + Add-On Heat Pump	23.19	1.77	2479.3
	4	2 + 3rd-Gen Heat Pump	26.82	1.53	2867.3
6,7,8	5	2 + Int Heat Pump	16.19	2.54	1730.8
	6	2 + GAMA Heat Pump	24.83	1.65	2654.8
4,5	7	3 + R-25 Insul	21.67	1.89	2316.7
	8	3 + Vacuum Insul	21.67	1.89	2316.7
2	9	2 + R-25 Insul	44.31	.93	4736.9
	10	9 + Off Peak	42.66	.96	4560.4
	11	10 + Solar Pre-Heat	19.20	2.14	2053.1
	12	0 + Tempering Tank	43.75	.94	4677.3

Energy Factor as a Function of Volume

For a fixed level of insulation, there is an approximately linear relationship between the volume of a water heater and its energy factor (81). The EF decreases with increasing tank volume because the test procedure assumes a constant usage per day. Since a large tank has greater standby losses, it requires more energy input to provide the same amount of hot water. The slope for these equations was found by fitting data from models listed in the October 1990 GAMA Directory (82). Only unique series of models with identical model numbers except for volume were chosen. Forty-six unique series were identified for electric storage water heaters. The slope used here was the average of the slope for each series of models. The intercept was chosen so that the linear equation yielded the EF from the analysis at the baseline volume.

Table 1.8 Energy Factor as Function of Volume for Electric Storage Water Heaters

Standard Level Number	Design Option Number	EF at baseline volume	Energy Factor Equation
1	2	0.896	= 0.957 - (0.001172 * Volume)
2	9	0.927	= 0.988 - (0.001172 * Volume)
3	3	1.771	= 1.831 - (0.001172 * Volume)
4	7	1.895	= 1.956 - (0.001172 * Volume)
5	7	1.895	= 1.956 - (0.001172 * Volume)
6	5	2.536	= 2.597 - (0.001172 * Volume)
7	5	2.536	= 2.597 - (0.001172 * Volume)
8	5	2.536	= 2.597 - (0.001172 * Volume)

1.4.3 Cost and Efficiency Data for Electric Storage Water Heaters

This section presents manufacturers' costs of electric storage water heaters at large-scale production. The cost to install water heaters with each of the design options is also presented here. The manufacturers' cost is the cost of making water heaters with the design options shown and does not include any markups to wholesalers or retailers.

The cost data for the more common design options were mostly from information supplied by manufacturers to GAMA and a report prepared by ADM Associates, Inc. (83) (84).

For many design options it was not possible to obtain manufacturing costs. For some of these design options, factory costs were estimated from current retail prices, and then reduced to reflect cost decreases due to increased production levels. For other design options, costs were obtained from suppliers to manufacturers.

The average incremental cost of any extra installation or modification procedures necessary to install a water heater with that design option was added to the installation cost of the previous design option. The baseline installation costs were from a report by Lerman and were adjusted for inflation since 1987 using Means Historical Cost Indices (85) (86). No maintenance costs were included, because of the relatively short life of water heaters.

The manufacturer and installation costs are listed in Table 1.9. The details and sources of the costs in this table are listed below for each design option. Disaggregated manufacturing costs are shown in Section A.4 of Appendix A of this volume. The EFs for the design options are from Table 1.8.

Table 1.9 Cost Data for Electric Storage Water Heaters

Standard Level Number	Design Option Number	Design Options	EF	Costs	
				Manufacturer 1990\$	Installation 1990\$
		Baseline	.86	89.68	126.12
	1	0 + Reduce Ht Leaks	.87	91.58	126.12
1	2	1 + Heat Traps	.90	95.00	126.12
3	3	2 + Add-On Heat Pump	1.77	291.50	226.12
	4	2 + Third-Gen Heat Pump	1.53	317.27	226.12
6,7,8	5	2 + Integral Heat Pump	2.54	674.74	226.12
	6	2 + Heat Pump (GAMA data)	1.65	747.00	226.12
4,5	7	3 + R-25 Insulation	1.89	300.51	248.65
	8	3 + Vacuum Insulation	1.89	348.16	226.12
2	9	2 + R-25 Insulation	.93	104.01	148.65
	10	9 + Off Peak	.96	152.80	173.65
	11	10 + Solar Pre-Heat	2.14	1133.43	957.0
	12	0 + Tempering Tank	.94	139.68	176.12

Baseline (Design Option #0)

The baseline manufacturer cost was from GAMA (87).

Reduce Heat Leaks (Design Option #1)

The incremental cost of \$1.90 for this design option was from GAMA (88). This cost was for gas water heaters. There were no changes to installation cost.

Heat Traps (Design Option #2)

The incremental manufacturer cost of \$3.43 for heat traps was the average of the cost of heat traps from GAMA and the ADM cost study (89) (90). The costs in the ADM study were increased by 1.13 to account for inflation from 1987 to 1990 (91). The cost of parts and materials from ADM were combined before averaging with the GAMA data.

Add-On Heat Pump (Design Option #3)

The \$196.50 manufacturers' cost for the add-on heat pump water was estimated from a list price of a current model.⁸ A suggested list price of \$655 provided by the manufacturer as of October 1989 was used in this analysis (92). The current factory price was estimated by dividing the suggested list price in half. This assumed a markup of 100% to retail. Increasing production to 100,000 units per year was estimated to reduce manufacturer cost to 60% of current costs.

Third-Generation Heat Pump (Design Option #4)

The incremental factory cost of \$222.27 was derived from EPRI's stated goal of an installed price of \$750 (93). The factory cost was estimated by subtracting the installation price and assuming a markup to retail of 100%.

Integral Heat Pump (Design Option #5)

The incremental factory cost of \$579.74 was from manufacturer's data. This was the manufacturers' factory cost at the highest production level provided, minus the factory cost of the baseline unit (94).

Heat Pump (GAMA data) (Design Option #6)

The incremental factory cost of \$652 was from the GAMA data request (95).

R-25 Insulation (Design Option #7)

The factory cost of \$300.51 was the average from GAMA and the ADM cost study (96) (97). The costs in the ADM study were multiplied by 1.13 to account for inflation from 1987 to 1990 (98). The cost of parts and materials from ADM were combined before averaging with the GAMA data. The additional installation cost of \$22.54 was to remove and replace door frames for an estimated 50% of the units. It was assumed that the thicker insulation would increase the difficulty of installation in half of the situations where water heaters were installed. The additional installation cost was from the ADM study and was increased for inflation.

Vacuum Insulation (Design Option #8)

The incremental cost to replace two inches of polyurethane foam insulation with either vacuum/powder insulation or aerogel insulation with an R-value of 25 was estimated at \$2.43/sq ft (99). The surface area is estimated as 23.4 sq ft. (50.5" high * PI * 18" diam and top & bottom). The tank dimensions were from the GAMA data request (100).

⁸Model # B108 manufactured by E-tech, Atlanta, GA.

R-25 Insulation (Design Option #9)

The incremental manufacturer cost of \$9.00 for the thicker insulation was the average of the cost from GAMA and the ADM cost study (101) (102). The costs in the ADM study were increased by 1.13 to account for inflation from 1987 to 1990 (103). The cost of parts and materials from ADM were combined before averaging with the GAMA data.

Off Peak (Design Option #10)

The incremental factory cost was \$48.79. This cost differential was estimated by increasing the materials cost by the ratio of surface area of an 80-gallon tank to a 52-gallon tank (33.0% more surface area). The tank dimensions were for the Rheemglas Standard water heaters (model #81V-80D and #81V-52D) (104). An estimated \$30 was added for cost of controls. Incremental installation costs were to be \$25.

Solar Pre-Heat (Design Option #11)

The cost data were the average for three different types of systems. The \$980.63 incremental factory cost, the \$360.33 installation cost, and the \$422.98 maintenance cost were the average of data provided by all three manufacturers.^{9,10,11} The maintenance cost was the present value at a 6% discount of maintenance for 30 years.

Tempering Tank (Design Option #12)

The incremental cost of the tank and installation were estimated to be \$50 each.

1.4.4 Maximum Technologically Feasible Design for Electric Storage Water Heaters

The most efficient design option analysed for electric storage water heaters was a heat pump water heater with the refrigerant-to-water heat exchanger built into the walls of the tank. One manufacturer currently makes a water heater using this technology. The EF for this model, not including the site to source conversion for electricity consumption, was calculated to be 2.54.

⁹The ASN II SKYLIGHT by American Solar Network is a drainback system using 2.5 gallons of tap water with a EDPM rubber absorber behind Lexan glazing. It uses "Qest" polybutylene connecting lines with copper fittings to reduce installation and materials costs. The working fluid is circulated with a 1/40 hp pump.

¹⁰The Copper Cricket by Sage Advance Corporation is a self-pumping double-tank (solar plus auxiliary) system using a copper absorber with black chrome coating. The working fluid is 15% methyl alcohol in water.

¹¹The SB56-225 Solar Boiler Solar System by Thermo Dynamics Ltd. is a two-solar-panel system using propylene glycol and water as a working fluid with a 80-gallon glass-lined storage tank.

All of the efficiency values in Tables 1.7 have some uncertainty associated with them. A 95% confidence interval was calculated for the maximum technologically feasible design. The low end of the interval was an EF of 2.00. The high end of the interval was 3.40. Volume A of this Technical Support Document provides a general discussion of how the 95% confidence interval is established for "max tech" designs.

1.5 OIL-FIRED STORAGE WATER HEATERS

Oil-fired storage water heaters are typically a glass-lined storage tank located above a burner. The burner is equipped with a pump and blower, which bring the oil to the burner and mixes it with sufficient air for combustion. The pump and blower are powered by a single motor. The oil is electronically ignited with a hot surface ignition device. The combustion products are vented through a center flue that goes up the middle of the storage tank. Another approach to venting uses an annular flue. In this design the flue products are directed around the outside of the storage tank, inside an insulated jacket. The insulation is typically three-fourths of an inch of fiberglass insulation.

Oil-fired storage water heaters have larger burners than gas-fired storage water heaters. Because of the larger capacity burners, the storage tank volumes are often smaller than gas-fired or electric storage water heaters.

1.5.1 Design Options for Oil-Fired Storage Water Heaters

The design options that were analyzed for oil-fired storage water heaters are listed in Table 1.10. These design options are changes that can be incorporated into oil-fired storage water heaters. The first design option is the baseline model. It represents the typical oil-fired storage water heater that just meets the current efficiency standards. The design options are explained more fully following the table.

Table 1.10 Design Options for Oil-Fired Water Heaters

0	Baseline
1	1-Inch Foam Insulation
2	1.5-Inch Fiberglass Insulation
3	Heat Traps
4	Reduce Heat Leaks
5	2-Inch Foam Insulation
6	Flue Damper
7	Multiple Flues
8	Condensing

Baseline

The baseline model chosen for this analysis was a 32-gallon tank with three-fourths of an inch fiberglass insulation (105) (106). A center flue design was chosen as being the most representative of current oil-fired storage water heaters. An input rate of 103,875 Btuh was used. This is equivalent to 0.75 gallons per hour. The pump and blower motor was 1/8 HP (93.5 watts).

One-Inch Foam Insulation

This design option replaced the insulation with one inch of polyurethane foam. No other changes were made, except to enlarge the jacket to accommodate the increased thickness of insulation.

1.5-Inch Fiberglass Insulation

This design option replaced the insulation with one and one-half inches of fiberglass insulation. No other changes were made, except to enlarge the jacket to accommodate the increased thickness of insulation.

Heat Traps

This design option is described in Section 1.3.1, "Design Options for Gas-Fired Storage Water Heaters".

Reduce Heat Leaks

This design option is also described in Section 1.3.1, "Design Options for Gas-Fired Storage Water Heaters".

2-Inch Foam Insulation

This design option replaced the insulation with two inches of polyurethane foam. No other changes were made, except to enlarge the jacket to accommodate the increased thickness of insulation.

Flue Damper

A flue damper is an electrically activated damper in the flue which restricts heat loss up the flue when the burner is not firing. These systems are available on commercial gas-fired water heaters, but are not yet offered on residential water heaters.

Multiple Flues

This design option is described for gas-fired storage water heaters.

Condensed Flue Gases

This design option is described for gas-fired storage water heaters. No residential condensing oil-fired storage water heaters are currently available on the market.

1.5.2 Energy Calculations for Oil-Fired Storage Water Heaters

The annual oil and electricity energy consumption for each of these design options was calculated from the oil and electricity input rates and from the number of hours the burner was firing. It was assumed no energy was consumed when the burner was not firing. The equations are listed here:

$$\begin{aligned} \text{Annual Oil Consumption} = \\ \text{Oil}_{\text{Input}} * \text{Hours}_{\text{On}} * 365 \left[\frac{\text{days}}{\text{year}} \right] * 10^{-6} \left[\frac{\text{MMBtu}}{\text{Btu}} \right] \end{aligned} \quad (1)$$

$$\begin{aligned} \text{Annual Electricity Consumption} = \\ \text{Elec}_{\text{Input}} * \text{Hours}_{\text{On}} * 365 \left[\frac{\text{days}}{\text{year}} \right] * 10^{-3} \left[\frac{\text{kW}}{\text{W}} \right] \end{aligned} \quad (2)$$

where:

Hours_{On} = number of hours burner was on in 24 hours;

$\text{Oil}_{\text{Input}}$ = oil input rate in Btuh when burner was on; and

$\text{Elec}_{\text{Input}}$ = electricity input rate in watts when burner was on.

The number of hours the burner was fired each day was determined from the average daily energy consumption (ADEC) and the oil and electricity input rates as follows:

$$\text{Burner operating hours} = \frac{\text{ADEC}}{(\text{Elec}_{\text{Input}} * 3.412 + \text{Oil}_{\text{Input}})} \quad (3)$$

The efficiency data used for the analysis of oil-fired storage water heaters were provided as an EF for individual, independent design options. Each EF (using site conversion of kWhs to Btus) was converted to ADEC. To calculate the savings that could be attributed to each design option, the ADEC for each design option was subtracted from the ADEC of the baseline model, or the previous design option in the case of different thicknesses of insulation. Because EF contains the inverse of the fuel consumption, EFs could not be combined directly. The EF for combined design options was calculated as the daily load divided by the oil and electricity rates multiplied by the number of burner operating hours. The equation for EF calculated with a source conversion of electricity is listed here:

$$\text{EF}_{\text{source}} = \frac{\text{daily}_{\text{load}}}{(\text{Elec}_{\text{Input}} * 3.37 [\frac{\text{source}}{\text{site}}] * 3.412 [\frac{\text{Btuh}}{\text{W}}] + \text{Oil}_{\text{Input}}) * \text{Hours}_{\text{On}}} \quad (4)$$

where :

$\text{daily}_{\text{load}}$ = the heat added to the water drawn from the water heater, 41,059 Btu.

The daily load was calculated according to the new DOE test procedure (107). Table 1.11 summarizes the energy calculations for oil-fired storage water heaters. The EF listed in Table 1.9 was calculated with a source conversion of electricity to Btuh.

Table 1.11 Energy Calculations for Oil-Fired Water Heaters

Standard Level Number	Design Option Number	Design Options	ADEC <i>kBTU/day</i>	EF	Burner On		On <i>Hrs/Day</i>	Energy Use	
					Elec	Oil		Oil	Elec
					<i>Watts</i>	<i>Btu/hr</i>		<i>MMBtu/yr</i>	<i>kWh/yr</i>
	0	Baseline	77.59	0.525	94	103875	0.7	28.2	25.4
1	1	0 + 1-in Foam	70.67	0.577	94	103875	0.7	25.7	23.1
	2	0 + 1.5-in Fiberglass	71.43	0.571	94	103875	0.7	26.0	23.4
	3	1 + Heat Traps	69.02	0.591	94	103875	0.7	25.1	22.6
2	4	3 + Reduce Heat Leaks	68.35	0.596	94	103875	0.7	24.9	22.4
	5	4 + 2-in Foam	65.36	0.624	94	103875	0.6	23.8	21.4
3, 4	6	5 + Flue Damper	60.77	0.671	94	103875	0.6	22.1	19.9
5, 6,7	7	6 + Multiple Flues	58.77	0.694	94	103875	0.6	21.4	19.2
8	8	0 + Condensing	52.24	0.780	94	103875	0.5	19.0	17.1

Energy Factor as a Function of Volume

For a fixed level of insulation, a relationship exists between the volume of a water heater and its energy factor (108). The EF decreases with increasing tank volume because the test procedure assumes a constant usage per day. Since a large tank has greater standby losses, it requires more energy input to provide the same amount of hot water. The slope for these equations was found by fitting data from gas-fired storage water heater models listed in the October 1990 GAMA Directory (109). Only unique series of models with identical model numbers except for volume were chosen. Twenty-five unique series were identified for gas-fired storage water heaters. The slope used here was the average of the slope for each series of models. The intercept was chosen so that the linear equation yielded the EF from the analysis at the baseline volume. It was assumed the slope for oil-fired storage water heaters would be similar to the slope for gas-fired storage water heaters.

The derivation of these equations was based on the old EF. The EF now contains a factor for converting electric energy consumption to source energy consumption. The relation of EF to volume was assumed to remain unchanged when the conversion factor was applied to electricity use.

Table 1.12 Energy Factor as Function of Volume for Oil-Fired Storage Water Heaters

Trial Standard Level	Design Option Number	EF at baseline volume	Energy Factor Equation
1	1	0.577	= 0.631 - (0.001707 * Volume)
2	4	0.596	= 0.651 - (0.001707 * Volume)
3	6	0.671	= 0.725 - (0.001707 * Volume)
4	6	0.671	= 0.725 - (0.001707 * Volume)
5	7	0.694	= 0.748 - (0.001707 * Volume)
6	7	0.694	= 0.748 - (0.001707 * Volume)
7	7	0.694	= 0.748 - (0.001707 * Volume)
8	8	0.780	= 0.835 - (0.001707 * Volume)

1.5.3 Cost Data for Oil-Fired Storage Water Heaters

This section presents manufacturers' costs at large-scale production of oil-fired water heaters for each of the design options included in this analysis. Installation costs are also presented here. The manufacturers' cost is the cost per unit of making water heaters with the listed design options. It does not include any markups to wholesale or retail price. The cost data were mostly from the ADM cost study (110). For design options similar to ones considered for gas-fired storage water heaters, costs from the GAMA data request were combined with those from ADM. No maintenance costs were included for oil-fired water heaters (111). Baseline

installation costs were assumed to be similar to baseline installation costs for gas-fired storage water heaters.

The manufacturer and installation costs are listed in Table 1.13. The details and sources of costs in this table are listed below for each design option. Details of disaggregated manufacturer costs are listed in Section A.5 of Appendix A of this volume. The EFs for each design option are included for comparison.

Table 1.13 Cost Data for Oil-Fired Storage Water Heaters

Standard Level Number	Design Option Number	Design Options	EF	Costs	
				Manufacturer 1990\$	Install 1990\$
	0	Baseline	.53	160.00	126.12
1	1	0 + 1-in Foam	.58	164.31	126.12
	2	0 + 1.5-in Fiberglass	.57	165.90	126.12
	3	1 + Heat Traps	.59	167.88	126.12
2	4	3 + Reduce Heat Leaks	.60	169.78	126.12
	5	4 + 2-in Foam	.63	179.31	126.12
3, 4	6	5 + Flue Damper	.68	199.43	126.12
5, 6, 7	7	6 + Multiple Flues	.70	252.39	126.12
8	8	0 + Condensing	.79	554.37	226.12

Baseline (Design Option #0)

Disaggregated manufacturing data for the baseline model were from manufacturers (112). GAMA collected the data from manufacturers and de-identified it to preserve the confidentiality of the sources. Installation costs were from a report prepared for Bonneville Power Administration and Pacific Power and Light (113). This was adjusted for inflation using the Historical Cost Indexes from Means (114).

One-Inch Foam (Design Option #1)

The disaggregated manufacturers costs data were from the ADM cost study (115.) ADM costs were adjusted for inflation from 1987 to 1990, using a multiplier of 1.127 (116).

Close examination of the data for oil-fired storage water heaters in the ADM cost study showed the values were duplicated from the gas-fired storage water heater data. For design options affected by the size of the water heater, such as amount of insulation, materials costs

were reduced. To correct for this effect, materials costs for this design option were multiplied by 0.705, the ratio of oil-fired water heater surface area to gas-fired water heater surface area.

One and One-Half Inch Fiberglass (Design Option #2)

The disaggregated manufacturer cost data were from the ADM cost study (117). ADM costs were adjusted for inflation from 1987 to 1990, using a multiplier of 1.127 (118). The material cost for this design option was multiplied by 0.705 for the reason listed in design option #1.

Heat Traps (Design Option #3)

The cost data were the average of the data obtained from the GAMA data request for gas-fired water heaters and the ADM cost study for oil-fired water heaters (119). ADM costs were adjusted for inflation from 1987 to 1990 using a multiplier of 1.127 (120). The materials cost for this design option was multiplied by 0.705 for the reason listed in design option #1.

Reduce Heat Leaks (Design Option #4)

The incremental manufacturers' cost to reduce heat leaks were from the GAMA data request for gas water heaters.

Two-Inch Foam (Design Option #5)

The incremental cost to go from one inch of foam insulation to two inches of foam insulation were the average of the data obtained from the GAMA data request for gas water heaters and ADM cost study. ADM costs were adjusted for inflation from 1987 to 1990 using a multiplier of 1.127 (121). The material cost for this design option was multiplied by 0.705, for the reason listed in design option #1.

Flue Damper (Design Option #6)

The disaggregated cost data were the average of the GAMA data request for gas water heaters and the ADM cost study, except for materials cost (122).

Multiple Flues (Design Option #7)

The incremental cost for this design option was from the ADM cost study.

Condensing (Design Option #8)

The cost data for an oil-fired condensing water heater were from the oil-fired condensing pulse water heater design option in the ADM cost study. It is not obvious that a pulse combustion design could be made for oil-fired water heaters. Condensing oil-fired water heaters,

not based on pulse combustion, could certainly be made. Many of the features would be common to both types of combustion systems, so the price estimate was thought to be reasonable.

1.5.4 Maximum Technologically Feasible Design for Oil-Fired Storage Water Heaters

The most efficient design option analysed for oil-fired storage water heaters was to condense the flue gases. No manufacturers currently make residential water heaters using this technology. The EF for this model, including the site to source conversion for electricity consumption, was calculated to be 0.780.

All of the efficiency values in Table 1.11 have some uncertainty associated with them. A 95% confidence interval was calculated for the maximum technologically feasible design. The low end of the interval was an EF of 0.721. The high end of the interval was 0.849. Volume A provides a general discussion of how the 95% confidence interval is established for "max tech" designs.

1.6 GAS-FIRED INSTANTANEOUS WATER HEATERS

Gas-fired instantaneous water heaters do not have any storage tank. The water is heated only when it is being drawn through the heater. The combustion chamber is surrounded by a heat exchanger. The heat exchanger is typically copper tubing brazed to the outside wall of the combustion chamber. The burner is activated by water flow. A diaphragm, moved by water flow, opens the gas valve and causes the main burner to fire. Some models have thermostatically controlled modulating burners. These models can keep water temperature constant over a wide range of flow rates.

Current models available in the U.S. use a standing pilot for ignition. No gas-fired instantaneous water heaters are manufactured domestically. Although the new DOE test procedure includes methods for testing instantaneous water heaters, currently there is no minimum efficiency standard.

1.6.1 Design Options for Gas-Fired Instantaneous Water Heaters

No information was found for design options for gas-fired instantaneous water heaters. Gas-fired instantaneous water heaters are similar in basic function and design to pool and spa heaters. Information was obtained from manufacturers for design options for pool and spa heaters. Therefore, the design options considered in this analysis for gas-fired instantaneous water heaters were taken from the analysis for pool heaters. These design options are listed in Table 1.14. (See Volume G of this Technical Support Document.)

Table 1.14 Design Options for Gas-Fired Instantaneous Water Heaters

0	Baseline
1	Electronic Ignition
2	Non-condensing Limit
3	Induced Draft
4	Pulse Combustion
5	Power Burner

Baseline

The baseline model gas-fired instantaneous water heater used for this analysis had a burner rated at 125,000 Btuh, and a pilot light consumption of 559 Btuh. The baseline EF was chosen to be .62. The recovery efficiency was chosen to be 79%. This was the average of data from five gas-fired instantaneous water heaters. One gas instantaneous water heater was tested according to the new DOE test procedure (123). Four instantaneous water heaters were tested by the National Bureau of Standards (124). This report was prepared as part of the effort to determine the new DOE water heater test procedure. The EF and recovery efficiencies were the average of all the tests listed in the report. Testing procedures were not according to the new DOE test procedure.

Electronic Ignition

The only standby loss for gas-fired instantaneous water heaters is from the standing pilot. The standing pilot can be replaced with electronic ignition. This would nearly eliminate consumption during standby.

Non-condensing Limit

It is possible to increase the recovery efficiency by increasing heat exchanger area or effectiveness. There is a practical limit to increasing recovery efficiency with existing designs. If the recovery efficiency is increased too much, condensation of flue gases will occur in the water heater or the venting system, and the buoyancy of the flue gases will not be sufficient to provide adequate draw for complete combustion. The cost and efficiency improvements for this design option were based on estimates by pool heater manufacturers of the practical limits to non-condensing units.

Induced Draft (Condensing)

In this design option an induced draft fan is used to pull the combustion products through the heat exchanger. Because auxiliary power is being used to vent the flue gases instead of thermal buoyancy, flue gases can be cooled to a much lower temperature. The water heater

would have to be redesigned to properly handle condensation. The cost and efficiency improvements for this design option were based on estimates by pool heater manufacturers.

Pulse Combustion (Condensing)

Pulse combustion provides another way to force flue gases out the venting system. Condensing pulse combustion furnaces are currently available. While no pulse combustion residential water heaters are available in the U.S., there are no theoretical reasons preventing development of instantaneous condensing pulse combustion water heaters. The cost and efficiency improvements for this design option were based on estimates by pool heater manufacturers.

Power Burner (Condensing)

Power burners use a fan to pressurize a gas and air mixture upstream of the burner. The burner can be a ceramic matrix or metal fiber pad. This type of burner can be used to increase radiant heat transfer and reduce NO_x emissions. A condensing pool heater using this type of combustion system is currently on the market. The cost and efficiency improvements for this design option were based on estimates by pool heater manufacturers.

1.6.2 Energy Calculations for Gas-Fired Instantaneous Water Heaters

Annual gas and electricity consumption for each of the design options were calculated from the gas and electricity input rates, and the number of hours the main burner was firing. The equations that were used are listed here:

$$\begin{aligned} \text{Annual Gas Consumption} = & \\ [\text{Gas}_{\text{On}} * \text{Hours}_{\text{On}} + \text{Gas}_{\text{Off}} * (24 - \text{Hours}_{\text{On}})] * 365 \left[\frac{\text{days}}{\text{year}} \right] * 10^{-6} \left[\frac{\text{MMBtu}}{\text{Btu}} \right] & \quad (5) \end{aligned}$$

$$\begin{aligned} \text{Annual Electricity Consumption} = & \\ [\text{Elec}_{\text{On}} * \text{Hours}_{\text{On}} + \text{Elec}_{\text{Off}} * (24 - \text{Hours}_{\text{On}})] * 365 \left[\frac{\text{days}}{\text{year}} \right] * 10^{-3} \left[\frac{\text{kW}}{\text{W}} \right] & \quad (6) \end{aligned}$$

where:

Hours_{On} = number of hours burner was on in 24 hours;

Gas_{On} = gas input rate in Btuh when burner was on;

Gas_{Off} = gas input rate in Btuh when burner was off;

Elec_{On} = electricity input rate in watts when burner was on; and

Elec_{Off} = electricity input rate in watts when burner was off.

The number of hours the main burner was firing was determined from the daily load, the recovery efficiency, and the input rate as follows:

$$\text{Hours}_{\text{On}} = \frac{\text{daily}_{\text{load}}}{(E_R * \text{Gas}_{\text{On}})} \quad (7)$$

where:

$\text{daily}_{\text{load}}$ = the energy in the daily hot water draw under the new DOE test procedure in Btus. This value is 41059 Btu.

Gas_{On} = the input of the water heater when the main burner is on.

E_r = the recovery efficiency of the water heater.

The ADEC was calculated from the gas and electricity input rates and the number of hours the main burner was firing. The equations that were used are listed here:

$$\text{ADEC} = \text{Hours}_{\text{On}} * (\text{Gas}_{\text{On}} + \text{Elec}_{\text{On}} * 3.41276) + (24 - \text{Hours}_{\text{On}}) * (\text{Elec}_{\text{Off}} * 3.41276) \quad (8)$$

where:

3.41276 = Btus per watt-hour, and the other terms are as defined above.

The $\text{EF}_{(\text{old})}$ was calculated with electricity converted to Btus at the site.

$$\text{EF}_{(\text{old})} = \frac{\text{daily}_{\text{load}}}{\text{ADEC}} \quad (9)$$

A new source EF was also calculated that converted electricity to Btus at the source. The equation is listed here:

$$EF = \frac{\text{daily}_{\text{load}}}{[(\text{Elec}_{\text{On}} * 3.412 * F_{\text{factor}} + \text{Gas}_{\text{On}}) * \text{Hours}_{\text{On}} + (\text{Elec}_{\text{Off}} * 3.412 * F_{\text{factor}} + \text{Gas}_{\text{Off}}) * (24 - \text{Hours}_{\text{On}})]} \quad (10)$$

where:

F_{factor} = a multiplier of 3.37, used to account for transmission losses and electricity generation inefficiencies.

Table 1.15 summarizes the energy calculations for gas-fired instantaneous water heaters. The recovery efficiency for the first and second design options was from test results (125). The recovery efficiencies for design options 3, 4, and 5 were taken from the pool heater analysis. These values were the average thermal efficiency for pool heaters as estimated by four manufacturers.¹²

The gas input rate for the baseline model, when the burner was on, was a combination of the values of the rated input and the pilot. The other designs did not have a pilot light, so that amount was subtracted from the gas input rate when the burner was on. All the design options except the baseline had no gas consumption when the burner was off. The gas consumption rate, when the burner is off, for the baseline model is the input to the pilot. The electric input rates were estimated.

¹² Comfortzone, Hydrotech, Raypak, and Teledyne-Lars.

Table 1.15 Energy Calculations for Gas-Fired Instantaneous Water Heaters

Standard Level Number	Design Option Number	Description	EF	ADEC kBTU /day	EF(old)	RE	Burner On		Burner Off		Hours On	Energy Use	
							Elec Watts	Gas Btu/hr	Elec Watts	Gas Btu/hr		Gas MBtu/yr	Elec kWh/yr
1,2,3		Baseline	0.623	65.94	0.623	0.79	0	125559	0	559	0.42	24.1	0
4,5,6	1	0 + IID	0.753	52.57	0.781	0.79	25	125000	10	0	0.41	18.9	89.87
7	2	1 + Noncondensing Limit	0.776	50.84	0.808	0.82	50	125000	10	0	0.40	18.2	93.44
	3	0 + Induced Draft	0.853	46.07	0.891	0.91	50	125000	10	0	0.36	16.5	92.88
8	4	0 + Pulse Combustion	0.897	43.71	0.939	0.96	50	125000	10	0	0.34	15.6	92.60
	5	0 + Power Burner	0.874	44.94	0.914	0.93	50	125000	10	0	0.35	16.1	92.75

IID = Intermittent Ignition Device

1.6.3 Cost Data for Gas-Fired Instantaneous Water Heaters

This section presents manufacturers' costs and the cost of installation and maintenance for the consumer. The manufacturers' cost is the cost to the manufacturer to make water heaters with the design options shown. It does not include any wholesale or retail markups. The manufacturers' cost for the baseline model was estimated as the average retail price for several models divided by two. The baseline manufacturer cost was one-half of \$573.39. This is the average suggested retail price of eight instantaneous water heaters of 100 kBtu/hr to 150 kBtu/hr according to Peter du Pont (126). These prices were updated to 1990 using the Consumer Price Index from the *Monthly Energy Review* (127) (128). The manufacturers' costs for the other design options were increased by the average incremental cost for the equivalent design options on pool heaters. Those incremental costs were obtained by interviews with pool heater manufacturers (Comfortzone, Hydrotech, Raypak, and Teledyne-Lars). The uncertainty on factory cost for each design option was estimated by applying the average uncertainty for that design option from all pool heater manufacturers to the factory cost.

Installation cost for the baseline model was from a retail supplier of gas-fired instantaneous water heaters (129). The incremental installation cost of a plug-in transformer and running low-voltage wiring for an electronic ignition is \$5.60 (130). The installation cost for the condensing design options (numbers 3, 4, and 5) includes the cost of installing a condensate line and providing a hard-wired electrical supply. The uncertainty on installation cost was estimated to be 30% for all design options, except the uncertainty of installing a condensate drain was estimated at \$50.

Gas-fired instantaneous water heaters have several parts that require replacement over the lifetime of the water heater. The maintenance cost is the present value, at a 6% real discount rate, of replacing the diaphragm and the valve seat gasket every three years and the heat exchanger at ten years (131). The parts for diaphragm and gaskets were estimated at \$20, labor at \$50. The heat exchanger cost of parts was estimated at \$200, labor at \$50. The lifetime of the unit was estimated to be 15 years (132). It was assumed that this type of maintenance would apply to all the design options. The design options with electronic ignition, all except the baseline, were given additional maintenance cost for the ignition system. The cost of maintenance was assumed to be \$182 (133). This cost was multiplied by the present worth factor and the percent of electronic ignition's failing for each year then summed over the lifetime of the unit. The uncertainty on maintenance costs was estimated at 30%.

Table 1.16 Cost Data for Gas-Fired Instantaneous Water Heaters

Standard Level Number	Design Option Number	Design Options	EF	Costs					
				Manufacturer 1990\$	Uncert 1990\$	Install 1990\$	Uncert 1990\$	Maint 1990\$	Uncert 1990\$
1, 2, 3	0	Baseline	.623	286.70	11.47	175.00	52.50	323.94	97.18
4, 5, 6	1	0 + IID	.753	326.08	25.35	180.60	1.68	378.87	113.66
7	2	1 + Non-condensing Limit	.776	381.75	31.81	180.60	0.00	378.87	113.66
	3	0 + Induced Draft	.853	692.38	103.86	323.00	50.00	378.87	113.66
8	4	0 + Pulse Combustion	.894	1047.38	226.93	323.00	50.00	378.87	113.66
	5	0 + Power Burner	.874	1190.71	238.14	323.00	50.00	378.87	113.66

1.6.4 Maximum Technologically Feasible Design for Gas-Fired Instantaneous Water Heaters

The most efficient design option analysed for gas-fired instantaneous water heaters was to condense the flue gases with a pulse combustion technology. No residential water heaters using this technology are currently sold in the U.S. The EF for this model, including the site to source conversion for electricity consumption, was calculated to be 0.894.

All of the efficiency values in Table 1.15 have some uncertainty associated with them. A 95% confidence interval was calculated for the maximum technologically feasible design. The low end of the interval was an EF of 0.863. The high end of the interval was 0.925. Volume A of this Technical Support Document provides a general discussion of how the 95% confidence interval is established for "max tech" designs.

CHAPTER 2. BASE CASE FORECASTS: WATER HEATERS

Analyzing impacts of federal energy-efficiency standards requires comparing projected U.S. residential energy consumption with and without the standards. The cases without standards are referred to as *base case projections*. These base case projections are compared to projections of conditions that would be likely to prevail if standards were enacted (see Chapter 3). The difference between the two projections is defined as the incremental impact of standards.

Projections are made for a number of demographic, economic, and energy variables, including energy prices, household income, housing stock, housing starts, mix of house types (single-family, multifamily, mobile homes), building-shell thermal characteristics, appliance purchases, equipment prices, unit energy consumption, and aggregate residential energy consumption by fuel type.

2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS

The demographic and economic assumptions are described in Volume A, Chapter 5.

2.2 AVERAGE EQUIPMENT LIFETIME

A distribution of equipment lifetimes, or the rates at which appliances retire as a function of years since purchase, are determined by analyzing historical shipments reported by the industry trade association. Average lifetimes are 10.1 years for electric water heaters and 13.9 years for gas water heaters. Shipments data were not analyzed for instantaneous or oil water heaters.

Table 2.1 Average Equipment Lifetime (Years) of Water Heaters

	Years	Source
Electric	10.10	LBL
Gas	13.86	LBL
Instantaneous	15.00	-
Oil	11.00	-

2.2 BASE CASE PROJECTIONS

This section contains projections of unit energy consumption of new appliances, annual appliance installations, annual residential energy consumption, and price of purchased appliances.

2.2.1 New Appliance Unit Energy Consumptions

Annual unit energy consumption (UEC) of new appliances is projected based upon a set of designs available (each design characterized by a purchase price and an energy-efficiency factor or UEC), and a market discount rate (derived from implicit decision-making in recent purchase decisions for the product). Average efficiency factors for new water heaters sold in past years are calculated from shipments and model data from the trade association (GAMA). The LBL-REM produces projections of annual energy consumption of new appliances after 1984. Table 2.2 shows the trends in efficiency and annual unit energy consumption.

Table 2.2 Base Case Projection of Unit Energy Consumption for New Water Heaters

Year	Average Efficiency Factor			UEC per year		
	Electric	Gas	Oil	Electric (kWh)	Gas (MMBtu)	Oil (MMBtu)
1981	0.82	0.49	0.49	5364	30.64	30.71
1990	0.88	0.55	0.55	4991	27.22	27.25
1996	0.91	0.58	0.57	4842	25.78	25.71
2000	0.92	0.59	0.57	4804	25.27	25.71
2030	0.96	0.63	0.57	4648	23.46	25.71

Source: LBL-REM (1985-2030).

2.2.1.1 Efficiency Distributions

For each class of appliances the range of efficiencies currently available is determined from industry sources such as directories (GAMA). In future years, the relative distribution of efficiencies around the projected average is assumed to be similar to the current distribution. Standards diminish the range of available models and alter the shape of the distribution, causing an increase in models at the standards level.

2.2.1.2 Usage

Usage is assumed constant over time.

2.2.2 Annual U.S. Appliance Installations

The market for appliances is seen as having two segments: new construction and existing housing. All new households are considered eligible to purchase each appliance. The pool of potential purchasers among existing households each year is defined as households that retired a unit that year, plus a fraction of households that did not previously own the product.

The initial (1980) fraction of new (and of existing) households expected to purchase each product and fuel type is specified as input to LBL-REM. LBL-REM produces projected fractions, for each year, of new households (and of existing households) that purchase the product. The projection is based on market share elasticities with respect to income, equipment price, and annual operating expense. Market share elasticities are given in Appendix B of this Volume.

The projection for the period 1981-1990 is calibrated to reasonable agreements with available data, including domestic shipments (from published trade association data) and surveys of appliance ownership (e.g., from DOE/EIA RECS (134) and the Bureau of the Census).

Tables 2.3 and 2.4 show the significant trends in the installation and saturation of this product.

Table 2.3 Annual Installations of New Water Heaters in U.S. Households (Thousands)

Year	Indiv	Indiv	Indiv	Common	Common	Total
	Electric	Gas	Oil	Electric	Gas	
1981	2619	3047	322	129	727	6844
1990	2975	3816	490	156	891	8328
1996	3364	4113	530	174	952	9133
2000	3532	4198	562	186	986	9464
2030	4847	4177	807	228	987	11046

Table 2.4 Percent of Occupied U.S. Housing Units Having Water Heaters

Year	Indiv	Indiv	Indiv	Common	Common	Total
	Electric	Gas	Oil	Electric	Gas	
1980	31	49	6	12	1	99
1990	34	47	5	11	2	99
1996	33	48	5	11	2	99
2000	33	48	5	11	2	99
2030	37	43	6	10	2	99

Source: LBL-REM.

2.2.3 U.S. Residential Energy Consumption

U.S. residential energy consumption for this product is calculated each year as the product of: number of occupied households, fraction of households owning the appliance, average unit energy consumption (engineering estimate), and usage behavior factor.

Table 2.5 shows the U.S. energy consumption, expressed in quadrillion Btu of primary energy using a conversion factor for electricity of one kWh per 11,500 Btu.

Table 2.5 U.S. Residential Energy Consumption for Water Heaters (Quadrillion Btu, Primary Energy)

Year	Electric	Gas	Oil	Total
1981	1.67	1.50	0.16	3.33
1990	2.00	1.63	0.15	3.78
1996	2.00	1.70	0.15	3.84
2000	2.04	1.72	0.15	3.91
2030	2.63	1.67	0.21	4.51

Source: LBL-REM.

2.2.4 Price of Purchased Appliances

Prices of new units increase over time as energy-efficiency improvements are incorporated. Table 2.6 shows projected shipment-weighted average prices.

Table 2.6 Average Price of New Water Heaters in U.S. Households (1990 Dollars)

Year	Electric	Gas	Oil
1981	266	289	725
1990	276	307	730
1996	289	342	739
2000	294	364	739
2030	320	431	739

Source: LBL-REM.

2.3 SENSITIVITY ANALYSIS OF THE BASE CASE

The sensitivity cases selected are defined as follows:

- *Lower Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level are decreased by the estimated uncertainty interval.
- *Higher Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level are increased by the estimated uncertainty interval.

- ***Lower Energy Price.*** Assume lower energy prices. Starting from 1992 to 2030, electricity prices are 3% lower while gas and distillate prices are 5% lower than those in the AEO 1991(135) forecast.
- ***Higher Energy Price.*** Assume higher energy prices. Starting from 1992 to 2030, electricity prices are 3% higher while gas and distillate prices are 5% higher than those in the AEO 1991 forecast.
- ***High Equipment Efficiency.*** Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.
- ***Market Discount Rates Decline.*** Assume that market discount rates used to determine future efficiency choices are declining over time by 2% per year, i.e., efficiency improvements appear in the marketplace sooner.

The results of these six sensitivity cases are presented in the following tables. Tables 2.7a to 2.7c show how the average price varies. Tables 2.8a to 2.8c show the differences in unit energy consumption or efficiency. The first line of these tables gives the results of the reference case described in the previous section; the remaining lines give the corresponding results of the sensitivity cases listed above.

Table 2.7a Average Purchase Price of New Electric Water Heaters (1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	266	276	289	294	320
1	246	264	274	278	293
2	284	288	300	307	346
3	266	276	289	294	320
4	266	276	289	294	320
5	266	276	334	366	706
6	266	276	289	294	320

Table 2.7b Average Purchase Price of New Gas Water Heaters (Weighted-Average in 1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	289	307	342	364	431
1	266	287	320	333	386
2	312	327	362	394	478
3	289	307	340	364	431
4	289	307	342	364	431
5	289	307	435	599	1195
6	289	307	342	364	443.

Table 2.7c Average Purchase Price of New Oil Water Heaters (1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	725	730	738	738	738
1	705	718	718	718	718
2	745	743	740	740	740
3	725	730	738	738	738
4	725	730	738	738	738
5	725	730	777	849	2241
6	725	730	738	738	746.

Source: LBL-REM.

Table 2.8a Average Unit Consumption of New Electric Water Heaters (kWh/Year)

Year:	1981	1990	1996	2000	2030
Reference	5364	4991	4842	4804	4648
1	5364	4991	4882	4839	4658
2	5364	4991	4842	4804	4648
3	5364	4991	4842	4804	4648
4	5364	4991	4842	4804	4648
5	5364	4991	4549	4324	2264
6	5364	4991	4842	4804	4648.

Table 2.8b Average Unit Consumption of New Gas Water Heaters (Weighted-Average in MMBtu/Year)

Year:	1981	1990	1996	2000	2030
Reference	30.64	27.22	25.78	25.27	23.46
1	30.60	27.20	25.80	25.30	23.40
2	30.60	27.20	25.80	25.30	23.50
3	30.60	27.20	25.80	25.30	23.50
4	30.60	27.20	25.80	25.30	23.50
5	30.60	27.20	23.40	21.80	17.00
6	30.60	27.20	25.80	25.30	23.30

Table 2.8c Average Unit Consumption of New Oil Water Heaters (MMBtu/Year)

Year:	1981	1990	1996	2000	2030
Reference	30.71	27.25	25.71	25.71	25.71
1	30.70	27.20	27.20	27.20	27.20
2	30.70	27.20	25.70	25.70	25.70
3	30.70	27.20	25.70	25.70	25.70
4	30.70	27.20	25.70	25.70	25.70
5	30.70	27.20	24.10	22.30	19.00
6	30.70	27.20	25.70	25.70	25.10

Source: LBL-REM.

CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: WATER HEATERS

The LBL Residential Energy Model (LBL-REM) projects a number of economic and energy-use variables that are used to assess the impact of proposed standards on consumers, electric utilities, and appliance manufacturers. This chapter presents projections from the model, which assume various trial standards. The principal outputs from the LBL-REM for each year are:

- unit equipment price and operating expense by product,
- projected annual shipments of residential appliances,
- energy consumption by end use and fuel, and
- differences in these quantities between a base case and each trial standards case.

These outputs are provided annually (or for selected years) and cumulatively over a period of time, i.e., 1996-2030. Energy savings are given for each year from implementation of standards to the end of the period. Net present value of the standards is evaluated for each regulated product and for the end use(s) comprising the regulated and competing products. The sensitivity of the outputs to the key assumptions and data is analyzed; the results of this analysis are also presented.

Section 3.1 presents the trial standards levels analyzed. Section 3.2 presents the historical and projected energy consumption, including unit energy consumption for new purchases and total national energy consumption. Section 3.3 presents historical and projected annual installations. Section 3.4 presents purchase prices. Section 3.5 presents net present value and Section 3.6 discusses the results of the sensitivity analyses. An overview of the general LBL-REM methodology and demographic assumptions is in Volume A of this Technical Support Document. Product-specific input data are described in Appendix C of this volume.

3.1 STANDARDS LEVELS

Table 3.1 shows the correspondence between the trial standards levels, the engineering design levels, and the associated energy factors.

Table 3.1 Trial Standards Levels for Water Heaters

	Trial Standard Level							
	1	2	3	4	5	6	7	8
Engineering design option:								
Electric Storage Water Heaters	2	9	3	7	7	5	5	5
Gas-Fired Storage Water Heaters	0	2	3	3	14	14	12	24
Instantaneous Gas-Fired Water Heaters	0	0	0	1	1	1	2	4
Oil-Fired Storage Water Heaters	1	4	6	6	7	7	7	8
Minimum energy factor:								
Electric Storage Water Heaters	0.90	0.93	1.77	1.89	1.89	2.54	2.54	2.54
Gas-Fired Storage Water Heaters	0.54	0.55	0.55	0.55	0.58	0.58	0.63	0.86
Instant. Gas-Fired Water Heaters	0.62	0.62	0.62	0.78	0.78	0.78	0.81	0.94
Oil-fired Storage Water Heaters	0.58	0.60	0.68	0.68	0.70	0.70	0.70	0.79

3.2 ENERGY CONSUMPTION

Tables 3.2a to 3.2d show the past and projected average energy use of new water heaters. In the absence of amended standards, the average unit energy consumption (UEC) of new electric water heaters is projected to decrease from 4991 kWh/yr in 1990 to 4842 kWh/yr in 1996. For the same time period, UEC of an average new gas-fired storage water heater would drop from 27.2 MMBtu/yr to 25.8 MMBtu/yr, UEC of an average new instantaneous gas-fired water will decrease from 24.2 MMBtu/yr to 18.9 MMBtu/yr, and UEC of an average new oil-fired water heater will decrease from 27.2 MMBtu/yr to 25.7 MMBtu/yr in the absence of amended standards.

Table 3.2a Unit Energy Consumption for New Electric Storage Water Heater (kWh/Year)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	5364								
1990	4991								
1996	4842	4813	4720	2479	2317	2317	1731	1731	1731
2000	4804	4789	4711	2479	2317	2317	1731	1731	1731
2015	4703	4698	4677	2479	2317	2317	1731	1731	1731
2030	4648	4643	4637	2479	2317	2317	1731	1731	1731

Table 3.2b Unit Energy Consumption for New Gas-Fired Storage Water Heater (Million Btu/Year)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	30.7								
1990	27.2								
1996	25.8	25.8	25.8	25.6	25.6	25.5	25.5	23.2	17.0
2000	25.3	25.3	25.3	25.2	25.2	25.2	25.2	23.3	17.0
2015	24.1	24.1	24.1	24.0	24.0	24.0	24.0	23.1	17.0
2030	23.5	23.5	23.5	23.4	23.4	23.4	23.4	23.0	17.0

Table 3.2c Unit Energy Consumption for New Instantaneous Gas-Fired Water Heater (Million Btu/Year)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	24.2								
1990	24.2								
1996	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.2	15.6
2000	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.2	15.6
2015	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.2	15.6
2030	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.2	15.6

Table 3.2d Unit Energy Consumption for New Oil-Fired Water Heater (kWh/Year)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	30.7								
1990	27.2								
1996	25.7	25.7	24.9	22.1	22.1	21.4	21.4	21.4	19.0
2000	25.7	25.7	24.9	22.1	22.1	21.4	21.4	21.4	19.0
2015	25.7	25.7	24.9	22.1	22.1	21.4	21.4	21.4	19.0
2030	25.7	25.7	24.9	22.1	22.1	21.4	21.4	21.4	19.0

Tables 3.3a to 3.3d present projections of total energy savings for: (a) electric water heaters, (b) gas-fired water heaters, (c) oil-fired water heaters, and (d) all water heaters. Standards are projected to produce cumulative energy savings ranging from 0.09 Quads for standards level 1 to 54.45 Quads for standards level 8, during the period 1996-2030.

Table 3.3a U.S. Electricity Consumption for Water Heaters (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	1.670								
1990	2.003								
1996	1.996	1.995	1.987	1.786	1.749	1.750	1.670	1.669	1.697
2000	2.039	2.036	2.017	1.503	1.440	1.443	1.252	1.250	1.322
2015	2.294	2.292	2.279	1.415	1.272	1.342	1.015	1.011	1.136
2030	2.630	2.628	2.624	1.647	1.559	1.561	1.181	1.177	1.283
1996-2030	79.83	79.75	79.26	51.63	49.06	49.14	38.74	38.62	42.33
Cumulative Savings:		0.08	0.57	28.20	30.77	30.69	41.09	41.21	37.50
Percent of Base:		0.1%	0.7%	35.3%	38.5%	38.4%	51.5%	51.6%	47.0%

Table 3.3b U.S. Gas Consumption for Water Heaters (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	1.502								
1990	1.633								
1996	1.695	1.695	1.695	1.668	1.665	1.663	1.664	1.649	1.564
2000	1.721	1.720	1.719	1.662	1.657	1.653	1.665	1.629	1.418
2015	1.708	1.707	1.705	1.606	1.650	1.599	1.630	1.585	1.168
2030	1.670	1.669	1.668	1.554	1.548	1.548	1.577	1.558	1.161
1996-2030	59.75	59.74	59.67	56.55	56.35	56.30	57.18	55.87	43.61
Cumulative Savings:		0.01	0.08	3.20	3.40	3.45	2.57	3.88	16.14
Percent of Base:		0.0%	0.1%	5.4%	5.7%	5.8%	4.3%	6.5%	27.0%

Table 3.3c U.S. Oil Consumption for Water Heaters (Quadrillion Btu, Primary) (Includes Individual Units)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	0.157								
1990	0.146								
1996	0.148	0.148	0.147	0.142	0.142	0.141	0.142	0.142	0.142
2000	0.150	0.150	0.148	0.137	0.136	0.134	0.136	0.136	0.137
2015	0.176	0.176	0.173	0.154	0.136	0.149	0.153	0.152	0.152
2030	0.211	0.211	0.208	0.185	0.184	0.179	0.183	0.182	0.174
1996-2030	6.10	6.10	6.02	5.40	5.38	5.25	5.37	5.34	5.29
Cumulative Savings:		0.00	0.08	0.70	0.72	0.85	0.73	0.76	0.81
Percent of Base:		0.0%	1.3%	11.5%	11.8%	13.9%	12.0%	12.5%	13.3%

Table 3.3d U.S. Energy Consumption for Electric + Gas + Oil Water Heaters (Quadrillion Btu, Primary) (Includes Individual and Common Units)

Year	Trial Standard Level								
	Base	1	2	3	4	5	6	7	8
1981	3.329								
1990	3.782								
1996	3.839	3.838	3.829	3.596	3.556	3.554	3.476	3.460	3.403
2000	4.469	3.906	3.884	3.302	3.233	3.230	3.053	3.015	2.877
2015	4.178	4.175	4.157	3.175	3.058	3.090	2.798	2.748	2.456
2030	4.511	4.508	4.500	3.386	3.291	3.288	2.941	2.917	2.618
1996-2030	145.68	145.59	144.95	113.58	110.79	110.69	101.29	99.83	91.23
Cumulative Savings:		0.09	0.73	32.10	34.89	34.99	44.39	45.85	54.45
Percent of Base:		0.1%	0.5%	22.0%	23.9%	24.0%	30.5%	31.5%	37.4%

3.3 ANNUAL INSTALLATIONS

As shown in Table 3.4, installations¹³ of water heaters are affected by standards. This result is a function of the change in operating expense, change in equipment price, and market share elasticities. The projection shows a change of between 0% and 21.9% increase from base for the various standards levels for cumulative shipments of electric water heaters from 1996 to 2030. For the same time period, cumulative shipments of gas-fired water heaters showed a change of between 0% and 17% decrease, cumulative shipments of oil-fired water heaters showed a change of between 0.3% increase and 7.4% decrease as a result of the various standards.

The forecasting model distinguishes individual water heaters from common units. Common units serve more than one household, are assumed to be larger capacity, and are not affected by efficiency standards.

¹³ If there are no imports or exports, annual installations are equivalent to domestic shipments. Domestic shipments can be calculated as annual installations, less imports, plus exports.

Table 3.4 Cumulative Installations of Water Heaters (Millions)

1996-2030	Trial Standard Level								
	Base	1	2	3	4	5	6	7	8
Indiv elec	141.9	142.0	142.1	157.2	158.1	158.4	153.8	153.1	172.9
Indiv gas	146.9	146.9	146.7	135.2	134.5	134.6	138.0	138.7	121.9
Indiv oil	23.1	23.1	23.2	21.8	21.7	21.4	21.9	21.8	21.9
SUBTOTAL	311.9	311.9	312.0	314.2	314.4	314.4	313.7	313.6	316.8
Common gas	34.5	34.5	34.5	34.1	34.1	34.1	34.2	34.2	34.1
Common elec	7.1	7.1	7.1	7.0	7.0	7.0	7.1	7.1	7.0
TOTAL	353.5	353.5	353.6	355.4	355.5	355.5	355.0	354.9	357.9
<i>Change from Base</i>									
Electric		0.1	0.2	15.3	16.2	16.5	11.9	11.2	31.0
Gas		-0.1	-0.2	-11.7	-12.4	-12.3	-8.9	-8.2	-25.0
Oil		0.0	0.1	-1.3	-1.4	-1.7	-1.2	-1.3	-1.2
SUBTOTAL		0.0	0.1	2.3	2.4	2.5	1.8	1.7	4.9
Common gas		0.0	0.0	-0.4	-0.4	-0.4	-0.3	-0.3	-0.4
Common elec		0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
TOTAL		0.0	0.0	1.8	2.0	2.0	1.5	1.3	4.4
<i>Percent Change</i>									
Electric		0.0%	0.1%	10.8%	11.4%	11.6%	8.4%	7.9%	21.9%
Gas		0.0%	-0.1%	-8.0%	-8.4%	-8.4%	-6.1%	-5.6%	-17.0%
Oil		0.0%	0.3%	-5.7%	-6.1%	-7.4%	-5.0%	-5.6%	-5.0%
SUBTOTAL		0.0%	0.0%	0.7%	0.8%	0.8%	0.6%	0.6%	1.6%
Common gas		0.0%	0.0%	-1.1%	-1.2%	-1.2%	-0.8%	-0.9%	-1.2%
Common elec		0.0%	0.0%	-1.0%	-1.1%	-1.1%	-0.7%	-0.8%	-1.1%
TOTAL		0.0%	0.0%	0.5%	0.6%	0.6%	0.4%	0.4%	1.2%

3.4 APPLIANCE PRICES

Projections of the purchase prices for new water heaters in 1990 dollars are shown in Tables 3.5a through 3.5d. The prices typically increase when standards come into effect. Prices more than double for electric water heaters at standards levels 3 through 8; and for gas, instantaneous, and oil water heaters at standards level 8.

Table 3.5a Average Purchase Price for New Electric Water Heater (1990 Dollars Per Unit)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	266								
1990	276								
1996	289	290	310	627	660	660	1100	1100	1100
2000	294	294	311	627	660	660	1100	1100	1100
2015	311	311	316	627	660	660	1100	1100	1100
2030	320	320	321	627	660	660	1100	1100	1100

Table 3.5b Average Purchase Price for New Gas Water Heater (1990 Dollars Per Unit)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	283								
1990	300								
1996	334	334	335	339	339	356	356	396	1183
2000	356	356	357	358	358	364	364	399	1183
2015	399	399	399	400	369	402	402	418	1183
2030	424	424	424	425	425	427	427	435	1183

Table 3.5c Average Purchase Price for New Instantaneous Gas Water Heater (1990 Dollars Per Unit)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	960								
1990	960								
1996	1094	1094	1094	1094	1094	1094	1094	1162	2322
2000	1094	1094	1094	1094	1094	1094	1094	1162	2322
2015	1094	1094	1094	1094	1094	1094	1094	1162	2322
2030	1094	1094	1094	1094	1094	1094	1094	1162	2322

Table 3.5d Average Purchase Price for New Oil Water Heater (1990 Dollars Per Unit)

Year	Base	Trial Standard Level							
		1	2	3	4	5	6	7	8
1981	725								
1990	730								
1996	739	739	758	857	857	992	992	992	2241
2000	739	739	758	857	857	992	992	992	2241
2015	739	739	758	857	857	992	992	992	2241
2030	739	739	758	857	857	992	992	992	2241

3.5 NET PRESENT VALUE (NPV)

The NPV of standards for any product is calculated by first determining the difference in present value of unit life-cycle costs between the base case and standards case each year. That difference is then multiplied by the standards case shipments for the year. The NPV for the period 1996-2030 is the sum over the years of the annual values. A positive NPV of standards results when the new units in the standards case have a lower present value of life-cycle costs than do new units in the base case. Table 3.6 shows the NPV to society of the trial standards levels.

3.6 SENSITIVITY ANALYSIS

The base case and standards levels as described above constitute a reference case against which the impacts of standards under different assumptions may be compared. The sensitivity analysis is performed by running the LBL-REM for the base case and *trial standards level 4* for water heaters. For each sensitivity case, the results for the trial standards level are compared to the corresponding base-case run and the differences are tabulated.

The assumptions in the sensitivity cases are described in Section 2.3 and listed in Table 3.7. Tables 3.8a through 3.8c show results for cumulative energy consumption. The sensitivity analysis of product shipments are given in Tables 3.9a through 3.9c. Table 3.10 shows the net present values. The first line of these tables gives the results of the reference case (base case, standards level, and difference). The rest of the lines each give the results corresponding to one of the sensitivity cases, including the base case, standards case, and difference. Note that the changes in the impact of standards as a function of the changed assumptions (difference between the base and standards cases) are the principal results of the sensitivity analysis.

Table 3.6 Net Present Value for Water Heaters Purchased from 1996-2030 (Billion 1990\$ Discounted at 7.0%)¹⁴

	Trial Standard Level							
	1	2	3	4	5	6	7	8
Fuel costs savings:								
Electricity	0.21	1.23	52.20	56.31	56.44	68.13	67.83	77.36
Gas	0.00	0.06	0.19	0.19	0.30	0.30	3.23	17.63
Oil	0.00	0.19	0.74	0.74	0.85	0.88	0.87	1.12
TOTAL benefit (energy):	0.21	1.47	53.14	57.24	57.59	69.31	71.94	96.11
Equipment costs:								
Electric	0.01	0.41	12.57	13.92	13.96	30.17	30.04	34.28
Gas	0.00	0.01	0.06	0.06	0.27	0.28	1.28	25.72
Oil	0.00	0.06	0.33	0.33	0.69	0.71	0.71	3.62
TOTAL cost (equipment):	0.01	0.48	12.97	14.32	14.92	31.16	32.02	63.61
NET = benefit - cost:								
Electric	0.19	0.82	39.63	42.39	42.49	37.96	37.79	43.08
Gas	0.00	0.05	0.13	0.13	0.02	0.02	1.95	-8.09
Oil	0.00	0.13	0.41	0.40	0.17	0.17	0.17	-2.50
TOTAL across fuels:	0.19	0.99	40.17	42.92	42.68	38.15	39.91	32.50
Ratio: Benefit/cost:	15.7	3.1	4.1	4.0	3.9	2.2	2.2	1.5

Table 3.7 Sensitivity Analysis Cases

Case	Description
1	Lower Equipment Prices
2	Higher Equipment Prices
3	Lower Energy Price
4	Higher Energy Price
5	High Equipment Efficiency
6	Market Discount Rates Decline

¹⁴Normalized to standards case shipments.

Table 3.8a Cumulative Energy Consumption of Electric Water Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)

	Base	Trial Standard	
		Level 4	Difference
Reference	76.09	45.36	30.73
1	76.34	45.56	30.78
2	76.19	45.39	30.80
3	75.57	44.91	30.66
4	76.61	45.83	30.78
5	62.57	38.68	23.89
6	76.07	45.36	30.71

Table 3.8b Cumulative Energy Consumption of Gas Water Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)

	Base	Trial Standard	
		Level 4	Difference
Reference	47.54	44.25	3.29
1	47.70	44.18	3.52
2	47.49	44.22	3.27
3	47.80	44.65	3.15
4	47.29	43.84	3.45
5	35.49	34.80	0.69
6	47.48	44.21	3.27

Table 3.8c Cumulative Energy Consumption of Oil Water Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)

	Base	Trial Standard	
		Level 4	Difference
Reference	6.10	5.38	0.72
1	6.20	5.36	0.84
2	6.13	5.39	0.74
3	6.03	5.33	0.70
4	6.18	5.44	0.74
5	5.27	5.06	0.21
6	6.08	5.38	0.70

Table 3.9a Cumulative Shipments of Electric Water Heaters During the Period 1996-2030 (Millions)

	Trial Standard		Difference
	Base	Level 4	
Reference	142	158	-16
1	141	158	-17
2	142	158	-16
3	141	156	-15
4	143	160	-17
5	166	168	-2
6	142	158	-16

Table 3.9b Cumulative Shipments of Gas Water Heaters During the Period 1996-2030 (Millions)

	Trial Standard		Difference
	Base	Level 4	
Reference	147	135	12
1	148	134	13
2	147	134	12
3	148	136	12
4	146	133	13
5	127	127	1
6	147	135	12

Table 3.9c Cumulative Shipments of Oil Water Heaters During the Period 1996-2030 (Millions)

	Trial Standard		Difference
	Base	Level 4	
Reference	23	22	1
1	23	22	1
2	23	22	1
3	23	21	1
4	23	22	1
5	22	21	1
6	23	22	1

Table 3.10 Total Net Present Value to Consumers for Units Sold During the Period 1996-2030
(Discounted to 1990 at 7% Real)

Case	Net Present Value (Billion 1990\$)
	Trial Standard Level 4
Reference	42.92
1	45.12
2	42.79
3	40.75
4	45.14
5	17.71
6	42.88

Source: LBL-REM.

CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS

The effect of standards on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The net effect is analyzed by calculating the life-cycle cost, using the engineering data (Chapter 1) for energy consumption and equipment price, and assuming the energy price projected for 1996. Section 4.1 presents the life-cycle costs (LCC) for each design option. The results are displayed as graphs and as tables of values. Sections 4.2 through 4.4 show the impacts of standards on consumers. Section 4.5 presents the effect of different assumptions on the life-cycle cost calculations

The difference due to standards is calculated (Sections 4.2 to 4.4) after a base case forecast is made (see Chapter 2). The base case forecast accounts for market-based shifts in efficiency and usage that are projected to occur independently of standards. Then only those appliance purchasers who are impacted by standards (i.e., those who would have chosen a design eliminated by standards) are included in calculating the impact of standards on consumers. The impact of standards is expressed by three measures:

- Section 4.2: Payback Period (PBP),
- Section 4.3: Change in Life-Cycle Cost (LCC), and
- Section 4.4: Cost of Conserved Energy (CCE).

4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS

The LCC is the sum of the purchase price (PC) and the operating expense (OC) discounted over the lifetime (N) of the appliance.

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

If operating expenses are constant over time, Eq. 1 simplifies to

$$LCC = PC + PWF \cdot OC, \quad (2)$$

where we have defined the present worth factor:

$$PWF = \sum_{t=1}^N \frac{1}{(1+r)^t} = \frac{1}{r} \left[1 - \frac{1}{(1+r)^N} \right] \quad (3)$$

The LCC is calculated for each class in the year standards are imposed, using a discount rate, r .

4.1.1 LCC Data Inputs

The purchase price is based on the factory costs in the Engineering Analysis (Chapter 1) and includes a factory markup plus distributor and retailer markups, calculated by LBL-MIM. Installation and maintenance costs are also from the Engineering Analysis. Purchase price and installation costs are added to the present value of operating expenses (including maintenance, if applicable), discounted, and summed over the life of the product. Expenses in future years are discounted to the year of purchase, 1996. For the residential sector, the discount rate is 6% real, with sensitivity analysis performed at 2% and 10% real.

The energy price is the projected 1996 average residential energy price, times an end-use multiplier of 0.9 (electric) or 0.98 (gas). (See Volume A, Section 5.1.5.)

4.1.2 LCC Results

Figures 4.1 through 4.4 show the LCCs by design option. The values used to produce these figures are presented in Tables 4.1 to 4.4.

Figure 4.1 Life-Cycle Cost for an Electric Storage Water Heater

Table 4.1 Life-Cycle Costs of Electric Storage Water Heaters

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-		Energy kWh/yr	Annual Energy Cost	Life-Cycle Costs		
					ment Price	Energy Factor			4%	6%	10%
	0	Baseline	126.12	139.19	265.31	0.86	5096.2	379.77	3370.69	3080.93	2612.72
	1	0 + Reduce Heat Leaks	126.12	141.88	268.00	0.87	5024.3	374.41	3329.56	3043.94	2582.29
1	2	1 + Heat Traps	126.12	146.04	272.16	0.90	4899.5	365.11	3257.70	2979.17	2528.98
3	3	2 + Add On Heat Pump	226.12	400.55	626.67	1.77	2479.3	184.76	2137.44	1996.49	1768.68
	4	2 + 3rd Generation Heat Pump	226.12	429.81	655.93	1.53	2867.3	213.67	2403.11	2240.11	1976.65
6,7,8	5	2 + Integral Heat Pump	226.12	873.50	1099.62	2.54	1730.8	128.98	2154.26	2055.27	1896.84
	6	2 + Heat Pump (GAMA data)	226.12	955.64	1181.76	1.65	2654.8	197.84	2799.48	2648.56	2404.62
4,5	7	3 + R-25 Insulation	248.65	411.04	659.69	1.89	2316.7	172.64	2071.36	1939.66	1726.79
	8	3 + Vacuum Insulation	226.12	481.00	707.12	1.89	2316.7	172.64	2118.78	1987.08	1774.22
2	9	2 + R-25 Insulation	148.65	158.70	307.35	0.93	4736.9	352.99	3193.79	2924.51	2489.26
	10	9 + Off Peak	173.65	221.03	394.68	0.96	4560.4	339.84	3173.59	2914.34	2495.31
	11	10 + Solar Pre-Heat	533.99	1407.13	1941.12	2.14	2053.1	153.00	2513.45	2407.75	2388.52
	12	0 + Tempering Tank	176.12	206.24	382.36	0.94	4677.3	348.55	3232.44	2966.55	2536.79

Notes: Average lifetime for all designs is 10.1 years, except for design option 11, which is 30 years; all costs are in 1990 dollars; electricity rate is 7.45 cent/kWh (1996); consumer costs include installation costs, but no maintenance costs.

Figure 4.2 Life-Cycle Cost for a Gas Storage Water Heater

Table 4.2 Life-Cycle Costs for Gas-Fired Storage Water Heaters

Standard Level	Design No.	Design Option	Equip-			Energy Factor	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
			Install & Maint	Retail Price	ment Price		Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1	0	Baseline	126.12	155.48	281.60	0.54	27.55	0.0	166.12	2023.09	1815.61	1499.44
	1	0 + Heat Traps	126.12	160.60	286.72	0.55	27.22	0.0	164.15	2007.66	1802.62	1490.19
2	2	1 + Reduce Heat Leaks	126.12	162.83	288.95	0.55	27.07	0.0	163.25	2000.35	1796.46	1485.75
3,4	3	2 + R-16 Insulation	126.12	179.53	305.65	0.57	26.31	0.0	158.66	1969.02	1770.85	1468.86
	4	3 + Improve Flue Baffle, Std	363.49	372.27	735.76	0.66	22.63	0.0	136.43	2166.09	1995.68	1736.01
	5	4 + IID w/ Flue Damper	374.69	436.24	810.93	0.71	20.56	137.1	135.80	2234.66	2065.03	1806.56
	6	3 + Submrg Combustion, Std	363.49	179.22	542.71	0.64	23.59	0.0	142.24	2033.91	1856.24	1585.52
	7	6 + IID w/ Flue Damper	374.69	252.54	627.23	0.70	21.00	137.3	138.47	2078.87	1905.92	1642.38
	8	3 + Improve Flue Baffle, Side	206.72	419.99	626.71	0.66	22.34	124.7	145.45	2151.57	1969.89	1693.06
	9	8 + IID	206.72	430.39	637.11	0.68	21.63	131.8	141.80	2123.64	1946.53	1676.65
	10	3 + Indirect Heating w/IID	137.32	543.26	680.58	0.68	21.72	112.8	140.70	2155.61	1979.87	1712.08
	11	3 + Multiple Flues	126.12	410.13	536.25	0.59	25.35	0.0	152.88	2139.01	1948.06	1657.08
7	12	3 + IID w/ Flue Damper	137.32	252.83	390.15	0.63	23.37	137.9	152.80	1992.04	1801.19	1510.37
	13	3 + Submrg Combustion, Side	206.72	236.02	442.74	0.63	23.30	126.6	151.38	2029.75	1840.68	1552.55
5,6	14	3 + R-25 Insulation	148.65	192.55	341.20	0.58	26.02	0.0	156.92	1986.25	1790.26	1491.60
	15	3 + Incr.Baffl.&Frc Draft, Side	206.72	596.83	803.55	0.67	22.29	30.4	137.05	2240.28	2069.10	1808.27
	16	3 + Incr.Baffl.&Frc Draft, Std	363.49	596.83	960.32	0.67	22.29	30.4	137.05	2397.05	2225.88	1965.04
	17	3 + IID & Power Vent	206.72	242.04	448.76	0.62	23.84	136.3	155.47	2078.67	1884.48	1588.57
	18	3 + Vacuum Insulation	126.12	407.51	533.63	0.57	26.14	0.0	157.65	2186.34	1989.44	1689.39
	19	0 + Tempering Tank	176.12	365.01	541.13	0.59	25.54	0.0	153.97	2155.34	1963.02	1669.97
	20	0 + Submerged Combustion	280.37	551.21	831.58	0.90	15.47	356.0	123.94	2130.89	1976.09	1740.20
	21	0 + Indirect w/IID & Pl. Tank	137.32	612.96	750.28	0.74	19.87	110.7	129.37	2063.72	1908.07	1671.63
	22	0 + Directly Fired	280.37	594.34	874.71	0.90	15.47	356.0	123.94	2174.02	2019.22	1783.33
	23	0 + TPV Generator	126.12	554.65	680.77	0.64	23.42	0.0	141.20	2161.04	1984.68	1715.94
8	24	0 + Condense Flu Gases	380.37	803.03	1183.40	0.86	17.01	122.4	113.10	2369.06	2227.80	2012.55
	25	0 + Condensing Pulse	380.37	725.11	1105.48	0.82	17.90	96.5	116.25	2324.18	2178.98	1957.73

Notes:

This class represents 99% of the gas water heaters sold in 1989.

Average lifetime for all designs is 13.86 years, except for design option 21, which is 15.0 years.

All costs are in 1990 dollars.

Electricity rate is 8.61 cent/kWh (1996).

Gas rate is 6.030 \$/MMBtu (1996).

Consumer costs include installation costs, but no maintenance costs.

Figure 4.3 Life-Cycle Cost for an Oil Storage Water Heater

Table 4.3 Life-Cycle Costs for Oil-Fired Storage Water Heaters

Standard Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	Energy Factor	Annual Energy Use			Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)	Annual Energy Cost	4%	6%	10%
1	0	Baseline	126.12	598.54	724.66	0.53	28.23	25.41	210.74	2570.83	2386.73	2093.42
	1	0 + 1" foam	126.12	612.43	738.55	0.58	25.71	23.15	191.94	2420.05	2252.37	1985.22
	2	0 + 1.5" fiberglass	126.12	616.82	742.94	0.57	25.99	23.40	194.02	2442.66	2273.17	2003.12
2	3	1 + Heat Traps	126.12	619.37	745.49	0.59	25.12	22.61	187.48	2387.94	2224.15	1963.21
	4	3 + Reduce Heat Leaks	126.12	632.13	758.25	0.60	24.87	22.39	185.66	2384.69	2222.50	1964.10
	5	4 + 2" foam	126.12	659.87	785.99	0.63	23.78	21.41	177.53	2341.27	2186.17	1939.08
3,4	6	5 + Flue Damper	126.12	731.09	857.21	0.68	22.11	19.90	165.06	2303.23	2159.03	1929.29
5,6,7	7	6 + Multiple Flues	126.12	865.56	991.68	0.70	21.39	19.25	159.63	2390.12	2250.66	2028.49
8	8	0 + Condensing Pulse	226.12	2014.96	2241.08	0.79	19.01	17.11	141.90	3484.17	3360.21	3162.71

Notes: All costs are in 1990 dollars; average lifetime for all designs is 11.0 years; electricity rate is 8.61 cent/kWh (1996); oil rate is 7.387 \$/MMBtu (1996); consumer costs include installation costs, but no maintenance costs.

Figure 4.4 Life-Cycle Cost for an Instantaneous Gas Water Heater

Table 4.4 Life-Cycle Costs for Instantaneous Gas-Fired Water Heaters

Standard Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	Energy Factor	Annual Energy Use Gas (MMBtu)	Annual Energy Use Elec (kWh)	Annual Energy Cost	Life-Cycle Costs		
										4%	6%	10%
1,2,3	0	Baseline	498.94	460.72	959.66	0.62	24.07	0.00	145.12	2628.57	2369.11	1980.00
4,5,6	1	0 + IID	559.47	534.55	1094.02	0.78	18.88	89.87	121.58	2514.41	2274.87	1917.05
7	2	1 + Noncondensing Limit	559.47	602.82	1162.29	0.81	18.24	93.44	118.03	2543.12	2308.58	1958.26
	3	0 + Induced Draft (condensing)	701.87	1270.65	1972.52	0.89	16.50	92.88	107.48	3236.14	3016.43	2688.31
8	4	0 + Pulse Combustion (cond.)	701.87	1620.21	2322.08	0.94	15.64	92.60	102.27	3527.73	3315.35	2998.21
	5	0 + Power Burner (condensing)	701.87	2066.47	2768.34	0.91	16.09	92.75	104.98	4004.14	3787.94	3465.09

Notes: This class represents 1% of the gas water heaters sold in 1989.
Average lifetime for all designs is 15.0 years.
All costs are in 1990 dollars.
Electricity rate is 8.61 cent/kWh (1996).
Gas rate is 6.030 \$/MMBtu (1996).
Consumer costs include installation costs, but no maintenance costs.

4.2 PAYBACK PERIODS BY STANDARD LEVEL

The payback period (PBP) measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. PBP is found by solving the equation:

$$\Delta PC + \sum_{t=1}^{PAY} \Delta OC_t = 0 \quad (4)$$

for *PAY*. In general, *PAY* is found by interpolating between the two years when the expression in Eq. 4 changes sign. If the operating cost is constant, the equation has the simple solution:

$$PAY = -\frac{\Delta PC}{\Delta OC} \quad (5)$$

Numerically, the PBP is the ratio of the increase in purchase (and installation) price from the base to the standards cases to the decrease in annual operating expenditures (including maintenance). PBPs are expressed in years. A PBP of three years means that the increased purchase price is equal to three times the value of reduced operating expenses achieved in the year of purchase, or that the increased purchase price is recovered in approximately three years because of lower operating expenses. PBPs greater than the life of the product mean that the increased purchase price is not recovered in reduced operating expenses.

4.2.1 PBP Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.2.2 PBP Results

The PBP by standards level shown in Tables 4.5 through 4.8 are the weighted averages. They compare that portion of the projected distribution of designs in the base case which are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts.

Table 4.5 shows the calculation of LCC differences, payback, and CCE. The table is composed of several parts. Table 4.5.a summarizes the equipment cost, operating cost, LCC, and energy use for each design option. Table 4.5.b shows the distribution of units sold in 1996, according to the base case forecast. In the other columns, part of this distribution is expressed as the percent of eliminated units due to standards. That is, if 78% of the units sold in the base case correspond to design 0, and standards level 1 (equivalent to design 1) eliminates only design 0, then the fraction of eliminated units due to standards level 1 is 100% for design 0.

Table 4.5.c applies the weights in Table 4.5.b to the values in Table 4.5.a to obtain the weighted-average values shown. Table 4.5.d shows the resulting LCC differences, PBPs, and CCE.

4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS

The impact of standards is calculated as the difference in LCC, base case minus standards case. If the LCC difference is greater than zero (positive savings), the standard provides a net decrease in expenses to the consumer. That is, the present value of decreased operating expenses offsets the increased purchase price. Conversely, if the LCC difference is negative, the standard causes a net increase in expenses to the consumer.

4.3.1 Data Inputs for Change in LCC

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standards level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.3.2 Results for Change in LCC

Tables 4.5 through 4.8 show the LCC differences by standard level, one table for each class. The results are the weighted-average of LCC differences comparing that portion of the projected distribution of designs in the base case that are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts. These LCCs are calculated at a 6% discount rate; a higher discount rate (e.g., 10%) gives a smaller difference.

Tables 4.5d to 4.8d show lower LCC (positive LCC difference) for all standards levels for electric water heaters; for standards levels 2 through 4 for gas water heaters; for standards levels 4 through 6 for instantaneous water heaters; and for standards levels 1 through 7 for oil water heaters.

4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS

The CCE is the increase in purchase price amortized over the lifetime of the appliance at the consumer discount rate divided by the annual energy savings, ΔE :

$$CCE = -\frac{CRF \cdot \Delta PC}{\Delta E} \quad (6)$$

where the capital recovery factor is used to annualize the capital costs. Note that although the CCE can be measured in cents per kWh, it does not depend on current or future energy prices. The consumer will benefit whenever the cost of conserved energy is less than the price of energy for that end use.

4.4.1 CCE Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.4.2 CCE Results

Tables 4.5a through 4.8d show the cost of conserved energy at the site of the standards levels as compared to the base case. Note that the current (1990) and projected (1996) average residential electricity prices are 8.11 and 8.29 cents per kWh respectively (136). These are equivalent to 23.74 and 24.28 dollars per million Btu, respectively, where one kWh is taken as 3,412 Btu site energy. The residential price of natural gas was \$5.69 per million Btu in 1990 and is projected to be \$6.15 in 1996 (1). The residential price of oil was \$7.64 per million Btu in 1990 and is projected to be \$7.39 in 1996 (136).

Standard levels with CCEs less than projected (1996) costs of energy supply include: for electric storage water heaters, all standard levels; for gas storage water heaters, standards levels 1, 2, 3, and 7; for instantaneous gas water heaters, standards levels 4, 5, and 6; for oil-fired storage water heaters, standards levels 1 through 4.

Table 4.5.a Cost and Energy-Use Summary Electric Storage Water Heaters

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use	
	(1990 \$)	(1990 \$)	(1990 \$)	(kWh)	(MMBtu)
0	265.31	379.77	3080.98	5097	17.39
1	268.00	374.41	3043.94	5026	17.15
2	272.16	365.11	2979.17	4900	16.72
9	307.35	352.99	2924.51	4739	16.17
3	626.67	184.76	1996.49	2479	8.46
7	659.69	172.64	1939.66	2318	7.91
5	1099.62	128.98	2055.87	1732	5.91

Table 4.5.b Distribution of Units Sold Below Standards, Electric Storage Water Heaters

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
0	3.26%	15.16%	5.68%	3.29%	3.26%	3.26%	3.26%	3.26%	3.26%
1	18.24%	84.84%	31.79%	18.38%	18.24%	18.24%	18.24%	18.24%	18.24%
2	35.87%	<Std>	62.52%	36.15%	35.87%	35.87%	35.87%	35.87%	35.87%
9	41.85%		<Std>	42.18%	41.85%	41.85%	41.85%	41.85%	41.85%
3	0.77%			<Std>	0.77%	0.77%	0.77%	0.77%	0.77%
7	0.00%				<Std>	<Std>	0.00%	0.00%	0.00%
5	0.00%						<Std>	<Std>	<Std>

Table 4.5.c Weighted-Averages of Units Sold Below Standards, Electric Storage Water Heaters

Weighted-Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
Equip. Price (1990 \$)	267.59	270.45	286.01	288.64	288.64	288.64	288.64	288.64
Operating Cost (1990 \$)	375.22	368.90	362.19	360.82	360.82	360.82	360.82	360.82
Life-Cycle Cost (1990 \$)	3049.56	3005.55	2971.37	2963.86	2963.86	2963.86	2963.86	2963.86
Energy Use (MMBtu/yr)	17.19	16.89	16.59	16.53	16.53	16.53	16.53	16.53

Table 4.5.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Electric Storage Water Heaters

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
LCC difference	70.4	81.0	974.9	1024.2	1024.2	908.0	908.0	908.0
Payback	0.5	2.3	1.9	2.0	2.0	3.5	3.5	3.5
CCE (cent/kWh)	0.5	2.3	1.9	2.0	2.0	3.5	3.5	3.5
CCE (\$/MMBtu)	1.3	6.9	5.7	5.8	5.8	10.3	10.3	10.3

Table 4.6.a Cost and Energy-Use Summary, Gas-Fired Storage Water Heaters

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	281.60	166.12	1815.61	27.55
1	286.72	164.15	1802.62	27.22
2	288.95	163.25	1796.46	27.07
3	305.65	158.66	1770.85	26.31
14	341.20	156.92	1790.26	26.02
12	390.15	152.80	1801.19	23.84
24	1183.40	113.10	2227.80	17.43

Table 4.6.b Distribution of Units Sold Below Standards, Gas-Fired Storage Water Heaters

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
0	5.45%	<Std>	99.82%	21.93%	21.93%	11.50%	11.50%	6.67%	5.49%
1	0.01%		0.18%	0.04%	0.04%	0.02%	0.02%	0.01%	0.01%
2	19.39%		<Std>	78.03%	78.03%	40.92%	40.92%	23.72%	19.52%
3	22.53%			<Std>	<Std>	47.55%	47.55%	27.56%	22.68%
14	34.37%					<Std>	<Std>	42.04%	34.61%
12	17.57%							<Std>	17.69%
24	0.68%								<Std>

Table 4.6.c Weighted-Averages of Units Sold Below Standards, Gas-Fired Storage Water Heaters

Weighted-Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
Equip. Price (1990 \$)	NA	281.61	287.34	287.34	296.05	296.05	315.03	328.32
Operating Cost (1990 \$)	NA	166.12	163.88	163.88	161.40	161.40	159.52	158.33
Life-Cycle Cost (1990 \$)	NA	1815.59	1800.66	1800.66	1786.49	1786.49	1788.07	1790.39
Energy Use (MMBtu/yr)	NA	27.55	27.18	27.18	26.76	26.76	26.45	25.99

Table 4.6.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gas-Fired Storage Water Heaters

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
LCC difference	NA	19.1	29.8	29.8	-3.8	-3.8	-13.1	-437.4
Payback	NA	2.6	3.5	3.5	10.1	10.1	11.2	18.9
CCE (\$/MMBtu)	NA	1.7	2.3	2.3	6.6	6.6	3.1	10.8

Table 4.7.a Cost and Energy-Use Summary, Instantaneous Gas-Fired Water Heaters

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	959.66	145.12	2369.11	24.07
1	1094.02	121.58	2274.87	19.19
2	1162.00	118.03	2308.58	18.56
4	2322.06	102.27	3315.35	15.95

Table 4.7.b Distribution of Units Sold Below Standards, Instantaneous Gas-Fired Water Heaters

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
0	0.00%	<Std>	<Std>	<Std>	100.00%	100.00%	100.00%	0.00%	0.00%
1	100.00%				<Std>	<Std>	<Std>	100.00%	100.00%
2	0.00%							<Std>	0.00%
4	0.00%								<Std>

Table 4.7.c Weighted-Averages of Units Sold Below Standards, Instantaneous Gas-Fired Water Heaters

Weighted-Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
Equip. Price (1990 \$)	NA	NA	NA	959.66	959.66	959.66	1094.02	1094.02
Operating Cost (1990 \$)	NA	NA	NA	145.12	145.12	145.12	121.58	121.58
Life-Cycle Cost (1990 \$)	NA	NA	NA	2369.11	2369.11	2369.11	2274.87	2274.87
Energy Use (MMBtu/yr)	NA	NA	NA	24.07	24.07	24.07	19.19	19.19

Table 4.7.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Instantaneous Gas-Fired Water Heaters

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
LCC difference	NA	NA	NA	94.2	94.2	94.2	-33.7	-1040.5
Payback	NA	NA	NA	5.7	5.7	5.7	19.2	63.6
CCE (\$/MMBtu)	NA	NA	NA	2.8	2.8	2.8	11.2	39.0

Table 4.8.a Cost and Energy-Use Summary, Oil-Fired Storage Water Heaters

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	724.66	210.74	2386.73	28.32
1	738.55	191.94	2252.37	25.79
3	745.49	187.48	2224.15	25.19
4	758.25	185.66	2222.50	24.95
5	785.99	177.53	2186.17	23.86
6	857.21	165.06	2159.03	22.18
7	991.68	159.63	2250.66	21.45
8	2241.08	141.90	3360.21	19.07

Table 4.8.b Distribution of Units Sold Below Standards, Oil-Fired Storage Water Heaters

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
0	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
1	100.00%	<Std>	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
3	0.00%		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
4	0.00%		<Std>	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
5	0.00%			0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
6	0.00%			<Std>	<Std>	0.00%	0.00%	0.00%	0.00%
7	0.00%					<Std>	<Std>	<Std>	0.00%
8	0.00%								<Std>

Table 4.8.c Weighted-Averages of Units Sold Below Standards, Oil-Fired Storage Water Heaters

Weighted-Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
Equip. Price (1990 \$)	724.66	738.55	738.55	738.55	738.55	738.55	738.55	738.55
Operating Cost (1990 \$)	210.74	191.94	191.94	191.94	191.94	191.94	191.94	191.94
Life-Cycle Cost (1990 \$)	2386.73	2252.37	2252.37	2252.37	2252.37	2252.37	2252.37	2252.37
Energy Use (MMBtu/yr)	28.32	25.79	25.79	25.79	25.79	25.79	25.79	25.79

Table 4.8.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Oil-Fired Storage Water Heaters

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6	Trial Standard Level 7	Trial Standard Level 8
LCC difference	134.4	29.9	93.3	93.3	1.7	1.7	1.7	-1107.8
Payback	0.7	3.1	4.4	4.4	7.8	7.8	7.8	30.0
CCE (\$/MMBtu)	0.7	3.0	4.2	4.2	7.4	7.4	7.4	28.3

4.5 LCC SENSITIVITY ANALYSIS

The sensitivity of the national LCC results were tested by varying assumptions about energy prices and equipment prices. These tables should be compared to the first set of tables in Section 4.1.

Low and high energy prices were defined as the minimum and maximum, respectively, of states' energy prices. Projected (1992) state energy prices (137) relative to the national average were applied to the projected 1996 national average price from the *Annual Energy Outlook 1991* to obtain state prices for 1996. (This represents a wider range of prices than analyzed in previous analyses, which used the average across Census regions.)

Low and high equipment prices were defined as one standard deviation below and above, respectively, the equipment prices used elsewhere in this chapter (from the Engineering Analysis). Note that the uncertainty in the baseline price is a percent of the total price, while the uncertainty in the price of other designs is applied to the incremental price of that design.

The following sensitivity cases were analyzed:

- (1) low (state) energy prices,
- (2) high equipment prices,
- (3) low (state) energy prices and high equipment prices,
- (4) high (state) energy prices,
- (5) low equipment prices, and
- (6) high (state) energy prices and low equipment prices.

Figures 4.5 and 4.6 and Tables 4.9 and 4.10 summarize the results of the sensitivity analysis. They include:

- graph of highest and lowest LCC sensitivity, and reference case, and
- a table of LCCs for all sensitivity cases. The table also shows the number of sensitivity cases for which each design option is the minimum LCC.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 6

Figure 4.6 Sensitivity Analysis for a Gas-fired Storage Water Heater

Table 4.9 Sensitivity Summary of Life-Cycle Costs of Electric Water Heaters

Standard Level								Std Level	Design
Design Option	0	1	2	3	5	7	9	@ min LCC	Option @ min LCC
Reference	3081	3044	2979	1996	2056	1940	2925	4,5	7
1	1811	1792	1758	1379	1624	1362	1744	4,5	7
2	3101	3044	2980	2072	2215	1989	2948	4,5	7
3	1831	1792	1759	1455	1784	1411	1768	4,5	7
4	4411	4355	4258	2644	2508	2544	4161	6,7,8	5
5	3061	3044	2979	1921	1896	1891	2901	4,5	7
6	4391	4355	4257	2568	2348	2495	4137	6,7,8	5
# of cases as min LCC							2 5		

Table 4.10 Sensitivity Summary of Life-Cycle Costs of Gas Water Heaters

Standard Level Design Option	1 0	2 1	2 2	3,4 3	7 12	5,6 14	8 24	Std Level @ min LCC	Design Option @ min LCC
Reference	1816	1803	1796	1771	1801	1790	2228	3,4	3
1	1354	1346	1343	1330	1442	1354	1971	3,4	3
2	1837	1806	1800	1776	1833	1818	2535	3,4	3
3	1375	1350	1347	1335	1474	1382	2279	3,4	3
4	4288	4246	4227	4133	3936	4126	3787	8	24
5	1794	1799	1792	1766	1769	1762	1920	5,6	14
6	4267	4243	4223	4128	3904	4098	3480	8	24
# of cases as min LCC				4		1	2		

CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF WATER HEATERS

5.1 LONG-RUN IMPACTS

The analysis shows that compared to the 1996 base case at all trial standards levels except level 1, the water heater industry is likely to experience a return on equity (ROE) increase. At standards level 1, there is approximately a 51% chance that ROE will increase, with an expected increase of less than 0.00%. At standards level 2, there is approximately a 53% chance of a increase in ROE with an expected increase of 0.01%. At standards level 3, there is approximately a 56% chance of an increase in ROE with an expected increase of 0.42%. At standards level 4, there is approximately a 56% chance of an increase in ROE with an expected increase of 0.40%. At standards level 5, there is approximately a 55% chance of an increase in ROE with an expected increase of 1.23%. At standards level 6, there is approximately a 55% chance of an increase in ROE with an expected increase of 1.37%. At standards level 7, there is approximately a 54% chance of an increase in ROE with an expected increase of 1.50%. At standards level 8, there is approximately a 55% chance of an increase in ROE with an expected increase of 0.40%. These results are based on Table 5.1. The probabilities of change are computed from the expected change, the standard error of this estimate, and the assumption of a normal distribution.

5.1.1 Qualitative Analysis

According to reports from within the industry, water heater manufacturing is characterized by economies of scale, which means that for the purposes of price determination, there are fixed costs. Depending on the standards level considered, these fixed costs are estimated to be approximately 10% of total costs. Since increases in fixed costs cannot be passed on, this implies that the markup over variable costs must be approximately 10% if the average firm is to have near-average ROE. To the extent that this markup is the same after standards are imposed, and to the extent that standards induce an increase in variable costs, such costs will be more than completely passed on in the form of a price increase, which in itself is profitable, but which also tends to reduce profit because of the effect of a price increase on sales.

If standards induce an increase in fixed costs, this cost cannot be passed on and will negatively influence profit. Because of the mandated increase in efficiency, operating costs will necessarily decline, which will tend to increase profit by making water heaters more attractive and, thereby increasing demand. Since demand is specified as a function of purchase price and operating cost (i.e., life-cycle cost) under constant life-cycle cost elasticity, as price changes, so does price elasticity, and consequently, markup. For instance, as price rises, price elasticity rises, and markup falls. The model calculates that these effects, when combined with the relatively low price elasticity of water heaters, are more likely to increase economic profits than decrease them at all standards levels.

5.1.2 Quantitative Analysis

Table 5.1 summarizes all essential outputs from the LBL-MIM simulations using the primary scenario for water heaters. Six other scenarios are summarized and discussed in the sensitivity section, Section 5.4.

Once the above interpretations are understood, the results of the model concerning the long-run impact of standards on the water heater manufacturing industry can be read from the output table.

Table 5.1 Water Heater Output Table: Primary Scenario - Long Run

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.43	1.43	1.43	1.38	1.38	1.38	1.21	1.20	1.09
% change		0.04%	0.04%	-3.22%	-3.23%	-3.39%	-15.32%	-16.09%	-23.53%
S.E.		1.09%	1.30%	20.31%	70.75%	19.06%	19.25%	80.88%	52.80%
Price	\$131.82	\$132.13	\$134.58	\$229.31	\$234.00	\$236.61	\$419.42	\$435.71	\$636.44
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.17%	230.53%	382.80%
S.E.		3.62%	3.83%	26.47%	28.21%	68.60%	79.19%	119.60%	27.56%
Revenue (in \$M)	187.89	188.41	191.90	316.33	322.77	325.81	506.20	521.14	693.72
% change		0.27%	2.13%	68.36%	71.79%	73.40%	169.41%	177.36%	269.22%
S.E.		2.90%	3.24%	37.55%	109.14%	73.04%	76.84%	354.15%	85.18%
Net Income (in \$M)	0.21	0.21	0.22	0.45	0.44	0.44	0.90	0.97	1.07
Difference		-0.00	0.01	0.24	0.23	0.23	0.70	0.77	0.86
S.E.		0.11	0.13	2.62	8.64	5.29	5.20	22.06	6.70
ROE	0.37%	0.37%	0.39%	0.79%	0.77%	0.77%	1.61%	1.74%	1.87%
Difference		-0.00%	0.01%	0.42%	0.40%	0.40%	1.23%	1.37%	1.50%
S.E.		0.19%	0.22%	3.56%	3.48%	10.74%	11.90%	20.18%	3.13%

5.2 SHORT-RUN IMPACTS

The business cycle presents the water heater manufacturing industry with fairly sharp periodic fluctuations in demand, much larger than the fluctuations predicted for any of the standards levels. These normal demand fluctuations present the same types of opportunities for price competition that will accompany fluctuations resulting from a change in standards. Regressing price on demand and a time trend for the past 18 years shows that a 10% fall in demand typically leads to a 0.3% fall in the price of water heaters; a 10% demand increase has the reverse effect. This effect is taken into account as described in Volume A, Chapter 3, Section 3.3.4.2, and is used to produce a short-run version of the output table that is displayed in Table 5.2. Note that at each standards level analyzed for the water heater manufacturing industry, the short-run ROE results are generally lower than the long-run results. For reasons that are explained in the above reference, the short-run change has been overestimated. Thus the values for change in Table 5.2 should be viewed as somewhat too large in absolute value.

Table 5.2 Water Heater Output Table: Primary Scenario - Short Run

	1990 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.43	1.43	1.43	1.38	1.38	1.38	1.22	1.22	1.14
% change		0.05%	0.05%	-3.07%	-3.07%	-3.23%	-14.10%	-14.74%	-20.05%
Price	\$131.82	\$132.01	\$134.46	\$227.99	\$232.65	\$235.18	\$409.78	\$425.26	\$615.90
% change		0.15%	2.00%	72.95%	76.49%	78.41%	210.86%	222.61%	367.22%
Revenue (in \$M)	187.89	188.26	191.75	314.99	321.42	324.39	501.70	516.78	701.86
% change		0.20%	2.05%	67.65%	71.07%	72.65%	167.02%	175.05%	273.55%
Net Income (in \$M)	0.21	-0.10	-0.15	-1.85	-1.99	-2.11	-9.63	-10.11	-18.09
Difference		-0.31	-0.36	-2.05	-2.20	-2.31	-9.83	-10.32	-18.30
ROE	0.37%	-0.18%	-0.27%	-3.25%	-3.48%	-3.68%	-17.09%	-18.09%	-31.74%
Difference		-0.55%	-0.64%	-3.62%	-3.85%	-4.05%	-17.46%	-18.46%	-32.11%
S.E.		2.30%	2.84%	20.51%	17.10%	200.10%	156.15%	187.87%	20.44%

5.3 IMPACT AS A FUNCTION OF FIRM SIZE

Firms in this industry may be divided into two groups: those that compete on large, sales volume products and those that compete in small, specialized markets. Small firms are generally forced to specialize in small-market niches that offer some protection from the cost advantage that large firms hold when they can produce in volume. This effect can even be observed among the major producers in the tendency of the smaller major producers to make somewhat more specialized products.

First, consider differences among the major firms. Typically, average cost decreases with increasing firm size. Thus, the industry has economies of scale, and large firms (to the extent that their facilities are up-to-date) have lower average costs than small firms. This fact, coupled with the increasing competitiveness of the national market, probably accounts for the continuing consolidation that has been occurring for several decades. The fact that the consolidation has been producing larger firms strongly corroborates the finding that large firms have a cost advantage.

A principal implication of consolidation is that the smaller of the major firms will be, on average, in more danger of failing or being bought out than will the larger firms. Because of the greater precariousness of smaller firms, any decrease in average profitability is more likely to seriously damage a smaller firm, and an increase in average profitability is more likely to mean the difference between success and failure for a smaller firm.

From the point of view of competitiveness, a decrease in average profitability could speed up the process of consolidation, producing a less competitive industry, and an increase in average profitability could help maintain the current level of competition. Either effect might well be temporary because in the long run the number of firms should be determined by the industry's cost structure and by the way a single firm's elasticity of demand relates to the number of competing firms.

Although larger firms have a cost advantage because of economies of scale, the very small firms in the water heater manufacturing industry have found market niches in which to survive profitably. There are at least two small firms that manufacture standard electric-resistance water heaters. However, there are also two small firms that manufacture heat-pump water heaters. Therefore, if a high-efficiency standard for water heaters is mandated, we can expect that given the small margins in the industry, some small firms may will probably have to leave the market. On the other hand, the small firms that specialize in higher efficiency models (such as heat-pump water heaters) would probably experience a boom.

The small firms that sell niche products such as heat-pump water heaters usually find that these markets have higher margins. As a result, it is possible that small firms would have an easier time passing through increased variable costs that result from standards, and thus may be more positively affected by standards than large firms. However, this prediction should be tempered by the observation that if standards are technologically difficult to meet, they may hurt selected smaller firms the most because smaller firms have less sophisticated research and development capabilities.

5.4 SENSITIVITY ANALYSIS FOR WATER HEATERS

The three following subsections discuss different aspects of the sensitivity analysis conducted by LBL-MIM. The first subsection, on sensitivity charts, shows the implications of the uncertainty of each control variable for the prediction of ROE. The next subsection shows six alternative scenarios that are of particular importance and deserve a more detailed analysis than those randomly generated by Monte Carlo runs. The last subsection shows the use of Monte Carlo runs to find combinations of errors that would cause the change in ROE to be considerably more negative than is predicted.

5.4.1 Sensitivity Charts

Table 5.3 shows the sensitivity of ROE to changes in control panel inputs. The variables analyzed are industry price elasticity of demand (IPE), discount rate (RD), the equity cost of capital (ECC), economic profit (EP), the fixed part of costs (FCA), the fixed part of one-time costs (FIX), one-time capital costs (CC.N), one-time variable costs (dVC.N), and the shape parameter of the demand curve (ro.N).

Table 5.3 Water Heaters Sensitivity Chart: Primary Scenario (Sensitivity of ROE to 1 S.E. Change in Control Variable)

Control Variables			Possible Standards Levels							
Name	Value	Changed	1	2	3	4	5	6	7	8
IPE	-0.120	-0.276	0.01%	0.01%	-0.88%	-0.95%	-6.03%	-0.06%	-0.11%	-0.01%
RD	106.30%	244.40%	0.00%	0.04%	1.58%	1.67%	4.75%	0.05%	0.08%	0.02%
ECC	0.068	0.075	0.00%	0.00%	-0.02%	-0.03%	-0.11%	0.00%	0.00%	0.00%
EP	-0.065	-0.055	0.00%	0.00%	0.03%	0.03%	0.29%	0.00%	0.00%	0.00%
FCA	0.085	0.136	-0.01%	-0.01%	0.55%	0.58%	3.16%	0.03%	0.05%	0.01%
FIX	0.111	0.193	-0.06%	-0.06%	-0.20%	-0.26%	-0.50%	0.00%	-0.01%	0.00%
CC.N	3.718	4.532	0.00%	0.01%	0.01%	0.00%	-0.25%	0.00%	-0.01%	0.00%
dVC.N	15.088	20.237	0.05%	0.06%	0.32%	0.32%	0.72%	0.01%	0.01%	0.00%
ro.N	0.000	0.050	0.00%	0.00%	-0.07%	-0.07%	-0.48%	-0.01%	-0.01%	0.00%

As can be seen from the table, three control variables account for nearly all of the uncertainty in the determination of ROE. These are (1) the industry elasticity of demand with respect to price (IPE), (2) the discount rate (RD) from which operating cost elasticity is derived, and (3) fixed part of costs (FCA). The reasons that these three variables are important are discussed below.

5.4.2 Alternative Scenarios

The sensitivity analysis shows that both price and operating cost elasticities (the latter being derived from the discount rate) play crucial roles in determining the model's output. These are both *industry* elasticities as opposed to single-firm elasticities; this means they measure the effect on demand of a change in price by all firms and a change in operating cost of all water heaters. The estimates of standard errors that are calculated by the Monte Carlo analysis fully acknowledge the uncertainties of these two variables. However, in order to show in detail all of the ramifications of changing one or both of them, six alternative scenarios have been run. The six scenarios include low and high price elasticity scenarios, a constant shipments scenario (i.e., industry price and operating cost elasticity set to zero), high and low discount rate scenarios (i.e., high and low operating cost scenarios), and a low discount rate and high price elasticity scenario. Tables 5.4 through 5.9 show the results of running these six scenarios for the water heater manufacturing industry.

In these alternative scenarios, note the impact of a change in the discount rate. A high RD input value lowers ROE, and a lower RD value increases ROE. Because markup is determined by price elasticity, it will tend to change as the ratio of price to operating cost changes. Standards will always increase this ratio, which decreases markup. This effect is strongest when appliance demand is relatively elastic with respect to operating cost. That is, a more elastic operating cost elasticity will result in a greater decrease in markup under standards, resulting in a greater decrease in profitability.

The other tables show that increasing price elasticity also tends to lower ROE. This effect is probably due to the greater decline in shipments when price elasticity is greater.

5.4.3 Monte Carlo Analysis

The Monte Carlo approach is described in Volume A, Chapter 3, Section 3.3.4.3, and the standard errors it generates are reported in the output tables. Table 5.10 shows the control panels from two Monte Carlo runs, which were selected because they show a decrease in long-run ROE. Both Monte Carlo runs were done on standards level 2. In the first run, we see how large increases in price elasticity coupled with increases in the percentage of both fixed costs and one-time costs (which are not passed through via prices) and the discount rate are the primary factors in reducing ROE. In the second, increases in price elasticity and one-time costs with a smaller increase in the discount rate reduce ROE despite a small decrease in fixed costs.

Table 5.4 Water Heater Output Table, Low Industry Price Elasticity Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
% change		0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%	-0.01%	-0.02%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
Price	\$131.82	\$132.13	\$134.58	\$229.31	\$234.00	\$236.61	\$419.42	\$435.71	\$636.44
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.17%	230.53%	382.80%
S.E.		3.77%	3.99%	27.56%	25.50%	28.12%	69.67%	70.23%	118.15%
Revenue (in \$M)	189.07	189.52	193.03	328.89	335.61	339.35	601.49	624.84	912.62
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.13%	230.48%	382.69%
S.E.		3.77%	3.99%	27.55%	25.49%	28.11%	69.64%	70.20%	118.09%
Net Income (in \$M)	0.27	0.26	0.28	0.91	0.91	0.94	3.78	4.02	6.77
Difference		-0.01	0.01	0.64	0.64	0.67	3.51	3.75	6.50
S.E.		0.11	0.13	1.17	0.99	1.13	3.95	3.62	6.39
ROE	0.48%	0.47%	0.49%	1.55%	1.54%	1.58%	5.83%	6.21%	9.70%
Difference		-0.01%	0.01%	1.07%	1.06%	1.09%	5.35%	5.73%	9.22%
S.E.		0.20%	0.23%	1.96%	1.66%	1.90%	6.02%	5.58%	9.01%

Table 5.5 Water Heater Output Table, High Industry Price Elasticity Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.42	1.42	1.42	1.33	1.33	1.32	1.02	1.00	0.83
% change		0.08%	0.07%	-6.33%	-6.35%	-6.67%	-28.30%	-29.58%	-41.52%
S.E.		0.95%	1.07%	5.88%	6.15%	6.42%	8.35%	8.33%	9.18%
Price	\$131.82	\$132.13	\$134.58	\$229.31	\$234.00	\$236.61	\$419.42	\$435.71	\$636.44
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.17%	230.53%	382.80%
S.E.		3.59%	4.06%	27.17%	28.65%	29.93%	72.88%	73.68%	128.24%
Revenue (in \$M)	186.72	187.30	190.77	304.25	310.41	312.79	425.95	434.57	527.20
% change		0.31%	2.17%	62.95%	66.25%	67.52%	128.13%	132.74%	182.35%
S.E.		2.60%	2.93%	13.87%	14.35%	14.88%	21.70%	21.80%	25.45%
Net Income (in \$M)	0.15	0.15	0.16	0.00	-0.01	-0.04	-1.51	-1.57	-3.28
Difference		0.00	0.01	-0.14	-0.16	-0.18	-1.66	-1.71	-3.42
S.E.		0.04	0.05	0.29	0.33	0.34	1.14	1.07	1.97
ROE	0.26%	0.27%	0.28%	0.01%	-0.02%	-0.07%	-3.08%	-3.23%	-6.93%
Difference		0.00%	0.02%	-0.26%	-0.29%	-0.33%	-3.34%	-3.50%	-7.19%
S.E.		0.07%	0.08%	0.56%	0.62%	0.66%	2.64%	2.43%	4.62%

Table 5.6 Water Heater Output Table, Constant Shipments Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
% change		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Price	\$131.82	\$132.13	\$134.58	\$229.31	\$234.00	\$236.61	\$419.42	\$435.71	\$636.44
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.17%	230.53%	382.80%
S.E.		3.53%	3.86%	25.66%	28.60%	27.99%	69.50%	72.76%	125.08%
Revenue (in \$M)	189.07	189.52	193.03	328.90	335.62	339.36	601.57	624.93	912.83
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.17%	230.53%	382.80%
S.E.		3.53%	3.86%	25.66%	28.60%	27.99%	69.50%	72.76%	125.08%
Net Income (in \$M)	0.27	0.27	0.27	0.91	0.911	0.94	3.78	4.02	6.78
Difference		-0.01	0.01	0.64	0.64	0.67	3.51	3.76	6.51
S.E.		0.12	0.13	0.94	1.12	1.13	4.68	4.02	7.35
ROE	0.48%	0.47%	0.49%	1.55%	1.54%	1.58%	5.83%	6.21%	9.71%
Difference		-0.01%	0.01%	1.07%	1.06%	1.10%	5.35%	5.73%	9.23%
S.E.		0.21%	0.23%	1.58%	1.88%	1.89%	7.23%	6.15%	10.55%

Table 5.7 Water Heater Output Table, High Discount Rate Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.43	1.43	1.43	1.38	1.38	1.38	1.21	1.20	1.09
% change		0.04%	0.04%	-3.22%	-3.23%	-3.39%	-15.32%	-16.09%	-23.53%
S.E.		0.49%	0.55%	3.20%	3.24%	3.12%	4.77%	5.07%	5.93%
Price	\$131.82	\$132.13	\$134.58	\$229.31	\$234.00	\$236.61	\$419.42	\$435.71	\$636.44
% change		0.24%	2.09%	73.95%	77.51%	79.49%	218.17%	230.53%	382.80%
S.E.		3.73%	4.15%	28.19%	29.07%	27.41%	69.55%	76.14%	120.25%
Revenue (in \$M)	187.89	188.41	191.90	316.33	322.77	325.81	506.20	521.14	693.72
% change		0.27%	2.13%	68.36%	71.79%	73.40%	169.41%	177.36%	269.22%
S.E.		3.22%	3.57%	21.01%	21.37%	20.29%	41.21%	44.48%	60.73%
Net Income (in \$M)	0.21	0.21	0.22	0.45	0.44	0.44	0.90	0.97	1.07
Difference		0.00	0.01	0.24	0.23	0.23	0.70	0.77	0.86
S.E.		0.05	0.07	0.61	0.58	0.47	1.78	1.96	3.34
ROE	0.37%	0.37%	0.39%	0.75%	0.77%	0.77%	1.61%	1.74%	1.87%
Difference		0.00%	0.01%	0.42%	0.40%	0.40%	1.23%	1.37%	1.50%
S.E.		0.10%	0.13%	1.13%	1.07%	0.85%	3.26%	3.63%	6.07%
ROE	0.37%	-0.18%	-0.27%	-3.25%	-3.48%	-3.68%	-17.09%	-18.09%	-31.74%
Difference		-0.55%	-0.64%	-3.62%	-3.85%	-4.05%	-17.46%	-18.46%	-32.11%
S.E.		0.83%	0.94%	10.74%	8.32%	7.60%	33.46%	27.37%	40.02%

Table 5.8 Water Heater Output Table, High Discount Rate Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (in Mil)	1.42	1.42	1.41	1.33	1.32	1.20	1.19	1.11	1.33
% change		-0.01%	-0.17%	-6.19%	-6.56%	-15.49%	-16.07%	-21.69%	-6.41%
S.E.		0.46%	0.52%	2.22%	2.33%	3.45%	3.23%	3.77%	2.29%
Price	\$132.09	\$132.41	\$134.90	\$231.30	\$238.73	\$424.12	\$440.65	\$644.35	\$236.08
% change		0.24%	2.13%	75.11%	80.74%	221.09%	233.61%	387.82%	78.73%
S.E.		3.62%	4.10%	25.80%	27.96%	73.64%	74.52%	121.67%	26.97%
Revenue (in \$M)	187.14	187.58	190.81	307.40	316.02	507.79	523.98	714.85	313.05
% change		0.23%	1.96%	64.27%	68.87%	171.35%	180.00%	281.99%	67.28%
S.E.		3.14%	3.55%	19.90%	21.39%	49.66%	50.27%	74.30%	20.75%
Net Income (in \$M)	0.40	0.40	0.44	1.77	1.83	4.49	4.76	7.18	1.80
Difference		0.00	0.04	1.37	1.44	4.10	4.36	6.78	1.41
S.E.		0.17	0.18	2.02	2.09	6.17	5.81	9.90	2.04
ROE	0.71%	0.72%	0.79%	3.21%	3.31%	8.03%	8.55%	12.44%	3.26%
Difference		0.00%	0.07%	2.50%	2.60%	7.32%	7.84%	11.72%	2.55%
S.E.		0.32%	0.33%	3.78%	3.92%	11.41%	10.82%	17.18%	3.80%

Table 5.9 Water Heater Output Table, Low Discount Rate & High Price Elasticity Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
Shipments (Mil)	1.70	1.73	1.82	6.79	7.76	7.00	7.19	12.87	7.65
% change		1.51%	6.73%	299.07%	356.36%	311.29%	322.35%	656.58%	349.52%
S.E.		1.06%	1.19%	46.62%	60.35%	108.10%	107.71%	385.22%	51.03%
Price	\$131.55	\$131.85	\$134.25	\$227.22	\$234.38	\$414.49	\$430.53	\$628.13	\$231.82
% change		0.23%	2.05%	72.74%	78.18%	215.09%	227.29%	377.50%	76.23%
S.E.		3.78%	3.97%	25.54%	27.99%	70.53%	72.27%	118.68%	24.85%
Revenue (\$M)	223.80	227.70	243.77	1542.74	1819.81	2900.38	3093.62	8085.33	1772.92
% change		1.74%	8.92%	589.33%	713.13%	1195.9%	1282.3%	3512.7%	692.2%
S.E.		2.72%	2.98%	61.43%	75.76%	118.42%	136.23%	1057.84%	74.33%
Net Income (\$M)	1.81	1.97	2.55	36.86	44.38	51.29	53.07	125.97	43.23
Difference		0.16	0.74	35.05	42.58	49.48	51.26	124.16	41.42
S.E.		0.15	0.37	15.08	17.05	22.02	23.10	73.00	16.07
ROE	2.74%	2.94%	3.62%	14.27%	15.04%	18.86%	19.02%	25.41%	14.88%
Difference		0.20%	0.87%	11.53%	12.30%	16.12%	16.28%	22.67%	12.13%
S.E.		0.20%	0.45%	4.85%	4.64%	4.42%	5.01%	5.61%	4.56%

Table 5.10 Water Heater Monte Carlo Runs: Searching for Low ROE

		Scenario: Primary		Standard Level = 3		
WATER HEATERS CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity		-0.120	0.87	100%	-0.248	IPE
Consumer Discount Rate		106.30%	1.05	100%	253.85%	RD
Equity Cost of Capital		0.068	-0.85	10%	0.062	ECC
Economic Profit		-0.065	-0.97	1%	-0.075	EP
L-R Fixed Part of Costs & Assets		0.085	-1.76	50%	0.037	FCA
L-R Fixed Part of 1-X Cap. Cost		0.075	1.40	60%	0.162	F1X
One-Time Capital Costs		21.058	-0.83	20%	17.855	CC.N
Unit Variable Cost Increase		\$109.93	0.46	30%	125.718	dVC.N
Elasticity Curve Parameter		0.000	1.14	5%	0.057	ro.N
Short Run Price Response to Demand		0.157	-1.46	76%	0.023	SRPR
		NAECA	NEW		PRVIOUS	NEW
SUMMARY		BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments		1.40	1.21	-13.94%	-15.32%	1.21
Price		\$131.71	\$243.88	85.17%	218.17%	\$243.02
Revenue (in \$M)		184.53	294.06	59.36%	169.41%	293.76
Net Income		-0.76	-1.52	-0.76	0.70	-3.16
ROE		-1.39%	-3.06%	-1.67%	1.23%	-6.37%
08-Sep-92		16:00	Trys =		78.00	

		Scenario: Primary		Standard Level = 5		
WATER HEATERS CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity		-0.120	1.30	100%	-0.355	IPE
Consumer Discount Rate		106.30%	1.35	100%	327.64%	RD
Equity Cost of Capital		0.068	-0.55	10%	0.064	ECC
Economic Profit		-0.065	-0.21	1%	-0.067	EP
L-R Fixed Part of Costs & Assets		0.085	-0.63	50%	0.063	FCA
L-R Fixed Part of 1-X Cap. Cost		0.078	-1.11	60%	0.042	F1X
One-Time Capital Costs		56.210	0.50	20%	62.089	CC.N
Unit Variable Cost Increase		\$293.74	-1.83	30%	171.602	dVC.N
Elasticity Curve Parameter		0.000	-0.02	5%	-0.001	ro.N
Short Run Price Response to Demand		0.157	-0.54	76%	0.076	SRPR
		NAECA	NEW		PRVIOUS	NEW
SUMMARY		BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments		1.38	1.02	-26.38%	-3.22%	1.06
Price		\$131.93	\$297.15	125.23%	73.95%	\$291.21
Revenue (in \$M)		182.42	302.48	65.82%	68.36%	308.37
Net Income		-0.21	-1.54	-1.33	0.24	-8.59
ROE		-0.38%	-3.07%	-2.69%	0.42%	-17.15%
08-Sep-92		16:03	Trys =		3.00	

CHAPTER 6. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES: WATER HEATERS

6.1 INTRODUCTION

Appliance efficiency standards have four principal effects on electric utilities: (1) they allow utilities to avoid fuel and other operating costs because less electricity needs to be generated, (2) they may allow utilities to defer construction of new generating capacity, (3) they may allow utilities to defer construction of new or upgraded transmission and distribution (T&D) capacity, and (4) they reduce revenues from electricity sales. The second section of this chapter presents the results of the avoided-cost calculations. The third section presents the expected peak load and reliability savings for the analyzed standard levels. The fourth section presents the results of the revenue-loss calculation. More details on methodology may be found in Appendix E of Volume A.

6.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS

Figure 6.1 shows avoided energy and reliability costs for electricity savings from water heaters. These figures show the sum of avoided costs for the base-, high-, and low-energy price cases.¹⁵ The value per million Btu (MMBtu) of avoided reliability costs is the same in all three energy price cases. The avoided fuel and capital component depends on fuel prices and varies among the three cases. As explained in Appendix E of Volume A, this component implicitly contains the costs avoided when baseload power plants are deferred or canceled (it also contains avoided T&D capital costs). These avoided costs represent a simple summary of the utility analysis, and they are a measure of the societal benefit of the electricity saved in each year. They are used in the LBL-REM to value electricity savings from the societal perspective.

6.3 PEAK LOAD AND CAPACITY REDUCTIONS

Table 6.1 shows peak load reductions for water heaters for the relevant standard levels. Table 6.2 shows capacity savings for water heaters for the relevant standard levels. The base case peak load in the second column of Table 6.1 represents coincident peak load of all such appliances in the residential sector.

¹⁵ Fuel price forecasts for the period 1990 to 2000 are taken from the DOE/EIA *Annual Energy Outlook 1991* (DOE/EIA-0383(91)). The forecasts for years after 2000 were linearly extrapolated using the methodology described in Volume A. The high (low) energy price case is derived by increasing (decreasing) the reference case AEO fuel price forecasts for gas and coal by 5%.

Figure 6.1 Utility Avoided Costs for Water Heaters

Table 6.1 Peak Demand Reductions (GW) - Water Heaters

Year	Peak Load	Peak Demand Savings							
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
1996	22.8	0.0	0.1	2.4	2.9	2.9	3.8	3.8	3.4
1997	22.8	0.0	0.1	3.4	3.9	3.9	5.1	5.1	4.6
1998	22.9	0.0	0.2	4.3	4.9	4.9	6.5	6.5	5.8
1999	23.1	0.0	0.2	5.3	6.0	5.9	7.9	7.9	7.1
2000	23.3	0.0	0.3	6.3	7.0	7.0	9.2	9.2	8.3
2001	23.5	0.0	0.3	7.2	8.0	8.0	10.6	10.6	9.5
2002	23.8	0.0	0.3	8.1	9.0	8.9	11.8	11.8	10.6
2003	24.1	0.0	0.3	8.9	9.8	9.7	12.9	12.9	11.6
2004	24.3	0.0	0.4	9.5	10.3	10.3	13.6	13.6	12.2
2005	24.6	0.0	0.4	9.8	10.7	10.6	14.1	14.1	12.7
2006	24.7	0.0	0.3	10.0	10.8	10.8	14.3	14.3	12.9
2007	24.9	0.0	0.3	10.1	10.9	10.9	14.4	14.5	13.0
2008	25.0	0.0	0.3	10.1	11.0	10.9	14.5	14.6	13.0
2009	25.2	0.0	0.3	10.1	11.0	11.0	14.6	14.6	13.1
2010	25.4	0.0	0.3	10.2	11.0	11.0	14.7	14.7	13.1
2011	25.5	0.0	.02	10.2	11.1	11.0	14.8	14.8	13.2
2012	25.7	0.0	0.2	10.2	11.1	11.1	14.8	14.9	13.3
2013	25.9	0.0	0.2	10.3	11.1	11.1	14.9	14.9	13.3
2014	26.0	0.0	0.2	10.3	11.2	11.1	15.0	15.0	13.4
2015	26.2	0.0	0.2	10.3	11.2	11.2	15.1	15.1	13.5
2016	26.4	0.0	0.2	10.4	11.3	11.2	15.2	15.2	13.6
2017	26.6	0.0	0.1	10.4	11.3	11.3	15.3	15.3	13.7
2018	26.9	0.0	0.1	10.5	11.4	11.4	15.4	15.4	13.8
2019	27.1	0.0	0.1	10.6	11.5	11.5	15.5	15.5	13.9
2020	27.4	0.0	0.1	10.7	11.6	11.6	15.6	15.7	14.1
2021	27.6	0.0	0.1	10.7	11.7	11.6	15.7	15.8	14.2
2022	27.9	0.0	0.1	10.8	11.8	11.7	15.9	15.9	14.3
2023	28.1	0.0	0.1	10.9	11.8	11.8	16.0	16.0	14.5
2024	28.4	0.0	0.1	10.9	11.9	11.9	16.1	16.1	14.6
2025	28.7	0.0	0.1	11.0	12.0	12.0	16.2	16.3	14.8
2026	28.9	0.0	0.1	11.1	12.1	12.1	16.4	16.4	14.9
2027	29.2	0.0	0.1	11.2	12.2	12.2	16.5	16.5	15.1
2028	29.5	0.0	0.1	11.3	12.3	12.3	16.6	16.7	15.2
2029	29.8	0.0	0.1	11.4	12.4	12.4	16.8	16.8	15.4
2030	30.1	0.0	0.1	11.5	12.5	12.5	16.9	17.0	15.6

Table 6.2 Capacity Savings (GW) - Water Heaters

Year	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
1996	0.1	0.1	2.0	22.4	2.4	3.2	3.2	2.9
1997	0.0	0.1	2.9	3.3	3.3	4.3	4.3	3.9
1998	0.0	0.2	3.7	4.1	4.1	5.5	5.5	4.9
1999	0.0	0.3	6.4	7.1	7.1	9.4	9.4	8.5
2000	0.0	0.3	7.5	8.4	8.4	11.1	11.1	10.0
2001	0.0	0.3	8.7	9.6	9.6	12.7	12.7	11.4
2002	0.1	0.4	9.7	10.8	10.7	14.2	14.2	12.8
2003	0.1	0.4	10.7	11.7	11.7	15.4	15.5	13.9
2004	0.1	0.4	11.3	12.4	12.3	16.3	16.3	14.7
2005	0.1	0.4	11.8	12.8	12.8	16.9	16.9	15.2
2006	0.1	0.4	12.0	13.0	13.0	17.2	17.2	15.4
2007	0.0	0.4	12.1	13.1	13.1	17.3	17.4	15.5
2008	0.0	0.4	12.1	13.1	13.1	17.4	17.5	15.6
2009	0.0	0.3	12.2	13.2	13.1	17.5	17.6	15.7
2010	0.0	0.3	12.2	13.2	13.2	17.6	17.6	15.8
2011	0.0	0.3	12.2	13.3	13.2	17.7	17.7	15.8
2012	0.0	0.3	12.3	13.3	13.3	17.8	17.8	15.9
2013	0.0	0.2	12.3	13.4	13.3	17.9	17.9	16.0
2014	0.0	0.2	12.4	13.4	13.4	18.0	18.0	16.1
2015	0.0	0.2	12.4	13.5	13.4	18.1	18.1	16.2
2016	0.0	0.2	12.5	13.5	13.5	18.2	18.2	16.3
2017	0.0	0.2	12.5	13.6	13.6	18.3	18.4	16.4
2018	0.0	0.2	12.6	13.7	13.7	18.5	18.5	16.6
2019	0.0	0.2	12.7	13.8	13.8	18.6	18.7	16.7
2020	0.0	0.1	12.8	13.9	13.9	18.7	18.8	16.9
2021	0.1	12.9	14.0	14.0	14.0	18.9	18.9	17.1
2022	0.1	13.0	14.1	14.1	14.1	19.0	19.1	17.2
2023	0.1	13.0	14.2	14.2	14.2	19.2	19.2	17.4
2024	0.1	13.1	14.3	14.3	14.3	19.3	19.4	17.5
2025	0.1	13.2	14.4	14.4	14.4	19.5	19.5	17.7
2026	0.1	13.3	14.5	14.5	14.5	19.6	19.7	17.9
2027	0.1	13.4	14.6	14.6	14.6	19.8	19.9	18.1
2028	0.1	13.5	14.7	14.7	14.7	20.0	20.0	18.3
2029	0.1	13.6	14.9	14.8	14.8	20.2	20.2	18.5
2030	0.1	13.8	15.0	15.0	15.0	20.3	20.4	18.7

The total peak demand and the savings are calculated using the appropriate conservation load factors, a T&D loss factor of 1.06, and estimates of energy consumption calculated using the LBL-REM. Capacity savings are peak load savings in regions that need additional capacity, multiplied by 1.2 to account for reserve margin needed for adequate reliability. The amount of capacity saved can be somewhat less than the peak demand savings in years before 1999 because capacity savings are only counted in regions that need capacity. After 1998, capacity savings consistently exceed peak load savings by the reserve margin of 20% (numbers may not exactly correspond to this rule because of rounding errors).

Peak demand reductions from the standards for water heaters range from 0 to 9.2 GW in 2000, and from 0 to 17.0 GW in 2030. Capacity savings for water heaters range from 0 to 11.1 GW in 2000 and from 0 to 20.4 GW in 2030.

6.4 REVENUE LOSSES

Appliance standards allow utilities to avoid the variable costs of generating electricity, but standards also reduce electricity sales. In a rate case, the utility and the regulators agree on the revenue requirements and rates based on some estimate of future sales. If the effects of appliance efficiency standards are not included in this forecast, actual sales will be less than forecasted sales, which implies that the utility will not be able to recover some of the fixed costs that were included in the original revenue requirements calculation. This effect can be eliminated if electric utilities and regulators, when calculating rates, use the most current information on the impacts of appliance efficiency standards.

Utilities routinely petition regulators for change in rates. In the course of such a petition, the utility's forecasted sales can be adjusted to account for the appliance efficiency standards and hence eliminate these "lost" revenues. Those revenues lost as a result of time lags in regulation are not a true economic cost, but are a transfer payment from the utility to utility customers. The size of this transfer payment depends on regulatory behavior and on the net change in revenues, which is equal to the difference between sales reductions and avoided costs.

Since the magnitude of these losses is dependent on assumptions about regulatory behavior, and because this behavior is so varied among states, it is difficult to perform this calculation for the nation. An additional complication is that unanticipated sales growth from other sectors may compensate for the revenue shortfall. Two cases are presented here, one that assumes that regulators adjust the rates to reflect the reduced sales in five years, and one that assumes they never adjust the rates. These cases assume there is no unanticipated sales growth. These results are presented both on a year-by-year and a present-value basis.

It is possible that the regulators could adjust the rates in anticipation of the new standards, in which case there would be no revenue impact at all. It is also possible that the regulators would not grant rate relief for several years after the standards go into effect, which is approximated by the five-year-lag case. While it is unlikely that regulators would never adjust the rates to reflect the post-standard sales forecast, this case is included as an absolute upper bound. Figure 6.2 shows annual revenue losses and avoided costs over time for level 3 standards, and Table 6.3 shows net revenue losses for all standards levels. Cumulative net revenue losses for water heaters range from \$0.1 to 42.5 billion.

Figure 6.2 Revenue Reductions and Avoided Costs for Water Heating

Table 6.3 Net Revenue Losses - Water Heaters (Million 1990 Dollars)

Year	Net Revenue Losses							
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
1996	3	28	679	799	794	1055	1056	953
1997	4	38	904	1039	1033	1372	1372	1235
1998	6	47	1121	1272	1265	1678	1679	1508
1999	6	50	1193	1342	1335	1769	1771	1590
2000	8	56	1359	1520	1512	2003	2004	1801
2001	8	60	1491	1659	1651	2185	2187	1967
2002	8	63	1595	1765	1757	2324	2326	2094
2003	8	64	1656	1822	1814	2399	2402	2161
2004	8	63	1666	1819	1811	2396	2399	2157
2005	7	59	1632	1772	1765	2337	2340	2101
2006	7	55	1597	1728	1722	2283	2287	2050
2007	6	50	1543	1670	1664	2210	2214	1982
2008	5	44	1482	1605	1600	2128	2132	1907
2009	4	40	1421	1539	1534	2045	2049	1831
2010	3	35	1359	1473	1469	1961	1965	1754
2011	3	30	1272	1379	1375	1840	1843	1645
2012	2	26	1185	1285	1282	1717	1721	1535
2013	2	22	1098	1191	1188	1594	1598	1425
2014	1	19	1010	1096	1093	1469	1473	1313
2015	1	16	922	1001	999	1344	1347	1202
2016	1	13	835	907	905	1219	1222	1090
2017	1	11	748	813	811	1093	1096	979
2018	1	9	661	718	717	967	969	868
2019	1	7	572	622	621	838	840	754
2020	1	5	483	525	524	708	710	638
2021	1	4	393	427	426	576	578	520
2022	0	3	301	328	327	443	444	400
2023	0	2	209	227	227	307	308	278
2024	0	1	115	126	125	170	170	154
2025	0	0	21	23	23	21	31	28
2026	0	-1	-75	-81	-81	-110	-110	-100
2027	0	-1	-172	-187	-187	-253	-254	-231
2028	0	-2	-270	-294	-294	-398	-399	-364
2029	-1	-2	-370	-403	-402	-546	-547	-500
2030	-1	-3	-471	-513	-512	-696	-697	-639
Total	106	910	29167	32015	31895	42467	42525	38085

The figures show utility revenue losses, assuming no regulator adjustment. When this adjustment is made, rates will be increased over the base case forecast, and utilities will cease to lose revenue. Total residential rates would increase 1.8% and 1.9% (0.14¢/kWh and 0.16¢/kWh) in 2000 and 2005, respectively, if water heaters are subject to level 4 standards and regulators only change commercial rates to compensate for any loss in revenue.

Table 6.4 shows the present value of net revenue losses at a 5% real utility discount rate for all standard levels and for the two assumptions about regulatory behavior. This discount rate is based on an assumed average utility capital structure and current rates of return.

Table 6.4 Present Value of Revenue Losses - Water Heaters (Million 1990 Dollars)

Regulatory Lag	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
None	0	0	0	0	0	0	0	0
1996-2001	18	146	3511	3994	3971	5268	5272	4740
1996-2030	54	455	13542	14934	14874	19773	19801	17757

For water heaters, the present value of net lost revenues may range from \$0.2 to 5.3 billion for a five-year lag, and would be as large as \$20 billion if the regulators did not make adjustment. The present values over the period 1996 to 2030 also represent the rate increases needed over this period to compensate for lost revenues, assuming that regulators adjust immediately.

6.5 SENSITIVITY ANALYSIS

Tables 6.5 and 6.5 show the peak demand reductions and capacity savings for the sensitivity cases. Table 6.7 shows the present value of net lost revenues for the same sensitivity cases. The assumptions for these sensitivity cases are the same for those for previous tables.

Table 6.5 Peak Demand Reductions (GW) - Water Heaters (Sensitivity Cases)

Year	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1996	2.9	3.0	3.0	2.9	3.1	3.0
2000	7.1	7.2	7.2	7.1	6.9	7.2
2010	11.3	11.3	11.2	11.2	10.0	11.2
2020	11.9	11.9	11.8	11.9	8.7	11.8
2030	12.8	12.9	12.7	12.9	5.8	12.8

Table 6.6 Capacity Savings (GW) - Water Heaters (Sensitivity Cases)

Year	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1996	2.4	2.5	2.5	2.5	2.6	2.5
2000	8.6	8.6	8.6	8.6	8.2	8.6
2010	13.6	13.5	13.5	13.5	12.0	13.5
2020	14.2	14.2	14.2	14.2	10.4	14.2
2030	15.4	15.4	15.3	15.5	6.9	15.4

Table 6.7 Present Value of Net Lost Revenues (Million 1990 \$) - Water Heaters (Sensitivity Cases)

Regulatory Lag	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
None	0	0	0	0	0	0
1996-2001	-195	-197	4023	9019	-194	-196
1996-2030	-1417	-1419	15379	69714	-1192	-1414

CHAPTER 7. ENVIRONMENTAL EFFECT

7.1 INTRODUCTION

The environmental effects from a range of new candidate energy conservation standards for water heaters are presented here. The results are presented for each potential standard level. Each measure of possible environmental change is an alternative action, and it is compared to what is expected to happen if no new standards for water heaters were finalized, i.e., the "no action" alternative.

The main environmental concern addressed is emissions from fossil-fueled electricity generation. All of the design options for water heaters result in decreased electricity use and, therefore, a reduction of power plant emissions. The proposed efficiency standards will generally decrease air pollution by decreasing future energy demand. The greatest decreases in air pollution will be for sulfur oxides, listed in equivalent weight of sulfur dioxide, or SO_2 . Reductions of nitrogen oxides and carbon dioxide also occur and are listed by weight of NO_x and CO_2 , respectively. CO_2 emissions from fossil-fuel burning is considered an environmental hazard because it contributes to the "greenhouse effect" by trapping heat energy from the earth that is emitted as infrared radiation. The "greenhouse effect" is expected to gradually raise the mean global temperature. Since water heaters include product classes that consume fuel (i.e., gas- and oil-fired water heaters), design options will also reduce in-home fuel consumption, resulting in lower emissions from these fuel-burning appliances.

For a detailed description of the methodology that was used in estimating the environmental impacts, refer to the Environmental Assessment in Volume A of this Technical Support Document.

7.2 RESULTS

The following tabular results indicate what changes can be brought about in the amounts of emitted CO_2 , SO_2 , and NO_x by imposing efficiency standards for water heaters. A table is presented for each of the appliance's trial standard levels. Each table details the changes that occur to each of the three emissions (i.e., CO_2 , SO_2 , and NO_x) through the imposition of an appliance's specific trial standard level. Each table includes the following information for a specific year between 1996 and 2030: the amount of emission abated from power plant generation, the amount abated from in-home generation, the net change in the emissions, and the percent the net change comprises of total U.S. power plant emissions. Also included are the cumulative changes of each pollutant (between the years 1996 and 2030).

Decreases in the amounts of CO_2 , SO_2 , and NO_x emitted at trial standards levels 1 through 8 are summarized in Tables 7.1 through 7.8.

7.2.1 Sulfur and Nitrogen Oxide Emissions

SO₂ emissions would be decreased by a cumulative total of up to 7.12 million tons between 1996 and 2030 in the level 8 scenario. In the year 1996, decreases in SO₂ will represent about 1.14% of the SO₂ emissions estimated to come from power plants in that year. In the year 2030, decreases in SO₂ emissions will represent about 2.44% of the SO₂ emissions estimated to come from power plants in that year. Because of provisions in the Clean Air Act Amendments (Pub. L. 101-549, November 15, 1990), the possible reductions of SO₂ that are caused by standards can be earned as credits by the utility realizing the reductions. To the extent SO₂ credits are used for future emissions, the net effect on SO₂ emissions from standards would be only a postponement of those SO₂ emissions.

Level 8 design changes to water heaters would result in an estimated decrease in NO_x emissions of 7.11 million tons between 1996 and 2030. NO_x decreases would represent 1.21% and 2.81% of the NO_x emissions estimated to come from power plants in the years 1996 and 2030, respectively.

7.2.2 Carbon Dioxide Emissions

The cumulative reduction in CO₂ emissions from level 8 design changes is 4,113 million tons of CO₂. For the year 1996, the estimated CO₂ reduction is 33,450 thousand tons of CO₂, or about 1.46% of estimated U.S. total CO₂ emissions in 1996. For the year 2030, the estimated CO₂ reduction is 142,630 thousand tons of CO₂, or about 2.97% of estimated U.S. total CO₂ emissions in 2030.

Table 7.1
Reduction of Pollutants for Water Heaters - Level One

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	86	0	86	0.00%
2000	252	0	252	0.01%
2005	338	139	477	0.02%
2010	170	0	170	0.01%
2015	85	0	85	0.00%
2020	169	55	224	0.01%
2025	83	55	138	0.00%
2030	166	0	166	0.00%

Cumulative CO2 reduction, 1996-2030 = 7 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	483	0	483	0.00%
2000	903	0	903	0.01%
2005	1,027	157	1,184	0.01%
2010	444	0	444	0.01%
2015	178	0	178	0.00%
2020	285	0	285	0.00%
2025	109	0	109	0.00%
2030	165	0	165	0.00%

Cumulative SO2 reduction, 1996-2030 = 16,662 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	303	0	303	0.00%
2000	672	0	672	0.01%
2005	826	117	944	0.01%
2010	385	0	385	0.01%
2015	165	0	165	0.00%
2020	285	52	338	0.01%
2025	120	53	172	0.00%
2030	203	0	203	0.00%

Cumulative NOx reduction, 1996-2030 = 14,405 tons

Table 7.2
Reduction of Pollutants for Water Heaters - Level Two

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	689	84	773	0.03%
2000	1,845	224	2,068	0.08%
2005	2,619	418	3,037	0.11%
2010	1,955	334	2,289	0.07%
2015	1,269	418	1,687	0.05%
2020	928	334	1,261	0.03%
2025	584	279	863	0.02%
2030	497	363	860	0.02%

Cumulative CO2 reduction, 1996-2030 = 59 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	3,866	157	4,022	0.03%
2000	6,624	313	6,937	0.08%
2005	7,960	470	8,429	0.10%
2010	5,101	313	5,414	0.06%
2015	2,668	470	3,138	0.04%
2020	1,568	313	1,881	0.03%
2025	766	313	1,079	0.02%
2030	496	470	966	0.02%

Cumulative SO2 reduction, 1996-2030 = 145,477 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	2,427	65	2,492	0.03%
2000	4,931	182	5,114	0.08%
2005	6,404	352	6,757	0.10%
2010	4,433	287	4,720	0.06%
2015	2,474	352	2,826	0.04%
2020	1,568	287	1,855	0.03%
2025	840	235	1,075	0.02%
2030	610	300	910	0.02%

Cumulative NOx reduction, 1996-2030 = 118,434 tons

Table 7.3
Reduction of Pollutants for Water Heaters - Level Three

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	18,077	1,991	20,068	0.88%
2000	44,857	4,286	49,143	1.96%
2005	70,802	6,500	77,302	2.70%
2010	73,607	6,911	80,518	2.50%
2015	74,385	7,520	81,904	2.28%
2020	76,651	7,824	84,475	2.13%
2025	78,634	8,128	86,762	1.98%
2030	81,381	8,517	89,898	1.87%

Cumulative CO2 reduction, 1996-2030 = 2,607 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	101,482	939	102,421	0.80%
2000	161,086	2,035	163,120	1.81%
2005	215,169	3,287	218,455	2.51%
2010	192,061	3,130	195,191	2.32%
2015	156,360	3,443	159,803	2.10%
2020	129,550	3,600	133,149	1.99%
2025	103,128	3,756	106,884	1.84%
2030	81,306	4,069	85,375	1.78%

Cumulative SO2 reduction, 1996-2030 = 5,381,123 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	63,703	1,808	65,511	0.81%
2000	119,919	3,890	123,809	1.85%
2005	173,124	5,880	179,004	2.56%
2010	166,910	6,288	173,198	2.37%
2015	144,970	6,838	151,807	2.17%
2020	129,550	7,113	136,662	2.04%
2025	112,993	7,388	120,380	1.91%
2030	99,939	7,728	107,667	1.82%

Cumulative NOx reduction, 1996-2030 = 4,890,115 tons

Table 7.4
Reduction of Pollutants for Water Heaters - Level Four

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	21,263	2,156	23,418	1.02%
2000	50,139	4,645	54,784	2.19%
2005	76,885	6,775	83,660	2.92%
2010	79,727	7,270	86,997	2.70%
2015	80,732	7,850	88,581	2.47%
2020	83,312	8,154	91,466	2.31%
2025	85,563	8,598	94,160	2.15%
2030	88,666	8,986	97,652	2.03%

Cumulative CO2 reduction, 1996-2030 = 2,837 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	119,363	939	120,302	0.94%
2000	180,055	2,191	182,246	2.02%
2005	233,656	3,287	236,942	2.72%
2010	208,029	3,287	211,316	2.52%
2015	169,701	3,443	173,144	2.28%
2020	140,809	3,600	144,408	2.16%
2025	112,215	3,913	116,128	2.00%
2030	88,585	4,226	92,811	1.93%

Cumulative SO2 reduction, 1996-2030 = 5,885,240 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	74,927	1,965	76,892	0.95%
2000	134,041	4,218	138,258	2.06%
2005	187,999	6,143	194,141	2.77%
2010	180,787	6,615	187,402	2.57%
2015	157,339	7,153	164,491	2.35%
2020	140,809	7,428	148,236	2.21%
2025	122,949	7,820	130,769	2.08%
2030	108,886	8,160	117,046	1.98%

Cumulative NOx reduction, 1996-2030 = 5,337,547 tons

Table 7.5
Reduction of Pollutants for Water Heaters - Level Five

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	21,176	2,350	23,527	1.03%
2000	49,972	5,034	55,005	2.19%
2005	76,631	7,278	83,909	2.93%
2010	79,472	7,717	87,190	2.71%
2015	80,562	8,271	88,834	2.47%
2020	83,144	8,575	91,719	2.31%
2025	85,479	8,964	94,443	2.15%
2030	88,583	9,408	97,991	2.04%

Cumulative CO2 reduction, 1996-2030 = 2,845 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	118,879	1,096	119,975	0.94%
2000	179,453	2,504	181,957	2.02%
2005	232,885	3,913	236,798	2.72%
2010	207,364	3,913	211,276	2.52%
2015	169,346	4,226	173,571	2.28%
2020	140,524	4,382	144,906	2.16%
2025	112,106	4,695	116,801	2.01%
2030	88,502	5,008	93,510	1.95%

Cumulative SO2 reduction, 1996-2030 = 5,890,278 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	74,624	2,135	76,759	0.95%
2000	133,592	4,558	138,150	2.06%
2005	187,379	6,560	193,939	2.77%
2010	180,209	6,980	187,189	2.56%
2015	157,009	7,478	164,487	2.35%
2020	140,524	7,753	148,276	2.21%
2025	122,829	8,093	130,921	2.08%
2030	108,784	8,485	117,269	1.99%

Cumulative NOx reduction, 1996-2030 = 5,335,580 tons

Table 7.6
Reduction of Pollutants for Water Heaters - Level Six

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	28,063	2,211	30,274	1.32%
2000	65,986	4,205	70,191	2.80%
2005	101,218	5,620	106,838	3.73%
2010	105,906	5,785	111,692	3.47%
2015	108,235	6,284	114,519	3.19%
2020	112,067	6,588	118,655	2.99%
2025	115,530	6,977	122,507	2.79%
2030	119,960	7,475	127,436	2.65%

Cumulative CO2 reduction, 1996-2030 = 3,662 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	157,539	939	158,478	1.24%
2000	236,962	2,191	239,153	2.66%
2005	307,604	3,287	310,890	3.57%
2010	276,337	3,287	279,624	3.33%
2015	227,514	3,600	231,113	3.04%
2020	189,407	3,756	193,163	2.88%
2025	151,518	4,069	155,587	2.68%
2030	119,850	4,382	124,232	2.59%

Cumulative SO2 reduction, 1996-2030 = 7,795,782 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	98,892	2,018	100,909	1.25%
2000	176,405	3,798	180,202	2.69%
2005	247,497	5,040	252,537	3.61%
2010	240,150	5,198	245,348	3.36%
2015	210,940	5,643	216,582	3.09%
2020	189,407	5,918	195,325	2.92%
2025	166,011	6,258	172,268	2.73%
2030	147,316	6,703	154,019	2.61%

Cumulative NOx reduction, 1996-2030 = 6,995,324 tons

Table 7.7
Reduction of Pollutants for Water Heaters - Level Seven

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	28,149	3,175	31,324	1.37%
2000	66,154	6,215	72,368	2.89%
2005	101,471	8,400	109,871	3.84%
2010	106,246	8,620	114,866	3.57%
2015	108,573	8,788	117,361	3.27%
2020	112,404	8,597	121,002	3.05%
2025	115,864	8,546	124,410	2.84%
2030	120,291	8,605	128,896	2.68%

Cumulative CO2 reduction, 1996-2030 = 3,747 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	158,023	1,096	159,118	1.24%
2000	237,564	2,348	239,911	2.67%
2005	308,374	3,443	311,817	3.58%
2010	277,224	3,443	280,667	3.34%
2015	228,225	3,756	231,981	3.05%
2020	189,978	3,913	193,890	2.89%
2025	151,956	4,226	156,181	2.69%
2030	120,181	4,539	124,720	2.60%

Cumulative SO2 reduction, 1996-2030 = 7,823,000 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	99,195	2,923	102,117	1.26%
2000	176,853	5,700	182,553	2.72%
2005	248,117	7,678	255,795	3.65%
2010	240,921	7,888	248,809	3.41%
2015	211,599	8,018	219,617	3.14%
2020	189,978	7,820	197,798	2.95%
2025	166,491	7,740	174,231	2.77%
2030	147,723	7,765	155,488	2.64%

Cumulative NOx reduction, 1996-2030 = 7,085,801 tons

Table 7.8
Reduction of Pollutants for Water Heaters - Level Eight

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	25,739	7,711	33,450	1.46%
2000	60,117	17,651	77,768	3.10%
2005	92,008	26,630	118,639	4.14%
2010	95,877	30,070	125,946	3.91%
2015	97,910	31,723	129,634	3.61%
2020	102,201	31,866	134,067	3.38%
2025	106,265	31,573	137,837	3.14%
2030	111,516	31,114	142,630	2.97%

Cumulative CO2 reduction, 1996-2030 = 4,113 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	144,492	939	145,431	1.14%
2000	215,885	2,035	217,920	2.42%
2005	279,617	3,287	282,903	3.25%
2010	250,167	3,443	253,610	3.02%
2015	205,812	3,756	209,568	2.76%
2020	172,733	4,226	176,958	2.64%
2025	139,366	5,008	144,374	2.49%
2030	111,414	5,791	117,204	2.44%

Cumulative SO2 reduction, 1996-2030 = 7,124,332 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	90,701	7,268	97,969	1.21%
2000	160,714	16,648	177,362	2.65%
2005	224,979	25,095	250,074	3.57%
2010	217,407	28,363	245,770	3.37%
2015	190,819	29,910	220,729	3.15%
2020	172,733	30,000	202,733	3.03%
2025	152,696	29,643	182,339	2.89%
2030	136,946	29,128	166,073	2.81%

Cumulative NOx reduction, 1996-2030 = 7,109,299 tons

APPENDIX A. ENERGY USE AND COST DATA

A.1 ENERGY CALCULATIONS FOR GAS-FIRED STORAGE WATER HEATERS

The energy calculations for gas-fired storage water heaters in this analysis were based on the old DOE test procedure (138). This procedure calculated energy factor (EF), the ratio of the heat content of the water drawn to the heat content of the fuel used in a 24-hour test period, from recovery efficiency and standby losses. The inputs used in the calculation were recovery efficiency and a partitioned standby loss, along with input rates, temperatures, and tank volume. This appendix cites the sources of the recovery efficiency and the standby losses used for each design option in the analysis. Any assumptions and intermediate calculations are also explained here.

The annual energy consumption was calculated from the amount of time the burner was on and the input rates. The EF was not converted directly to annual energy consumption because energy consumption had to be divided between both gas and electricity. The equations that were used are listed here:

Annual Gas Consumption =

$$[\text{Gas}_{\text{On}} * \text{Hours}_{\text{On}} + \text{Gas}_{\text{Off}} * (24 - \text{Hours}_{\text{On}})] * 365 \left[\frac{\text{days}}{\text{year}} \right] * 10^{-6} \left[\frac{\text{MMBtu}}{\text{Btu}} \right]$$

Annual Electricity Consumption =

$$[\text{Elec}_{\text{On}} * \text{Hours}_{\text{On}} + \text{Elec}_{\text{Off}} * (24 - \text{Hours}_{\text{On}})] * 365 \left[\frac{\text{days}}{\text{year}} \right] * 10^{-3} \left[\frac{\text{kW}}{\text{W}} \right]$$

where:

- Hours_{On} = number of hours burner was on in 24 hours,
- Gas_{On} = gas input rate in Btuh when burner was on,
- Gas_{Off} = gas input rate in Btuh when burner was off,
- Elec_{On} = electricity input rate in watts when burner was on, and
- Elec_{Off} = electricity input rate in watts when burner was off.

The Average Daily Energy Consumption (ADEC) is equal to the energy in the daily hot water draw divided by EF, and it is also equal to the various input rates multiplied by the number of hours the burner was on in a day.

$$\begin{aligned}
 ADEC = & \text{Hours}_{\text{On}} * (\text{Gas}_{\text{On}} + \text{Elec}_{\text{On}} * 3.41276 [\frac{\text{Btu}}{\text{Wh}}]) \\
 & + (24 - \text{Hours}_{\text{On}}) * (\text{Gas}_{\text{Off}} + \text{Elec}_{\text{Off}} * 3.41276 [\frac{\text{Btu}}{\text{Wh}}])
 \end{aligned}$$

This equation was rewritten to solve for the number of hours the burner was on:

$$\text{Hours}_{\text{On}} = \frac{ADEC - 24 * (\text{Gas}_{\text{Off}} + \text{Elec}_{\text{Off}} * 3.41276 [\frac{\text{Btu}}{\text{Wh}}])}{(\text{Gas}_{\text{On}} - \text{Gas}_{\text{Off}}) + (\text{Elec}_{\text{On}} - \text{Elec}_{\text{Off}}) * 3.41276 [\frac{\text{Btu}}{\text{Wh}}]}$$

EF was calculated with ADEC and the daily load from the test procedure as follows.

$$\text{EF}_{(\text{old})} = \frac{\text{daily}_{\text{load}}}{ADEC}$$

where:

daily_{load} = the energy in the daily hot water draw under the new DOE test procedure in Btus. This value is 41059 Btu.

ADEC = the average daily energy consumption.

The calculations of ADEC, recovery efficiency, and standby loss were based on the old DOE test procedure (139). Because the new DOE test procedure had not become effective at the time this analysis was done, most of the available data were from the old test procedure. Also the old test procedure allows the EF to be calculated from the recovery efficiency and standby losses. The new test procedure determines EF in a much more direct manner. It can no longer be calculated from the recovery efficiency and standby losses. The EF for most of the design options listed here was calculated by combining the recovery efficiency and standby losses.

The ADEC was from the following equation in the old DOE test procedure:

$$ADEC = C_f + C_{\text{aux}} * 3,412 [\frac{\text{Btu}}{\text{kWh}}]$$

where:

C_f = average daily gas energy consumption, and
 C_{aux} = the average daily auxiliary electricity energy consumption.

C_f was calculated as follows:

(12)

and C_{aux} was calculated as follows:

$$C_{aux} = p_r * \frac{C_{wh}}{P} + p_s * \left(24 - \frac{C_{wh}}{P} \right)$$

where:

- C_{wh} = daily water heating energy consumption,
- C_{us} = average hourly hot water storage energy consumption,
- P = power input to the burner,
- p_r = auxiliary input during main burner operation, and
- p_s = auxiliary input during standby.

C_{wh} , the daily water heating energy consumption, is the energy required to heat water drawn from the tank and was calculated as:

$$C_{wh} = \frac{k * U * (T_o - T_i)}{E_r}$$

C_{us} , the average hourly hot water storage energy consumption, was calculated as follows:

$$C_{us} = S * k * V * (T_t - T_a)$$

where:

- k = nominal specific heat of water, 8.25 Btu/gallon,
- U = nominal daily hot water usage, 64.3 gallons,
- T_o = outlet water temperature, 160 °F,
- T_i = inlet water temperature, 70 °F,
- E_r = recovery efficiency,
- S = standby loss as fraction of heat content of tank per hour,
- V = tank volume, 40 gallons,
- T_t = mean tank temperature, 160 °F, and
- T_a = ambient temperature, 70 °F.

Recovery efficiencies were taken from either the California Energy Commission (CEC) or Gas Appliance Manufacturers Association (GAMA) water heater directories for existing models already containing the design option (140) (141).

When possible, the standby losses were converted to heat flows. These heat flows were apportioned among the fittings, the flue, and the jacket. Reductions in the apportioned heat flows were estimated for each of the design options. These reduced heat flows were then combined into a revised total standby loss.

The recovery efficiency measures how efficiently the water heater heats cold water to the setpoint temperature. The recovery efficiency for each design option that modified the flue and/or combustion chamber was taken to be the same as units currently on the market with the same flue and/or combustion chamber configuration. In cases where design options were stacked, i.e., more than one design option was applied, the highest recovery efficiency of all the stacked design options was used.

In the old DOE test procedure the recovery efficiency is determined with a cold-start test. The tank was filled with 70 °F water, then allowed to heat the water to 160 °F. The heat content of the fuel used in the test is compared to the heat added to the water in the tank. In most cases the recovery efficiency used here was from existing models of gas-fired storage water heaters as listed in either the California Energy Commission (CEC) or Gas Appliance Manufacturers Association (GAMA) water heater directories (142) (143).

Heat loss during standby occurs through three distinct, major routes in a gas-fired storage water heater. These are up the flue, through the jacket, and out through fittings, such as the inlet, outlet, pressure temperature relief valve, and the drain valve. The standby losses in the baseline model were apportioned to each of these heat-loss routes, and converted to Btuh. The reductions in standby loss along each of these routes were estimated in Btuh for each design option. These savings were subtracted from the standby losses of the previous design option for each heat-loss route. The sum of the standby heat losses was converted to a percentage of the heat content of the tank, using the tank and ambient temperatures specified in the old test procedure. This standby loss as a percentage of heat content of the tank was used in the calculations to derive EF using the formulas in the old test procedure.

Using the old test procedure, the standby loss was determined by measuring the heat content of the fuel used to maintain mean tank temperature at 160 °F during a 48-hour test with no draws. Any decline of tank temperature at the end of the test is compensated for by increasing the consumption by the amount necessary to raise the tank temperature back to 160 °F with an efficiency equal to the recovery efficiency.

The daily load is the heat added to the water drawn from the water heater during the test procedure. It was calculated from the specified hot water load and temperature difference. EF was calculated according to the old test procedure using recovery efficiency, standby loss, gas and electric inputs, and tank volume. The temperatures, conversion constants, and specific heat of water specified in the old test procedure were also used.

Baseline Model (Design Option #0)

The EF of the base line model used in the analysis was 0.544. This was calculated to exactly match the standard for a 40-gallon tank (144). The 1990 standard for gas-fired water heaters is given by the following equation:

$$EF = 0.62 - (0.0019 * \text{MeasuredVolume})$$

The recovery efficiency of 76% for the baseline model was supplied by manufacturers (145). The total standby loss of 3.79% was calculated from the old DOE test procedure, to match the baseline EF when the baseline recovery efficiency was also used. This is equivalent to 1125 Btuh. The losses were partitioned with the same percentages as reported for TANK I, a computer simulation model of gas-fired storage water heaters developed by Battelle, for GRI (146). They were using a 40-gallon glass-lined steel tank with a center flue as a baseline model. The burner was 40 kBtuh with a standing pilot of 400 Btuh. Heating losses per day were estimated for the new DOE 24-hour test procedure. Fitting losses were estimated at 8.0% (90 Btuh) of the hourly standby losses. Flue losses were estimated at 66.8% (751 Btuh) of total hourly standby losses. Jacket losses were estimated to be 25.2% (284 Btuh) of the total hourly standby losses.

The jacket temperature for the baseline model was calculated from the jacket surface area, insulation thickness, and jacket heat loss. The overall convective heat-transfer coefficient was determined for the baseline model from this jacket temperature and surface area. The surface area for the baseline model was assumed to be 23.08 sq ft. It was calculated as:

$$\text{Area} = \pi * D_j * L + \pi * (D_j^2 - D_f^2) / 4$$

where:

- D_j = jacket diameter, 20 inches,
- D_f = flue diameter, 3 inches, and
- L = height of tank, 48 inches.

The jacket temperature was calculated by solving this conductive heat-transfer equation:

$$Q_{j\text{cond}} = \frac{k * A_j * (T_i - T_j)}{t_h}$$

where:

$Q_{j_{cond}}$ = conductive heat loss through jacket, 25.2% of the total hourly standby loss, 284.23 Btu/h,

k = thermal conductivity of insulation, 0.17 Btu-in/hr-ft²-°F (147),

A_j = surface area of jacket, 23.08 sq.ft.,

t_h = thickness of jacket insulation, 1 inch

T_t = temperature of water in tank, 160°F, and

T_j = temperature of surface of jacket, 87.6°F (calculated).

The convective heat-loss equation with the same jacket temperature and surface area was solved for the overall heat-transfer coefficient.

$$Q_{j_{conv}} = h_j \cdot A_j \cdot (T_j - T_{amb})$$

where:

$Q_{j_{conv}}$ = convective heat loss from jacket, 25.2% of the total hourly standby loss, 284 Btu/h,

A_j = surface area of jacket, 23.08 sq ft.,

T_j = temperature of surface of jacket, 87.6 °F (calculated),

T_{amb} = ambient temperature, 70 °F, and

h_j = overall heat transfer coefficient, 0.70 Btu/hr-°F-sq.ft. (calculated).

Heat Traps (Design Option #1)

Heat traps were assumed to provide a savings of 9 watts per 50 °C on the hot water outlet and 7 watts per 50 °C on the fitting losses only (148). If adjusted to temperatures used in the new test procedure and converted to Btu/h, the use of heat traps gave a total savings of 46.7 Btu/h.

Reduce Heat Leaks (Design Option #2)

Reducing heat leaks was assumed to reduce the fitting losses by 50% of what heat traps could accomplish. This gave a savings of 21.66 Btuh on fitting losses only.

R-16 Insulation (Design Option #3)

The thickness of foam insulation was increased to two inches. The decrease in heat loss is not directly proportional to the increase in thickness. An overall convective heat-transfer coefficient was estimated from the baseline model. This overall convective heat-transfer coefficient, the increased insulation thickness, and the increased jacket surface area were used to calculate a new jacket heat loss.

The heat loss through the jacket of the baseline unit with two inches of insulation was calculated using the heat-transfer coefficient from the baseline, the new surface area (25.63 sq ft.) required for the thicker insulation, and the new R-value. This gave a jacket temperature of 79.7 °F and a jacket heat loss of 174 Btuh. This was a jacket heat loss reduction of 109 Btuh from a baseline model with one inch of insulation. No changes were made to recovery efficiency or the other portions of the standby heat loss.

Improve Flue Baffle with Standard Venting (Design Option #4)

The energy factor, recovery efficiency, and standby losses were for the Bradford-White Optimizer (model # M-III-403T5CN-*) and an apparently identical model without the improved flue baffling (model # M-II-40T5CN-*). The data were from the CEC water heater directory (149). The standby losses for these two models were converted to Btuh. The difference, 235.9 Btuh, was attributed to reductions in standby flue losses by this design option. The recovery efficiency used for this design option was 85%. This is the same recovery efficiency as the model with improved flue baffling listed above. Because of the high recovery efficiency of this design option, it must be vented to a Type-B venting system.

Electronic Ignition with Flue Damper (Design Option #5)

The electronic ignition and flue damper were assumed to provide savings on the flue loss only. Battelle estimated an EF of 0.6064 for a baseline model with electronic ignition and flue damper (150). The recovery efficiency for the model Battelle used was assumed to be 76%. The standby loss was calculated from this EF and recovery efficiency. Converted to Btuh this was 407 Btuh. This was a 54% reduction in flue losses. These percentage savings were applied to the flue loss of the previous design option, 515 Btuh, to get a standby flue loss of 236 Btuh.

The pilot input rate was added to the main burner input rate to get gas consumption when the burner was on for the baseline model. The standing pilot ignition system of 400 Btuh was eliminated with this design option. Consumption of the main burner was reduced to 34,000 Btuh. During standby, electricity consumption was 15 watts. When the burner was on, electricity use was increased to 25 watts. The electric consumption was for a 24 volt plug-in transformer with low-voltage wire between the outlet and the water heater (10 watts), the electronic ignition (2.5 watts on), a flue damper (5 watts off), and a gas valve (12 watts on). The data were from the Battelle study (151).

Submerged Combustion Chamber with Standard Venting (Design Option #6)

The incremental change in standby flue losses were estimated as the difference in standby losses between an American Appliance Nautilus (model # G*N463**) and a similar model without a submerged combustion chamber (model # G*F8443T*****). The data were listed in the CEC water heater directory (152). The standby losses for these two models were converted to Btuh. The difference, 99 Btuh, was attributed to reductions in standby flue losses by this design option. The recovery efficiency used for this design option was 85%. This is the same recovery efficiency as the model with the submerged combustion chamber listed above. Because of the high recovery efficiency of this design option, it must be vented to a Type-B venting system.

Electronic Ignition with Flue Damper (Design Option #7)

The same energy calculations were done as for design option #5, except the standby flue loss was 632 Btuh for the previous design option. The 54% reduction in flue losses reduced this to 298 Btuh.

Improve Flue Baffle with Side Venting (Design Option #8)

This is the same as design option #4, except sidewall venting was used to reduce reventing costs. An induced draft fan and controls were added to pull combustion products out the sidewall vent. The additional electricity use reduced the EF by 0.004.

The electric consumption was for a fan (50 watts on), gas valve (12 watts on), transformer losses (10 watts) and a relay (5 watts on). The electric consumption data were from the Battelle report (153).

Electronic Ignition (Design Option #9)

An electronic ignition was assumed to reduce standby losses by 24% (96 Btuh) of the pilot light input. This was the portion of the pilot light heat that would be lost if the pilot had the same recovery efficiency as the main burner of the baseline model. Because the pilot input rate was included in the main burner input rate of the baseline model, the burner input was reduced by 400 Btuh when the pilot was removed. The electric consumption was for an electronic ignition (2.5 watts on) (154). This design option is only used after 24 volt is already supplied to the water heater. No additional auxiliary power would be drawn during standby because the transformer and controls were already in the previous design option.

Indirect Heating with Electronic Ignition (Design Option #10)

Indirect heating used a standard electric water heater with an external burner and a heat exchanger. A small circulation pump circulated the water through the heat exchanger when the burner was on. The burner had electronic ignition. Auxiliary power was supplied by a

low-voltage plug-in transformer. This is the system used by the Marathon gas-fired water heaters manufactured by Water Heater Innovations.

The standby fitting loss for the baseline model was estimated as 90 Btuh. The standby loss for the indirect heating with electronic ignition design option was calculated as the difference between standby losses for similar gas and electric Marathon water heaters (models MG40345 and M40245) plus the standby loss for an equivalent standard 40-gallon electric water heater. This standby loss was 1.290%, or 383 Btu/h (155) (156). It was assumed that this standby loss was almost entirely fitting losses. The difference in these fitting losses was an increase of 293 Btuh. This was added to the fitting losses of the previous design option. The recovery efficiency, 0.81, was from the Marathon gas water heater (model MG40345). The flue losses were entirely eliminated. Jacket losses were assumed to remain the same.

Multiple Flues (Design Option #11)

The recovery efficiency used for this design option, 0.80, was from the Rheemglas Tri-Power (model 44V40) (157). It was assumed there were no changes in standby losses.

Electronic Ignition with Flue Damper (Design Option #12)

The same energy calculations were done as for design option #5, except the standby flue loss was 751 Btu/h for the previous design option. The 54% reduction in flue losses reduced this to 344 Btu/h.

Submerged Combustion Chamber with Sidewall Venting (Design Option #13)

This is the same as design option #6, except sidewall venting was used to reduce reventing costs. An induced draft fan and controls were added to pull combustion products out the sidewall vent. The additional electricity use reduced the EF by 0.006.

The electric consumption was for a fan (50 watts on), gas valve (12 watts on), transformer losses (10 watts), and a relay (5 watts on). The electric consumption data were from the Battelle report (158).

R-25 Insulation (Design Option #14)

The heat loss through the jacket of a baseline model with three inches of insulation was calculated using the heat-transfer coefficient from the baseline, the new surface area (28.23 sq ft) required for the thicker insulation, and the new insulation thickness. This gave a jacket temperature of 76.7 °F and a jacket heat loss of 133 Btu/h. This was a jacket heat loss reduction of 42 Btuh from a baseline model with two inches of insulation. No changes were made to recovery efficiency or the other portions of the standby heat loss.

Increase Baffling and Forced Draft with Sidewall Venting (Design Option #15)

Flue baffling and forced draft were assumed to reduce remaining flue standby losses by 37.5%. The electric consumption was for a fan (50 watts on) and a relay (5 watts on) (159). No changes were made in fitting or jacket standby heat losses. The recovery efficiency was increased to 0.84. This was enough to give the energy factor reported in the GAMA data request when combined with the estimated reduction in standby flue losses.

Increase Baffling and Forced Draft with Standard Venting (Design Option #16)

In terms of energy calculations, this design option is the same as design option #15. There was no difference in recovery efficiency, standby loss, or auxiliary power requirements.

Electronic Ignition and Power Vent (Design Option #17)

The reduction of flue standby losses from electronic ignition and power vent were assumed to be 40.7%. This was 75% of what electronic ignition and flue dampers were estimated to accomplish. Because the pilot input rate was added to the input rate of the main burner of the baseline model to get gas consumption when the burner was on, gas consumption was reduced by 400 Btu/h when the pilot was removed. The electric consumption was for a fan (50 watts on), electronic ignition (2.5 watts on), gas valve (12 watts on), transformer losses (10 watts) and a relay (5 watts on) (160). No changes were made to jacket and fitting standby heat losses, or to recovery efficiency.

Vacuum Insulation (Design Option #18)

The thickness of insulation was decreased from two inches to one inch. The conductivity of the insulation was assumed to be $0.0567 \text{ Btu-in/hr-ft}^2 \text{ } ^\circ\text{F}$, one-third of the value for polyurethane foam insulation. The heat loss through the jacket was calculated using the heat-transfer coefficient from the baseline model, the new surface area (23.08 sq ft) from the thinner insulation, the conductivity of vacuum insulation, and the new insulation thickness.

This gave a jacket temperature of 76.7°F and a jacket heat loss of 109 Btu/h. This was a jacket heat loss reduction of 66 Btu/h from a baseline model with two inches of insulation. No changes were made to recovery efficiency or the other portions of the standby heat loss.

Tempering Tank (Design Option #19)

In the new DOE test procedure, the ambient temperature was specified to be 67.5°F and the inlet temperature was specified to be 58°F . This design option was assumed to increase the inlet water temperature to the ambient temperature. This is equivalent to decreasing the change of water temperature during recovery by 9.5°F . This would reduce the energy consumption during the recovery efficiency test by the ratio of the reduced temperature change to the original temperature change. This can be written as:

$$Q_{\text{test}_{\text{mod}}} = Q_{\text{test}} * \frac{(90-9.5)}{90}$$

where:

Q_{test} = the energy consumption during the recovery efficiency test, and
 $Q_{\text{test}_{\text{mod}}}$ = the modified energy consumption.

A modified recovery efficiency can be calculated from this modified energy consumption as follows:

$$\begin{aligned} E_{r_{\text{mod}}} &= \frac{(k * V * \Delta T)}{Q_{\text{test}_{\text{mod}}}} = \frac{(k * V * \Delta T)}{Q_{\text{test}} * \frac{(90-9.5)}{90}} \\ &= \frac{(k * V * \Delta T)}{Q_{\text{test}}} * \frac{90}{(90-9.5)} = E_r * \frac{90}{(90-9.5)} \\ &= E_r * 1.118 \end{aligned}$$

where:

$E_{r_{\text{mod}}}$ = modified recovery efficiency to adjust for increased inlet temperature,
 k = specific heat of water,
 V = volume of water during recovery efficiency test,
 ΔT = temperature difference between inlet water, upstream from the tempering tank, and setpoint temperature, and
 E_r = recovery efficiency of water heater without tempering tank.

This is equivalent to a 11.8% increase in the recovery efficiency. No changes were made to standby losses or to gas and electric inputs.

Submerged Combustion (Design Option #20)

This design option was from a domestic gas water heater market assessment done by Science Applications, Inc., for GRI in 1981 (161). The estimated recovery efficiency of 0.97 and the auxiliary power consumption of 600 watts were both from this report. The standby loss was for an equivalent standard 40-gallon electric water heater, but was not used in the energy consumption calculations (162). The electricity consumption when the burner was off was an estimate.

Indirect with Electronic Ignition and Plastic Tank (Design Option #21)

The energy factor and recovery efficiency were from the Marathon water heater (model MG40345) produced by Water Heater Innovations as listed in the CEC water heater directory (163). The standby losses were calculated from the energy factor and recovery efficiency, but were not used in the energy consumption calculations. The electric consumption was for a 24-volt plug-in transformer with low-voltage wire between the outlet and the water heater (10 watts), the electronic ignition (2.5 watts on), a gas valve (12 watts on), and a circulating pump (estimated at 25 watts on) (164).

Directly Fired (Design Option #22)

The data for the energy calculations for this design were the same as for design option #20. The design option was from the domestic gas water heater market assessment done by Science Applications, Inc., for GRI in 1981 (165). The estimated recovery efficiency of 0.97 and the auxiliary power consumption of 600 watts were both from this report. The standby loss was for an equivalent standard 40-gallon electric water heater, but was not used in the energy consumption calculations (166). The electricity consumption when the burner was off was an estimate.

Thermophotovoltaic Generator (Design Option #23)

The energy factor for this design was estimated at 0.64 and the recovery efficiency at 0.80 (167) (168). The standby loss was calculated from the energy factor and recovery efficiency using the old test procedure calculations, but was not used in the energy consumption calculations. This design option does not have a pilot light and does not need auxiliary power.

Condense Flue Gases (Design Option #24)

The energy factor of 0.86 and the recovery efficiency of 0.94 were from the Polaris water heater (model DVPB35) manufactured by American/Mor-Flo as listed in the CEC water heater directory (169). The standby loss was calculated from the energy factor and recovery efficiency, but was not used in the energy consumption calculations. The electric consumption was for a fan (50 watts on), electronic ignition (2.5 watts on), gas valve (12 watts on), transformer losses (10 watts), and a relay (5 watts on) (170).

Condensing Pulse (Design Option #25)

The energy factor recovery efficiency and standby losses were the average of those reported in the ADM study and by Thrasher et al. (171) (172). An energy factor of 0.824 was calculated from Thrasher's data using a recovery efficiency of 0.903 and a standby loss of 0.7%. A standby loss of 0.87% was calculated from the ADM energy factor of 0.82 and a recovery efficiency of 0.91.

The electric consumption was for a gas valve (12 watts on), transformer losses (10 watts), and a relay (5 watts on) (173). Fan and ignitor consumption were not counted because they are operating only until combustion is established.

A.2 DISAGGREGATED MANUFACTURER COSTS FOR GAS-FIRED STORAGE WATER HEATERS

The cost data for the more common design options were mostly from information supplied by manufacturers to GAMA and a report prepared by ADM Associates, Inc. (174) (175). The cost data from GAMA were the midpoint of the range of costs reported by the manufacturers. This value was used to preserve the confidentiality of costs supplied by individual manufacturers. The manufacturing cost data from these two sources were supplied in several categories for each design option. These cost categories were material costs, labor, tooling, shipping, and overhead. Material costs covered both raw materials, such as sheet steel and paint, and parts, such as gas valves and thermostats. Labor included both direct and indirect labor costs. Tooling costs were the costs of any new equipment necessary to incorporate that design option into the water heater during the assembly process. The tooling costs represented the total cost of the tooling divided by the number of water heaters anticipated to be built with that tooling. Overhead included the general and administrative costs associated with manufacturing each design option.

The baseline model manufacturing costs were total costs. The manufacturing costs for the other design options were presented as incremental costs. The estimated uncertainty (at a 95% confidence level) for total incremental costs are provided for each design option. The total manufacturing cost is included as a separate column in Table A.1 and represents cumulative manufacturer cost for the combined design options.

For many design options, it was not possible to get disaggregated manufacturing costs. In some cases, only one or two manufacturers are currently producing that design option. They did not wish to reveal manufacturing costs because there would not be any way to preserve confidentiality. For some of these design options, factory costs were estimated from current retail prices, then reduced to reflect cost decreased due to increased production levels. For other design options, costs were obtained from suppliers to manufacturers. Where possible, estimates were made of disaggregated manufacturer costs. (See Table A.1.)

Table A.1 Disaggregated Manufacturer Costs for Gas-Fired Storage Water Heaters

Standard Level Number	Design Option Number	Description	Manufacturing Costs							Total 1990\$
			Material 1990\$	Labor 1990\$	Tooling 1990\$	Shipping 1990\$	Overhead 1990\$	Incremental 1990\$	Uncert 1990\$	
1	0	Baseline	64.00	5.50	1.13	1.00	24.00	95.63	1.00	95.63
	1	0 + Heat Traps	2.63	0.25	0.13	0.08	0.50	3.58	1.50	99.20
2	2	1 + Reduce Heat Leaks	1.00	0.53	0.20	0.00	0.18	1.90	0.19	101.10
3,4	3	2 + R-16 Insulation	10.82	0.38	0.15	0.63	0.75	12.72	1.00	113.82
	4	3 + Improve Flue Baffle,std						20.00	10.00	133.82
	5	4 + IID w/ Flue Damper	49.00	2.00	0.85	1.50	0.60	53.95	12.50	187.77
	6	3 + Submerged Combustion Chamber,std	-5.00		5.00			0.00	10.00	113.82
	7	6 + IID w/ Flue Damper	49.00	2.00	0.85	1.50	0.60	53.95	12.50	167.77
	8	3 + Improve Flue Baffle,side						60.00	25.00	173.82
	9	8 + IID	7.50	0.00	0.55	1.20	-0.40	8.85	4.00	182.67
	10	3 + Indirect Heating w/IID						154.11	50.00	267.93
	11	3 + Multiple Flues						51.48	5.00	165.30
7	12	3 + IID w/ Flue Damper	49.00	2.00	0.85	1.50	0.60	53.95	12.50	167.77
	13	3 + Submerged Combustion Chamber,side	35.00		5.00			40.00	20.00	153.82
5,6	14	3 + R-25 Insulation	7.88	0.11	0.64	0.75	1.00	10.38	2.00	124.20
	15	3 + Increase Baffling & Forced Draft,side	250.00	25.00	7.50	15.00	15.00	312.50	87.50	426.32
	16	3 + Increase Baffling & Forced Draft,std	250.00	25.00	7.50	15.00	15.00	312.50	87.50	426.32
	17	3 + IID & Power Vent	40.00	2.00	0.85	1.50	0.60	44.95	20.00	158.77
	18	3 + Vacuum Insulation						49.16	30.00	162.98
	19	0 + Tempering Tank						50.00	30.00	145.63
	20	0 + Submerged Combustion						197.70	50.00	293.33
	21	0 + Indirect w/IID & Plastic Tank						248.78	100.00	344.41
	22	0 + Directly Fired						233.65	100.00	329.27
	23	0 + TPV Generator						200.00	50.00	295.63
8	24	0 + Condense Fla Gases						358.23	100.00	453.86
	25	0 + Condensing Pulse	271.55	116.06	1.13	0.00		388.73	58.31	484.36

IID = Intermittent Ignition Device.

A.3 ENERGY CALCULATIONS FOR ELECTRIC STORAGE WATER HEATERS

The energy calculations for electric storage water heaters in this analysis were based on test conditions in the new DOE test procedure (176). This procedure calculated energy factor (EF), the ratio of the heat content of the water drawn to the heat content of the fuel used in a 24-hour period. The energy calculations for electric storage water heaters were based on average daily energy consumption (ADEC). The ADEC is the energy input to the water heater during the 24-hour simulated draw test. EF is the ratio of heat content of the water drawn during the test to the ADEC. Changes of efficiency caused by design options were changed to reductions in ADEC. These savings were subtracted from the ADEC of the previous design options. Any assumptions and intermediate calculations are also explained here.

Baseline Model (Design Option #0)

The EF of the base line model used in the analysis was 0.86. This was calculated to exactly match the standard for a 52-gallon electric water heater (177). The 1990 standard is the

following equation:

$$EF = 0.93 - (0.00132 * \text{Rated Volume})$$

For this analysis, measured volume was used instead of rated volume in the standard to be consistent with the test procedure.

Reduce Heat Leaks (Design Option #1)

Reducing heat leaks was estimated to save 0.7 kBtu/day (178).

Heat Traps (Design Option #2)

Heat traps were assumed to provide a savings of 9 watts per 50 °C on the hot water outlet and 7 watts per 50 °C on the cold water inlet, or 983 and 573 Btu/day respectively (179). The savings for both inlet and outlet heat traps were adjusted for the change in ambient temperature in the new test procedure for a total savings of 1.2 kBtu/day.

Add-On Heat Pump (Design Option #3)

The savings were estimated at 22.6 kBtu/day. The EF of 2.2 was for a currently available model of an add-on heat pump water heater (model #B108 manufactured by E-tech, Atlanta, GA) as listed in the GAMA directory (180). The EF was reduced by 25% to account for reductions due to the changes in the DOE test procedure for heat pump water heaters. This derating figure was an estimate based on a 15 to 20% reduction reported from a testing laboratory and a 30%

reduction reported by a simulation model (181) (182). Also, the EF in the GAMA data request was 27% lower than the lowest EF listed in their directory. The derating factor was applied to the EF before calculating the reduction in ADEC for this design option.

Third-Generation Heat Pump (Design Option #4)

The Electric Power Research Institute is currently developing a third-generation heat pump water heater. The efficiency goal is energy savings of 40%, presumably compared to a baseline water heater (183). This was calculated to be 19 kBtu/day.

Integral Heat Pump (Design Option #5)

This design option was based on an integral heat pump water heater currently on the market (model TS-HP-52 HR manufactured by DEC International, Therma-Stor Products Group). The EF of 3.2 was reduced by 25% (see design option #3) in anticipation of different results from the revised DOE test procedure (184). The incremental energy savings were calculated to be 17.9 kBtu/day. These savings have been reduced by the 0.8 kBtu/day to avoid double-counting heat trap savings. The existing model already has heat traps.

GAMA Heat Pump (Design Option #6)

The information from GAMA indicated a heat pump water heater could save 21.0 kBtu/day (185).

R-25 Insulation (Design Option #7)

The EFs from GAMA and the ADM report were converted to ADECs and then averaged. The savings were calculated to be 1.5 kBtu/day. This design option combined R-25 insulation with design option #3.

Vacuum Insulation (Design Option #8)

The 1.5 kBtu/day savings for this design option were estimated to be the same as for design option #7.

R-25 Insulation (Design Option #9)

The 1.5 kBtu/day savings for this design option were the same as for design option #7. This design option combined R-25 insulation with design option #2.

Off Peak (Design Option #10)

The average daily energy consumption was calculated as the combination of the recovery and storage energy consumption. The recovery energy consumption was the daily load divided

by a recovery efficiency of 0.98. The storage energy consumption was calculated by assuming tank temperature was 96.5 °F for 12 hours. This temperature is midway between inlet and setpoint temperatures. The time was from the fourth draw until the elements were assumed to re-energize, 8 hours before the end of the test. The tank temperature is assumed to be 135 °F for the remaining time less the time the elements were consuming electricity (2.7 hours).

The savings for this design option were calculated to be 1.7 kBtu/day.

Solar Pre-Heat (Design Option #11)

The estimated savings from solar pre-heat was the average savings for three different types of systems. The systems were a drainback system with low-cost plastic collectors using tap water as the working fluid (ASN II SKYLIGHT, by American Solar Network), a self-pumping system using methyl alcohol and water as the working fluid (COPPER CRICKET, by Sage Advance Corp.), and a more traditional collector system using an anti-freeze working fluid (SB56-225 Solar Boiler Solar System, by Thermo Dynamics Ltd.). The performance data were provided by the manufacturers.

Baltimore, MD, was chosen as the city that most closely approximates the population-weighted average climate of the United States (186). The solar savings for the Copper Cricket were calculated by Sage Advance using the Oregon Department of Energy "Quick Calc." This system has been certified by the Solar Rating and Certification Corporation according to the Solar Water Heating System Standard 200-82. According to this rating procedure, the system delivered 22,000 Btu/day of solar energy with a heat loss coefficient of 4.3 Btu/hr-°F. The energy savings were calculated to be 1945 (kWh/yr), or 18.19 (kBtu/day).

The solar fraction of 52% for the ASN II SKYLIGHT was provided by American Solar Network from results of F-Chart runs. This was equivalent to a savings of 21.35 (kBtu/day).

Savings data for the Solar Boiler were provided by the manufacturer. These were based on WATSUN 12.0 simulations for New York, then adjusted to savings in Baltimore, using ratios of savings in Baltimore to savings in New York for the other two systems. The annual savings were estimated to be 3,294 (kWh/yr) or 30.81 (kBtu/day).

The average reduction in ADEC for these solar pre-heat systems was 23.45 kBtu/day.

Tempering Tank (Design Option #12)

In the new DOE test procedure, the ambient temperature was specified to be 67.5° F and the inlet temperature was specified to be 58° F. This design option was assumed to increase the inlet water temperature to the ambient temperature. This is equivalent to increasing the inlet water temperature by 9.5° F. Raising the volume of water drawn during the test procedure 9.5° F would require 3.9 kBtu. This was the assumed savings for the tempering tank.

A.4 DISSAGGREGATED MANUFACTURER COSTS FOR ELECTRIC STORAGE WATER HEATERS

Cost data for the more common design options were mostly from information supplied by manufacturers to GAMA and a report prepared by ADM Associates, Inc. (187),(188). The cost data from GAMA was the midpoint of the range of costs reported by the manufacturers. This value was used to preserve the confidentiality of costs supplied by individual manufacturers. The manufacturing cost data from these two sources were supplied in several categories for each design option. These cost categories were material costs, labor, tooling, shipping, and overhead. Material costs covered both raw materials, such as sheet steel and paint, and parts, such as heating elements and thermostats. Labor included both direct and indirect labor costs. Tooling costs were the costs of any new equipment necessary to incorporate that design option into the water heater during the assembly process. The tooling costs represented the total cost of the tooling divided by the number of water heaters anticipated to be built with that tooling. Overhead included the general and administrative costs associated with manufacturing each design option.

The cost data for the baseline model was from the GAMA data only. These manufacturing costs are total costs for the baseline model. The manufacturing costs for the other design options were averaged with the cost data from the ADM report and were presented as incremental costs. The total manufacturing cost is included as a separate column in Table A.2 and represents cumulative manufacturer cost.

For many design options it was not possible to get disaggregated manufacturing costs. In some cases only one or two manufacturers are currently producing that design option. They did not wish to reveal manufacturing costs because there would not be any way to preserve confidentiality. For some of these design options, factory costs were estimated from current retail prices, then reduced to reflect cost decreased due to increased production levels. For other design options, costs were obtained from suppliers to manufacturers. (See Table A.2.)

Table A.2 Manufacturer Costs for Electric Storage Water Heaters

Standard Level Number	Design Option Number	Design Options	Manufacturer Costs							
			Material 1990\$	Labor 1990\$	Tooling 1990\$	Shipping 1990\$	Indrct 1990\$	Increment 1990\$	Uncert 1990\$	Total 1990\$
	0	Baseline	57.00	6.50	1.20	0.98	24.00	89.68	0.00	89.68
	1	0 + Reduce Heat Leaks	1.00	0.53	0.20	0.00	0.18	1.90	0.19	91.58
1	2	1 + Heat Traps	2.63	0.15	0.08	0.08	0.50	3.43	0.19	95.00
3	3	2 + Add On Heat Pump						196.50	19.65	291.50
	4	2 + 3rd Generation Heat						222.27	22.23	317.27
6,7,8	5	2 + Integral Heat Pump						579.74	86.96	674.74
	6	2 + Heat Pump (GAMA	500.00	60.00	5.50	11.50	75.00	652.00	65.20	747.00
4,5	7	3 + R-25 Insulation	6.75	0.11	0.64	0.75	0.75	9.00	0.45	300.51
	8	3 + Vacuum Insulation						56.66	30.00	348.16
2	9	2 + R-25 Insulation	6.75	0.11	0.64	0.75	0.75	9.00	0.45	104.01
	10	9 + Off Peak						48.79	7.32	152.80
	11	10 + Solar Pre-Heat						980.63	125.85	1133.43
	12	0 + Tempering Tank						50.00	25.00	139.68

A.5 DISAGGREGATED MANUFACTURER COSTS FOR OIL-FIRED STORAGE WATER HEATERS

Cost data for most design options were from a report prepared by ADM Associates, Inc. (189). The manufacturing cost data were supplied in several categories for each design option. These cost categories were material costs, labor, tooling, shipping, and overhead. Material costs covered both raw materials, such as sheet steel and paint, and parts, such as heating elements and thermostats. Labor included both direct and indirect labor costs. Tooling costs were the costs of any new equipment necessary to incorporate that design option into the water heater during the assembly process. The tooling costs represented the total cost of the tooling divided by the number of water heaters anticipated to be built with that tooling. Overhead included the general and administrative costs associated with manufacturing each design option.

The cost data for the baseline model were total costs. The total manufacturing cost is included as a separate column in Table A.3 and represents cumulative manufacturer cost.

Table A.3 Manufacturer Costs for Oil-Fired Storage Water Heaters

Standard Level Number	Design Option Number	Description	Manufacturing Costs							Total 1990\$
			Material 1990\$	Labor 1990\$	Tooling 1990\$	Shipping 1990\$	Indirect 1990\$	Increment 1990\$	Uncert 1990\$	
	0	Baseline	112.68	34.93	1.13	11.27		160.00	0.00	160.00
1	1	0 + 1-in foam	3.18	0.00	1.13	0.00		4.31	0.43	164.31
	2	0 + 1.5-in fiberglass	4.77	0.00	1.13	0.00		5.90	0.59	165.90
	3	1 + Heat Traps	2.63	0.25	0.13	0.08	0.50	3.58	0.29	167.88
2	4	3 + Reduce Heat Leaks	1.00	0.53	0.20	0.00	0.18	1.90	0.19	169.78
	5	4 + 2-in foam	7.63	0.38	0.15	0.63	0.75	9.53	0.95	179.31
3,4	6	5 + Flue Damper	15.00	3.82	0.15	0.15	1.00	20.12	5.03	199.43
5,6,7	7	6 + Multiple Flues	41.69	10.14	1.13	0.00		52.96	5.30	252.39
8	8	0 + Condensing Pulse	276.06	116.06	2.25	0.00		394.37	59.15	554.37

APPENDIX B. LBL-REM INPUT DATA: WATER HEATERS

The complete input listing is available on electronic medium in ASCII format. The input database includes demographic, economic, and engineering data.

The following is the regular LBL-REM input for water heaters.

For standards cases, simply replace the input values for two variables in each class of each product regulated. The two variables are labelled: "first year for standard" and "UEC of standard." For example, for water heater standards taking effect in 1996, change the lines "first year for standard = 2031" to "first year for standard = 1996" and enter the appropriate maximum UEC values in the lines "UEC of standard" for each class.

WATER HEAT

total saturation = 1.00
elec price multiplier = 0.90
gas price multiplier = 0.98
ncalc = 2
ndr1 (1, read drate & curve) = 1
nv1 (# of eun inputs) = 2
nv5 (# of cap inputs) = 0
nv2 (# of peq inputs) = 0
nv4 (# of usage inputs) = 1
ndis (year to forecast eff) = 11

----- UEC of stock unit in base year by fuel type i (MMBTU/yr) -----

1	2	3	4	5	
62.1290	30.8361	30.8361	30.8361	62.1290	** SF **
62.1290	30.8361	30.8361	30.8361	62.1290	** MF **
62.1290	30.8361	30.8361	30.8361	62.1290	** MB **

----- Purchase price of a reference unit (\$1990) -----

1	2	3	4	5	
265.31	288.38	724.66	281.60	265.31	** SF **
265.31	288.38	724.66	281.60	265.31	** MF **
265.31	288.38	724.66	281.60	265.31	** MB **

----- Relative UEC and Capacity of a reference unit to a stock unit -----

1	2	3	4	5	
0.9433	0.8922	0.9184	0.8922	0.9433	** re **
1.00	1.00	1.00	1.00	1.00	** recap**

----- Base Year Saturations - c70 -----

1	2	3	4	5	6	
0.343	0.597	0.045	0.000	0.000	0.015	** SF **

0.182	0.240	0.121	0.408	0.045	0.004		** MF **
0.590	0.403	0.005	0.000	0.000	0.002		** MB **

----- Marginal Saturations for Replacement Units - cn(m=1) -----

1	2	3	4	5	6	
0.380	0.570	0.040	0.000	0.000	0.010	** SF **
0.175	0.255	0.095	0.385	0.070	0.020	** MF **
0.635	0.325	0.010	0.000	0.000	0.030	** MB **

----- Marginal Saturations for New Houses - cn(m=2) -----

1	2	3	4	5	6	
0.600	0.380	0.020	0.000	0.000	0.000	** SF **
0.426	0.164	0.020	0.336	0.054	0.000	** MF **
0.790	0.210	0.000	0.000	0.000	0.000	** MB **

----- Historical Shipments (from 1980 to 30 years back) -----

1 Electric Water Heaters

2.451	2.662	2.684	2.704	2.618	2.183	2.487	2.591	2.265	1.922
1.684	1.549	1.291	1.634	1.574	1.503	1.385	1.425	1.525	1.455
1.397	1.414	1.375	1.272	1.185	1.117	1.270	1.345	1.040	1.291

2 Gas Water Heaters

2.818	2.887	2.921	3.070	3.112	2.645	2.569	3.080	3.163	3.088
2.785	2.742	2.284	2.892	2.785	2.659	2.451	2.522	2.698	2.575
2.472	2.503	2.433	2.251	2.098	1.977	2.247	2.380	1.841	2.284

3 Oil Water Heaters

.6780	.5980	.5630	.5720	.6030	.6000	.5470	.5020	.4920	.4970
.4380	.4160	.4350	.4440	.4270	.4080	.3760	.3870	.4140	.3950
.3790	.3840	.3730	.3450	.3220	.3030	.3450	.3650	.2820	.3500

4 Gas Water Heaters (Common, assumed same as individual)

2.818	2.887	2.921	3.070	3.112	2.645	2.569	3.080	3.163	3.088
2.785	2.742	2.284	2.892	2.785	2.659	2.451	2.522	2.698	2.575
2.472	2.503	2.433	2.251	2.098	1.977	2.247	2.380	1.841	2.284

5 Electric Water Heaters (Common, assumed same as individual)

2.451	2.662	2.684	2.704	2.618	2.183	2.487	2.591	2.265	1.922
1.684	1.549	1.291	1.634	1.574	1.503	1.385	1.425	1.525	1.455
1.397	1.414	1.375	1.272	1.185	1.117	1.270	1.345	1.040	1.291

----- Retirement Function (from age 1 to 30 years) -----

for i 1 5

0.0000	0.0000	0.0000	0.0000	0.0004	0.0024	0.0110	0.0398	0.1156	0.2530
0.3463	0.2037	0.0275	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

for i 2 4

0.0000	0.0252	0.0339	0.0404	0.0452	0.0487	0.0511	0.0524	0.0529	0.0526
0.0517	0.0504	0.0485	0.0463	0.0439	0.0413	0.0386	0.0358	0.0330	0.0303
0.0276	0.0250	0.0227	0.0203	0.0182	0.0161	0.0143	0.0126	0.0111	0.0097

for i 3

.0000	.0000	.0000	.0003	.0020	.0081	.0246	.0602	.1219	.1995
.2477	.2091	.1019	.0229	.0018	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

----- Average Life Times (by fuel type i) -----

1	2	3	4	5
10.10	13.86	11.0	13.86	10.10

----- Operating Cost Elasticities (for 5 fuel types and income) -----

1	2	3	4	5	6	
-0.50	0.20	0.20	0.00	0.00	0.00	** j=1 **
0.20	-0.35	.275	0.00	0.00	0.00	** j=2 **
.125	0.10	-0.50	0.00	0.00	0.00	** j=3 **
0.00	0.00	0.00	-0.35	0.00	0.00	** j=4 **
0.00	0.00	0.00	0.00	-0.50	0.00	** j=5 **
0.00	.175	0.00	0.00	0.00	-.975	** j=6 **

----- Real Interest Rate for calc of Price Elast. (for 5 fuel types) -----

1	2	3	4	5	
0.12	0.15	0.15	0.00	0.00	** j=1 **
0.15	0.12	0.15	0.00	0.00	** j=2 **
0.15	0.15	0.12	0.00	0.00	** j=3 **
0.00	0.00	0.00	0.12	0.00	** j=4 **
0.00	0.00	0.00	0.00	0.12	** j=5 **

----- Usage Elasticities (for 5 fuel types and income) -----

1	2	3	4	5	
-0.25	0.00	0.00	0.00	0.00	** j=1 **
0.00	-0.25	0.00	0.00	0.00	** j=2 **
0.00	0.00	-0.25	0.00	0.00	** j=3 **
0.00	0.00	0.00	-0.25	0.00	** j=4 **
0.00	0.00	0.00	0.00	-0.25	** j=5 **
0.05	0.05	0.05	0.05	0.05	** j=6 **

----- Discount Rates for Replacement Units (m=1) -----

1	2	3	4	5	
1.9600	0.6260	0.7860	2.0000	2.0000	** SF **
1.5020	0.4770	0.6020	2.0000	2.0000	** MF **
1.6480	0.5220	0.6600	2.0000	2.0000	** MB **

----- Discount Rates for New Units (m=2) -----

1	2	3	4	5	
1.9600	0.6260	0.7860	2.0000	2.0000	** SF **
1.5020	0.4770	0.6020	2.0000	2.0000	** MF **
1.6480	0.5220	0.6600	2.0000	2.0000	** MB **

----- Cost-Efficiency Curve Parameters -----

1	2	3	4	5	
0.7760	0.5772	0.7010	0.5772	0.7760	** einf **
10.5477	3.8910	6.3870	3.8910	10.5477	** calfa **

----- Historical Relative Energy Use (eun) for New Units -----

i	1	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
4	0	1.1270	1.1224	1.1179	1.1134	1.1089	1.1044	1.0763	1.0496	1.0242	1.0000
5	0	1.0747	1.0673	1.0599	1.0526	1.0435	1.0344	1.0256	1.0170	1.0084	1.0000

----- Historical Usage Factors for Existing Units -----

i	1	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

of products in water heater= 3

product type id# = 7
 product name = EWH (Electric WH)
 end-use id# = 4
 fuel type id# = 1
 number of classes = 1

----- the 1st class -----

class id# = 31
 class name = Std (Standard Electric WH)
 discount rate = 1.91
 first year to forecast UEC = 1990
 first year for standard = 2031
 UEC of standard = 5080.6
 conversion (Kwh-MMBTU&usage) = .0034^{1/2}

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
.8188	.8245	.8303	.8360	.8433	.8507	.8580	.8653	.8727	.8800

----- Adjusted volumes (1981-2030) (64.3 gal/day * 77 degF * 8.2928 Btu/degF/gal / 3412Btu/kWh)

12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336
12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336
12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336	12.0336
12.0336	12.0336	12.0336	12.0336	12.0336					

----- Fraction of market share (1981-2030)

1 = 1 2 3

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	Kwh
265.31	5096.2
268.00	5024.3
272.16	4899.5
307.35	4736.9
626.67	2479.3
659.69	2316.7
1099.62	1730.8

----- Shipment Distribution

Eff	Units
0.7400	1.0
0.7600	1.0
0.7800	9.0
0.8000	2.0
0.8700	18.0
0.8800	97.0
0.8900	56.0
0.9000	90.0
0.9100	14.0
0.9200	40.0
0.9300	25.0
0.9400	54.0
0.9500	18.0
0.9600	33.0
0.9700	9.0

```
=====
product type id#      = 8
product name         = GWH (Gas WH)
end-use id#          = 4
fuel type id#         = 2
number of classes     = 2
```

----- the 1st class -----

```
class id#            = 32
class name           = Std (Gas WH, Storage)
discount rate        = 0.37
first year to forecast UEC = 1990
first year for standard = 2031
UEC of standard      = 27.55
conversion (usage)   = 1.000
```

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
.4880	.4900	.4920	.4940	.4960	.4980	.5110	.5240	.5370	.5500

----- Adjusted volumes (1981-2030) (64.3 gal/day * 77 degF * 8.2928 Btu/degF/gal * 1.e-6)

```
.041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058
.041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058
.041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058 .041058
.041058 .041058 .041058 .041058 .041058
```

----- Fraction of market share (1981-2030)

```
l = 1 2 3
0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99
0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99
0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99
0.99 0.99 0.99 0.99 0.99
```

----- UEC (MMBTU) & Purchase Price (\$1990) data

Price	MMBTU	Elec
281.60	27.55	0.000
286.72	27.22	0.000
288.95	27.07	0.000
305.65	26.31	0.000
341.20	26.02	0.000
390.15	23.37	0.471
1183.40	17.01	0.418

----- Shipment Distribution

Kwh	Units
0.4600	25.0
0.4700	19.0
0.4900	24.0
0.5300	2.0
0.5400	160.0
0.5500	339.0
0.5600	326.0
0.5700	65.0
0.5800	115.0
0.5900	35.0
0.6000	55.0
0.6100	25.0
0.6200	70.0
0.6300	13.0
0.7200	6.0
0.7400	4.0

----- the 2nd class -----

class id# = 33
class name = Inst (Gas WH, Instantaneous)
discount rate = 0.14
first year to forecast UEC = 1990
first year for standard = 2031
UEC of standard = 24.07
conversion (usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
.6200	.6200	.6200	.6200	.6200	.6200	.6200	.6200	.6200	.6200

----- Adjusted volumes (1981-2030) (64.3 gal/day * 77 degF * 8.2928 Btu/degF/gal * 1.e-6)

.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058					

----- Fraction of market share (1981-2030)

1 = 1 2 3

0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01					

----- UEC (MMBTU) & Purchase Price (\$1990) data

Price	MMBTU	elec
959.66	24.07	0.000
1094.02	18.88	0.307
1162.29	18.24	0.319
2322.08	15.64	0.316

----- Shipment Distribution

Kwh	Units
0.6194	1.0

```
=====
product type id#      = 9
product name         = OWH (Oil WH)
end-use id#          = 4
fuel type id#         = 3
number of classes     = 2
```

----- the 1st class -----

```
class id#            = 34
class name            = Indv (Oil WH, Storage)
discount rate         = 1.24
first year to forecast UEC = 1990
first year for standard = 2031
UEC of standard       = 28.23
conversion (usage)    = 1.000
```

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
.4880	.4900	.4920	.4940	.4960	.4980	.5110	.5240	.5370	.5500

----- Adjusted volumes (1981-2030) (64.3 gal/day * 77 degF * 8.2928 Btu/degF/gal * 1.e-6)

.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058					

----- Fraction of market share (1981-2030)

1 = 1 3

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00					

l = 2

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00					

----- UEC (MMBTU) & Purchase Price (\$1990) data

Price	MMBTU	
724.66	28.23	0.0867
738.55	25.71	0.0790
745.49	25.12	0.0772
758.25	24.87	0.0764
785.99	23.78	0.0731
857.21	22.11	0.0679
991.68	21.39	0.0657
2241.08	19.01	0.0584

----- Shipment Distribution

Eff	Units
0.5281	1.0

----- the 2nd class -----

class id#	= 35
class name	= Com (Common Oil WH)
discount rate	= 1.24
first year to forecast UEC	= 1990
first year for standard	= 2031
UEC of standard	= 28.23
conversion (usage)	= 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
.4880	.4900	.4920	.4940	.4960	.4980	.5110	.5240	.5370	.5500

----- Adjusted volumes (1981-2030) (64.3 gal/day * 77 degF * 8.2928 Btu/degF/gal * 1.e-6)

.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058	.041058
.041058	.041058	.041058	.041058	.041058					

----- Fraction of market share (1981-2030)

l = 1 3

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00					

l = 2

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00					

----- UEC (MMBTU) & Purchase Price (\$1990) data

Price	MMBTU
-------	-------

724.66	28.23 0.087
--------	-------------

----- Shipment Distribution

Eff	Units
-----	-------

0.5281	1.0
--------	-----

APPENDIX C. LBL MANUFACTURER IMPACT MODEL: WATER HEATERS

C.1 INTRODUCTION

The Lawrence Berkeley Laboratory Manufacturer Impact Model (LBL-MIM) collects all the calculations necessary to determine the impact of a change in appliance efficiency standards on an industry's profitability and scale of operation into one spreadsheet. Volume A, Appendix C of this Technical Support Document, provides an overview and description of the LBL-MIM. There is a description of the economic theory and a discussion of each of the model's modules. In this appendix, the LBL-MIM input data and model runs for the analysis of water heaters are described together.

C.1.1 Engineering Cost Data

The source of the engineering data is the Engineering Analysis performed in Chapter 1 of this volume. The data came from manufacturers of these products and/or discussions with industry consultants and other studies. The engineering data used as inputs to the model consist of several components:

1. The incremental unit variable cost incurred by the manufacturer for each of the design options such as raw materials, direct labor, purchased parts, and increased transportation costs, that increases the efficiency of the appliance. The incremental variable cost is listed for each design option for each product class.
2. The annual unit energy consumption (UEC) associated with each design option for each product class.
3. Some of the design options also require additional capital investment in the form of retooling, new tooling, or other capital expenditures. These expenses are listed as one figure for each design option requiring capital expenditures; the single figure covers all of the product classes.

The engineering input data are also listed for each standards level being analyzed (a 1990 calibration case, a 1996 base case using the 1990 standards, and standards levels 1, 2, 3, etc., which are the new levels being analyzed). The figures used are exactly the same as those used for the design options, but are calculated for standards levels instead. The engineering data used as inputs to the LBL-MIM are listed on the engineering data page of the model, which follows this section. The actual data are listed there rather than here since there are several tables of data. For a thorough description of the collection and meaning of the engineering data, see the Engineering Analysis.

C.1.2 Industry Market Data

Industry Shipments

These data include annual industry shipments for the 1990 calibration case, the 1996 base case (using the 1990 standards), and the 1996 shipments for each of the standards levels. The 1990 shipments figure is based on data from the Gas Appliance Manufacturers Association (GAMA) (190).

Elasticities

Price and operating cost elasticities determine the effect on shipments of changes in appliance price and operating cost. For water heaters, the price elasticity is estimated to be -0.12. The consumer discount rate is estimated to be 106.3%, which gives an operating cost elasticity of -0.27. The source is LBL.

Product Class Market Share

Each of the product classes has a share of the total water heater market, and the market share, or unit sales, for each product class is an input to the model. For water heaters, the market shares range from less than 1% for oil-fired and instantaneous water heaters to just over 50% for gas-fired water heaters. Source of the data is the GAMA publication noted earlier.

Markups

Manufacturers charge different markups over variable cost for different product classes, resulting in different profit margins for different product classes. For water heaters, the estimated markups range from 1.35 for an electric storage model to 2.06 for an instantaneous water heater.

Initial prices

The 1990 baseline manufacturer's selling price is used as a base to which are added incremental costs of reaching the higher efficiency levels. The unit price quoted for each product class refers to the most inexpensive, fewest-frills model produced by the manufacturer. The source of the baseline manufacturer's price for each product class is research by the Manufacturer Analysis team with review by industry consultants.

Energy price

This figure is the ratio of the price of a 1990 kWh to a 1996 kWh. The source is the LBL-REM. Industry market data appear on the Cost, Sales, and Revenues page of the model.

C.1.3 Financial Input Data

Financial Inputs

The financial inputs for water heaters are summarized in Tables C.1 to C.4.

Table C.1 Rates of Financial Costs

Variable	Value	Source
After-tax equity cost of capital ¹	6.8%	MIM calc. from public financial data ²
Interest rate on debt ¹	2.5%	MIM calc. from public financial data
Interest lost in cash ¹	1.0%	MIM calc. from public financial data
Rate of depreciation	17.7%	Public financial data
Tax rate	34.0%	Tax law

¹Cost of capital and interest rate are *real* rather than nominal.

²Public financial data include data from sources such as Value Line, Standard and Poor's, Moody's, individual company annual reports, and economic reports.

Table C.2 Other Financial Inputs

Variable	Value	Source
Cash	2.5%	Public financial data
Inventory and receivables	29.8%	Public financial data
Net depreciable assets	23.1%	Public financial data
General and administrative expenses	12.9%	Public financial data
Engineering expense	1.2%	Public financial data and industry sources ¹

¹Industry sources include consultants under contract to LBL and discussions with industry representatives.

Table C.3 Fixed, Variable, and Revenue-Related Cost Split

Variable	Value	Source
Fixed part of costs and depr. assets	8.5%	Industry sources
Fixed part of one-time capital costs	11.1%	Industry sources
Economic profit	-6.5%	MIM est. from financial data
Debt/equity ratio	67.3%	Public financial data
Markup on typical model	1.38	Industry sources
Ratio of highest to lowest markup	3.00	Industry sources

Table C.4 One-Time Costs

Variable	Value	Source
One-time capital cost's life	8 years	Industry sources
One-time capital cost's tax life	8 years	MIM calculation
Percent additional 1-X capital	50%	MIM estimate
Age of replaced capital	6 years	Public financial data

The expenditure schedule above lists the costs incurred over time for preparations to meet the new standards. A percentage of the total cost is attributed to each year before the standards go into effect since that is when these expenses will occur.

C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO

Table C.5 Water Heaters Version of MIM

Control Panel

WATER HEATERS CONTROL FACTORS	Scenario: Primary		Standard Level = 1		
	Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity	-0.120	0.00	100%	-0.120	IPE
Consumer Discount Rate	106.30%	0.00	100%	106.30%	RD
Equity Cost of Capital	0.068	0.00	10%	0.068	ECC
Economic Profit	-0.065	0.00	1%	-0.065	EP
L-R Fixed Part of Costs & Assets	0.085	0.00	50%	0.085	FCA
L-R Fixed Part of 1-X Cap. Cost	0.111	0.00	60%	0.111	FIX
One-Time Capital Costs	3.718	0.00	20%	3.718	CC.N
Unit Variable Cost Increase	\$15.09	0.00	30%	15.088	dVC.N
Elasticity Curve Parameter	0.000	0.00	5%	0.000	ro.N
Short Run Price Response to Demand	0.157	0.00	76%	0.157	SRPR
	NAECA	NEW		PRVIOUS	NEW
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments	1.43	1.43	0.04%	0.03%	1.43
Price	\$131.82	\$132.13	0.24%	0.27%	\$132.01
Revenue (in \$M)	187.89	188.41	0.27%	0.31%	188.26
Net Income	0.21	0.21	0.00	0.00	-0.10
ROE	0.37%	0.37%	0.00%	-0.02%	-0.18%
			Trys =	2.00	

Table C.6. Water Heaters Version of MIM

The Monte Carlo Module

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.						
				Seconds/iteration =	1.35	time
				Iterations to go =	0.00	nn
WATER HEATERS				Sample Size =	40.00	
	%dQ	%dP	%dR	dNI	dROE.N	dROE.S
Value	2.77%	-2.57%	0.13%	34.34%	0.62%	0.08%
Means	0.01%	1.74%	1.69%	3.37%	0.06%	-0.75%
Std. Dev	1.07%	6.95%	5.77%	13.36%	0.24%	2.05%
	0.03	-0.03	0.00	0.34	0.01	0.00
	0.00	0.00	0.00	0.01	0.00	0.00
	0.00	-0.06	-0.05	-0.07	0.00	-0.01
	-0.01	0.06	0.05	0.03	0.00	0.00
	0.01	-0.01	0.00	-0.02	0.00	0.00
	0.00	-0.02	-0.01	0.02	0.00	0.00
	0.00	0.00	0.00	-0.08	0.00	-0.02
	0.01	-0.02	-0.01	0.02	0.00	0.00
	-0.01	0.05	0.04	-0.03	0.00	0.00
	0.00	-0.01	0.00	0.02	0.00	0.01
	-0.01	0.08	0.06	0.08	0.00	0.00
	0.01	-0.03	-0.02	0.10	0.00	0.00
	0.00	0.02	0.02	0.02	0.00	0.00
	-0.02	0.07	0.05	-0.08	0.00	0.00
	0.00	-0.02	-0.02	-0.04	0.00	0.00
	0.01	-0.01	-0.01	0.01	0.00	-0.01
	0.00	0.06	0.06	0.49	0.01	0.00
	0.00	0.00	0.00	-0.05	0.00	-0.03
	0.00	-0.04	-0.04	-0.16	0.00	-0.01
	0.01	-0.02	-0.01	0.09	0.00	0.00
	0.00	0.00	0.00	-0.07	0.00	-0.01
	-0.01	0.11	0.11	0.25	0.00	0.00
	0.00	-0.01	0.00	0.03	0.00	-0.01
	0.00	0.04	0.04	0.03	0.00	0.00
	0.00	0.00	0.00	0.02	0.00	0.00
	0.00	-0.01	-0.01	-0.03	0.00	0.01
	0.00	0.05	0.04	0.01	0.00	-0.01
	0.00	0.01	0.01	0.00	0.00	-0.01
	0.00	0.07	0.06	-0.04	0.00	0.00
	0.00	-0.02	-0.02	-0.13	0.00	-0.01
	0.00	0.02	0.02	0.12	0.00	-0.02
	0.01	-0.01	0.00	0.06	0.00	0.00
	0.00	-0.03	-0.03	-0.07	0.00	0.00
	0.00	0.02	0.02	0.01	0.00	0.00

Table C.7 Water Heaters Version of MIM

The Accounting Module

ACCOUNTING SUMMARY		WATER HEATERS		
(All units are millions or millions of \$ unless labeled with \$ or %.)				
	1990	BASE '96	NEW '96	CHANGE
Revenue	167.23	187.89	188.41	0.3%
Expenses				
Cost of Goods Sold	121.86	142.16	142.66	0.3%
Selling & G & A	34.02	33.88	33.89	0.0%
Engineering	3.17	3.15	3.15	0.0%
Depreciation	7.03	7.03	7.03	NA
1-X Depreciation	0.00	0.45	0.46	NA
Total Expenses	166.07	186.67	187.19	0.3%
Earnings Before Interest & Taxes	1.16	1.21	1.20	-0.1%
Interest	0.91	0.87	0.87	0.1%
Earnings Before Taxes	0.25	0.34	0.34	-0.5%
Taxes	0.09	0.22	0.23	1.3%
Net Income	0.17	0.12	0.11	-3.8%
Gross Margin	27.13%	24.34%	24.28%	-0.22%
Return on Sales	0.10%	0.06%	0.06%	-4.1%
Total Assets	92.63	93.08	93.15	0.1%
Return on Assets (w/intrst taxed)	0.82%	0.74%	0.73%	0.0
Equity	55.37	55.64	55.68	0.1%
Return on Equity	0.30%	0.21%	0.20%	0.0
ECONOMIC ANALYSIS				
	1990	BASE '96	NEW '96	CHANGE
INCOME				
Shipments	1.43	1.43	1.43	0.0%
Price	\$116.59	\$131.82	\$132.13	0.2%
Revenue	167.23	187.89	188.41	0.3%
EXPENSE (W/ INTEREST)				
Fixed Costs	14.15	14.15	14.15	-9.2%
Variable Costs (w/ Q)	152.82	172.94	20.18	-11.5%
	20			
Total Expenses	0.00	0.00	0.00	-10.9%
ASSETS				
Cash	4.21	4.19	4.19	-10.8%
Inventories	49.77	49.46	49.47	0.0%
Depreciable	-860.14	-826.38	-732.33	-11.4%
Total Assets	92.63	93.08	93.15	0.1%

Table C.8 Water Heaters Version of MIM

The Engineering Inputs Module

Increment in Additional UVC by Level and Class																										
Base	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Elec	81	2	3	189	213	557	624	8	54	8	47	941	48													
Gas	87	3	2	12	130	53	-5	53	189	8	280	160	53	35	9	301	301	44	138	141	285	334	319	287	440	388
Oil	139	3	5	3	2	9	20	52	392																	
Inst	244	33	47	345	647	768																				
VCS Additional UVC. (Above Level 0 cost). Lots of Branches																										
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0	2	5	193	218	561	629	202	248	13	60	1001	48	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	3	5	17	147	200	12	65	186	194	277	178	70	52	27	318	318	61	175	141	285	334	319	287	440	388
2	0	3	5	6	8	17	37	89	392	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	33	81	345	647	768	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KWH Electricity Consumption in Kw Hrs /Yr																										
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Elec	5096	502	490	2479	2867	1731	2655	231	2317	473	456	2053	467	0	0	0	0	0	0	0	0	0	0	0	0	0
		4	0					7		7	0		7													
Gas	0	0	0	0	0	137	0	137	125	132	113	0	138	127	0	30	30	136	0	0	356	111	356	0	122	97
Oil	25	23	23	23	22	21	20	19	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inst	0	90	93	93	93	93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas and Oil Consumption in MBTU/Yr																										
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Gas	28	27	27	26	23	21	24	21	22	22	22	25	23	23	26	22	22	24	26	26	15	20	15	23	17	18
Oil	28	26	26	25	25	24	22	21	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Instant	24	19	18	16	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating Costs: Kwhrs and MBTUs converted to \$																										
KWSE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Electric	422	416	406	205	237	143	220	192	192	392	378	170	387	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	166	164	163	159	136	135	142	138	145	141	140	153	152	151	157	137	137	155	138	154	123	129	123	141	113	116
Oil	211	192	194	187	186	177	165	160	142	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Instant	145	121	118	107	102	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capital cost / unit / 7																										
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Electric	8	0	0	8	9	23	28	1	2	1	2	39	2													
Gas	8	0	0	0	4	1	5	1	5	0	8	5	1	5	1	12	12	1	5	4	9	10	10	9	14	1
Oil	1	1	1	0	0	0	0	1	2																	
Instant	43	6	8	61	114	136																				

Table C.8 Water Heaters Version of MIM

The Engineering Inputs Module (Continued)

CC.E	Additional CC./7 (Above Level 0 cost.): Lots of Branches																									
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	0	0	0	8	9	24	28	9	11	1	3	43	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	1	5	6	6	7	6	7	9	6	2	6	2	13	13	2	6	4	9	10	10	9	14	1
2	0	1	1	1	2	2	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	6	14	61	114	136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ADDC C.E	Additional CC *7: Lots of Branches																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Elect	0	2	3	58	66	166	199	64	74	9	23	298	14	0	0	0	0	0	0	0	0	0	0	0	0	0
Gas	0	2	4	6	34	42	41	49	43	46	63	41	14	41	13	90	90	14	41	31	62	72	69	62	95	8
Oil	0	8	8	10	12	14	17	25	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inst	0	41	100	426	799	949	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCEE.E	0	53	115	500	910	1171	258	138	133	55	86	339	28	41	13	90	90	14	41	31	62	72	69	62	95	8

Table C.9 Water Heaters Version of MIM

The Standards Level Module

Levl'n prev	LEV.B	lev.N	Eng:	0 ...	35	"Rmax				
-1	0	1	REM:	-1 ...	8	"Smax				
1	1	1	1 ==> Stndrds	0 ==> Eng.						
SIE	SIE.B	SIE.N	Esc = QUIT							
VCS.R	Additional UVC by Level and Class. (Above Base cost.)									
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6	7	8
Electric	3.12	8.97	9.71	14.38	193.49	201.63	561.39	561.39	561.39	201.63
Gas	6.72	29.37	29.37	29.64	32.71	37.18	37.18	72.73	440.24	32.71
Oil	0.48	3.18	3.18	8.13	36.95	88.78	88.78	88.78	392.11	36.95
Instant	0.00	33.48	33.48	33.48	33.48	33.48	33.48	80.80	646.58	33.48
KWS.R	Kw Hrs /Yr									
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6	7	8
Electric	414	401	399	391	205	192	143	143	143	192
Gas	164	158	158	158	157	156	156	152	113	157
Oil	208	192	192	186	165	160	160	160	142	165
Instant	145	121	121	121	121	121	121	118	102	121
CC.R										
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6	7	8
Electric	0.33	0.84	0.90	1.39	8.34	9.20	23.67	23.67	23.67	9.20
Gas	0.34	1.37	1.37	1.40	1.49	1.94	1.94	2.01	13.62	1.49
Oil	0.17	1.13	1.13	1.65	2.48	3.61	3.61	3.61	2.25	2.48
Instant	0.00	5.91	5.91	5.91	5.91	5.91	5.91	14.26	114.10	5.91
ADDITIONAL CAPITAL COST *7 (Calibration Case Shipments Weights)										
ADDC.R	-1=1990	0=1996	1	2	3	4	5	6	7	8
Electric	2.29	5.90	6.30	9.76	58.36	64.41	165.67	165.67	165.67	64.41
Gas	2.38	9.59	9.59	9.79	10.45	13.56	13.56	14.08	95.31	10.45
Oil	1.18	7.89	7.89	11.58	17.35	25.24	25.24	25.24	15.77	17.35
Instant	0.00	41.36	41.36	41.36	41.36	41.36	41.36	99.81	798.72	41.36
CCEE.R (Calibration Case Shipments Weights)										
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6	7	8
Cumltv CC	0	0	5	5	5	61	71			
	5.85	64.74	65.13	72.49	127.52	144.56	245.83	304.80	1075	133.56
	Base	NS			Base	NS		Weighted		
	Wgt d	Wgt d			Wgt dP	Wgt dP		Op Cost		
Electric	1.08	1.21			2.71	3.07		186.03		
Gas	2.47	2.46			12.01	11.96		89.43		
Oil	0.02	0.02			0.01	0.01		0.85		
Instant	0.04	0.04			0.05	0.05		0.20		
	3.60	3.72			14.78	15.09		276.51		
	CC.B0	CC.N0			dVC.B0	dVC.N0		F		

Table C.10 Water Heaters Version of MIM

The Costs, Sales, and Revenue Module

							bb	0
							aa	314
Ratio of highest to lowest markup:				ratio.0	3.00		ratio.cv	0.20
Typical markup over UVC				mid.0	0.38		mid.cv	0.20
Size of firm as % of industry				size.0	0.20			
CALIBRATION CASE (1990)								
	Indst	Relative	Firm					
	Shipments	Shipments	Ship.	Price	Rev.			Weighted
		Q%	Q.1	P.1/Range	R.1	m.1	UVC.1	"UVC
Electric	3.23	0.45	0.65	111.35	71.85	1.35	82.25	37.00
Gas	3.91	0.54	0.78	119.60	93.43	1.38	86.67	47.20
Oil	0.03	0.00	0.01	217.65	1.28	1.69	128.65	0.53
Instant	0.01	0.00	0.00	333.86	0.67	2.06	161.96	0.23
	-----	-----	-----	-----	-----	-----	-----	-----
TOTAL S	7.17	20.00%	1.43	\$117	167.23	1.37	20.00%	84.96
	"TS.0	"Q.CV	Q.0	P.0	R		"P.CV	UVC
BASE CASE (1996)								
	Rule-of-	Rule-of-		Op Cost	Weightd			
	Thb d P	Thb Price	Pi.B	Ratio	OpCat-R	Qi.B	Ri.B	
Electric	8.54	79.32	48.23	\$119.17	0.97	0.45	0.66	78.84
Gas	32.52	114.95	799.35	\$141.60	0.96	0.51	0.76	107.00
Oil	6.01	1.37	0.22	\$223.31	0.92	0.00	0.01	1.37
Instant	79.83	0.81	12.44	\$350.25	0.84	0.00	0.00	0.68
	-----	-----	-----	-----	-----	-----	-----	-----
	0.01	196.45	860.24	\$131.82	187.89	-0.03	1.43	187.89
	Alpha.B	Sum P (2)	Sum (3)	"P.B	Sum(Ri)	OC%.B0	"Q.B	"R.B
				check=R.B.				
NEW STANDARDS CASE (1996)								
	Rule-of-	Rule-of-		% Chng	Weightd			
	Thb d P	Thb Price	Pi.N	Op Cost	OpCat-R	Qi.N	Ri.N	
Electric	9.61	80.46	61	\$120.0	0.96	0.45	0.67	79.85
Gas	32.53	114.48	796	\$141.5	0.96	0.51	0.75	106.49
Oil	6.01	1.39	0	\$223.3	0.92	0.00	0.01	1.39
Instant	79.84	0.81	12	\$349.7	0.84	0.00	0.00	0.68
	-----	-----	-----	-----	-----	-----	-----	-----
TOTAL	0.01	197.14	870	132.1	188.41	-0.04	1.4259	188.41
	Alpha.N	Sum P (2)	Sum (3)	"P.N	Sum(Ri)	OC%.N0	"Q.N	"R.N
					check=R.N			

Table C.10 Water Heaters Version of MIM

The Costs, Sales, and Revenue Module (Continued)

Alfa	0.43							
ALFA.S								
Cal	Base	1	2	3	4	5	6	7
0.00	0.35	0.43	0.68	-0.26	-0.27	-0.11	-0.12	-1.77
Cross-Elasticity Demand Calculations								
PLalfa	PBalfa	PLalfa	COi	QBvec	QLvec	Q%.B.0	Q%.B	Q%.N
7.6	7.8	7.9	3.41	0.44	0.43	0.467	0.464	0.466
7.8	8.7	8.7	4.26	0.49	0.49	0.527	0.530	0.528
10.1	10.2	10.2	0.04	0.00	0.00	0.004	0.004	0.004
12.2	13.3	13.3	0.02	0.00	0.00	0.001	0.001	0.001
				0.93	0.93			
REM Shipments: Percentage of Total								
	Base	1	2	3	4	5	6	7
Electric	0.466	0.466	0.467	0.510	0.513	0.498	0.495	0.570
Gas	0.534	0.534	0.533	0.490	0.487	0.502	0.505	0.430
Oil	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CheckSum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
REM Shipments in 2003 New Standards Case								
	Base	1	2	3	4	5	6	7
Electric	3.73	3.73	3.73	4.09	4.12	4.00	3.99	4.53
Gas	4.27	4.26	4.26	3.93	3.92	4.04	4.06	3.42
Oil								
Total	7.99	7.99	7.99	8.02	8.04	8.04	8.05	7.95

Table C.11 Water Heaters Version of MIM

The Financial Module

INPUT	NAME	VALUE	NAME	Factor
RATES of COST				
After Tax Equity Cost of Capital	BCC.0	0.07	BCC.CV	10%
Interest Rate on Debt	I.0	2.50%	LCV	100%
Interest Lost on Cash	ICash.0	0.01	ICASH.CV	100%
Rate of Depreciation	Dep.0	0.18		
Tax Rate	T.0	34.00%	T.CV	20%
ASSETS and COSTS as a PERCENT of REVENUE				
Cash	C:R.0	3%	C:R.CV	100.00%
Inventory & Receivables	IR:R.0	30%	IR:R.CV	27.19%
Depreciable Assets	DA:R.0	23%	DA:R.CV	36.89%
G & A	G&A.0	13%	G&A.CV	40.00%
Engineering	Eng	1.20%		
FIXED AND VARIABLE COST SPLIT				
Fixed Part of All Costs & Depr Assets	FDA.0	8.46%	PCA.CV	50.00%
Fixed Part of 1-X Capital Cost	FIX.0	11.09%	FIX.CV	60.00%
OTHER				
Economic Profit	EP.0	-6.50%	EP.CV	1.00%
Debt to Equity ratio	DER.0	67.30%	DER.CV	43.36%
Markup on typical model	"mid	38.00%		
Ratio of highest to lowest markup	"ratio	300.00%		
OUTPUT				
Depreciation	DRR	4.2%		
G&A to Overhead Ratio	G:O	91.5%		
Engineering to Overhead Ratio	E:O	8.5%		
Debt Ratio	DR	40.2%		
Equity Ratio	ER	59.8%		
Pre-Tax Equity Cost of Capital*	PECC	10.3%		
Weighted Average Cost of Capital	WACC	7.2%		
After Tax WACC	ATWACC	4.7%		
Return on Equity	ROE	0.30%		
ROE (Real, from financial statements)	'ROE.0	0.30%		

All interest rates and costs of capital are "real".

*When Pre-Tax ECC is used, all costs are counted tax-exempt.

Table C.12 Water Heaters Version of MIM

The One-Time Cost Amortization Module

NOTES

Economic life of existing capital	L	8.00 years
Tax life of existing capital	TL	6.00 years
Age of existing capital	AGE	1.00 years
Percent of 1X capital that is add-on (as opposed to replacement capital)	%NC	50%

COMPUTATIONS

DESCRIPTION	NAME	VALUE	
Continuous After-Tax WACC	ATR	4.62%	
Weighted CC Lead-Time Factors	0.00	0.28	0.54 0.26
Cumulative CC Lead-Time Factors	LTC.0	1.076	
$\exp(-ATR \cdot TL)$	EMRT	0.758	
$\exp(-ATR \cdot L)$	EMRL	0.691	
Rate of tax benefit	3.30	BN	0.057
Remaining tax life	RTL	5.00 years	
Tax Benefit Rate: $(1 - \%NC) \cdot BN$	BEN	0.028	
Discount factor: $@\exp(-ATR \cdot (L - (TL - RTL)))$	DIS	0.72	
Loss of tax benefit on portion of existing capital with remaining tax life	LBC1	0.126	
Loss of tax benefit on discounted existing capital expenditure in the future	LBC2	0.107	
LEVELIZED CC		GROSS CC	TAX EFF
Initial Cost		1.000	
Tax Benefit of Straight-Line Depreciation			0.297
Savings from not replacing existing Capital later		-0.362	
Loss of Tax Benefit from existing Capital			-0.234
Present Value of CC:		0.638	0.063
Adjusted for Capital Lead Time		0.687	0.068
Levelized Tax Benefit: 1-X dep. of existing Cap.			0.004
LEVELIZED CC FACTOR	CCLF	0.103	0.014
AVERAGE ASSET FACTOR			
Asset Factor for Any New Cap. or Asset	AFB	0.561	
Average Asset Factor for Add-on Capital	AAF	0.281	

INPUT

NEW CAP. COST: 1990-96 (\$000)	CC.B0	3.60
1996 CHANGE	CC.N	3.72
COEFFICIENTS OF VARIATION	CCL.CV	0.20

OUTPUT

	BASE CASE 1996		NEW STNDS 1996	
Levelized 1-X CC: Gross	LCC.B	0.37	LCC.N	0.38
Levelized 1-X CC: Tax Effects	LCC.TB	0.05	LCC.TN	0.05
Levelized 1-X CC: Net	LCC.NB	0.320933	LCC.NN	0.33107
Levelized 1-X Assets	LA.B	1.01	LA.N	1.04

Table C.13 Water Heaters Version of MIM

The Long-Run Model Module

1990 CASE		A.F	A.Q	A:R	A
Assets -->		0.020	0.534	0.554	93
Costs except taxes		TC.F	TC.Q	TC:R	TC
and equity -->		0.085	0.914	0.998	167
		EC.F	EC.Q	EC:R	EC
Economic costs -->		0.057	0.625	1.022	171
	Economic Income			EI:R	-0.0215
	Markup ($\mu - 1$)			μ 1	0.0562
	Price Leader's elasticity of demand:				-18.8
BASE 1996		A.BF	A.BQ		A.B
Assets		3.27	62.30		93.08
		TC.BF	TC.BQ		TC.B
Costs except taxes		14.15	121.33		187
		EC.BF	EC.BQ		EC.B
Economic costs		9.52	82.84		184
NEW 1996		A.NF	A.NQ		A.N
Assets		3.27	62.30		93.15
		TC.NF	TC.NQ		TC.N
Costs except taxes		14.15	121.64		188
		EC.NF	EC.NQ		EC.N
Economic costs		9.52	83.05		185
Assets	-----1990-----	---BASE 1996---		---NEW 1996---	
Shipments	"Q 1.43	Q.B 1.43		Q.N 1.43	
Price	"P \$116.59	P.B \$131.82		P.N \$132.13	
Revenue	"R 167.23	R.B 187.89		R.N 188.41	
Unit Var. Cost	"UVC \$84.96	UVC.B \$99.74		UVC.N \$100.05	
V. Cost Goods Sold	VCGS 121.86	VCGS.B 142.16		VCGS.N 142.66	
1X tax benefit		X1T.B 0.05		X1T.N 0.05	
Pre-tax cost	PTC 166.97	PTC.B 187.46		PTC.N 187.97	
Taxes	TAX 0.09	TAX.B 0.22		TAX.N 0.23	
Net Income	NI 0.17	NLB 0.21		NLN 0.21	
Economic Income	EI -3.60	ELB -3.58		ELN -3.58	
Equity	EQ 55.37	EQ.B 55.64		EQ.N 55.68	
Retm on Equity	"ROE 0.30%	ROE.B 0.37%		ROE.N 0.37%	
Interest not 1X	IC 0.91	IC.B 0.85		IC.N 0.86	
Pre-intrst cst	PIC 166.07	PIC.B 186.68		PIC.N 187.20	
1X depreciation		X1D.B 0.45		X1D.N 0.46	
1X interest		X1LB 0.01		X1LN 0.01	
1X equity cost		X1E.B 0.04		X1E.N 0.04	

Table C.14 Water Heaters Version of MIM

The Short-Run Model Module

Short-Run "Supply Elasticity of Price": (Q/P)*dP/dQ			SRQE.0	0.157
Standard Error of SRQE			SRQE.SD	0.120
Random Value selected for this run:			*SRQE	0.157
R.S	188.26		*P.N	\$132.13
UVC.S	\$100.05		*Q.N	1.43
VCGS.S	142.67			
TC.S	187.61			
TAX.S	0.27	P=a+bQ	ap	bp
PTC.S	188.09		0.98	111.39
NLS	-0.10	Q=c+dP	cq	dq
A.S	93.15			1.62
EQ.S	55.68		P.S	132.01
ROES	-0.18%		Q.S	1.43
		Check P	\$132.14	
		Check Q		1.4258

Short-Run Assumptions:

The industry installs the long-run optimal level of capital.

The industry produces to meet demand at the low short-run price.

Table C.15 Water Heaters Version of MIM

The Charts Module

CHARTS OF SENSITIVITY AND PROFIT FOR WATER HEATERS

Sensitivity of ROE to 1 S.E. change in Control Variable

Scenario = Primary

Control Variables			Possible Standards Levels							
Name	Value	Changed	1	2	3	4	5	6	7	8
IPE	-0.120	-0.276	0.01%	0.01%	-0.88%	-0.95%	-0.06	-0.06	-0.11	-0.89%
RD	106.30%	244.40%	0.00%	0.04%	1.58%	1.67%	0.05	0.05	0.08	1.63%
ECC	0.068	0.075	0.00%	0.00%	-0.02%	-0.03%	0.00	0.00	0.00	-0.02%
EP	-0.065	-0.055	0.00%	0.00%	0.03%	0.03%	0.00	0.00	0.00	0.03%
FCA	0.085	0.136	-0.01%	-0.01%	0.55%	0.58%	0.03	0.03	0.05	0.55%
FIX	0.111	0.193	-0.06%	-0.06%	-0.20%	-0.26%	-0.01	0.00	-0.01	-0.24%
CC.N	3.718	4.532	0.00%	0.01%	0.01%	0.00%	0.00	0.00	-0.01	0.01%
dVC.N	15.088	20.237	0.05%	0.06%	0.32%	0.32%	0.01	0.01	0.01	0.32%
ro.N	0.000	0.050	0.00%	0.00%	-0.07%	-0.07%	0.00	-0.01	-0.01	-0.07%
SRPR	0.157	0.594	0	0	0	0	0	0	0	0

Change in Long-Run ROE from 1996 NAECA Base Case by Engineering and Standards Levels

Scenario= Primary

Level	Engin	Stdnds
1	-0.02%	
2	-0.01%	
3	0.19%	
4	0.77%	
5	0.75%	
6	0.63%	
7	0.50%	
8	0.97%	

REFERENCES

1. U.S. DOE, Energy Information Data, Office of Energy Markets and End Use, 1990. *Household Energy Consumption and Expenditures 1987, Part 1: National Data*. Washington, DC, DOE/EIA-0321/1(87). Figure ES1, "U.S. Energy Consumption per Household by End Use, 1987." pg viii.
2. ADM Associates Inc. (ADM). 1987. *Costing analysis of design options for residential appliances and space conditioning equipment*. Sacramento, CA, December 1987. pp 5-6,7,8.
3. U.S. DOE, Office of Conservation and Renewable Energy. 1990. *Energy Conservation Program for Consumer Products; Final Rule Regarding Test Procedures and Energy Conservation Standards for Water Heaters*. Federal Register, 55(201): 42162-42177, Oct. 17, 1990.
4. U.S. Office of the Federal Register. 1990. *Code of Federal Regulations*, Title 10, Energy. Part 430. Subpart B, Appendix E: *Uniform Test Method for Measuring the Energy Consumption of Water Heaters*. Washington, DC.
5. U.S. DOE, Office of Conservation and Renewable Energy. 1990. *Energy Conservation Program for Consumer Products; Advanced Notice of Proposed Rulemaking Regarding Energy Conservation Standards for 9 Types of Consumer Products, (ANOPR)*. Federal Register, 55(189): 39624-39634, Sept 28, 1990.
6. Gas Appliance Manufacturers Association, Inc. (GAMA). 1990. *Statistical Release, Residential Gas Water Heaters*. Arlington, VA, December 1990.
7. *Ibid.*
8. F. Stanonik. *Personal communication*. GAMA, Arlington, VA, April 5, 1991.
9. W. Katz. *Personal communication*. Aquavec, Oakland, CA, February 1, 1991.
10. International Association of Plumbing and Mechanical Officials. 1991. *Uniform Plumbing Code*. Chapter 10. Section 1002. Walnut, CA.
11. *Ibid.*
12. J.M. Torrey, D.L. Peterka, and R.C. Erickson. 1981. *Domestic Gas Water Heater Market Assessment*. Prepared by Science Applications Inc., La Jolla, CA, for Gas Research Institute, GRI-80/0089, November 1981, p 18.

13. W.H. Thrasher. 1986. *Pulse Combustion Residential Water Heater*. Prepared by American Gas Association Laboratories, Cleveland, OH, for Gas Research Institute, Contract No. 5080-345-0369, October 1986.
14. U.S. Office of the Federal Register, 1990. *Op. cit.*
15. California Energy Commission (CEC). 1989. *Directory of Certified Water Heaters*. Building and Appliance Efficiency, Energy Efficiency and Local Assistance Division, Sacramento, CA, P400-89-024.
16. GAMA. 1990. *Consumer's Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment*. ETL Testing Laboratories, Cortland, NY, October 1990.
17. U.S. DOE, Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems, Consumer Product Efficiency Branch. *1980 Technical Support Document No. 5, Engineering Analysis, Energy Efficiency Standards for Consumer Products*. DOE/CS-0166, June 1980.
18. GAMA. 1990. *Op. cit.*
19. F. Stanonik. 1990. *Water Heater Baseline Engineering Data and Manufacturing Cost Questionnaire*. GAMA, Arlington, VA, December 7, 1990.
20. ADM, 1987. *Op. cit.* pp 5-14.
21. D. I. Lerman. 1988. *Regional Study of Residential Water Heating Equipment: Phase II, Final Report, May 1988*. Prepared by ERC International, Portland, OR, for Bonneville Power Administration and Pacific Power & Light, p 26.
22. W. D. Mahoney. 1989. *Means Mechanical Cost Data, 1990*. R.S. Means Company Inc., Kingston, MA, p 376.
23. Stanonik, 1990. *Op. cit.* December 7, 1990.
24. Lerman, 1988. *Op. cit.*
25. Mahoney, 1989. *Op. cit.*
26. Stanonik, 1990. *Op. cit.* December 7, 1990.
27. ADM, 1987. *Op. cit.* p 5-14.
28. U.S. DOE, Energy Information Administration. 1990. *Monthly Energy Review, May 1990*. August 1990, p 17 from the Consumer Price Index.

29. Stanonik, 1990. *Op. cit.* December 7, 1990.
30. *Ibid.*
31. ADM, 1987. *Op. cit.* p 5-14.
32. J. Bock. 1991. *Personal communication.* Bock Water Heaters, Madison, WI, March 21, 1991.
33. D.D. Paul, G.H. Stickford, and D.W. Locklin. 1991. *Assessment of Technology for Improving the Efficiency of Residential Gas Water Heaters, Second Interim Report.* Prepared by Battelle, Columbus, OH, for GRI, June 3, 1991. Appendix C: "Information on Vent Types" and Table 8.1; "Vent Installation Incremental Costs."
34. P. Chan, *Personal communication.* Lawrence Berkeley Laboratory, Berkeley, CA, August 16, 1991.
35. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options E: "Electric Ignition with 24V Flue Damper."
36. Stanonik, 1990. *Op. cit.* December 7, 1990.
37. Paul, Stickford, and Locklin, 1991. *Op. cit.*
38. R. Cook. 1991. *Personal communication.* A.O. Smith, Seminole, FL, retired, February 20, 1991.
39. J. Bock. 1991. *Personal communication.* *Op. cit.*
40. M. Olsen. 1990. *Personal communication with Greg Rosenquist of Lawrence Berkeley Laboratory.* Magnetek, Owosso, MI, October 1, 1990.
41. G. Lemon. 1990. *Personal communication with Greg Rosenquist of Lawrence Berkeley Laboratory.* Ametek, Kent, OH, October 8, 1990.
42. Stanonik, 1990. *Op. cit.* December 7, 1990.
43. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options G: "Increased Flue Baffling with Forced Draft - With Electric Ignition."
44. *Ibid.* Table 8.1: "Vent Installation Incremental Costs."
45. Stanonik, 1990. *Op. cit.* December 7, 1990.
46. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options E: "Electric Ignition with 24V Flue Damper."

47. *Ibid.* p 70.
48. *Ibid.* Appendix B, Options E: "Electric Ignition with 24V Flue Damper."
49. Stanonik, 1990. *Op. cit.* December 7, 1990.
50. Paul, Stickford, and Locklin, 1991. *Op. cit.*
51. M. Olsen, 1990. *Op. cit.* 1990.
52. G. Lemon. 1990. *Op. cit.* October 8, 1990.
53. Stanonik, 1990. *Op. cit.* December 7, 1990.
54. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options G: "Increased Flue Baffling with Forced Draft - With Electric Ignition."
55. Paul, Stickford, and Locklin, 1991. *Op. cit.* Table 8.1: "Vent Installation Incremental Costs."
56. Stanonik, 1990. *Op. cit.* December 7, 1990.
57. ADM, 1987. *Op. cit.* p 5-15.
58. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
59. *Ibid.*
60. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options G: "Increased Flue Baffling with Forced Draft - With Electric Ignition."
61. *Ibid.* Table 8.1, "Vent Installation Incremental Costs."
62. M. Olsen. 1990. *Op. cit.* October 1, 1990.
63. G. Lemon. *Op. cit.* October 8, 1990.
64. Stanonik, 1990. *Op. cit.* December 7, 1990.
65. M. Shepard, *et al.* 1990. *The State of the Art: Appliances.* Rocky Mountain Institute, COMPETITEK Information Service, Snowmass, CO, August 1990, p 47.
66. Torrey, Peterka, and Erickson, 1981. *Op. cit.* Table 3-1: "Summary of High Efficiency Gas Water Heater Designs," p 25.
67. A.J. Thompson. 1991. *Letter to Isaac Turiel of Lawrence Berkeley Laboratory.* Southern California Gas Company, Los Angeles, CA, February 20, 1991.

68. Southern Gas Association. 1990. *Comments on the Advanced Notice Of Proposed Rulemaking Regarding Energy Conservation Standards for 9 Types of Consumer Products*. FR 55(189): 39624, September 28, 1990. Docket Number CE-RM-90-201, Comment Number 4, December 5, 1990.
69. Sears, Roebuck Inc. 1990. *Home Hardware, Auto, and Leisure Catalog*. Fall/Winter 1990, Kenmore Survivor Gas Model, p 488.
70. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options E: "Electric Ignition with 24V Flue Damper."
71. Torrey, Peterka, and Erickson, 1981. *Op. cit.* Table 3-1, "Summary of High Efficiency Gas Water Heater Designs," p 25.
72. M. Goldstein. 1991. *Personal communication*. President of Quantum Group, San Diego, CA, January 14, 1991.
73. W. Harrigill. 1991. *Personal communication*. Vice-President of Engineering of Rheem, Atlanta, GA, February 20, 1991.
74. A.J. Thompson. 1991. *Op. cit.* February 20, 1991.
75. Southern Gas Association. 1990. *Op. cit.* December 5, 1990.
76. ADM, 1987. *Op. cit.* p 5-14
77. US DOE/EIA, 1990. *Op. cit.* on the Consumer Price Index.
78. Stanonik, 1990. *Op. cit.* December 6, 1990.
79. U.S. Office of the Federal Register. 1990. *Op. cit. Energy Conservation Standards and Effective Dates, [d] Water Heaters*. 1990.
80. *Ibid.*
81. U.S. DOE, Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems, Consumer Product Efficiency Branch. 1980. *Op. cit.*
82. GAMA, 1990. *Op. cit.*
83. Stanonik, 1990. *Op. cit.* December 7, 1990.
84. ADM, 1987. *Op. cit.* p 5-15.
85. Lerman, 1988. *Op. cit.*
86. Mahoney, 1989. *Op. cit.*

87. Stanonik, 1990. *Op. cit.* December 7, 1990.
88. *Ibid.*
89. *Ibid.*
90. ADM, 1987. *Op. cit.* p 5-15.
91. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
92. A.C. Shedd and D.W. Abrams. 1990. *Commercial Heat Pump Water Heaters Applications Handbook*. Prepared by D.W.Abrams, P.E. & Associates, Atlanta, GA, for EPRI, #CU-6666, January 1990, pp A3-18.
93. R. Beckerman, L. Gordon, and V. Schueler. 1990. *Heat Pump Water Heaters: An Assessment of Current Technical and Economic Feasibility As a Demand-Side Resource in the Pacific Northwest*. Prepared by the Washington State Energy Office for the Office of Energy Resources, Bonneville Power Administration, Olympia, WA, November 1990, p 11.
94. K. Gehring. 1990. *Personal communication*. Therma-Stor Products Group of DEC International, Madison, WI, November, 1990.
95. Stanonik, 1990. *Op. cit.* December 7, 1990.
96. *Ibid.*
97. ADM, 1987. *Op. cit.* p 5-15.
98. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
99. Shepard *et al.*, 1990. *Op. cit.* p 47.
100. Stanonik, 1990. *Op. cit.* December 7, 1990.
101. *Ibid.*
102. ADM, 1987. *Op. cit.* p 5-15.
103. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
104. CEC, 1989. *Op. cit.*
105. ADM, 1987, *Op. cit.* p 5-16.
106. J. Bock. 1991. *Personal communication*. Bock Water Heaters, Madison, WI, January 31, 1991.

107. U.S. DOE, Office of Conservation and Renewable Energy. 1990. *Op. cit.*
108. U.S. DOE, *Op. cit.* June 1980.
109. GAMA, 1990. *Op. cit.*
110. ADM, 1987. *Op. cit.* p 5-16.
111. Stanonik, 1990. *Op. cit.* December 7, 1990.
112. *Ibid.*
113. Lerman, 1988. *Op. cit.* p 26.
114. Mahoney, 1989. *Op. cit.* p 376.
115. ADM, 1987. *Op. cit.* p 5-16.
116. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
117. ADM, 1987. *Op. cit.* p 5-16.
118. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
119. Stanonik, 1990. *Op. cit.* December 7, 1990.
120. US DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
121. *Ibid.*
122. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options E: "Electric Ignition with 24V Flue Damper."
123. BR Laboratories, Inc, *Report # 9101-07*, Huntington Beach, CA,. Jan. 1991, prepared for the CEC under Contract 400-88-014.
124. Harris, James E. and Greenberg, Joseph, *Performance of Instantaneous Gas-Fired Water Heaters*, US Dept of Commerce, National Bureau of Standards, Washington, DC, May 1987, NBSIR 87-3537.
125. BR Laboratories, Inc. 1991. *Report on, 1. THERMAR TL-200, 2. DAALDEROP 07092634 Electric 4 Gallon Storage Water Heater*, Report # 9101-07, prepared by BR Laboratories, Inc., for the CEC, #400-88-014, Huntington Beach, CA, Jan. 1991, p 2.
126. P. du Pont. 1989. "Going Tankless." *Home Energy*, 6(5):34-37, September/October 1989.

127. U.S. DOE/EIA, 1990. *Op. cit.* p 17 from the Consumer Price Index.
128. U.S. Department of Labor, Bureau of Labor Statistics. 1990. *Summary of CPI News Release*. Washington, DC, December 1990.
129. Sales representative. *Personal communication*. 1991. Whole Earth Access Company, Berkeley, CA. March 4, 1991.
130. Paul, Stickford, and Locklin, 1991. *Op. cit.* Appendix B, Options G: "Increased Flue Baffling with Forced Draft - With Electric Ignition."
131. W. Kratz. 1991. *Personal communication*. Aquavac, Oakland, CA, March 6, 1991.
132. *Ibid.*
133. S. Boghosian and G. Rosenquist. 1991. *Personal communication*. Lawrence Berkeley Laboratory, March 4, 1991.
134. U.S. DOE, Energy Information Administration. 1990. *Household Energy Consumption and Expenditures 1987*. DOE/EIA-0321/1(87).
135. U.S. DOE, Energy Information Administration. 1991. *Annual Energy Outlook 1991*. DOE/EIA-0383(91).
136. *Ibid.*
137. U.S. DOE, Energy Information Administration, 1991. *State Energy Price Projections for the Residential Sector, 1991-1992*. Service Report SR/EMEU/91-04, November.
138. U.S. Office of the Federal Register, 1990. *Op. cit.*
139. *Ibid.*
140. CEC. 1989. *Op. cit.*
141. GAMA. 1990. *Op. cit.*
142. CEC, 1989. *Op. cit.*
143. GAMA. 1990. *Op. cit.* October 1990.
144. U.S. DOE, Office of Conservation and Renewable Energy. 1990. *Energy Conservation Program for Consumer Products; Final Rule Regarding Test Procedures and Energy Conservation Standards for Water Heaters*. Federal Register, 55(201): 42162-42177, October 17, 1990.

145. F. Stanonik. 1990. *Water Heater Baseline Engineering Data and Manufacturing Cost Questionnaire*. GAMA, Arlington, VA, December 7, 1990.
146. D. Paul. *Personal communication*. Battelle Memorial Institute, Columbus, OH, April 29, 1991.
147. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1989. *Handbook of Fundamentals*. Atlanta, GA. Table 4: "Typical Thermal Properties of Common Building and Insulating Materials - Design Values," for cellular polyurethane, p 22.7.
148. Harris, James E., 1982, *Test Results on the Effectiveness of Heat Traps on Water Heaters*, Letter Report, Building Equipment Division, Center for Building Technology, National Bureau of Standards, Washington, DC, prepared for Department of Energy, May 1982.
149. CEC, 1989. *Op. cit.*
150. D.D. Paul, G.H. Stickford, and D.W. Locklin. 1991. *Assessment of Technology for Improving the Efficiency of Residential Gas Water Heaters, Second Interim Report*. Prepared by Battelle Memorial Institute, Columbus, OH, for GRI, June 3, 1991.
151. Paul, Stickford, and Locklin, 1991. *Op. cit.* Table 7.5: "Electrical Consumption of Components," p 56.
152. CEC, 1989. *Op. cit.*
153. Paul, Stickford, and Locklin, 1991. *Op. cit.*
154. Paul, Stickford, and Locklin, 1991. *Op. cit.*
155. B. Latvala. 1991. *Personal communication*. California Energy Commission, Appliance Program, Sacramento, CA, June 20, 1991.
156. F. Stanonik. 1990. *Op. cit.* December 7, 1990.
157. CEC, 1989. *Op. cit.*
158. Paul, Stickford, and Locklin, 1991. *Op. cit.*
159. *Ibid.*
160. *Ibid.*
161. J.M. Torrey, D.L. Peterka, and R.C. Erickson. 1981. *Op. cit.* p. 25, Table 3-1: "Summary of High Efficiency Gas Water Heater Designs."

162. GAMA, 1990. *Op. cit.*
163. CEC, 1989. *Op. cit.*
164. Paul, Stickford, and Locklin, 1991. *Op. cit.*
165. Torrey, Peterka, and Erickson, 1981. *Op. cit.*
166. GAMA, 1990. *Op. cit.*
167. M. Goldstein. 1991. *Personal communication.* President of Quantum Group Inc., San Diego, CA, January 14, 1991.
168. W. Harrigill. 1991. *Personal communication.* Rheem Water Heaters, Atlanta, GA, February 20, 1991.
169. CEC, 1989. *Op. cit.*
170. Paul, Stickford, and Locklin, 1991. *Op. cit.*
171. ADM Associates Inc (ADM). 1987. *Costing Analysis of Design Options for Residential Appliances and Space Conditioning Equipment.* Sacramento, CA, December 1987, pp 5-14.
172. W. Thrasher, R. Kodology, and J. Fuller. 1984. "Development of a Space Heater and a Residential Water Heater Based on the Pulse Combustion Principle." *Proceedings of the ACEEE 1984 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy Efficient Economy (ACEEE), Washington, DC, Volume E.
173. Paul, Stickford, and Locklin, 1991. *Op. cit.*
174. Stanonik, 1990. *Op. cit.* December 7, 1990.
175. ADM, 1987. *Op. cit.*
176. U.S. Office of the Federal Register. 1990. *Op. cit.*
177. US DOE/ Office of Conservation and Renewable Energy, 1990, *Op. cit.* October 17, 1990.
178. Stanonik, 1990. *Op. cit.*
179. Harris, J. 1982. *Op. cit.* May 1982.
180. GAMA. 1990. *Op. cit.* October 1990.

181. J. Sabelli. 1991. *Personal communication*. ETL Laboratories, Cortland, NY, January 28, 1991.
182. C. Hiller. 1991. *Personal communication*. Electric Power Research Institute (EPRI), Palo Alto, CA, July 23, 1991.
183. R. Beckerman, L. Gordon, and V. Schueler. 1990. *Op. cit.*
184. GAMA. 1990. *Op. cit.* October 1990.
185. Stanonik, 1990. *Op. cit.*
186. B. Anderson, W.L. Carroll, and M.R. Matin. 1986. "Aggregation of U.S. Population Centers Using Climate Parameters Related to Building Energy Use." *Journal of Climate and Applied Meteorology*, 25(5), May 1986, pp 596-614.
187. Stanonik, 1990. *Op. cit.*
188. ADM, 1987. *Op. cit.*
189. ADM, 1987. *Op. cit.*
190. "Statistical Highlights," 1991. Gas Appliance Manufacturers Association.

Volume G

Table of Contents

CHAPTER 1. ENGINEERING ANALYSIS	1-1
1.1 INTRODUCTION	1-1
1.2 PRODUCT CLASSES	1-1
1.3 DESIGN OPTIONS	1-3
1.4 ENERGY CALCULATIONS FOR POOL AND SPA HEATERS	1-5
1.5 COST AND EFFICIENCY DATA FOR POOL HEATERS	1-7
1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN	1-9
 CHAPTER 2. BASE CASE FORECASTS: POOL HEATERS	 2-1
2.2 AVERAGE EQUIPMENT LIFETIME	2-1
2.3 BASE CASE PROJECTIONS	2-1
2.3.1 New Appliance Unit Energy Consumptions	2-1
2.2.2 Annual U.S. Appliance Installations	2-2
2.3.3 U.S. Residential Energy Consumption	2-3
2.3.4 Price of Purchased Appliances	2-4
2.4 SENSITIVITY ANALYSIS OF THE BASE CASE	2-4
 CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: POOL HEATERS	 3-1
3.1 STANDARDS LEVELS	3-1
3.2 ENERGY CONSUMPTION	3-2
3.3 ANNUAL INSTALLATIONS	3-3
3.4 APPLIANCE PRICES	3-4
3.5 NET PRESENT VALUE (NPV)	3-4
3.6 SENSITIVITY ANALYSIS	3-5
 CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS: POOL HEATERS	 4-1
4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS	4-1
4.1.1 LCC Data Inputs	4-2
4.1.2 LCC Results	4-2
4.2 PAYBACK PERIODS BY STANDARD LEVEL	4-5
4.2.1 PBP Data Inputs	4-5
4.2.2 PBP Results	4-5
4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS	4-6
4.3.1 Data Inputs for Change in LCC	4-6
4.3.2 Results for Change in LCC	4-6
4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS	4-6
4.4.1 CCE Data Inputs	4-7
4.4.2 CCE Results	4-7
4.5 LCC SENSITIVITY ANALYSIS	4-8

CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF POOL HEATERS	5-1
5.1 LONG-RUN IMPACTS	5-1
5.1.1 Qualitative Analysis	5-1
5.1.2 Quantitative Analysis	5-2
5.2 SHORT-RUN IMPACTS	5-2
5.3 IMPACT AS A FUNCTION OF FIRM SIZE	5-3
5.4 SENSITIVITY ANALYSIS FOR POOL HEATERS	5-4
5.4.1 Sensitivity Charts	5-4
5.4.2 Alternative Scenarios	5-5
5.4.3 Monte Carlo Analysis	5-6
CHAPTER 6. IMPACTS OR STANDARDS ON ELECTRIC UTILITIES: POOL HEATERS	6-1
6.1 INTRODUCTION	6-1
CHAPTER 7. ENVIRONMENTAL EFFECTS	7-2
7.1 INTRODUCTION	7-3
7.2 RESULTS	7-3
7.2.1 Sulfur and Nitrogen Oxide Emissions	7-3
7.2.2 Carbon Dioxide Emissions	7-4
APPENDIX A. ENERGY CALCULATIONS	A-1
A.1 CALCULATION OF AVERAGE HEAT LOAD FOR POOL & SPA HEATERS	A-1
APPENDIX B. LBL-REM INPUT DATA: POOL HEATER	B-1
APPENDIX C. LBL MANUFACTURER IMPACT MODEL: POOL HEATERS	C-1
C.1 INTRODUCTION	C-1
C.1.1 Engineering Cost Data	C-1
C.1.2 Industry Market Data	C-2
C.1.3 Financial Input Data	C-3
C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO	C-4

List of Tables

Table 1.1	Design Options for Gas-Fired Pool Heaters	1-3
Table 1.2	Energy Calculations for Gas-Fired Pool & Spa Heaters	1-7
Table 1.3	Manufacturers Cost for Gas-Fired Pool and Spa Heaters	1-9
Table 2.1	Average Equipment Lifetime (Years) of Pool Heaters	2-1
Table 2.2	Base Case Projection of Unit Energy Consumption for New Pool Heaters	2-2
Table 2.3	Annual Installations of Pool Heaters in U.S. Households (Thousands)	2-3
Table 2.4	Percent of Occupied U.S. Housing Units Having Pool Heaters	2-3
Table 2.5	U.S. Residential Energy Consumption for Pool Heaters (Quadrillion Btu, Primary Energy)	2-3
Table 2.6	Average Price of New Pool Heaters in U.S. Households (1990 Dollars) . .	2-4
Table 2.8	Average Unit Consumption of New Pool Heaters (MMBtu/Year)	2-5
Table 3.1	Trial Standards Levels for Gas-fired Pool and Spa Heaters	3-2
Table 3.2	Unit Energy Consumption for New Pool Heaters (MMBtu/Year)	3-2
Table 3.3	U.S. Consumption of Gas for Pool Heaters (Quadrillion Btu, Primary) . . .	3-3
Table 3.4	Cumulative Installations of Pool Heaters (Millions)	3-3
Table 3.5	Average Purchase Price for New Pool Heaters (1990 Dollars Per Unit) . . .	3-4
Table 3.6	Net Present Value for Pool Heaters Purchased from 1996-2030 (1990\$ Discounted at 7%)	3-5
Table 3.7	Sensitivity Analysis Cases	3-5
Table 3.8	Cumulative Energy Consumption of Pool Heaters During the Period 1996- 2030 (Quadrillion Btu, Primary)	3-6
Table 3.9	Cumulative Shipments of Pool Heaters During the Period 1996-2030 (Millions)	3-6
Table 3.10	Total Net Present Value to Consumers for Units Sold during the Period 1996-2030 (Discounted to 1990 at 7% Real)	3-6
Table 4.1	Life-Cycle Costs of Gas-Fired Pool and Spa Heaters	4-3
Table 4.2.a	Cost and Energy Use Summary Gas-Fired Pool and Spa Heaters	4-4
Table 4.2.b	Distribution of Units Sold Below Standards Gas-Fired Pool and Spa Heaters	4-4
Table 4.2.c	Weighted-Averages of Units Sold Below Standards Gas-Fired Pool and Spa Heaters	4-4
Table 4.2.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gas-Fired Pool and Spa Heaters	4-4
Table 4.3	Sensitivity Summary of Life-Cycle Costs of Gas-Fired Pool Heaters	4-9
Table 5.1.	Pool Heater Output Table: Primary Scenario	5-2
Table 5.2.	Pool Heater: Primary Scenario	5-3
Table 5.3.	Sensitivity of ROE to 1 S.E. Change in Control Variable	5-4
Table 5.4	Pool Heater Output Table: Low Price Elasticity Scenario	5-7
Table 5.5	Pool Heater Output Table: High Price Elasticity Scenario	5-7
Table 5.6	Pool Heater Output Table: Constant Shipments Scenario	5-8
Table 5.7	Pool Heater Output Table: Low Discount Rate Scenario	5-8

Table 5.8	Pool Heater Output Table: High Discount Rate Scenario	5-9
Table 5.9	Pool Heater Output Table: Low Discount Rate and High Price Elasticity Scenario	5-9
Table 5.10	Pool Heater Monte Carlo Runs: Searching for Low ROE	5-10
Table A.1	Conditional Demand Analysis (CDA) Studies with Pool and Spa Heaters .	A-2
Table A.2	Estimated Percentage of Heaters Serving Pools, Spas, and Both	A-3
Table C.1	Rates of Financial Costs	C-3
Table C.2	Other Financial Inputs	C-3
Table C.3	Fixed, Variable, and Revenue-Related Cost Split	C-3
Table C.4	One-Time Costs	C-4
Table C.5	Pool Heaters Version of LBL-MIM - Control Panel	C-4
Table C.6	Pool Heaters Version of LBL-MIM - Monte Carlo Module	C-5
Table C.7	Pool Heaters Version of LBL-MIM - Accounting Module	C-6
Table C.8	Pool Heaters Version of LBL-MIM - Engineering Inputs Module	C-7
Table C.9	Pool Heaters Version of LBL-MIM - Standards Level Module	C-8
Table C.10	Pool Heaters Version of LBL-MIM - Costs, Sales and Revenue Module ..	C-9
Table C.11	Pool Heaters Version of LBL-MIM - Financial Module	C-10
Table C.12	Pool Heaters Version of LBL-MIM - One-Time Cost Amortization Module	C-11
Table C.13	Pool Heaters Version of LBL-MIM - Long-Run Model Module	C-12
Table C.14	Pool Heaters Version of LBL-MIM - Short-Run Model Module	C-13
Table C.15	Pool Heaters Version of LBL-MIM - Charts Module	C-14

CHAPTER 1. ENGINEERING ANALYSIS

1.1 INTRODUCTION

A pool heater is defined by NAECA as "an appliance designed for heating non-potable water contained at atmospheric pressure, including heating water in swimming pools, spas, hot tubs, and similar applications" (1). This definition is limited to residential pools and spas by the general application of NAECA to consumer products only (2).

Pool heaters are used for residential swimming pools and spas. Spas are much smaller than swimming pools, but the temperatures are usually higher. To keep the warm-up time short, the heater will often be as large or almost as large as a heater used for a swimming pool. Also 18% of spas use the same water and equipment as a swimming pool (3). For these reasons separate product classes were not analyzed for spa heaters and pool heaters.

Water is heated as it passes through a pool heater. The pool heater does not store heated water. The heaters are installed on the water line that circulates pool water through the filter. This plumbing arrangement avoids an additional pump for the heater. When the circulating pool water temperature is too low, a thermostat turns on the heater. After the pool water reaches the desired temperature, the heater is turned off.

1.2 PRODUCT CLASSES

Only gas-fired pool and spa heaters were included in this analysis. An American National Standards Institute (ANSI) test method is referred to for testing gas-fired and oil-fired pool heaters (4) (5). No reference is made to any test procedure for electric or solar pool heaters. Standards may not be adopted for appliances if a test procedure has not been prescribed (6). No residential oil-fired pool heaters were found. Therefore this analysis was limited to natural gas-fired pool heaters. Gas-fired pool heaters must currently have a 78% thermal efficiency (E_t) as defined by the ANSI standard.

The majority of pool heaters being manufactured consist of finned copper tube heat exchangers in a rectangular combustion chamber. The burner is at the bottom of the combustion chamber. Most pool heaters are designed to be installed outdoors. The venting is directly out of the combustion chamber, with some extra baffling on the vent for protection from the elements. (See Figure 1.1.)

Figure 1.1 Typical Pool Heater

A typical production line begins with sheet steel being fabricated into the top and sides of the heater. This process includes punching and cutting all the required holes and vents, and then painting the metal. The finned copper tube heat exchangers and burners are either made in-house or purchased separately. The heat exchanger sub-assembly is fabricated and inserted above the combustion chamber. Refractory material is placed around the inside of the combustion chamber. The burner and ignition system sub-assembly is inserted in the bottom of the combustion chamber. The remaining components, labels, instructions, and decoration are applied. Packaging is done near the end of the production line, with a complete package including instructions and labels coming off the line. The unit is usually stored in inventory to keep production levels steady. A general flow diagram of the production process is shown in Figure 1.2.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

3 of 6

Figure 1.2 Schematic of Pool Heater Manufacturing

1.3 DESIGN OPTIONS

Five design options were identified as possible methods to reduce the energy consumption of pool heaters. They are listed in Table 1.1. The first option listed is the baseline. This represents the typical pool water heater that just meets the current efficiency standards for pool heaters.

Table 1.1 Design Options for Gas-Fired Pool Heaters

Design Option	Standard Level	Description
0		Baseline
1	1	Electronic Ignition
2	2	Non-condensing Limit
3	3	Condensing Induced Draft
4	4	Condensing Pulse Combustion
5		Condensing Power Burner

Baseline

The baseline pool heater chosen for this analysis had a rated input of 250 kBtu/h and a continuously burning pilot light of 1,000 Btu/h. The baseline thermal efficiency was set to 78% to match the current ANSI standard (7).

Electronic Ignition

One of the most common ways to reduce energy consumption by pool heaters is to eliminate the standing pilot light as a method of igniting the main burner. All of the manufacturers already make heaters with electronic ignition for sale within California. Since February 1984, California has required that pool heaters not have standing pilot lights (8).

Non-condensing Limit

Pool heaters are currently close to the steady state efficiency level where potentially damaging condensation will start to occur on the heat exchanger. Discussions with manufacturers revealed that a small increase in efficiency was possible while still avoiding condensation. The heat exchanger surface area would need to be increased and the burner configuration might have to be changed. A fan would not be included in this design option.

Condensing Induced Draft

To increase the efficiency significantly, the water vapor in the flue gases must be condensed. At this state the flue gases are not warm enough to have enough buoyancy to provide adequate draft. This design option uses an induced draft fan to pull flue gases through the much larger heat exchanger area required for condensation. Changes to the configuration of other parts of the pool heater, such as the combustion chamber and burner, were assumed to be limited.

Condensing Pulse Combustion

Pulse combustion burners operate with self-sustaining resonating pressure waves that alternately rarify the combustion chamber (causing a fresh fuel/air mixture to enter the chamber) and pressurize it (causing ignition by compression of the mixture to its flash point). This process is initiated by a blower that supplies an initial fuel and air mixture to the chamber. The fuel and air mixture is ignited with a spark ignitor. Once resonance is established, the process becomes self-sustaining. Pulse frequencies are about 100 cycles per second (9). Pulse combustion systems feature high heat-transfer rates. High-efficiency gas-fired boilers using pulse combustion are currently available.

Condensing Heater with Radiant Power Burner

The most efficient pool heater on the market today uses this technology. A ceramic matrix radiant burner is located above a series of finned heat exchanger tubes. A blower forces an air and gas mixture through the burner and out past the heat exchanger. Most of the heat is radiatively transferred to the heat exchanger. This allows the burner to be above the heat exchanger and out of the way of any condensation.

1.4 ENERGY CALCULATIONS FOR POOL AND SPA HEATERS

Annual energy consumption for the baseline model and for each of the additional design options were calculated from the gas and electricity inputs, the burner operating hours, and the pool operating hours. The burner operating hours are the number of hours the burner is on during a year. It is determined from the weighted-average pool and spa-heating load divided by the rate at which heat is delivered to the water. The rate at which heat is delivered to the water is the rated gas input multiplied by the thermal efficiency (E_t) from the ANSI test. The thermal efficiency, (E_t) of the various design options is given as the average of estimates from several manufacturers. A weighted-average pool- and spa-heating load of 203 therms per year was used for this analysis. The calculation of weighted-average pool- and spa-heating load is explained in detail in Appendix A of this volume. The pilot light or electrical standby losses were assumed to be present during the pool operating hours when the burner was not operating. The pool operating hours were the number of hours the pool heater was operational. For this analysis, the pool operating hours were assumed to equal 4,464 hours per year. The derivation of pool operating hours is also explained in Appendix A.

The annual average energy use for both gas and electricity were calculated as shown in the following equations:

$$UEC_{gas} = (Q_{in} * BOH + Q_{pilot} * (POH - BOH)) \quad (1)$$

$$UEC_{elec} = (PE * BOH + PE_{off} * (POH - BOH)) \quad (2)$$

where:

Q_{in} = rated input, (Btu/h),
 Q_{pilot} = pilot input, (Btu/h),
 PE = electrical input when the burner is operating, (Btu/h),
 PE_{off} = electrical input when the burner is not operating, (Btu/h),
 BOH = burner operating hours, (hours/year), and
 POH = pool operating hours, (hours/year).

The burner operating hours (BOH) were calculated as follows:

$$\text{BOH} = \text{load} / (Q_{in} * E_t) \quad (3)$$

where:

Load = weighted-average heating load, 203 therms/year, and
 E_t = thermal efficiency.

The annual energy consumption calculations for the baseline unit and the design options are listed in Table 1.2.

The annual efficiency (AE) is from the proposed DOE test procedure for pool heaters. It is defined as the ratio of the annual output of energy delivered to the pool water to the annual (fossil fuel) energy input to the pool heater. The annual efficiency modifies the thermal efficiency to include standby losses. It also accounts for electricity consumption. The energy content of electricity in the annual efficiency has been increased by 3.37. This is the ratio of the energy consumed at the source of electrical generation to the electrical energy delivered to the pool heater.

The annual efficiency is defined as follows:

for pool heaters with pilot light ignition,

$$\text{AE} = E_t * \frac{E_{on}}{(E_F + F * E_{ac})} \quad (4)$$

for pool heaters with no continuous pilot light,

$$\text{AE} = \frac{E_t}{\left[1 + \frac{(F-1)*PE}{Q_{in}+PE} \right]} \quad (5)$$

where:

$$E_{on} = (\text{BOH}) * (Q_{in} + \text{PE}) =$$

average annual energy consumption when the burner is on, Btu,

$$E_F = (BOH * Q_{in}) + (POH - BOH) * Q_{pilot} =$$

average annual fossil fuel consumption, Btu

$$E_{ac} = (BOH) * (PE) =$$

average annual auxiliary electrical energy consumption, Btu, and

F = ratio of source energy to electrical energy delivered, 3.37.

Table 1.2 Energy Calculations for Gas-Fired Pool & Spa Heaters

Standard Level	Design Number	Design Options	E_f	AE	Burner On		Burner Off		BOH	Energy Use	
					Elec	Gas	Elec	Gas		Gas	Elec
					Watts	Btu/hr	Watts	Btu/hr		MBtu/yr	kWh/yr
	0	Baseline	78.0%	66.8%		250000		1000	104	30.5	0.0
1	1	0 + IID	78.0%	78.0%		250000	0.5	0	104	26.0	2.2
2	2	1 + Non-condensing Limit	82.2%	82.2%		250000	0.5	0	99	24.7	2.2
3	3	0 + Condensing Induced Draft	90.8%	90.7%	50	250000	0.5	0	89	22.3	6.7
4	4	0 + Condensing Pulse Combustion	95.8%	95.7%	50	250000	0.5	0	85	21.2	6.5
	5	0 + Condensing Power Burner	93.2%	93.0%	50	250000	0.5	0	87	21.8	6.6

1.5 COST AND EFFICIENCY DATA FOR POOL HEATERS

This section presents manufacturers cost at large-scale production and incremental costs to install pool heaters with each of the design options included in this analysis. The manufacturers cost is the cost to the manufacturer of making water heaters with the design options shown and does not include any markups to wholesalers or retailers.

Cost data for all the design options came from discussions with representatives of all the major manufacturers of gas-fired pool and spa heaters. Only total factory costs were reported here. The total factory cost of the baseline model was the average of the current manufacturers costs from the different manufacturers. The total factory costs of the other design options were calculated by adding the average incremental costs from the manufacturers to the cost of the previous design option. The uncertainty of factory costs was estimated as the difference between the most extreme and the average incremental costs, except that the uncertainty for the non-condensing limit design option was reduced to keep incremental costs positive in all cases.

The incremental installation cost of condensing design options, \$100, was the estimated cost of installing a condensate drain line. The uncertainty on this installation cost was estimated. No data were available for maintenance costs for pool heaters. The manufacturer and installation costs are listed in Table 1.3.

Table 1.3 Manufacturers Cost for Gas-Fired Pool and Spa Heaters

Standard Level Number	Design Option Number	Design Options	AE	Manufacturer Cost			Installation Costs	
				Total 1990\$	Incremental 1990\$	Uncert 1990\$	1990\$	Uncert 1990\$
	0	Baseline	66.9%	531.65				
1	1	0 + ID	78.0%	571.04	39.39	11.89	0.00	0.00
2	2	1 + Non-condensing Limit	82.2%	626.70	55.67	50.00	0.00	0.00
3	3	0 + Condensing Induced Draft	90.7%	937.33	405.68	276.68	100.00	50.00
4	4	0 + Condensing Pulse Combustion	95.7%	1282.33	760.68	561.68	100.00	50.00
	5	0 + Condensing Power Burner	93.0%	1435.67	904.02	554.02	100.00	50.00

1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN

The maximum technologically feasible design is represented by condensing pulse combustion. The estimated efficiencies were based on discussions with manufacturers. All of the efficiency values (and manufacturing costs as well) in Table 1.3 have some uncertainty associated with them.

For the maximum technologically feasible design, (95.7% AE), the 95% confidence interval for the annual efficiency is estimated to range from 92.0% to 99.0%.

CHAPTER 2. BASE CASE FORECASTS: POOL HEATERS

Analyzing impacts of federal energy-efficiency standards requires comparing projected U.S. residential energy consumption with and without the standards. The cases without standards are referred to as *base case projections*. These base case projections are compared to projections of conditions that would be likely to prevail if standards were enacted (see Chapter 3). The difference between the two projections is defined as the incremental impact of standards.

Projections are made for a number of demographic, economic, and energy variables, including energy prices, household income, housing stock, housing starts, mix of house types (single-family, multifamily, mobile homes), building shell thermal characteristics, appliance purchases, equipment prices, unit energy consumption, and aggregate residential energy consumption by fuel type.

2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS

The demographic and economic assumptions are described in Volume A, Chapter 5.

2.2 AVERAGE EQUIPMENT LIFETIME

Average lifetimes are assumed to be 15 years for pool heaters. (Table 2.1)

Table 2.1 Average Equipment Lifetime (Years) of Pool Heaters

	Years	Source
Pool Heaters	15.0	LBL

2.3 BASE CASE PROJECTIONS

This section contains projections of unit energy consumption (UEC) of new appliances, annual appliance installations, annual residential energy consumption, and price of purchased appliances.

2.3.1 New Appliance Unit Energy Consumptions

Annual UEC of new appliances is projected based upon a set of designs available (each design characterized by a purchase price and an energy-efficiency factor or UEC), and a market discount rate (derived from implicit decision-making in recent purchase decisions for the product). The LBL-REM produces projections of annual energy consumption of new appliances after 1980. Table 2.2 shows the trends in efficiency and annual unit energy consumption.

Table 2.2 Base Case Projection of Unit Energy Consumption for New Pool Heaters

Year	Average Energy Factor	UEC (MMBtu/year)
1981	0.753	31.58
1990	0.780	30.49
1996	0.780	30.49
2000	0.780	30.49
2030	0.913	26.03

Source: LBL-REM (1980-2030).

2.3.1.1 Efficiency Distributions

Because this product is not part of the federal appliance labeling program, no distribution is available; instead, all shipments in each year are taken to be of a single design option.

2.3.1.2 Usage

Usage is assumed constant over time.

2.2.2 Annual U.S. Appliance Installations

The market for appliances is seen as having two segments: new construction and existing housing. All new households are considered eligible to purchase each appliance. The pool of potential purchasers among existing households each year is defined as households that retired a unit that year, plus a fraction of households that did not previously own the product.

The initial (1980) fraction of new (and of existing) households expected to purchase each product and fuel type is specified as input to LBL-REM. LBL-REM produces projected fractions, for each year, of new households (and of existing households) that purchase the product. The projection is based on market share elasticities with respect to income, equipment price, and annual operating expense. Market share elasticities are given in Appendix B of this volume.

The projection for the period 1981-1990 is calibrated to reasonable agreement with available data, including domestic shipments (from published trade association data) and surveys of appliance ownership (e.g., from DOE/EIA RECS (10) and the Bureau of the Census).

Tables 2.3 and 2.4 show the significant trends in the installation and saturation of this product.

Table 2.3 Annual Installations of Pool Heaters in U.S. Households (Thousands)

Year	Pool Heater
1981	114
1990	134
1996	173
2000	210
2030	356

Table 2.4 Percent of Occupied U.S. Housing Units Having Pool Heaters

Year	Pool Heater
1980	1
1990	2
1996	2
2000	2
2030	4

Source: LBL-REM.

2.3.3 U.S. Residential Energy Consumption

U.S. residential energy consumption for this product is calculated each year as the product of: number of occupied households, fraction of households owning the appliance, average unit energy consumption (engineering estimate), and usage behavior factor.

Table 2.5 shows the U.S. energy consumption, expressed in quadrillion Btu of primary energy.

Table 2.5 U.S. Residential Energy Consumption for Pool Heaters (Quadrillion Btu, Primary Energy)

Year	Pool Heater
1981	0.03
1990	0.05
1996	0.06
2000	0.07
2030	0.12

Source: LBL-REM.

2.3.4 Price of Purchased Appliances

Prices of new units increase over time as energy-efficiency improvements are incorporated. Table 2.6 shows projected shipment-weighted average prices.

Table 2.6 Average Price of New Pool Heaters in U.S. Households (1990 Dollars)

Year	Pool Heater
1981	1297
1990	1297
1996	1297
2000	1297
2030	1384

2.4 SENSITIVITY ANALYSIS OF THE BASE CASE

The sensitivity cases selected are defined as follows:

1. *Lower Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level is decreased by the estimated uncertainty interval.
2. *Higher Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level is increased by the estimated uncertainty interval.
3. *Lower Energy Price.* Assume lower energy prices. Starting from 1992 to 2030, electricity prices are 3% lower while gas and distillate prices are 5% lower than those in the AEO 1991 (11) forecast.
4. *Higher Energy Price.* Assume higher energy prices. Starting from 1992 to 2030, electricity prices are 3% higher while gas and distillate prices are 5% higher than those in the AEO 1991 forecast.
5. *High Equipment Efficiency.* Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.
6. *Market Discount Rates Decline.* Assume that market discount rates used to determine future efficiency choices are declining over time by 2% per year, i.e., efficiency improvements appear in the marketplace sooner.

The results of these six sensitivity cases are presented in the following tables. Tables 2.7 shows how the average price varies. Table 2.8 shows the differences in unit energy consumption or efficiency. The first line of these tables gives the results of the reference case described in the previous section; the rest of the lines give the corresponding results of the sensitivity cases listed above.

Table 2.7 Average Purchase Price of New Pool Heaters (1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	1297	1297	1297	1297	1384
1	1297	1297	1371	1371	1371
2	1297	1297	1297	1297	1410
3	1297	1297	1297	1297	1384
4	1297	1297	1297	1384	1384
5	1297	1297	1361	1481	3137
6	1297	1297	1384	1384	1384

Table 2.8 Average Unit Consumption of New Pool Heaters (MMBtu/Year)

Year:	1981	1990	1996	2000	2030
Reference	31.6	30.5	30.5	30.5	26.0
1	31.6	30.5	24.7	24.7	24.7
2	31.6	30.5	30.5	30.5	26.0
3	31.6	30.5	30.5	30.5	26.0
4	31.6	30.5	30.5	26.0	26.0
5	31.6	30.5	27.2	25.0	21.2
6	31.6	30.5	26.0	26.0	26.0

Source: LBL-REM.

CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: POOL HEATERS

The LBL Residential Energy Model (LBL-REM) projects a number of economic and energy-use variables that are used to assess the impact of proposed standards on consumers, electric utilities, and appliance manufacturers. This chapter presents projections from the model, which assume various trial standards.

The principal outputs from the LBL-REM for each year are:

- unit equipment price and operating expense by product,
- projected annual shipments of residential appliances,
- energy consumption by end use and fuel, and
- differences in these quantities between a base case and each trial standards case.

These outputs are provided annually (or for selected years) and cumulatively over a period of time, i.e., 1996-2030. Energy savings are given for each year from implementation of standards to the end of the period. Net present value of the standards is evaluated for each regulated product and for the end use(s) comprising the regulated and competing products. The sensitivity of the outputs to the key assumptions and data is analyzed; the results of this analysis are also presented.

Section 3.1 presents the trial standards levels analyzed. Section 3.2 presents the historical and projected energy consumption, including unit energy consumption for new purchases, and total national energy consumption. Section 3.3 presents historical and projected annual installations. Section 3.4 presents purchase prices. Section 3.5 presents net present value and Section 3.6 discusses the results of the sensitivity analyses.

An overview of the general REM methodology and demographic assumptions is in Volume A. Product-specific input data are described in Appendix C of this volume.

3.1 STANDARDS LEVELS

Table 3.1 shows the correspondence between the trial standards levels, the engineering design levels, and the associated unit energy consumption.

Table 3.1 Trial Standards Levels for Gas-fired Pool and Spa Heaters

	Trial Standard Level			
	1	2	3	4
Engineering design option	1	2	3	4
Annual energy consumption (MMBtu)	26.03	24.71	22.35	21.18

3.2 ENERGY CONSUMPTION

Table 3.2 shows the past and projected average energy use of new pool heaters. The unit energy consumption of an average new pool heater is projected to remain the same for units bought from 1990 to 1996 in the absence of amended standards.

Table 3.2 Unit Energy Consumption for New Pool Heaters (MMBtu/Year)

Year	Base	Trial Standard Level			
		1	2	3	4
1981	31.6				
1990	30.5				
1996	30.5	26.0	24.7	22.4	21.2
2000	30.5	26.0	24.7	22.4	21.2
2015	26.0	26.0	24.7	22.4	21.2
2030	26.0	26.0	24.7	22.4	21.2

Table 3.3 presents projections of total energy savings for gas-fired pool and spa heaters. Standards are projected to produce cumulative energy savings ranging from 0.07 Quads for standards level 1 to 0.78 Quads for standards level 4, during the period 1996-2030.

Table 3.3 U.S. Consumption of Gas for Pool Heaters (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level			
		1	2	3	4
1981	0.027				
1990	0.047				
1996	0.062	0.060	0.060	0.058	0.058
2000	0.073	0.067	0.066	0.062	0.059
2015	0.094	0.093	0.088	0.077	0.070
2030	0.123	0.123	0.117	0.100	0.091
1996-2030	3.24	3.17	3.02	2.66	2.46
Cumulative Savings:		0.07	0.23	0.58	0.78
Percent of Base:		2.3%	7.0%	17.9%	24.2%

Source: LBL-REM.

3.3 ANNUAL INSTALLATIONS

As shown in Table 3.4, installations¹ of pool heater are affected by standards. This result is a function of the change in operating expense, change in equipment price, and market share elasticities. The projection shows a change of between 0.2% increase and 8% decrease from base for the various standards levels for cumulative shipments of pool heaters from 1996 to 2030.

Table 3.4 Cumulative Installations of Pool Heaters (Millions)

1996-2030	Base	Trial Standard Level			
		1	2	3	4
	9.26	9.28	9.25	8.84	8.49
Change from Base:		0.02	-0.01	-0.42	-0.77
Percent Change:		0.2%	-0.1%	-4.5%	-8.3%

Source: LBL-REM.

¹ If there are no imports or exports, annual installations are equivalent to domestic shipments. Domestic shipments can be calculated as annual installations, less imports, plus exports.

3.4 APPLIANCE PRICES

Projections of the purchase prices for new pool heaters in 1990 dollars are shown in Table 3.5. The prices typically increase when standards come into effect, by \$2 (0.6%) at standard level 1, up to \$18 (5%) at standard level 3.

Table 3.5 Average Purchase Price for New Pool Heaters (1990 Dollars Per Unit)

Year	Base	Trial Standard Level			
		1	2	3	4
1981	1297				
1990	1297				
1996	1297	1384	1511	2322	3137
2000	1297	1384	1511	2322	3137
2015	1384	1384	1511	2322	3137
2030	1384	1384	1511	2322	3137

Source: LBL-REM.

3.5 NET PRESENT VALUE (NPV)

The NPV of standards for any product is calculated by first determining the difference in present value of unit life-cycle costs between the base case and standards case each year. That difference is then multiplied by the standards case shipments for the year. The NPV for the period (1996-2030) is the sum over the years of the annual values. A positive NPV of standards results when the new units in the standards case have lower present value of life-cycle cost than do new units in the base case. A negative NPV indicates higher costs with standards, relative to the base case.

Table 3.6 shows positive NPV (reduced costs) to society of \$.22 billion (standard 1) to \$.34 billion (standard 2). The ratio of benefit to cost ranges from 4.5 (standard 1) to 1.6 (standard 3).

Table 3.6 Net Present Value for Pool Heaters Purchased from 1996-2030 (1990\$ Discounted at 7%)²

	Trial Standard Level			
	1	2	3	4
Benefit (energy)	0.18	0.45	0.89	1.08
Cost (equip)	0.05	0.32	1.98	3.52
Net = benefit - cost	0.14	0.13	-1.09	-2.44
RATIO: BENEFIT/COST	3.75	1.41	0.45	0.31

Source: LBL-REM.

3.6 SENSITIVITY ANALYSIS

The base case and standards levels as described above constitute a reference case against which the impacts of standards under different assumptions may be compared. The sensitivity analysis is performed by running the LBL-REM for the base case and *trial standard level 2* for pool heaters. For each sensitivity case, the results for the trial standards level are compared to the corresponding base-case run and the differences are tabulated.

The assumptions in the sensitivity cases are described in Section 2.4 and listed in Table 3.7. Table 3.8 shows results for cumulative energy consumption. The sensitivity analysis of product shipments is given in Table 3.9. Table 3.10 shows the net present values. The first line of Tables 3.8 through 3.10 gives the results of the reference case (base case, standards level, and difference). The rest of the lines each give the results corresponding to one of the sensitivity cases, including the base case, standards case, and difference. Note that the changes in the impact of standards as a function of the changed assumptions (difference between the base and standards cases) are the principal results of the sensitivity analysis.

Table 3.7 Sensitivity Analysis Cases

Case	Description
1	Lower Equipment Prices
2	Higher Equipment Prices
3	Lower Energy Price
4	Higher Energy Price
5	Higher Equipment Efficiency
6	Market Discount Rates Decline

²Normalized to standards case shipments.

**Table 3.8 Cumulative Energy Consumption of Pool Heaters During the Period 1996-2030
(Quadrillion Btu, Primary)**

	Base	Trial Standard	
		Level 2	Difference
Reference	3.24	3.02	0.22
1	3.03	3.03	0.00
2	3.36	2.99	0.37
3	3.29	3.03	0.26
4	3.21	3.00	0.21
5	2.70	2.55	0.15
6	3.19	3.02	0.17

Table 3.9 Cumulative Shipments of Pool Heaters During the Period 1996-2030 (Millions)

	Base	Trial Standard	
		Level 2	Difference
Reference	9	9	0
1	9	9	0
2	9	9	0
3	9	9	0
4	9	9	0
5	9	9	0
6	9	9	0

Source: LBL-REM.

**Table 3.10 Total Net Present Value to Consumers for Units Sold during the Period 1996-2030
(Discounted to 1990 at 7% Real)**

Case	Net Present Value (Billion 1990\$)	
	Trial	Standard Level 2
Reference	0.13	
1	0.00	
2	0.07	
3	0.16	
4	0.12	
5	-0.71	
6	0.00	

Source: LBL-REM.

CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS: POOL HEATERS

The effect of standards on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The net effect is analyzed by calculating the life-cycle cost, using the engineering data (Chapter 1) for energy consumption and equipment price, and assuming the energy price projected for 1996. Section 4.1 presents the life-cycle costs (LCC) for each design option. The results are displayed as graphs and as tables of values. Sections 4.2 through 4.4 show the impacts of standards on consumers. Section 4.5 presents the effect of different assumptions on the life-cycle cost calculations.

The *difference* due to standards is calculated (Sections 4.2 to 4.4) after a base case forecast is made (see Chapter 2). The base case forecast accounts for market-based shifts in efficiency and usage that are projected to occur independently of standards. Then only those appliance purchasers who are impacted by standards (i.e., those who would have chosen a design eliminated by standards) are included in calculating the impact of standards on consumers. The impact of standards is expressed by three measures:

- Section 4.2: Payback Period (PBP),
- Section 4.3: Change in Life-Cycle Cost (LCC), and
- Section 4.4: Cost of Conserved Energy (CCE).

4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS

The LCC is the sum of the purchase price (PC) and the operating expense (OC) discounted over the lifetime (N) of the appliance.

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

If operating expenses are constant over time, Eq. 1 simplifies to:

$$LCC = PC + PWF \cdot OC, \quad (2)$$

where we have defined the present worth factor:

$$PWF = \sum_{t=1}^N \frac{1}{(1+r)^t} = \frac{1}{r} \left[1 - \frac{1}{(1+r)^N} \right] \quad (3)$$

The LCC is calculated for each class in the year standards are imposed, using a discount rate, r .

4.1.1 LCC Data Inputs

The purchase price is based on the factory costs in the Engineering Analysis (Chapter 1) and includes a factory markup plus distributor and retailer markups, calculated by LBL-MIM. Installation and maintenance costs are also from the Engineering Analysis. Purchase price and installation costs are added to the present value of operating expenses (including maintenance, if applicable), discounted, and summed over the life of the product. Expenses in future years are discounted to the year of purchase, 1996. For the residential sector, the discount rate is 6% real, with sensitivity analysis performed at 2% and 10% real.

The energy price is the projected 1996 average residential energy price.

4.1.2 LCC Results

Figure 4.1 shows the LCCs by design option. The values used to produce these figures are presented in Table 4.1.

Figure 4.1 Life-Cycle Cost for a Gas-fired Pool and Spa Heater

Table 4.1 Life-Cycle Costs of Gas-Fired Pool and Spa Heaters

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	Energy Factor	Annual Energy Use			Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)	Energy Cost	4%	6%	10%
	0	Baseline	0.00	1296.95	1296.95	78%	30.49	0.00	225.13	3800.02	3483.46	3009.30
1	1	0 + IID	0.00	1384.08	1384.08	78%	26.03	2.23	192.36	3522.82	3252.34	2847.19
2	2	1 + Noncondensing Limit	0.00	1510.92	1510.92	82%	24.71	2.23	182.62	3541.31	3284.53	2899.91
3	3	0 + Induced Draft	100.00	2222.36	2322.36	91%	22.35	6.70	165.60	4163.51	3930.66	3581.89
4	4	0 + Pulse Combustion	100.00	3036.55	3136.55	96%	21.18	6.47	156.97	4881.76	4661.04	4330.45
	5	0 + Power Burner	100.00	3366.08	3466.08	93%	21.79	6.59	161.45	5261.18	5034.15	4694.11

Notes: Average lifetime for gas-fired pool and spa heaters is 15 years.
All costs are in 1990 dollars.
Electricity rate is 8.61 cent/kWh. (1996).
Gas rate is 7.38 \$/MMBtu (1996).
Consumer costs include installation costs but no maintenance costs.

Table 4.2.a Cost and Energy Use Summary Gas-Fired Pool and Spa Heaters

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	1296.95	225.13	3483.46	30.49
1	1384.08	192.36	3252.34	26.03
2	1510.92	182.62	3284.53	24.71
3	2322.36	165.60	3930.66	22.37
4	3136.55	156.97	4661.04	21.21

Table 4.2.b Distribution of Units Sold Below Standards Gas-Fired Pool and Spa Heaters

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4
0	100.00%	100.00%	100.00%	100.00%	100.00%
1	0.00%	<Standard>	0.00%	0.00%	0.00%
2	0.00%		<Standard>	0.00%	0.00%
3	0.00%			<Standard>	0.00%
4	0.00%				<Standard>

Table 4.2.c Weighted-Averages of Units Sold Below Standards Gas-Fired Pool and Spa Heaters

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4
Equip. Price (1990 \$)	1296.95	1296.95	1296.95	1296.95
Operating Cost (1990 \$)	225.13	225.13	225.13	225.13
Life-cycle Cost (1990 \$)	3483.46	3483.46	3483.46	3483.46
Energy Use (MMBtu/yr)	30.49	30.49	30.49	30.49

Table 4.2.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gas-Fired Pool and Spa Heaters

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4
LCC difference	231.1	198.9	-447.2	-1177.6
Payback	2.7	5.0	17.2	27.0
CCE (\$/MMBtu)	2.0	3.8	13.0	20.4

4.2 PAYBACK PERIODS BY STANDARD LEVEL

The payback period (PBP) measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. PBP is found by solving the equation:

$$\Delta PC + \sum_{i=1}^{PAY} \Delta OC_i = 0 \quad (4)$$

for *PAY*. In general, *PAY* is found by interpolating between the two years when the expression in Eq. 4 changes sign. If the operating cost is constant, the equation has the simple solution:

$$PAY = -\frac{\Delta PC}{\Delta OC} \quad (5)$$

Numerically, the PBP is the ratio of the increase in purchase (and installation) price from the base to the standards cases to the decrease in annual operating expenditures (including maintenance). Payback periods are expressed in years. A PBP of three years means that the increased purchase price is equal to three times the value of reduced operating expenses achieved in the year of purchase, or that the increased purchase price is recovered in approximately three years because of lower operating expenses. PBPs greater than the life of the product mean that the increased purchase price is not recovered in reduced operating expenses.

4.2.1 PBP Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.2.2 PBP Results

The PBPs by standard level shown in Table 4.2 are the weighted average. They compare that portion of the projected distribution of designs in the base case which are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts.

Table 4.2 shows the calculation of LCC differences, PBP, and CCE. The table is composed of several parts. Table 4.2a summarizes the equipment cost, operating cost, LCC, and

energy use for each design option. Table 4.2.b shows the distribution of units sold in 1996, according to the base case forecast. In the other columns, part of this distribution is expressed as the percent of eliminated units due to standards. That is, if 78% of units sold in the base case correspond to design 0, and standard level 1 (equivalent to design 1) eliminates only design 0, then the fraction of eliminated units due to standard level 1 is 100% for design 0.

Table 4.2.c applies the weights in Table 4.2.b to the values in Table 4.2.a to obtain the weighted-average values shown. Table 4.2.d shows the resulting LCC differences, PBPs, and CCE.

4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS

The impact of standards is calculated as the difference in LCC, base case minus standards case. If the LCC difference is greater than zero (positive savings), the standard provides a net decrease in expenses to the consumer. That is, the present value of decreased operating expenses offsets the increased purchase price. Conversely, if the LCC difference is negative, the standard causes a net increase in expenses to the consumer.

4.3.1 Data Inputs for Change in LCC

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.3.2 Results for Change in LCC

Table 4.2 shows the LCC differences by standard level, one table for each class. The results are the weighted average of LCC differences comparing that portion of the projected distribution of designs in the base case that are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts. These LCCs are calculated at a 6% discount rate; a higher discount rate (e.g., 10%) gives a smaller difference.

Tables 4.2.d shows lower LCC (positive LCC difference) for standard levels 1 and 2, and higher LCC for standard levels 3 and 4.

4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS

The CCE is the increase in purchase price amortized over the lifetime of the appliance at the consumer discount rate divided by the annual energy savings:

$$CCE = -\frac{CRF \cdot \Delta PC}{\Delta E} \quad (6)$$

where the capital recovery factor $CRF = 1/PWF$ is used to annualize the capital costs. Note that although the CCE can be measured in cents per kWh, it does not depend on current or future energy prices. The consumer will benefit whenever the cost of conserved energy is less than the price of energy for that end use.

4.4.1 CCE Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding the minimum compliance with the standard.

4.4.2 CCE Results

Table 4.2 show the cost of conserved energy at site of the standards levels as compared to the base case. Note that the current (1990) and projected (1996) average residential electricity prices are 8.11 and 8.29 cents per kWh respectively (12). These are equivalent to 23.74 and 24.28 dollars per million Btu, respectively, where one kWh is taken as 3,412 Btu site energy. The residential price of natural gas was \$5.69 per million Btu in 1990 and is projected to be \$6.15 in 1996 (12).

Standard levels 1 and 2 have CCEs less than projected costs of energy supply.

Standard levels 3 and 4 have CCEs greater than projected costs of energy supply.

4.5 LCC SENSITIVITY ANALYSIS

The sensitivity of the national LCC results were tested by varying assumptions about energy prices and equipment prices. These tables should be compared to the first set of tables in Section 4.1.

Low and high energy prices were defined as the minimum and maximum, respectively, of states' energy prices. Projected (1992) state energy prices (13) relative to the national average were applied to the projected 1996 national average price from the *Annual Energy Outlook 1991* to obtain state prices for 1996. (This represents a wider range of prices than analyzed in previous analyses, which used the average across Census regions.)

Low and high equipment prices were defined as one standard deviation below and above, respectively, the equipment prices used elsewhere in this chapter (from the Engineering Analysis). Note that the uncertainty in the baseline price is a percent of the total price, while the uncertainty in the price of other designs is applied to the incremental price of that design.

The following sensitivity cases were analyzed:

- (1) low (state) energy prices,
- (2) high equipment prices,
- (3) low (state) energy prices and high equipment prices,
- (4) high (state) energy prices,
- (5) low equipment prices, and
- (6) high (state) energy prices and low equipment prices.

Figure 4.2 and Table 4.3 summarize the results of the sensitivity analysis. They include:

- graph of highest and lowest LCC sensitivity, and reference case; and
- table of LCCs for all sensitivity cases.

The table also shows the number of sensitivity cases for which each design option is the minimum LCC.

Figure 4.2 Sensitivity Analysis for a Gas-fired Pool and Spa Heater

Table 4.3 Sensitivity Summary of Life-Cycle Costs of Gas-Fired Pool Heaters

Standard Level Design Option	0	1	2	3	4	Std Level @ min LCC	Design Option @min LCC
Reference	3483	3252	3285	3931	4661	1	1
1	2825	2691	2752	3450	4205	1	1
2	3483	3279	3425	4612	5996	1	1
3	2825	2717	2892	4131	5540	1	1
4	7008	6262	6141	6516	7112	2	2
5	3483	3226	3144	3250	3327	2	2
6	7008	6235	6001	5835	5777	4	4
# of cases as min LCC		4	2		1		

CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF POOL HEATERS

5.1 LONG-RUN IMPACTS

The analysis shows that compared to the 1996 base case, the pool heater industry is likely to experience a return on equity (ROE) increase at all trial standards levels. At standards level 1, there is approximately a 95% chance that ROE will increase, with an expected increase of 0.79%. At standards level 2, there is approximately a 99% chance of a increase in ROE with an expected increase of 2.18%. At standards level 3, there is approximately a 93% chance of an increase in ROE with an expected increase of 8.04%. At standards level 4, there is approximately a 65% chance of an increase in ROE with an expected increase of 11.96%. These results are based on Table 5.1. The probabilities of change are computed from the expected change, the standard error of this estimate, and the assumption of a normal distribution.

5.1.1 Qualitative Analysis

According to reports from within the industry, pool heater manufacturing is characterized by economies of scale, which means that for the purposes of price determination, there are fixed costs. Depending on the standards level considered, these fixed costs are estimated to be approximately 10% of total costs. Increases in fixed costs cannot be passed on, which implies that the markup over variable costs must be approximately 10% if the average firm is to have near-average ROE. To the extent that this markup is the same after standards are imposed, and to the extent that standards induce an increase in variable costs, such costs will be more than completely passed on in the form of a price increase, which in itself is profitable, but which also tends to reduce profit because of the effect of a price increase on sales.

If standards induce an increase in fixed costs, this cost cannot be passed on and will negatively influence profit. Because of the mandated increase in efficiency, operating costs will necessarily decline, which will tend to increase profit by making pool heaters more attractive and, thereby increasing demand. Since demand is specified as a function of purchase price and operating cost (i.e., life-cycle cost) under constant life-cycle cost elasticity, as price changes, so does price elasticity, and consequently, markup. For instance, as price rises, price elasticity rises, and markup falls. The model calculates that these effects, when combined with the relatively low price elasticity of pool heaters, are more likely to increase economic profits than decrease them at all standards levels.

5.1.2 Quantitative Analysis

Table 5.1 summarizes all essential outputs from the LBL-MIM simulations using the primary scenario for pool heaters. Six other scenarios are summarized and discussed in the sensitivity section, Section 5.4.

Once the above interpretations are understood, the results of the model concerning the long-run impact of standards on the pool heater manufacturing industry can be read from the output table.

Table 5.1. Pool Heater Output Table: Primary Scenario - Long Run

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		-0.47%	-1.20%	-4.47%	-7.05%
S.E.		0.78%	0.90%	4.46%	4.47%
Price	\$632.66	\$678.86	\$746.05	\$1,122.86	\$1,554.06
% change		7.30%	17.92%	77.48%	145.64%
S.E.		0.59%	0.28%	7.50%	91.57%
Revenue (in \$M)	12.02	12.84	14.00	20.38	27.45
% change		6.80%	16.50%	69.55%	128.33%
S.E.		0.25%	0.81%	14.42%	69.70%
Net Income (in \$M)	1.03	1.10	1.23	1.91	2.64
Difference		0.07	0.20	0.88	1.61
S.E.		0.03	0.02	0.38	2.94
ROE	17.93%	18.72%	20.11%	25.97%	29.89%
Difference		0.79%	2.18%	8.04%	11.96%
S.E.		0.50%	0.45%	5.54%	30.85%

5.2 SHORT-RUN IMPACTS

The business cycle presents the pool heater manufacturing industry with fairly sharp periodic fluctuations in demand, much larger than the fluctuations predicted for any of the standards levels. These normal demand fluctuations present the same types of opportunities for price competition that will accompany fluctuations resulting from a change in standards. Regressing price on demand and a time trend for the past 18 years shows that a 10% fall in demand typically leads to a 0.3% fall in the price of pool heaters; a 10% demand increase has the reverse effect. This effect is taken into account as described in Volume A, Chapter 3, Section 3.3.4.2, and is used to produce a short-run version of the output table that is displayed in Table 5.2. Note that at each standards level analyzed for the pool heater manufacturing industry, the short-run ROE results are generally lower than the long-run results. For reasons that are

explained in in the above reference, the short-run change has been overestimated. Thus the values for change in Table 5.2 should be viewed as somewhat too large in absolute value.

Table 5.2. Pool Heater: Primary Scenario - Short Run

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		-0.46%	-1.18%	-4.37%	-6.82%
Price	\$632.66	\$678.37	\$744.66	\$1,115.16	\$1,537.41
% change		7.23%	17.70%	76.27%	143.01%
Revenue (in \$M)	12.02	12.83	13.98	20.26	27.22
% change		6.73%	16.31%	68.56%	126.43%
Net Income (in \$M)	1.03	1.06	1.12	1.45	1.76
Difference		0.03	0.09	0.42	0.73
ROE	17.93%	18.01%	18.40%	19.69%	19.91%
Difference		0.08%	0.47%	1.76%	1.98%
S.E.		0.68%	1.01%	5.77%	25.13%

5.3 IMPACT AS A FUNCTION OF FIRM SIZE

Generally, we find that average costs fall as production rises, thus larger firms tend to have a cost advantage because of economies of scale. However, we find that the pool heater industry is of quite high concentration and apparently never had a large number of firms to begin with. Most firms manufacture gas-fired pool heaters as an adjunct to other larger lines of business (e.g., boilers, pool and swimming equipment, etc.). There are no real niche products. Further, given that the trial standards are not generally considered to be technologically difficult to manufacture and the projected forecasts to be profitable for all standards levels, we do not expect significant adverse impacts on smaller firms.

5.4 SENSITIVITY ANALYSIS FOR POOL HEATERS

The three following subsections discuss different aspects of the sensitivity analysis conducted by LBL-MIM. The first subsection, on sensitivity charts, shows the implications of the uncertainty of each control variable for the prediction of ROE. The next subsection shows six alternative scenarios that are of particular importance and deserve a more detailed analysis than those randomly generated by Monte Carlo runs. The last subsection shows the use of Monte Carlo runs to find combinations of errors that would cause the change in ROE to be considerably more negative than is predicted.

5.4.1 Sensitivity Charts

Table 5.3 lists the sensitivity of ROE to a change in control panel inputs. The variables analyzed are industry price elasticity of demand (IPE), discount rate (RD), the equity cost of capital (ECC), economic profit (EP), the fixed part of costs (FCA), the fixed part of one-time costs (FIX), one-time capital costs (CC.N), one-time variable costs (dVC.N), and the shape parameter of the demand curve (ro.N).

Table 5.3. Sensitivity of ROE to 1 S.E. Change in Control Variable

Control Variables			Possible Standards Levels			
Name	Value	Changed	1	2	3	4
IPE	-0.080	-0.184	-0.10%	-0.29%	-1.75%	-3.67%
RD	34.00%	78.17%	0.28%	0.46%	1.06%	1.48%
ECC	0.068	0.075	-0.01%	-0.02%	-0.11%	-0.21%
EP	0.111	0.121	0.03%	0.09%	0.36%	0.55%
FCA	0.102	0.164	0.55%	1.43%	5.36%	8.29%
FIX	0.102	0.178	-0.13%	-0.31%	-1.06%	-1.61%
CC.N	0.786	0.958	-0.06%	-0.16%	-0.96%	-1.88%
dVC.N	33.480	44.903	0.47%	1.07%	3.61%	5.38%
ro.N	0.000	0.300	-0.51%	-1.35%	-5.66%	-9.62%

As can be seen from the table, seven control variables account for nearly all of the uncertainty in the determination of ROE. These are (1) the industry elasticity of demand with respect to price (IPE), (2) the discount rate (RD) from which operating cost elasticity is derived, (3) fixed part of costs (FCA), (4) one-time variable costs (dVC.N), (5) one-time capital costs (CC.N), (6) the shape parameter of the demand curve (ro.N), and (7) fixed part of one-time costs (FIX). The reasons why these variables are important are discussed below.

5.4.2 Alternative Scenarios

The sensitivity analysis shows that both price and operating cost elasticities (the latter is derived from the discount rate) play crucial roles in determining the model's output. These are both *industry* elasticities as opposed to single-firm elasticities; this means they measure the effect on demand of a change in price by all firms and a change in operating cost of all pool heaters. The estimates of standard errors that are calculated by the Monte Carlo analysis fully acknowledge the uncertainties of these two variables. However, in order to show in detail all of the ramifications of changing one or both of them, six alternative scenarios have been run. The six scenarios include low and high price elasticity scenarios, a constant shipments scenario (i.e., industry price and operating cost elasticity set to zero), high and low discount rate scenarios (i.e., high and low operating-cost scenarios), and a low discount rate and high price elasticity scenario. Tables 5.4 through 5.9 show the results of running these six scenarios for the pool heater manufacturing industry.

In these alternative scenarios, note the impact of a change in the discount rate. A high RD input value lowers ROE, and a lower RD value increases ROE. Because markup is determined by price elasticity, it will tend to change as the ratio of price to operating cost changes. Standards will always increase this ratio, which decreases markup. This effect will be the strongest when appliance demand is relatively elastic with respect to operating cost. That is, a more elastic operating cost elasticity will result in a greater decrease in markup under standards, resulting in a greater decrease in profitability.

The other tables show that increasing price elasticity also tends to lower ROE. This effect is probably due to the greater decline in shipments when price elasticity is greater.

The percentage of fixed costs (FCA) is important because of its role in the model. It determines the LBL-MIM's estimate of the markup over variable cost, which, in turn, determines the firm's ability to pass on various combinations of fixed and variable costs. For a more detailed explanation, see Volume A, Appendix C. F1X is analogous to FCA for each standards level.

The incremental variable cost (dVC.L) is important because of its impact on price and because it is a variable cost. Firms will pass on increases in variable costs in the form of higher prices; therefore, profitability is affected by the amount of variable cost increase that can be passed on. As noted in Volume A, Appendix C, variable costs are passed on, while fixed costs are not, so variable costs in general do not hurt profitability. Further, as increased variable costs are translated into higher prices, price elasticity and markup are affected, and a change in markup affects profitability.

The shape of the demand curve parameter (ro.N) plays a role under certain circumstances. The demand function is specified as a function of life-cycle cost (i.e., of purchase price and operating cost). If purchase price plays a relatively large role in the demand function, then demand is less sensitive to changes in the shape parameter since in the limit, demand would be

a function of purchase price. Hence the shape parameter plays a larger role when operating cost and price play relatively equal roles in determining life-cycle cost. Also, it depends on how much of a change in operating costs result from a particular standards level under consideration. This is because a large change in operating cost will shift demand to a very different part of the demand curve.

The one-time capital cost (CC.N) variable is important because of its impact on price and because it is largely a fixed cost. Firms cannot pass on increases in fixed costs in the form of higher prices. Therefore, firm profitability is affected by the level of fixed costs. As noted in Volume A, Appendix C, variable costs are passed on, while fixed costs are not, so fixed costs hurt profitability.

5.4.3 Monte Carlo Analysis

The Monte Carlo approach is described in Volume A, Chapter 3, Section 3.3.4.3, and the standard errors it generates are reported in the output tables. Table 5.10 shows the control panels from two Monte Carlo runs which were selected because they show a decrease in long-run ROE. Both Monte Carlo runs were done on standards level 2. In both cases, we see how large increases in price elasticity coupled with increases in the percentage of both fixed costs and one-time costs (which are not passed through via prices) are the primary factors in reducing ROE despite drops in the discount rate.

Table 5.4 Pool Heater Output Table: Low Price Elasticity Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		0.00%	0.00%	-0.01%	-0.01%
S.E.		0.00%	0.00%	0.00%	0.00%
Price	\$632.66	\$678.86	\$746.05	\$1,122.86	\$1,554.06
% change		7.30%	17.92%	77.48%	145.64%
S.E.		2.21%	5.62%	23.64%	62.88%
Revenue (in \$M)	12.02	12.90	14.17	21.33	29.52
% change		7.30%	17.92%	77.47%	145.62%
S.E.		2.21%	5.62%	23.63%	61.45%
Net Income (in \$M)	1.03	1.11	1.25	2.07	3.01
Difference		0.08	0.23	1.04	1.98
S.E.		0.07	0.19	0.90	3.40
ROE	17.93%	18.80%	20.33%	27.28%	32.68%
Difference		0.87%	2.40%	9.35%	14.75%
S.E.		1.13%	3.11%	11.82%	37.85%

Table 5.5 Pool Heater Output Table: High Price Elasticity Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		-0.93%	-2.39%	-8.74%	-13.59%
S.E.		0.28%	0.73%	1.82%	2.52%
Price	\$632.66	\$678.86	\$746.05	\$1,122.86	\$1,554.06
% change		7.30%	17.92%	77.48%	145.64%
S.E.		1.93%	5.81%	24.02%	58.49%
Revenue (in \$M)	12.02	12.78	13.84	19.47	25.51
% change		6.31%	15.10%	61.98%	112.25%
S.E.		1.61%	4.76%	18.85%	46.15%
Net Income (in \$M)	1.03	1.09	1.20	1.75	2.29
Difference		0.07	0.17	0.72	1.27
S.E.		0.06	0.20	0.82	2.86
ROE	17.93%	18.65%	19.88%	24.63%	27.07%
Difference		0.72%	1.95%	6.70%	9.14%
S.E.		1.02%	3.43%	11.63%	34.11%

Table 5.6 Pool Heater Output Table: Constant Shipments Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		0.00%	0.00%	0.00%	0.00%
S.E.		0.00%	0.00%	0.00%	0.00%
Price	\$632.66	\$678.86	\$746.05	\$1,122.86	\$1,554.06
% change		7.30%	17.92%	77.48%	145.64%
S.E.		2.28%	4.99%	26.03%	87.97%
Revenue (in \$M)	12.02	12.90	14.17	21.33	29.53
% change		7.30%	17.92%	77.48%	145.64%
S.E.		2.28%	4.99%	26.03%	87.97%
Net Income (in \$M)	1.03	1.11	1.25	2.07	3.01
Difference		0.08	0.23	1.04	1.98
S.E.		0.09	0.17	1.07	6.26
ROE	17.93%	18.80%	20.33%	27.29%	32.68%
Difference		0.87%	2.40%	9.36%	14.75%
S.E.		1.47%	2.72%	14.28%	67.96%

Table 5.7 Pool Heater Output Table: Low Discount Rate Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		-0.47%	-1.20%	-4.47%	-7.05%
S.E.		0.16%	0.38%	0.94%	1.35%
Price	\$632.66	\$678.86	\$746.05	\$1,122.86	\$1,554.06
% change		7.30%	17.92%	77.48%	145.64%
S.E.		2.21%	5.91%	23.83%	125.25%
Revenue (in \$M)	12.02	12.84	14.00	20.38	27.45
% change		6.80%	16.50%	69.55%	128.33%
S.E.		2.02%	5.37%	21.13%	109.67%
Net Income (in \$M)	1.03	1.10	1.23	1.91	2.64
Difference		0.07	0.20	0.88	1.61
S.E.		0.06	0.20	0.97	8.10
ROE	17.93%	18.72%	20.11%	25.97%	29.89%
Difference		0.79%	2.18%	8.04%	11.96%
S.E.		1.13%	3.38%	13.54%	89.97

Table 5.8 Pool Heater Output Table: High Discount Rate Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		-0.58%	-1.34%	-4.56%	-7.04%
S.E.		0.17%	0.35%	0.95%	1.44%
Price	\$632.66	\$681.13	\$749.86	\$1,133.62	\$1,572.28
% change		7.66%	18.53%	79.18%	148.52%
S.E.		2.37%	5.75%	28.01%	52.71%
Revenue (in \$M)	12.02	12.87	14.06	20.56	27.77
% change		7.04%	16.94%	71.02%	131.03%
S.E.		2.17%	5.23%	24.95%	46.62%
Net Income (in \$M)	1.03	1.13	1.23	2.03	2.85
Difference		0.10	0.24	1.01	1.82
S.E.		0.09	0.23	1.24	253.41%
ROE	17.93%	19.19%	20.85%	27.70%	32.30%
Difference		1.26%	2.92%	9.77%	14.37%
S.E.		1.61%	3.77%	17.44%	29.02%

Table 5.9 Pool Heater Output Table: Low Discount Rate and High Price Elasticity Scenario

	1996 BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.02	0.02	0.02	0.02	0.02
% change		0.02%	-1.23%	-7.82%	-13.34%
S.E.		0.32%	0.73%	2.06%	3.05%
Price	\$632.66	\$672.37	\$735.12	\$1,092.01	\$1,501.84
% change		6.28%	16.20%	72.61%	137.39%
S.E.		2.00%	5.08%	22.55%	62.25%
Revenue (in \$M)	12.02	12.78	13.80	19.13	24.73
% change		6.29%	14.77%	59.11%	105.72%
S.E.		1.65%	4.12%	16.99%	46.09%
Net Income (in \$M)	1.03	1.03	1.09	1.43	1.74
Difference		0.00	0.06	0.40	0.71
S.E.		0.02	0.08	0.56	2.72
ROE	17.93%	17.43%	17.88%	19.94%	20.50%
Difference		-0.50%	-0.05%	2.01%	2.57%
S.E.		0.43%	1.35%	8.15%	35.17%

Table 5.10 Pool Heater Monte Carlo Runs: Searching for Low ROE

		Scenario: Primary		Standard Level = 2		
POOL HEATERS CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity		-0.080	0.36	100%	-0.108	IPE
Consumer Discount Rate		34.00%	-0.12	100%	30.81%	RD
Equity Cost of Capital		0.068	1.19	10%	0.077	ECC
Economic Profit		0.111	1.20	1%	0.123	EP
L-R Fixed Part of Costs & Assets		0.102	1.37	50%	0.194	FCA
L-R Fixed Part of 1-X Cap. Cost		0.102	1.18	60%	0.197	F1X
One-Time Capital Costs		1.897	1.53	20%	2.570	CC.N
Unit Variable Cost Increase		\$80.80	-0.59	30%	68.004	dVC.N
Elasticity Curve Parameter		0.000	2.20	30%	0.659	ro.N
Short Run Price Response to Demand		0.157	-0.94	76%	0.045	SRPR
		NAECA	NEW		PRVIOUS	NEW
SUMMARY		BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments		0.02	0.02	-1.34%	-0.47%	0.02
Price		\$632.66	724.88	14.58%	7.30%	724.44
Revenue (in \$M)		12.02	13.59	13.04%	6.80%	13.58
Net Income		1.14	1.15	0.00	0.07	1.03
ROE		19.99%	18.35%	-1.64%	0.79%	16.52%
08-Sep-92		16:09	Trys =		100.00	

		Scenario: Primary		Standard Level = 2		
POOL HEATERS CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity		-0.080	-0.28	100%	-0.063	IPE
Consumer Discount Rate		34.00%	-2.56	100%	4.05%	RD
Equity Cost of Capital		0.068	1.37	10%	0.078	ECC
Economic Profit		0.111	1.72	1%	0.129	EP
L-R Fixed Part of Costs & Assets		0.102	-0.66	50%	0.075	FCA
L-R Fixed Part of 1-X Cap. Cost		0.102	-0.43	60%	0.081	F1X
One-Time Capital Costs		1.897	1.43	20%	2.518	CC.N
Unit Variable Cost Increase		\$80.80	-0.99	30%	60.429	dVC.N
Elasticity Curve Parameter		0.000	-0.55	30%	-0.166	ro.N
Short Run Price Response to Demand		0.157	0.26	76%	0.221	SRPR
		NAECA	NEW		PRVIOUS	NEW
SUMMARY		BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments		0.02	0.02	0.09%	-1.20%	0.02
Price		\$632.66	714.14	12.88%	17.92%	714.28
Revenue (in \$M)		12.02	13.58	12.98%	16.50%	13.58
Net Income		1.18	1.19	0.01	0.20	1.09
ROE		20.65%	18.85%	-1.80%	2.18%	17.21%
08-Sep-92		16:14	Trys =		265.00	

CHAPTER 6. IMPACTS OR STANDARDS ON ELECTRIC UTILITIES: POOL HEATERS

6.1 INTRODUCTION

Only gas-fired pool heaters were evaluated. No impact on electric utilities is expected.

CHAPTER 7. ENVIRONMENTAL EFFECTS

7.1 INTRODUCTION

The environmental effects from a range of new candidate energy conservation standards for pool heaters are presented here. The results are presented for each potential standard level. Each measure of possible environmental change is an alternative action, and it is compared to what is expected to happen if no new standards for pool heaters were finalized, i.e., the "no action" alternative.

Since only gas pool heaters are being considered in this analysis, the only environmental concern addressed is emissions from the fuel-burning appliance. Most of the design options for gas pool heaters result in decreased fuel use. The proposed efficiency standards will generally decrease air pollution by decreasing the energy consumption of the appliance. Reductions of nitrogen oxides and carbon dioxide occur and are listed by weight of NO_x and CO_2 , respectively. CO_2 emissions from fossil-fuel burning are considered an environmental hazard because they contribute to the "greenhouse effect" by trapping heat energy from the earth that is emitted as infrared radiation. The "greenhouse effect" is expected to gradually raise the mean global temperature. The proposed efficiency standards for gas pool heaters will not decrease emissions of sulfur oxides.

For a detailed description of the methodology that was used in estimating the environmental impacts, please refer to the Environmental Assessment in Volume A.

7.2 RESULTS

The following tabular results indicate what changes can be brought about in the amounts of emitted CO_2 , SO_2 , and NO_x by imposing efficiency standards for pool heaters. A table is presented for each of the appliance's trial standard levels. Each table details the changes that occur to each of the three emissions (i.e., CO_2 , SO_2 , and NO_x) through the imposition of an appliance's specific trial standard level. Each table includes the following information for a specific year between 1996 and 2030: the amount of emission abated from power plant generation, the amount abated from in-home generation, the net change in the emissions, and the percent the net change comprises of total U.S. power plant emissions. Also included are the cumulative changes of each pollutant (between the years 1996 and 2030).

Decreases in the amounts of CO_2 , SO_2 , and NO_x emitted at trial standards levels 1 through 4 are summarized in Tables 7.1 through 7.4.

7.2.1 Sulfur and Nitrogen Oxide Emissions

Sulfur dioxide emissions would be decreased by a cumulative total of up to 0.00 million tons between 1996 and 2030 in the level 4 scenario. In the year 1996, decreases in sulfur dioxide will represent about 0.00% of the SO₂ emissions estimated to come from power plants in that year. In the year 2030, decreases in SO₂ emissions will represent about 0.00% of the SO₂ emissions estimated to come from power plants in that year.

Level 4 design changes to pool heaters would result in an estimated decrease in NO_x emissions of 0.04 million tons between 1996 and 2030. NO_x decreases would represent 0.003% and 0.03% of the NO_x emissions estimated to come from power plants in the years 1996 and 2030, respectively.

7.2.2 Carbon Dioxide Emissions

The cumulative reduction in CO₂ emissions from level 4 design changes is 43 million tons of CO₂. For the year 1996, the estimated CO₂ reduction is 270 thousand tons of CO₂ or about 0.01% of estimated U.S. total CO₂ emissions in 1996. For the year 2030, the estimated CO₂ reduction is 1744 thousand tons of CO₂, or about 0.04% of estimated U.S. total CO₂ emissions in 2030.

Table 7.1
Reduction of Pollutants for Pool Heaters - Level One

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	0	110	110	0.00%
2000	0	292	292	0.01%
2005	0	292	292	0.01%
2010	0	198	198	0.01%
2015	0	44	44	0.00%
2020	0	-11	-11	0.00%
2025	0	-11	-11	0.00%
2030	0	-17	-17	0.00%

Cumulative CO2 reduction, 1996-2030 = 4 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	0	0	0	0.00%
2005	0	0	0	0.00%
2010	0	0	0	0.00%
2015	0	0	0	0.00%
2020	0	0	0	0.00%
2025	0	0	0	0.00%
2030	0	0	0	0.00%

Cumulative SO2 reduction, 1996-2030 = 0 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	0	105	105	0.00%
2000	0	278	278	0.00%
2005	0	278	278	0.00%
2010	0	189	189	0.00%
2015	0	42	42	0.00%
2020	0	-10	-10	0.00%
2025	0	-11	-11	0.00%
2030	0	-16	-16	0.00%

Cumulative NOx reduction, 1996-2030 = 3,864 tons

Table 7.2
Reduction of Pollutants for Pool Heaters - Level Two

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	0	149	149	0.01%
2000	0	396	396	0.02%
2005	0	479	479	0.02%
2010	0	440	440	0.01%
2015	0	319	319	0.01%
2020	0	292	292	0.01%
2025	0	319	319	0.01%
2030	0	347	347	0.01%

Cumulative CO2 reduction, 1996-2030 = 12 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	0	0	0	0.00%
2005	0	0	0	0.00%
2010	0	0	0	0.00%
2015	0	0	0	0.00%
2020	0	0	0	0.00%
2025	0	0	0	0.00%
2030	0	0	0	0.00%

Cumulative SO2 reduction, 1996-2030 = 0 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	0	142	142	0.00%
2000	0	378	378	0.01%
2005	0	457	457	0.01%
2010	0	420	420	0.01%
2015	0	305	305	0.00%
2020	0	278	278	0.00%
2025	0	305	305	0.00%
2030	0	331	331	0.01%

Cumulative NOx reduction, 1996-2030 = 11,870 tons

Table 7.3
Reduction of Pollutants for Pool Heaters - Level Three

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	0	226	226	0.01%
2000	0	616	616	0.02%
2005	0	891	891	0.03%
2010	0	990	990	0.03%
2015	0	963	963	0.03%
2020	0	1,018	1,018	0.03%
2025	0	1,122	1,122	0.03%
2030	0	1,232	1,232	0.03%

Cumulative CO2 reduction, 1996-2030 = 32 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	0	0	0	0.00%
2005	0	0	0	0.00%
2010	0	0	0	0.00%
2015	0	0	0	0.00%
2020	0	0	0	0.00%
2025	0	0	0	0.00%
2030	0	0	0	0.00%

Cumulative SO2 reduction, 1996-2030 = 0 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	0	215	215	0.00%
2000	0	588	588	0.01%
2005	0	851	851	0.01%
2010	0	945	945	0.01%
2015	0	919	919	0.01%
2020	0	971	971	0.01%
2025	0	1,071	1,071	0.02%
2030	0	1,176	1,176	0.02%

Cumulative NOx reduction, 1996-2030 = 30,508 tons

Table 7.4
Reduction of Pollutants for Pool Heaters - Level Four

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	0	270	270	0.01%
2000	0	748	748	0.03%
2005	0	1,128	1,128	0.04%
2010	0	1,304	1,304	0.04%
2015	0	1,326	1,326	0.04%
2020	0	1,430	1,430	0.04%
2025	0	1,584	1,584	0.04%
2030	0	1,744	1,744	0.04%

Cumulative CO2 reduction, 1996-2030 = 43 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	0	0	0	0.00%
2005	0	0	0	0.00%
2010	0	0	0	0.00%
2015	0	0	0	0.00%
2020	0	0	0	0.00%
2025	0	0	0	0.00%
2030	0	0	0	0.00%

Cumulative SO2 reduction, 1996-2030 = 0 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	0	257	257	0.00%
2000	0	714	714	0.01%
2005	0	1,076	1,076	0.02%
2010	0	1,244	1,244	0.02%
2015	0	1,265	1,265	0.02%
2020	0	1,365	1,365	0.02%
2025	0	1,512	1,512	0.02%
2030	0	1,664	1,664	0.03%

Cumulative NOx reduction, 1996-2030 = 41,176 tons

APPENDIX A. ENERGY CALCULATIONS

A.1 CALCULATION OF AVERAGE HEAT LOAD FOR POOL & SPA HEATERS

The calculation of average heat load for pool and spa heaters was based on conditional demand analysis studies of natural gas customers in California.

Conditional demand analysis is a statistical method of inferring energy consumption by end use type (e.g., space heating, space cooling, water heating, and various appliances) for a representative sample of households from utility energy bills, weather data, and certain other data reported by the occupants of the sample houses.

Conditional demand analysis is an application of linear regression analysis where the dependent variable is the total gas or electric energy usage for a group of households over a given period (typically a monthly or bimonthly utility billing period), and the explanatory variables are the characteristics of the house and its occupants (especially the types of energy end use) and the weather data (heating and cooling degree days) for the corresponding billing period. The name, conditional demand analysis, derives from the fact that the total demand calculated (in therms or kWh) is conditional upon the utilization of a specific end use. The regression coefficients of the analysis represent the average energy consumption associated with particular end-use types (14).

Several conditional demand analysis studies were found that included gas-fired pool and spa heaters. These are listed in Table A.1, with one additional report that included metered data. These studies were all done in California. The data for the first two studies were collected statewide and were from houses built after 1984. Thus, these heaters would not have had standing pilots. The other four conditional demand analysis studies were done for Southern California Gas Company, and were limited to southern California. The southern California studies were done before standing pool heater pilot lights were prohibited in California. The lower spa heater energy consumption in the first study may be due to the elimination of standing pilots. The larger pool heater energy consumption in the first two studies is probably due to more heat loss from the swimming pools in cooler climates. The metered pool used 558, then 1,151 therms per year, in the first two years of monitoring. After the second year a pool cover was used. No heating was required in the last two years the pool was metered.

The average annual energy consumption from the first two studies was used to calculate heating loads of swimming pools because the weather during the swimming season was thought to better match weather in other parts of the country. Using these studies also avoided having to correct for the energy consumption of pilot lights. The annual energy consumption for spa heating from the first study was used to calculate spa heating load, again to avoid the pilot light energy consumption. Both annual energy consumption values were multiplied by 75%, the estimated average pool and spa heater efficiency in the mid 1980s, to determine the heating loads. This gave an average annual heating load for swimming pools of 196 therms and an average annual heating load for spas of 91 therms.

Table A.1 Conditional Demand Analysis (CDA) Studies with Pool and Spa Heaters

Report	Pool (therms/yr)	Spa	Sample Size	Study Type	Location
BSG/Xenergy (15)	283	121	~80 pools, ~200 spas	CDA	Calif
CEC (16)	240		?	CDA	Calif
Van Lierop-2 ³ (17)	192	279	~9 pools, ~19 spas	CDA	Southern Calif
Van Lierop-1 ⁴ (18)	162	223	~85 pools, ~76 spas	CDA	Southern Calif
Parti (1981) ⁵ (19)	199	306	~54 pools, ~33 spas	CDA	Southern Calif
Parti (1979) ⁶ (20)	332		?	CDA	Southern Calif
Wei (1979) (21)	427		1 pool, 4 years	meter	Northern Calif

To calculate an average annual heat load for pool and spa heaters, the average pool and spa heating loads must be weighted by the number of heaters supplying each type of load. Pool heater manufacturers estimate heater shipments are about evenly split between new pool installations and the replacement market. In new pool installations, pools and spas are often installed to use the same heater. The shipments to new and replacement installations were combined to give estimates of percentage of heater shipments installed on pools only, spas only, and both pools and spas. These estimates are listed in Table A.2.

³This is for houses built between 1979-1983 during Phase 1 of the California energy efficiency standards.

⁴This is for houses built before 1979, before the California energy efficiency standards were applied.

⁵This study used data taken in 1981.

⁶This study used data taken in 1979.

Table A.2 Estimated Percentage of Heaters Serving Pools, Spas, and Both

	Pool Only	Spa Only	Both	Total
New	40%	10%	50%	50%
Replacement	80%	20%	0%	50%
Total	60%	15%	25%	

Weighting the estimated annual heat load for spas and pools with the percentage of heaters serving pools only, spas only, and both pools and spas gives an average heat load for all heaters shipped. Using these estimates, the weighted-average annual heating load for all pool heaters shipped was 203 therms per year, as calculated below.

Weighted Average Heating Load =

Percentage Pools Only * Pool Heating Load +

Percentage Spas Only * Spa Heating Load +

Percentage Pools and Spas * (Pool Heating Load + Spa Heating Load)

APPENDIX B. LBL-REM INPUT DATA: POOL HEATER

The complete input listing is available on electronic medium in ASCII format. The input database includes demographic, economic, and engineering data.

The following is the regular LBL-REM input for pool heaters.

For standards cases, simply replace the input values for two variables in each class of each product regulated. The two variables are labelled: "first year for standard" and "UEC of standard." For example, for pool heater standards taking effect in 1996, change the line "first year for standard = 2031" to "first year for standard = 1996" and enter the appropriate maximum UEC values in the line "UEC of standard."

Pool Heater

total saturation = 1.00
elec price multiplier = 1.04
gas price multiplier = 1.00
ncalc = 0
ndr1 (1, read drate & curve) = 0
nv1 (# of eun inputs) = 0
nv5 (# of cap inputs) = 0
nv2 (# of peq inputs) = 0
nv4 (# of usage inputs) = 1
ndis (year to forecast eff) = 11

----- UEC of stock unit in base year by fuel type i (MMBTU/yr) -----

1	2	3	4	5	
0.00	32.803	0.00	0.00	0.00	** SF **
0.00	32.803	0.00	0.00	0.00	** MF **
0.00	32.803	0.00	0.00	0.00	** MB **

----- Purchase price of a reference unit (\$1990) -----

1	2	3	4	5	
0.00	1296.95	0.00	0.00	0.00	** SF **
0.00	1296.95	0.00	0.00	0.00	** MF **
0.00	1296.95	0.00	0.00	0.00	** MB **

----- Relative UEC and Capacity of a reference unit to a stock unit -----

1	2	3	4	5	
0.00	.9295	0.00	0.00	0.00	** re **
0.00	1.00	0.00	0.00	0.00	** recap**

```

----- Base Year Saturations - c70 -----
      1      2      3      4      5      6
0.000  0.014  0.000  0.000  0.000  0.986      ** SF **
0.000  0.000  0.000  0.000  0.000  1.000      ** MF **
0.000  0.000  0.000  0.000  0.000  1.000      ** MH **

----- Marginal Saturations for Replacement Units - cn(m=1) -----
      1      2      3      4      5      6
0.000  0.900  0.000  0.000  0.000  0.100      ** SF **
0.000  0.000  0.000  0.000  0.000  1.000      ** MF **
0.000  0.000  0.000  0.000  0.000  1.000      ** MH **

----- Marginal Saturations for New Houses - cn(m=2) -----
      1      2      3      4      5      6
0.000  0.030  0.000  0.000  0.000  0.970      ** SF **
0.000  0.000  0.000  0.000  0.000  1.000      ** MF **
0.000  0.000  0.000  0.000  0.000  1.000      ** MH **

----- Historical Shipments (from 1980 to 30 years back) -----
2 Gas
.1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000
.1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000
.1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000 .1000

----- Retirement Function (from age 1 to 30 years) -----
for i 2
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0380
.0690 .0930 .1110 .1210 .1240 .1210 .1110 .0930 .0690 .0380
.0120 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000

----- Average Life Times (by fuel type i) -----
      1      2      3      4      5
0.00  15.00  0.00  0.00  0.00

----- Operating Cost Elasticities (for 5 fuel types and income) -----
      1      2      3      4      5      6
0.00  0.00  0.00  0.00  0.00  0.00      ^ j=1 ^/
0.00 -0.65  0.00  0.00  0.00  0.00      ^ j=2 ^/
0.00  0.00  0.00  0.00  0.00  0.00      ^ j=3 ^/
0.00  0.00  0.00  0.00  0.00  0.00      ^ j=4 ^/
0.00  0.00  0.00  0.00  0.00  0.00      ^ j=5 ^/
0.00  0.00  0.00  0.00  0.00 -0.05      ^ j=6 ^/

----- Real Interest Rate for calc of Price Elast. (for 5 fuel types) -----
      1      2      3      4      5
0.00  0.00  0.00  0.00  0.00      ^ j=1 ^/
0.00  0.08  0.00  0.00  0.00      ^ j=2 ^/
0.00  0.00  0.00  0.00  0.00      ^ j=3 ^/
0.00  0.00  0.00  0.00  0.00      ^ j=4 ^/
0.00  0.00  0.00  0.00  0.00      ^ j=5 ^/

```


----- Usage Elasticities (for 5 fuel types and income) -----

1	2	3	4	5	
0.00	0.00	0.00	0.00	0.00	/ j=1 */
0.00	-0.10	0.00	0.00	0.00	/ j=2 */
0.00	0.00	0.00	0.00	0.00	/ j=3 */
0.00	0.00	0.00	0.00	0.00	/ j=4 */
0.00	0.00	0.00	0.00	0.00	/ j=5 */
0.00	0.10	0.00	0.00	0.00	/ j=6 */

----- Historical Usage Factors for Existing Units -----

i	1	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
2	0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

of products in pool heater = 1

```
=====
product type id#      = 23
product name          = PIHt (Gas Pool Heater)
end-use id#           = 16
fuel type id#         = 2
number of classes     = 1
```

----- the 1st class -----

```
class id#             = 91
class name             = Gas Pool Heater
discount rate         = 0.34
first year to forecast UEC = 1990
first year for standard = 2031
UEC of standard        = 3.728
conversion (usage)     = 1.000
```

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
.753	.756	.759	.762	.765	.768	.771	.774	.777	.780

----- Adjusted volumes (1981-2030) (30.49*.78 /365)

```
.065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157
.065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157
.065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157 .065157
.065157 .065157 .065157 .065157 .065157
```

----- Fraction of market share (1981-2030)

```
l = 1 2 3
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
1.00 1.00 1.00 1.00 1.00
```

----- UEC (MMBTU) & Purchase Price (\$1990) data

Price	MMBTU	
1296.95	30.49	0.0000
1384.08	26.03	0.0076
1510.92	24.71	0.0076
2322.36	22.35	0.0229
3136.55	21.18	0.0221

----- Shipment Distribution

EF	Units
0.78	1.

APPENDIX C. LBL MANUFACTURER IMPACT MODEL: POOL HEATERS

C.1 INTRODUCTION

The Lawrence Berkeley Laboratory Manufacturer Impact Model (LBL-MIM) collects all the calculations necessary to determine the impact of a change in appliance efficiency standards on an industry's profitability and scale of operation into one spreadsheet. Volume A, Appendix C, provides an overview and description of the LBL-MIM. There is a description of the economic theory and a discussion of each of the model's modules. In this appendix, the LBL-MIM input data and model runs for the analysis of pool heaters are described together.

C.1.1 Engineering Cost Data

The source of the engineering data is the Engineering Analysis performed in Chapter 1 of this volume. The data came from manufacturers of these products and/or discussions with industry consultants and other studies. The engineering data used as inputs to the model consist of several components:

1. The incremental unit variable cost incurred by the manufacturer for each of the design options such as raw materials, direct labor, purchased parts, and increased transportation costs that increases the efficiency of the appliance. The incremental variable cost is listed for each design option for each product class.
2. The annual unit energy consumption (UEC) associated with each design option for each product class.
3. Some of the design options also require additional capital investment in the form of retooling, new tooling, or other capital expenditures. These expenses are listed as one figure for each design option requiring capital expenditures; the single figure covers all of the product classes.

The engineering input data are also listed for each standards level being analyzed (a 1990 calibration case, a 1996 base case using the 1990 standards, and standards levels 1, 2, 3, etc., which are the new levels being analyzed). The figures used are exactly the same as those used for the design options, but are calculated for standards levels instead. The engineering data used as inputs to the LBL-MIM are listed on the engineering data page of the model, which follows this section. The actual data are listed there rather than here since there are several tables of data. For a thorough description of the collection and meaning of the engineering data, see the Engineering Analysis.

C.1.2 Industry Market Data

Industry Shipments

These data include annual industry shipments for the 1990 calibration case, the 1996 base case (using the 1990 standards), and the 1996 shipments for each of the standards levels. The 1990 shipments figure is based on estimates from the industry (22) and Gas Appliance Manufacturers Association (23).

Elasticities

Price and operating cost elasticities determine the effect on shipments of changes in appliance price and operating cost. For pool heaters, the price elasticity is estimated to be -0.08. The consumer discount rate is estimated to be 34%, which gives an operating cost elasticity of -0.001. The source of these elasticities is LBL. Because these elasticities are very important, a sensitivity analysis using different elasticities is done.

Product Class Market Share

Each of the product classes has a share of the total pool heater market, and the market share, or unit sales, for each product class is an input to the model. For pool heaters, there is only one product class under consideration (gas-fired pool heaters) so the market shares are 100% of that one product class.

Markups

Manufacturers charge different markups over variable cost for different product classes, resulting in different profit margins for different product classes. For pool heaters, the estimated markup is 1.40 and is based on discussions with the industry and their responses to LBL questionnaires.

Initial prices

The 1990 baseline manufacturer's selling price is used as a base to which are added incremental costs of reaching the higher efficiency levels. The unit price quoted for each product class refers to the most inexpensive, fewest-frills model produced by the manufacturer. The source of the baseline manufacturer's price for each product class is research by the Manufacturer Analysis team with review by industry consultants.

Energy price

This figure is the ratio of the price of a 1990 kWh to a 1996 kWh. The source is the LBL-REM. Industry market data appear on the Cost, Sales, and Revenues page of the model.

C.1.3 Financial Input Data

Financial Inputs

The financial inputs for pool heaters are summarized in Tables C.1 to C.4.

Table C.1 Rates of Financial Costs

Variable	Value	Source
After-tax equity cost of capital ¹	6.8%	MIM calc. from public financial data ²
Interest rate on debt ¹	2.5%	MIM calc. from public financial data
Interest lost in cash ¹	1.0%	MIM calc. from public financial data
Rate of depreciation	17.7%	Public financial data
Tax rate	34.0%	Tax law

¹Cost of capital and interest rate are real rather than nominal.

²Public financial data include data from sources such as Value Line, Standard and Poor's, Moody's, individual company annual reports, and economic reports.

Table C.2 Other Financial Inputs

Variable	Value	Source
Cash	4.6%	Public financial data
Inventory and receivables	29.9%	Public financial data
Net depreciable assets	25.1%	Public financial data
General and administrative expenses	13.3%	Public financial data
Engineering expense	1.2%	Public financial data and industry sources ¹

¹Industry sources include consultants under contract to LBL and discussions with industry representatives.

Table C.3 Fixed, Variable, and Revenue-Related Cost Split

Variable	Value	Source
Fixed part of all costs and depr. assets	10.2%	Industry sources
Fixed part of one-time capital costs	10.2%	Industry sources
Economic profit	11.1%	MIM est. from financial data
Debt/equity ratio	25%	Public financial data
Markup on typical model	1.4	Industry sources
Ratio of highest to lowest markup	0.00	Industry sources

Table C.4 One-Time Costs

Variable	Value	Source
One-time capital cost's life	8 years	Industry sources
One-time capital cost's tax life	8 years	MIM calculation
Percent additional 1-X capital	50%	MIM estimate
Age of replaced capital	6 years	Public financial data

The expenditure schedule above lists the costs incurred over time for preparations to meet the new standards. A percentage of the total cost is attributed to each year before the standards go into effect, since that is when these expenses will occur.

C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO

Table C.5 Pool Heaters Version of LBL-MIM

Control Panel

		Scenario: Primary		Standard Level = 1	
POOL HEATERS		Input		Vari-	Progrm
CONTROL FACTORS		Value	Cntrl	ation	Value Name
Price Elasticity		-0.080	0.00	100%	-0.080 IPE
Consumer Discount Rate		34.00%	0.00	100%	34.00% RD
Equity Cost of Capital		0.068	0.00	10%	0.068 ECC
Economic Profit		0.111	0.00	1%	0.111 EP
L-R Fixed Part of Costs & Assets		0.102	0.00	50%	0.102 FCA
L-R Fixed Part of 1-X Cap. Cost		0.102	0.00	60%	0.102 FIX
One-Time Capital Costs		0.786	0.00	20%	0.786 CCN
Unit Variable Cost Increase		\$33.48	0.00	30%	33.480 dVCN
Elasticity Curve Parameter		0.000	0.00	30%	0.000 roN
Short Run Price Response to Demand		0.157	0.00	76%	0.157 SRPR
		NAECA	NEW	PRVIOUS	NEW
SUMMARY		BASE	L-RUN	CHANGE	S-RUN
Shipments		0.02	0.02	-0.47%	0.02
Price		\$632.66	678.86	7.30%	678.37
Revenue (in \$M)		12.02	12.84	6.80%	12.83
Net Income		1.03	1.10	0.07	1.06
ROE		17.93%	18.72%	0.79%	18.01%
		Trys =		2.00	

Table C.6 Pool Heaters Version of LBL-MIM

The Monte Carlo Module

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.						
		Secnds/iteration =			2.78	time
		Iterations to go =			0.00	nn
POOL HEATERS		Sample Size =			46.00	
	%dQ	%dP	%dR	%dNI	dROE.N	dROE.S
Value	0.04%	4.86%	4.90%	0.09%	-0.74%	-1.50%
Means	-0.67%	10.26%	9.27%	9.11%	0.86%	-0.31%
Std. Dev	1.57%	17.31%	13.93%	12.72%	1.25%	1.87%
History	0.00	0.05	0.05	0.00	-0.01	-0.02
...	0.00	0.10	0.10	0.20	0.03	0.02
Range	-0.01	0.09	0.08	0.06	0.01	0.00
Name	0.00	0.12	0.12	0.18	0.03	0.02
Is	0.00	0.09	0.09	0.05	0.00	0.00
Carlo	-0.01	0.07	0.06	0.05	0.00	-0.01
	0.00	0.06	0.06	-0.05	-0.02	-0.02
	0.00	0.08	0.08	0.05	0.00	-0.01
	0.00	0.06	0.06	0.09	0.01	0.00
	-0.03	0.09	0.05	0.09	0.02	0.01
	-0.01	0.11	0.10	0.05	0.00	-0.02
	0.00	0.06	0.06	0.01	0.00	-0.01
	-0.01	0.07	0.06	0.08	0.01	-0.01
	0.00	0.07	0.06	0.05	0.01	0.00
	0.00	0.07	0.07	0.07	0.01	0.00
	0.00	0.05	0.04	0.02	0.00	-0.01
	0.00	0.04	0.04	0.02	0.00	-0.01
	0.00	0.07	0.06	0.05	0.00	-0.01
	0.00	0.06	0.06	0.02	0.00	-0.01
	0.00	0.09	0.09	0.17	0.02	0.02
	-0.01	0.09	0.08	0.10	0.01	0.01
	-0.01	0.09	0.08	0.18	0.03	0.02
	-0.01	0.12	0.11	0.11	0.02	0.01
	0.00	0.09	0.09	0.05	0.00	0.00
	0.00	0.05	0.05	0.04	0.00	-0.01
	0.00	0.08	0.08	0.05	0.00	-0.01
	0.00	0.05	0.05	0.02	0.00	-0.01
	0.00	0.04	0.04	0.00	0.00	-0.01
	-0.01	0.05	0.04	0.03	0.00	-0.03
	-0.01	0.07	0.06	0.06	0.01	0.00
	0.00	0.08	0.08	0.04	0.00	-0.01
	-0.02	0.12	0.10	0.14	0.02	0.01
	0.00	0.07	0.07	0.12	0.01	0.00

Table C.7 Pool Heaters Version of LBL-MIM

The Accounting Module

(All units are millions or millions of \$ unless labeled with \$ or %.)

	1990	BASE '96	NEW '96	CHANGE
Revenue	12.02	12.02	12.84	6.8%
Expenses				
Cost of Goods Sold	8.59	8.59	9.18	6.9%
Selling & G & A	1.19	1.20	1.19	-0.3%
Engineering	0.11	0.11	0.11	-0.3%
Depreciation	0.55	0.55	0.55	NA
1-X Depreciation	0.00	0.00	0.10	NA
Total Expenses	10.43	10.44	11.13	6.6%
Earnings Before Interest & Taxes	1.59	1.58	1.71	8.1%
Interest	0.03	0.03	0.03	1.8%
Earnings Before Taxes	1.56	1.56	1.68	8.2%
Taxes	0.53	0.53	0.59	12.3%
Net Income	1.03	1.03	1.09	6.2%
Gross Margin	28.57%	28.57%	28.50%	-0.25%
Return on Sales	8.54%	8.54%	8.49%	-0.6%
Total Assets	7.16	7.16	7.35	2.7%
Return on Assets (w/intrst taxed)	14.66%	14.60%	15.08%	0.5
Equity	5.73	5.73	5.88	2.7%
Return on Equity	17.93%	17.93%	18.53%	0.6

ECONOMIC ANALYSIS

	1990	BASE '96	NEW '96	CHANGE
Shipments	0.02	0.02	0.02	-0.5%
Price	\$632.66	\$632.66	\$678.86	7.3%
Revenue	12.02	12.02	12.84	6.8%
Fixed Costs	1.23	1.23	1.23	-9.2%
Variable Costs (w/ Q)	9.24	9.24	0.02	-11.5%
Total Expenses	10.46	10.46	1.25	-10.9%
Cash	0.56	0.56	0.55	-10.8%
Inventories	3.59	3.59	3.57	-0.5%
Depreciable	-899.43	-866.43	-772.22	-10.9%
Total Assets	7.16	7.16	7.35	2.7%

Table C.8 Pool Heaters Version of LBL-MIM

The Engineering Inputs Module

ENGINE	ERING INPUT DATA							Cost of electricity					
	Increment in Additional UVC by Level and Class							(1990)					
Baseline	0	0+IID	1+Nonc ondensi ng Limit	0+Induc ed Draft	0+Pulse Combus tion	0+Powe r Burner						0.71	
Gas-Fired	0	33	47	345	647	768	0	0	0	0	0	0	0
VCS.E	Additional UVC. (Above Level 0 cost.)												
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
0.00	0	33	81	345	647	768	0	0	0	0	0	0	0
Energy Consumption - Natural Gas (Primary)													
MBTU	0	1	2	3	4	5	6	7	8	9	10	11	12
	30.5	26.0	24.7	22.3	21.2	21.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Energy Consumption - Electricity (Secondary, in KwHr)													
KWHR	0	1	2	3	4	5	6	7	8	9	10	11	12
	0.00	2.23	2.23	6.70	6.47	6.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual Operating Cost													
KWS.E	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas-Fired	225	192	183	166	157	161	0	0	0	0	0	0	0
Capital cost / unit / 7													
	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas-Fired	0	6	8	61	114	136	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CC.E Additional CC. (Above Level 0 cost.)													
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
0.00	0	6	14	61	114	136	0	0	0	0	0	0	0
	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas-Fired	0	1	2	8	15	18	0	0	0	0	0	0	0
CCEE.E													
	0	1	2	3	4	5	6	7	8	9	10	11	12
	0	1	2	8	15	18	0	0	0	0	0	0	0

Table C.9 Pool Heaters Version of LBL-MIM

The Standards Level Module

LevIn prev	LEV.B	lev.N	Eng:	0 ...	5	"Emax
-1	0	1	REM:	-1 ...	4	"Smax
1	1	1	1 ==> Stndrds		0 ==> Eng.	
SIE	SIE.B	SIE.N	Esc = QUIT			
VCS.R Additional UVC by Level and Class. (Above Base cost.)						
LEVEL -->	-1=1990	0=1996	1	2	3	4
Gas	0	0	33.48	80.8	344.83	646.58
KWS.R Kw Hrs /Yr						
LEVEL -->	-1=1990	0=1996	1	2	3	4
Gas	225	225	192	183	166	157
CC.R						
LEVEL -->	-1=1990	0=1996	1	2	3	4
Gas	0	0	5.91	14.26	60.85	114.1
CCEER						
LEVEL -->	-1=1990	0=1996	1	2	3	4
Gas	0	0	0.78603	1.89658	8.09305	15.1753
FCA and FIX.R						
LEVEL -->	-1=1990	0=1996	1	2	3	4
Gas	10.20%	10.20%	10.23%	10.23%	10.21%	10.21%
	FCA.R	~~~~~	Range Name is FIX.R		~~~~~	~~~~~
	1990	1996	NEW96	1990	1996	NEW96
	VC87	VCB	VCN	KW87	KWB	KWN
Micro	0	0	33.48	225.126	225.126	192.3578
	1990	1996	NEW96		Weighted	Weighted
	CPC87	CPCB	CPCN		Op Cost	Fuel Cost
Micro	0	0	5.91		225.126	F 19.39
---OUTPUT---						
CC.89	CCB	CCN	CC.B0	CC.N0		
0	0	0.78603	0	0.78603		

Table C.10 Pool Heaters Version of LBL-MIM

The Costs, Sales, and Revenue Module

							bb	632.66
							aa	0
Ratio of highest to lowest markup:					ratio.0	1.00	ratio.cv	0.20
Typical markup over UVC					mid.0	0.40	mid.cv	0.20
Size of firm as % of industry					size.0	0.20		
CALIBRATION CASE (1990)=								
Indst	Relatv	Firm		Price	Rev.			Weighted
Ship.	Ship.	Ship.	Q%	Q.1	P.1	R.1	m.1	UVC.1
Gas-Fired	0.10	1.00	0.02	632.66	12.02	1.40	451.90	451.90
TOTAL S	0.10	20.00%	0.02	\$633	12.02	1.40	20.00%	\$451.90
	"TS.0	"Q.CV	Q.0	P.0	R		"P.CV	UVC
BASE CASE (1996)								
Change	Weighted	Wghd		Op Cost	Weighted			
in UVC	C in UVC	d P	Pl.B	Ratio	OpCst-R	Qi.B	Ri.B	
Gas-Fired	0.00	0.00	0.00	\$633	1.00	1.00	0.0190	12.02
	0.00	0.00	0.00	\$633	12.02	0.00	0.0190	12.02
Mark.B	dVC.B	Pdiff.B	"P.B	Sum(Ri)	OC%.B0	"Q.B	"R.B	
dVC.B.CV	25.00%			check=R.B				
NEW STANDARDS CASE (1996)								
Change	Weighted	Wghd		% Chng	Weighted			
in UVC	C in UVC	d P	Pl.N	Op Cost	OpCst-R	Qi.N	Ri.N	
Gas-Fired	33.48	33.48	54.30	\$679	0.85	0.85	0.0189	12.84
TOTAL	0.85	33.48	54.30	\$679	25.68	-0.15	0.0189	12.84
Mark.N	dVC.N0	Pdiff.N	"P.N	Sum(Ri)	OC%.N0	"Q.N	"R.N	
				check=R.N				

Table C.11 Pool Heaters Version of LBL-MIM

The Financial Module

INPUT			C.V. or Control Factor	
NAME			VALUE	
NAME			VALUE	
RATES of COST				
After Tax Equity Cost of Capital	BCC.0	0.07	BCC.CV	10%
Interest Rate on Debt	LO	2.50%	LCV	100%
Interest Lost on Cash	ICash.0	0.01	ICASH.CV	100%
Rate of Depreciation	Dep.0	0.18		
Tax Rate	T.0	34.00%	T.CV	20%
ASSETS and COSTS as a PERCENT of REVENUE				
Cash	C:R.0	5%	C:R.CV	100.00%
Inventory & Receivables	IR:R.0	30%	IR:R.CV	27.19%
Depreciable Assets	DA:R.0	25%	DA:R.CV	36.89%
G & A	G&A.0	13%	G&A.CV	40.00%
Engineering	Eng	1.20%		
FIXED AND VARIABLE COST SPLIT				
Fixed Part of All Costs and Depr Assets	FDA.0	10.2%	FDA.CV	50.00%
Fixed Part of 1-X Capital Cost	FIX.0	10.23%	FIX.CV	60.00%
OTHER				
Economic Profit	EP.0	11.13%	EP.CV	1.00%
Debt to Equity ratio	DER.0	25.00%	DER.CV	43.36%
Markup on typical model	"mid	40.00%		
Ratio of highest to lowest markup	"ratio	0.00%		
OUTPUT				
NAME			VALUE	
Depreciation	DRR	4.6%		
G&A to Overhead Ratio	G:O	91.7%		
Engineering to Overhead Ratio	E:O	8.3%		
Debt Ratio	DR	20.0%		
Equity Ratio	ER	80.0%		
Pre-Tax Equity Cost of Capital*	PECC	10.3%		
Weighted Average Cost of Capital	WACC	8.7%		
After Tax WACC	ATWACC	5.8%		
Return on Equity	ROE	0.179		
Real ROE - Input	ROE.0	17.93%		

All interest rates and costs of capital are "real".

*When Pre-Tax ECC is used, all costs are counted tax exempt.

Table C.12 Pool Heaters Version of LBL-MIM

The One-Time Cost Amortization Module

NOTES

Economic life of existing capital	L	8.00	years
Tax life of existing capital	TL	6.00	years
Age of existing capital	AGE	1.00	years
Percent of 1X capital that is add-on (as opposed to replacement capital)	%NC	50%	

COMPUTATIONS

DESCRIPTION	NAME	VALUE	
Continuous After-Tax WACC	ATR	5.61%	
Weighted CC Lead-Time Factors	0.00	0.29	0.54 0.26
Cumulative CC Lead-Time Factors	LTC.0	1.092	
exp(-ATR*TL)	EMRT	0.714	
exp(-ATR*L)	EMRL	0.638	
Rate of tax benefit	3.30	BN	0.057
Remaining tax life	RTL	5.00	years
0.00 0.00 0.00 0.00 0.00	01-Jan	0.028	
Discount factor: @exp(-ATR*(L-(TL-RTL)))	DIS	0.68	
Loss of tax benefit on portion of existing capital with remaining tax life	LEC1	0.124	
Loss of tax benefit on discounted existing capital expenditure in the future	LEC2	0.097	
LEVELIZED CC		GROSS CC	TAX EFF
Initial Cost		1.000	
Tax Benefit of Straight-Line Depreciation			0.289
Savings from not replacing existing Capital later		-0.338	
Loss of Tax Benefit from existing Capital			-0.221
Present Value of CC:		0.662	0.068
Adjusted for Capital Lead Time		0.723	0.074
Levelized Tax Benefit: 1-X dep. of existing Cap.			0.004
LEVELIZED CC FACTOR	CCLF	0.112	0.016
AVERAGE ASSET FACTOR			
Asset Factor for Any New Cap. or Asset	AFB	0.574	
Average Asset Factor for Add-on Capital	AAF	0.287	

INPUT

NEW CAP. COST: 1990-96 (\$000)	CC.B0	0.00
1996 CHANGE	CC.N	0.79
COEFFICIENTS OF VARIATION	CCL.CV	0.20

OUTPUT

	BASE CASE 1996		NEW STNDS 1996	
Levelized 1-X CC: Gross	LCC.B	0.00	LCC.N	0.09
Levelized 1-X CC: Tax Effects	LCC.TB	0.00	LCC.TN	0.01
Levelized 1-X CC: Net	LCC.NB	0.00	LCC.NN	0.08
Levelized 1-X Assets	LA.B	0.00	LA.N	0.23

Table C.13 Pool Heaters Version of LBL-MIM

The Long-Run Model Module

1990 CASE		A.F	A.Q	A:R	A
Assets -->		0.026	0.570	0.595	7
Costs except taxes		TC.F	TC.Q	TC:R	TC
and equity -->		0.102	0.769	0.871	10
		EC.F	EC.Q	EC:R	EC
Economic costs -->		0.069	0.538	0.947	11
	Economic Income			EI:R	0.0530
	Markup ($\mu - 1$)			μ 1	0.2262
	Price Leader's elasticity of demand:				-5.4
BASE 1996		A.BF	A.BQ		A.B
Assets		0.31	360.56		7.16
		TC.BF	TC.BQ		TC.B
Costs except taxes		1.23	486.25		10
		EC.BF	EC.BQ		EC.B
Economic costs		0.83	340.54		11
NEW 1996		A.NF	A.NQ		A.N
Assets		0.31	360.56		7.35
		TC.NF	TC.NQ		TC.N
Costs except taxes		1.23	519.73		11
		EC.NF	EC.NQ		EC.N
Economic costs		0.83	366.80		12
Assets	-----1990-----	---BASE 1996---	---NEW 1996---		
Shipments	"Q 0.02	Q.B 0.02	Q.N 0.02		
Price	"P \$632.66	P.B \$632.66	P.N \$678.86		
Revenue	"R 12.02	R.B 12.02	R.N 12.84		
Unit Var. Cost	"UVC \$451.90	UVC.B \$451.90	UVC.N \$485.38		
V. Cost Goods Sold	VCGS 8.59	VCGS.B 8.59	VCGS.N 9.18		
1X tax benefit		X1T.B 0.00	X1T.N 0.01		
Pre-tax cost	PTC 10.46	PTC.B 10.46	PTC.N 11.14		
Taxes	TAX 0.53	TAX.B 0.53	TAX.N 0.59		
Net Income	NI 1.03	NI.B 1.03	NI.N 1.10		
Economic Income	EI 0.64	EI.B 0.64	EI.N 0.70		
Equity	EQ 5.73	EQ.B 5.73	EQ.N 5.88		
Retrn on Equity	"ROE 17.93%	ROE.B 17.93%	ROE.N 18.72%		

Table C.14 Pool Heaters Version of LBL-MIM

The Short-Run Model Module

Short-Run "Supply Elasticity of Price": (Q/P)*dP/dQ		SRQE.0	0.157
Standard Error of SRQE		SRQE.SD	0.120
Random Value selected for this run:		"SRQE	0.157
R.S	12.83	"P.N	\$678.86
UVC.S	\$485.38	"Q.N	0.02
VCGS.S	9.18		
TC.S	11.06		
TAX.S	0.62	P=a+bQ	ap bp
PTC.S	11.16	0.99	572.28 5609.56
NLS	1.06	Q=c+dP	cq dq
A.S	7.35		0.02 0.00
EQ.S	5.88	P.S	678.37
ROES	18.01%	Q.S	0.02
		Check P	\$678.37
		Check Q	0.0189

Short-Run Assumptions:

The industry installs the long-run optimal level of capital.

The industry produces to meet demand at the low short-run price.

Table C.15 Pool Heaters Version of LBL-MIM

The Charts Module

CHARTS OF SENSITIVITY AND PROFIT FOR POOL HEATERS

Sensitivity of ROE to 1 S.E. change in Control Variable

Scenario = Primary

Control Variables			Possible Standards Levels			
Name	Value	Changed	1	2	3	4
IPE	-0.080	-0.184	-0.10%	-0.29%	-1.75%	-3.67%
RD	34.00%	78.17%	0.28%	0.46%	1.06%	1.48%
ECC	0.068	0.075	-0.01%	-0.02%	-0.11%	-0.21%
EP	0.111	0.121	0.03%	0.09%	0.36%	0.55%
FCA	0.102	0.164	0.55%	1.43%	5.36%	8.29%
FIX	0.102	0.178	-0.13%	-0.31%	-1.06%	-1.61%
CC.N	0.786	0.958	-0.06%	-0.16%	-0.96%	-1.88%
dVC.N	33.480	44.903	0.47%	1.07%	3.61%	5.38%
ro.N	0.000	0.300	-0.51%	-1.35%	-5.66%	-9.62%
SRPR	0.157	0.594	0.00	0.00	0.00	0.00

Change in Long-Run ROE from 1996 NAECA Base Case by Engineering and Standards Levels

Scenario= Primary

Level	Engin	Stdnds
1	0.79%	0.79%
2	2.18%	2.18%
3	8.04%	8.04%
4	11.96%	11.96%

REFERENCES

1. National Appliance Energy Conservation Act (NAECA). 1987. Public Law 100-12, Part B - *Energy Conservation Program for Consumer Products Other than Automobiles*. 42 USC 6291, Section 321(a) 25, Definitions, p 5.
2. NAECA, 1987. *Op. cit.*
3. Oxtoby-Smith Inc. 1990. *1990 Report on Owners and Prospects for Swimming Pools and Spas*. Prepared by Oxtoby-Smith, New York, NY, for National Spa & Pool Institute, August 1990, p 43.
4. American National Standards Institute, Inc (ANSI). *American National Standard for Gas-Fired Pool Heaters*. New York, NY, April 19, 1989, ANSI Z21.56-1989.
5. US Office of the Federal Register, 1990. Code of Federal Regulations, Title 10, Energy, Part 430, Subpart B, Appendix P: *Uniform Test Method for Measuring the Energy Consumption of Pool Heaters*. Washington, DC.
6. NAECA, 1987. *Op. cit.* Section 325 (l)(3)(A): *Criteria for prescribing new or amended standards*.
7. ANSI. *Addenda to Z21.56-1989 Gas-Fired Pool Heaters*, New York, NY, April 30, 1990, ANSI Z21.56-1990A.
8. California Energy Commission (CEC). 1983. *California's Appliance Standards: An Historical Review, Analysis, and Recommendations*. Sacramento, CA, P400-83-020, p 7.
9. J.M. Torrey, D.L. Peterka, and R.C. Erickson. 1981. *Domestic Gas Water Heater Market Assessment*. Prepared by Science Applications Inc., La Jolla, CA, for Gas Research Institute, GRI-80/0089, November 1981, p 18.
10. U.S. DOE, Energy Information Administration. 1989. *Household Energy Consumption and Expenditures 1987*. Washington, DC, DOE/EIA-0321/1(87).
11. U.S. DOE, Energy Information Administration. 1991. *Annual Energy Outlook 1991*. Washington, DC, DOE/EIA-0383(91).
12. U.S. DOE, Energy Information Administration, 1991. *Op cit.*
13. U.S. DOE, Energy Information Administration, 1991. *State Energy Price Projections for the Residential Sector, 1991-1992*. Washington, DC, Service Report SR/EME/91-04, November.

14. Berkeley Solar Group and Xenergy. 1990. *Occupancy Patterns & Energy Consumption in New California Houses (1984-1988)*. Prepared by Berkeley Solar Group and Xenergy, Oakland, CA. The California Energy Commission, 90-009, September 1990, p 8-1.
15. Berkeley Solar Group and Xenergy, 1990. *Op. cit.* p 8-9.
16. CEC. *Electricity Report #8*. CEC, Forecasting Division, Sacramento, CA, as cited in the BGS/Xenergy Report.
17. J. Van Lierop and K.M. Parris. 1988. *Appliance Saturations and Gas Use in the Single-Family Sector*. Southern California Gas Company, Regulatory Affairs Department, Los Angeles, CA, February 1988, p 4-7.
18. Van Lierop and Parris, 1988. *Op. cit.*
19. M. Parti, K.M. Parris, C.E. Davis, A.E. McElwain, and B.A. Nakayama. 1983. *Residential Appliance Energy Consumption in the Southern California Gas Company Service Territory: A Conditional Energy Demand Analysis*. Prepared by Applied Econometrics Inc., for the Southern California Gas Company, August, 1983, p 2.
20. Parti *et al.*, 1983. *Op. cit.*
21. J. Wei, H. Sigworth Jr., C. Lederer, and A.H. Rosenfeld. 1979. *A Computer Program for Evaluating Swimming Pool Heat Conservation*. Lawrence Berkeley Laboratory, Berkeley, CA, LBL-9388, November 1979, p 5.
22. L. Ashton, Vice President, Engineering and Technical Services, Raypak, West Lake, CA, 21 December 1990 and R. Hamos, Vice President, Engineering, Moorpark, CA. . *Private communication*. December 19, 1990.
23. "Statistical Highlights," Published monthly. Gas Appliance Manufacturers Association.

Volume H

Table of Contents

CHAPTER 1. ENGINEERING ANALYSIS	1-1
1.1 INTRODUCTION	1-1
1.2 PRODUCT CLASSES	1-5
1.3 DESIGN OPTIONS	1-6
1.4 ENERGY-USE DATA	1-19
1.5 COST-EFFICIENCY DATA	1-45
1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN	1-47
CHAPTER 2. BASE CASE FORECASTS: DIRECT HEATING EQUIPMENT	2-1
2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS	2-1
2.2 AVERAGE EQUIPMENT LIFETIME	2-1
2.3 BASE CASE PROJECTIONS	2-1
2.3.1 New Appliance Unit Energy Consumptions	2-2
2.3.1.1 Efficiency Distributions	2-2
2.3.1.2 Usage	2-2
2.3.2 Annual U.S. Appliance Installations	2-3
2.3.3 U.S. Residential Energy Consumption	2-4
2.3.4 Price of Purchased Appliances	2-4
2.4 SENSITIVITY ANALYSIS OF THE BASE CASE	2-5
CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: DIRECT HEATING EQUIPMENT	3-1
3.1 STANDARDS LEVELS	3-1
3.2 ENERGY CONSUMPTION	3-3
3.3 ANNUAL INSTALLATIONS	3-5
3.4 APPLIANCE PRICES	3-6
3.5 NET PRESENT VALUE	3-7
3.6 SENSITIVITY ANALYSIS	3-8
CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS	4-1
4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS	4-1
4.1.1 LCC Data Inputs	4-2
4.1.2 LCC Results	4-2
4.2 PAYBACK PERIODS BY STANDARD LEVEL	4-19
4.2.1 PBP Data Inputs	4-19
4.2.2 PBP Results	4-19
4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS	4-20
4.3.1 Data Inputs for Change in LCC	4-20
4.3.2 Results for Change in LCC	4-20
4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS	4-21
4.4.1 CCE Data Inputs	4-21

4.4.2 CCE Results	4-21
4.5 LCC SENSITIVITY ANALYSIS	4-44
CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF DIRECT HEATING EQUIPMENT	
5.1 LONG-RUN IMPACTS	5-1
5.1.1 Qualitative Analysis	5-1
5.1.2 Quantitative Analysis	5-2
5.2 SHORT-RUN IMPACTS	5-2
5.3 IMPACT AS A FUNCTION OF FIRM SIZE	5-3
5.4 SENSITIVITY ANALYSIS FOR DIRECT HEATING EQUIPMENT	5-4
5.4.1 Sensitivity Charts	5-4
5.4.2 Alternative Scenarios	5-5
5.4.3 Monte Carlo Analysis	5-5
CHAPTER 6. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES: DIRECT HEATING EQUIPMENT	
6.1 INTRODUCTION	6-1
6.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS	6-1
6.3 PEAK LOAD AND CAPACITY REDUCTIONS	6-2
6.4 REVENUE LOSSES	6-2
6.5 SENSITIVITY ANALYSIS	6-6
CHAPTER 7. ENVIRONMENTAL EFFECTS	
7.1 INTRODUCTION	7-1
7.2 RESULTS	7-1
7.2.1 Sulfur and Nitrogen Oxide Emissions	7-2
7.2.2 Carbon Dioxide Emissions	7-2
APPENDIX A. ENGINEERING ANALYSIS - SUPPORTING DOCUMENTATION	
A.1 CALCULATION METHOD FOR DETERMINING THE AVERAGE ANNUAL AUXILIARY ELECTRICAL CONSUMPTION (E_{AE}), THE AVERAGE ANNUAL FUEL ENERGY CONSUMPTION (E_F), AND THE BURNER OPERATING HOURS (BOH)	A-1
A.2 MANUFACTURER COST DATA FOR DIRECT HEATING EQUIPMENT	A-3
APPENDIX B. LBL-REM INPUT DATA: DIRECT HEATING EQUIPMENT	
APPENDIX C. LBL MANUFACTURER IMPACT MODEL:DIRECT HEATING EQUIPMENT	
C.1 INTRODUCTION	C-1
C.1.1 Engineering Cost Data	C-1
C.1.2 Industry Market Data	C-2
C.1.3 Financial Input Data	C-3

C.2	LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY	
	SCENARIO	C-4
REFERENCES		R-1

List of Tables

Table 1.1	Product Classes for Direct Heating Equipment	1-5
Table 1.2	Design Options for Direct Heating Equipment	1-6
Table 1.3	Results from Derating Forced-Air Room Heater	1-8
Table 1.4	Results from Derating Gravity Room Heater	1-9
Table 1.5	Forced-Air Heater: Summary of Results of Old and Current DOE Test Procedures	1-10
Table 1.6	Forced-Air Heater: Comparison of Test Procedure Efficiency Increase Estimates	1-11
Table 1.7	Gravity Heater: Comparison of Test Procedure Efficiency Increase Estimates	1-11
Table 1.8	1989 Direct Heating Equipment Domestic Shipments	1-20
Table 1.9	Cost-Efficiency Table for Fan Wall Furnaces up to 42,000 Btu/h	1-29
Table 1.10	Cost-Efficiency Table for Fan Wall Furnaces over 42,000 Btu/h	1-30
Table 1.11	Cost-Efficiency Table for Gravity Wall Furnaces up to 10,000 Btu/h	1-31
Table 1.12	Cost-Efficiency Table for Gravity Wall Furnaces over 10,000 up to 12,000 Btu/h	1-32
Table 1.13	Cost-Efficiency Table for Gravity Wall Furnaces over 12,000 up to 15,000 Btu/h	1-33
Table 1.14	Cost-Efficiency Table for Gravity Wall Furnaces over 15,000 up to 19,000 Btu/h	1-34
Table 1.15	Cost-Efficiency Table for Gravity Wall Furnaces over 19,000 up to 27,000 Btu/h	1-35
Table 1.16	Cost-Efficiency Table for Gravity Wall Furnaces over 27,000 up to 46,000 Btu/h	1-36
Table 1.17	Cost-Efficiency Table for Gravity Wall Furnaces over 46,000 Btu/h	1-37
Table 1.18	Cost-Efficiency Table for Floor Furnaces up to 37,000 Btu/h	1-38
Table 1.19	Cost-Efficiency Table for Floor Furnaces over 37,000 Btu/h	1-39
Table 1.20	Cost-Efficiency Table for Room Heaters up to 18,000 Btu/h	1-40
Table 1.21	Cost-Efficiency Table for Room Heaters over 18,000 and up to 20,000 Btu/h	1-41
Table 1.22	Cost-Efficiency Table for Room Heaters over 20,000 and up to 27,000 Btu/h	1-42
Table 1.23	Cost-Efficiency Table for Room Heaters over 27,000 and up to 46,000 Btu/h	1-43
Table 1.24	Cost-Efficiency Table for Room Heaters over 46,000 Btu/h	1-44
Table 2.1	Average Equipment Lifetime (Years) of Direct Heating Equipment	2-1
Table 2.2	Base Case Projection of Unit Energy Consumption for New Gas Room Heater	2-2
Table 2.3	Projected Average Usage of Gas Room Heaters	2-2
Table 2.4	Annual Installations of Room Heaters in U.S. Households (Thousands)	2-3
Table 2.5	Percent of Occupied U.S. Housing Units Having Room Heaters	2-3

Table 2.6	U.S. Residential Energy Consumption for Room Heaters (Quadrillion Btu, Primary Energy)	2-4
Table 2.7	Average Price of New Gas Room Heaters in U.S. Households (1990 Dollars)	2-4
Table 2.8	Average Purchase Price of New Gas Room Heaters (1990 Dollars)	2-6
Table 2.9	Average Unit Consumption of New Gas Room Heaters (MMBtu/Year)	2-6
Table 3.1	Trial Standards Levels for Direct Heating Equipment	3-2
Table 3.2	Unit Energy Consumption for New Direct Heating Equipment (Weighted-Average Million Btu/Year)	3-3
Table 3.3a	U.S. Electricity Consumption for Room Heat (Quadrillion Btu, Primary)	3-4
Table 3.3b	U.S. Gas Consumption for Direct Heating Equipment (Quadrillion Btu, Primary)	3-4
Table 3.3c	U.S. Oil Consumption for Direct Heating Equipment (Quadrillion Btu, Primary)	3-5
Table 3.3d	Total U.S. Energy Consumption for Room Heat (Quadrillion Btu, Primary)	3-5
Table 3.4	Cumulative Installations of Direct Heating Equipment (Millions)	3-6
Table 3.5	Average Purchase Price for New Direct Heating Equipment (1990 Dollars Per Unit)	3-6
Table 3.6	Net Present Value for Direct Heating Equipment Purchased from 1996-2030 1990 (Billion 90\$ Discounted at 7%	3-7
Table 3.7	Sensitivity Analysis Cases	3-8
Table 3.8	Cumulative Energy Consumption of Gas Room Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)	3-8
Table 3.9	Cumulative Shipments of Gas Room Heaters During the Period 1996-2030 (Millions)	3-9
Table 3.10	Total Net Present Value to Consumers for Units Sold During the Period 1996-2030 (Discounted to 1990 at 7% Real)	3-9
Table 4.1	Life-Cycle Costs of Fan Wall Heater up to 42K Btuh	4-3
Table 4.2	Life-Cycle Costs of Fan Wall Heater over 42K Btuh	4-4
Table 4.3	Life-Cycle Costs of Floor Heater up to 37K Btuh	4-5
Table 4.4	Life-Cycle Costs of Floor Heater over 37K Btuh	4-6
Table 4.5	Life-Cycle Costs of Gravity Wall Heater up to 10K Btuh	4-7
Table 4.6	Life-Cycle Costs of Gravity Wall Heater 10K to 12K Btuh	4-8
Table 4.7	Life-Cycle Costs of Gravity Wall Heater 12K to 15K Btuh	4-9
Table 4.8	Life-Cycle Costs of Gravity Wall Heater 15K to 19K Btuh	4-10
Table 4.9	Life-Cycle Costs of Gravity Wall Heater 19K to 27K Btuh	4-11
Table 4.10	Life-Cycle Costs of Gravity Wall Heater 27K to 46K Btuh	4-12
Table 4.11	Life-Cycle Costs of Gravity Wall Heater over 46K Btuh	4-13
Table 4.12	Life-Cycle Costs of Room Heater up to 18K Btuh	4-14
Table 4.13	Life-Cycle Costs of Room Heater 18K to 20K Btuh	4-15
Table 4.14	Life-Cycle Costs of Room Heater 20K to 27K Btuh	4-16
Table 4.15	Life-Cycle Costs Room Heater 27K to 46K Btuh	4-17
Table 4.16	Life-Cycle Costs of Room Heater over 46K Btuh	4-18
Table 4.17.a	Cost and Energy-Use Summary, Fan Wall Heater up to 42 kBtu	4-22

Table 4.17.b	Distribution of Units Sold Below Standards, Fan Wall Heater up to 42 kBtu	4-22
Table 4.17.c	Weighted-Averages of Units Sold Below Standards, Fan Wall Heater up to 42 kBtu	4-23
Table 4.17.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Fan Wall Heater up to 42 kBtu	4-23
Table 4.18.a	Cost and Energy Use Summary, Fan Wall Heater over 42 kBtu	4-23
Table 4.18.b	Distribution of Units Sold Below Standards, Fan Wall Heater over 42 kBtu	4-24
Table 4.18.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Fan Wall Heater over 42 kBtu	4-24
Table 4.19.a	Cost and Energy-Use Summary, Floor Furnace up to 37 kBtu	4-25
Table 4.19.b	Distribution of Units Sold Below Standards, Floor Furnace up to 37 kBtu	4-25
Table 4.19.c	Weighted-Averages of Units Sold Below Standards, Floor Furnace up to 37 kBtu	4-25
Table 4.19.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Floor Furnace up to 37 kBtu	4-26
Table 4.20.a	Cost and Energy-Use Summary, Floor Furnace over 37 kBtu	4-26
Table 4.20.b	Distribution of Units Sold Below Standards, Floor Furnace over 37 kBtu	4-26
Table 4.20.c	Weighted-Averages of Units Sold Below Standards, Floor Furnace over 37 kBtu	4-27
Table 4.20.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Floor Furnace over 37 kBtu	4-27
Table 4.21.a	Cost and Energy-Use Summary, Gravity Wall Heater up to 10 kBtu	4-27
Table 4.21.b	Distribution of Units Sold Below Standards, Gravity Wall Heater up to 10 kBtu	4-28
Table 4.21.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater up to 10 kBtu	4-28
Table 4.21.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater up to 10 kBtu	4-28
Table 4.22.a	Cost and Energy-Use Summary, Gravity Wall Heater 10 to 12 kBtu	4-29
Table 4.22.b	Distribution of Units Sold Below Standards, Gravity Wall Heater 10 to 12 kBtu	4-29
Table 4.22.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 10 to 12 kBtu	4-29
Table 4.22.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), And Costs of Conserved Energy (at 6% real) Gravity Wall Heater 10 to 12 kBtu	4-30
Table 4.23.a	Cost and Energy-Use Summary, Gravity Wall Heater 12 to 15 kBtu	4-30
Table 4.23.b	Distribution of Units Sold Below Standards, Gravity Wall Heater 12 to 15 kBtu	4-30
Table 4.23.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 12 to 15 kBtu	4-31
Table 4.23.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 12 to 15 kBtu	4-31
Table 4.24.a	Cost and Energy-Use Summary, Gravity Wall Heater 15 to 19 kBtu	4-31

Table 4.24.b	Distribution of Units Sold Below Standards, Gravity Wall Heater 15 to 19 kBtu	4-32
Table 4.24.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 15 to 19 kBtu	4-32
Table 4.24.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 15 to 19 kBtu	4-32
Table 4.25.a	Cost and Energy-Use Summary, Gravity Wall Heater 19 to 27 kBtu	4-33
Table 4.25.b	Distribution of Units Sold Below Standards, Gravity Wall Heater 19 to 27 kBtu	4-33
Table 4.25.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 19 to 27 kBtu	4-33
Table 4.25.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 19 to 27 kBtu	4-34
Table 4.26.a	Cost and Energy-Use Summary, Gravity Wall Heater 27 to 46 kBtu	4-34
Table 4.26.b	Distribution of Units Sold Below Standards, Gravity Wall Heater 27 to 46 kBtu	4-34
Table 4.26.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 27 to 46 kBtu	4-35
Table 4.26.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 27 to 46 kBtu	4-35
Table 4.27.a	Cost and Energy-Use Summary, Gravity Wall Heater over 46 kBtu	4-35
Table 4.27.b	Distribution of Units Sold Below Standards, Gravity Wall Heater over 46 kBtu	4-36
Table 4.27.c	Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater over 46 kBtu	4-36
Table 4.27.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater over 46 kBtu	4-36
Table 4.28.a	Cost and Energy-Use Summary, Room Heater up to 18 kBtu	4-37
Table 4.28.b	Distribution of Units Sold Below Standards, Room Heater up to 18 kBtu	4-37
Table 4.28.c	Weighted-Averages of Units Sold Below Standards, Room Heater up to 18 kBtu	4-37
Table 4.28.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater up to 18 kBtu	4-38
Table 4.29.a	Cost and Energy-Use Summary, Room Heater 18 to 20 kBtu	4-38
Table 4.29.b	Distribution of Units Sold Below Standards, Room Heater 18 to 20 kBtu	4-38
Table 4.29.c	Weighted-Averages of Units Sold Below Standards, Room Heater 18 to 20 kBtu	4-39
Table 4.29.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater 18 to 20 kBtu	4-39
Table 4.30.a	Cost and Energy-Use Summary, Room Heater 20 to 27 kBtu	4-39
Table 4.30.b	Distribution of Units Sold Below Standards, Room Heater 20 to 27 kBtu	4-40
Table 4.30.c	Weighted-Averages of Units Sold Below Standards, Room Heater 20 to 27 kBtu	4-40

Table 4.30.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater 20 to 27 kBtu	4-40
Table 4.31.a	Cost and Energy-Use Summary, Room Heater 27 to 46 kBtu	4-41
Table 4.31.b	Distribution of Units Sold Below Standards, Room Heater 27 to 46 kBtu . . .	4-41
Table 4.31.c	Weighted-Averages of Units Sold Below Standards, Room Heater 27 to 46 kBtu	4-41
Table 4.31.d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater 27 to 46 kBtu	4-42
Table 4.32.a	Cost and Energy-Use Summary, Room Heater over 46 kBtu	4-42
Table 4.32.b	Distribution of Units Sold Below Standards, Room Heater over 46 kBtu . . .	4-42
Table 4.32.c	Weighted-Averages of Units Sold Below Standards Room Heater over 46 kBtu	4-43
Table 4.33	Sensitivity Summary of Life-Cycle Costs of Gravity Wall Heater, 27K to 46K Btuh	4-45
Table 5.1	Direct Heating Equipment Output Table: Primary Scenario - Long-Run	5-2
Table 5.2	Direct Heating Equipment Output Table: Primary Scenario - Short-Run . . .	5-3
Table 5.3	Direct Heating Equipment Sensitivity Chart: Primary Scenario (Sensitivity of ROE to 1 S.E. Change in Control Variable)	5-4
Table 5.4	Direct Heating Equipment Output Table: Low-Price Elasticity Scenario	5-6
Table 5.5	Direct Heating Equipment Output Table: High-Price Elasticity Scenario	5-6
Table 5.6	Direct Heating Equipment Output Table: Constant-Shipments Scenario	5-7
Table 5.7	Direct Heating Equipment Output Table: Low-Discount Rate Scenario	5-7
Table 5.8	Direct Heating Equipment Output Table: High-Discount-Rate Scenario	5-8
Table 5.9	Direct Heating Equipment Output Table: Low-Discount-Rate and High-Price Elasticity Scenario	5-8
Table 5.10	Direct Heating Equipment Monte Carlo Runs: Searching for Low ROE	5-9
Table 6.1	Net Revenue Losses - Direct Heating Equipment (Million 1990 Dollars)	6-5
Table 6.2	Present Value of Revenue Losses - Direct Heating Equipment (Million 1990 Dollars)	6-6
Table 6.3	Present Value of Net Lost Revenues (Million 1990 \$) - Direct Heating Equipment (Sensitivity Cases)	6-6
Table A.1	Total Manufacturing Costs for Direct Heating Equipment (by Design Option)	A-4
Table C.1	Rates of Financial Costs	C-3
Table C.2	Other Financial Inputs	C-3
Table C.3	Fixed, Variable, and Revenue-Related Cost Split	C-3
Table C.5	Direct Heating Equipment Version of LBL-MIM - Control Panel	C-4
Table C.6	Direct Heating Equipment Version of LBL-MIM - Monte Carlo Module . . .	C-5
Table C.7	Direct Heating Equipment Version of LBL-MIM - Accounting Module	C-6
Table C.8	Direct Heating Equipment Version of LBL-MIM - Engineering Inputs Module	C-7
Table C.9	Direct Heating Equipment Version of LBL-MIM - Standards Level Module .	C-10
Table C.10	Direct Heating Equipment Version of LBL-MIM - Costs, Sales, and Revenue Module	C-13

Table C.11	Direct Heating Equipment Version of LBL-MIM - Financial Module	C-15
Table C.12	Direct Heating Equipment Version of LBL-MIM - One-Time Cost Amortization Module	C-16
Table C.13	Direct Heating Equipment Version of LBL-MIM - Long-Run Model Module	C-17
Table C.14	Direct Heating Equipment Version of LBL-MIM - Short-Run Model Module	C-18
Table C.15	Direct Heating Equipment Version of LBL-MIM - Charts Module	C-19

CHAPTER 1. ENGINEERING ANALYSIS

1.1 INTRODUCTION

All types of direct heating equipment have two items in common: (1) heat is conveyed without ducts from the point of generation to the room that is being heated and (2) flue products (products of combustion) are vented outside. Direct heating equipment comes in a wide variety of styles and models that can be categorized into four main groups: room heaters, gravity wall furnaces, fan wall furnaces, and floor furnaces. In each of the four main categories, heat is generated and conveyed much in the same way. Fuel gas is ignited at the burner and converted to heat by transferring the heat from the flue gases to a heat exchanger surface. This is accomplished without mixing the flue gases and the circulated heated air.

Room heaters are free-standing and are installed directly within the space they are heating. They are not recessed in the wall or floor. All currently manufactured models of room heaters are gravity-vented (without fan-assisted combustion) and draw their combustion air from the room. In most models, heated air is circulated without the assistance of an air circulation fan. Instead, thermal buoyant forces are relied upon to induce air flow upward past the heat exchanger and parallel to the flue gas flow. The thermal gradients produced by the hot heat exchanger surfaces, cause room air to enter through openings in the bottom of the heater, rise over the heat exchanger and exit back into the room through vents located at the top of the heater. Most models of gravity room heaters can be shipped with an optional air circulation fan or blower. Installation of the circulation fan will allow delivery of heated air from the bottom of the heater. The fan is a counterflow type forcing air flow in a direction opposite to that of the flow of flue products. Room heaters are also sold with factory installed counterflow fans. Some room heaters are also equipped with high-temperature glass panels and radiating surfaces to increase radiant heat transfer.

Wall furnaces are either installed on the wall as a free-standing unit or recessed within the wall. Units that are recessed into an inside wall can be fitted with a rear register, opposite from the primary outlet register. This turns the furnace from a single outlet to a dual outlet unit. All currently manufactured models of wall furnaces are gravity-vented (without fan-assisted combustion). Heated air can be furnished either by gravity or fan circulation. Gravity units operate in the same manner as gravity room heaters. Like room heaters, gravity units can be shipped with optional counterflow fans. Fan wall furnaces are equipped with factory installed air circulation fans. The efficiencies of fan wall units are relatively high as they are designed to take full advantage of the counterflow air circulation. Both gravity and fan wall furnaces are available in either conventional- or direct-vent models. Conventional-vent models draw their combustion air from the room. Flue products are vented via connections to a vent, chimney, or single-wall metal pipe venting system. Direct-vent models are mounted on walls with an outdoor exposure. Combustion air is drawn from outside through the outer ring of a direct wall vent, and

all combustion products are vented directly back outdoors through the inner tube of the same vent. Since the combustion system is completely sealed away from any contact with the room air, there are no infiltration losses associated with the direct-vent system. Because of this, direct-vent wall furnaces are inherently more efficient than conventional-vent systems.

Floor furnaces are suspended from the floor of the heated space. They are typically installed within an unconditioned crawl space; thus, they are directly exposed to the outside air. All currently manufactured models of floor furnaces are gravity-vented (without fan-assisted combustion) and draw their combustion air from the outside. In all models, heated air is provided without the assistance of an air circulation fan. Cold room air is returned at the periphery of the floor register and warm heated air comes up through the center portion of the register.

The present DOE test procedure provides three different methods for determining the Annual Fuel Utilization Efficiency (AFUE) of direct heating equipment (1). The AFUE is a seasonal efficiency rating that accounts for both on-cycle and off-cycle losses. The first method is used specifically for determining the AFUE of direct heating equipment equipped without manual controls and without thermal stack dampers. Temperature and carbon dioxide concentration measurements of the flue gas and stack gas at steady-state conditions are used to calculate the steady-state efficiency of the direct heater being tested. With the steady-state efficiency established, as well as the input rates to the heater and pilot, an empirically derived equation is then used to determine the AFUE. Within the direct heating industry, this method of establishing the AFUE is commonly referred to as the "short-cut" method, since only relatively simple measurements have to be made in order to calculate the AFUE. No additional measurements need to be made to establish the various off-cycle heat losses associated with the heater. The empirically derived equation accounts for these losses by prescribing off-cycle flue gas and stack gas draft factors based on the physical characteristics of the heater.

The second method provided by the DOE test procedure for determining the efficiency of direct heaters is used specifically for establishing the AFUE of equipment equipped with manual controls. Carbon dioxide concentration measurements of the flue gas and stack gas are used to establish the steady-state efficiency and part-load fuel utilization efficiency of the heater. The AFUE is then calculated from an equation that was originally adopted from the central furnace and boiler DOE test procedure. The heating degree days of the adopted equation were modified to be applicable to direct heating equipment.

The third and final method, commonly referred to as the tracer gas method, requires direct measurement of the stack gas mass flow and stack temperature. It is used specifically to establish the AFUE of heaters equipped with thermal stack dampers. This method can also be used on heaters without thermal dampers, but manufacturers typically use the "short-cut" method as it is simpler to perform. The tracer gas method is more complex than either of the prior two methods as measurements are conducted to specifically determine the various off-cycle and on-cycle heat losses associated with the heater. As with the second method, the tracer gas method uses the same modified form of the central furnace and boiler test procedure equation to establish the AFUE.

A large volume direct heating equipment manufacturer typically relies on a combination of automated and manual processes in the manufacturing flow. Because the direct heating equipment industry is relatively small, it tends to be more labor-intensive than other appliance industries. A manufacturing flow diagram is shown in Figure 1.1. Cabinets and heat exchangers are produced in-house. Cabinet sheet metal is either bought pre-cut to the proper size or cut in-house from large sheet metal rolls. Then the sheet metal is manually bent and stamped to form the correct cabinet shape. Once constructed, the cabinets are hung onto a conveyer line and sent into a paint room where an automated process is used to paint the cabinets. As with the cabinet, the heat exchanger is also made from sheet metal and is cut, bent, and stamped to provide the desired size and shape. Before the heater is assembled, the burner assembly is tested for gas leaks. The burner assembly consists of the burner and gas valve. The assembly of the heater, including the purchased parts (i.e., burner, gas valve, controls, fan motor, fan), the heat exchanger, and the cabinet, is done exclusively with manual labor. After assembly, the unit is packaged, labeled, and prepared for shipment.

Figure 1.1 Manufacturing Flow Diagram for Direct Heating Equipment

1.2 PRODUCT CLASSES

The sixteen product classes established by NAECA are being adopted by DOE for the analysis of direct heating equipment (listed in Table 1.1). The classes are categorized into four main groups: room heaters, gravity wall furnaces, fan wall furnaces and floor furnaces.

Table 1.1 Product Classes for Direct Heating Equipment

Fan Wall Furnaces	
1.	Up to 42,000 Btu/hour
2.	Over 42,000 Btu/hour
Gravity Wall Furnaces	
3.	Up to 10,000 Btu/hour
4.	Over 10,000 up to 12,000 Btu/hour
5.	Over 12,000 up to 15,000 Btu/hour
6.	Over 15,000 up to 19,000 Btu/hour
7.	Over 19,000 up to 27,000 Btu/hour
8.	Over 27,000 up to 46,000 Btu/hour
9.	Over 46,000 Btu/hour
Floor Furnaces	
10.	Up to 37,000 Btu/hour
11.	Over 37,000 Btu/hour
Room Heaters	
12.	Up to 18,000 Btu/hour
13.	Over 18,000 up to 20,000 Btu/hour
14.	Over 20,000 up to 27,000 Btu/hour
15.	Over 27,000 up to 46,000 Btu/hour
16.	Over 46,000 Btu/hour

Additional classes were not adopted for units with an electric power cord. It has been reported that between 90% to 93% of residential electricity customers experience no electricity outages longer than four hours per year (2). Because of the large proportion of homes that are not effected by power outages, the ability of a heater to provide heat during an electricity outage is not considered a unique consumer utility. Designs requiring electricity will instead be evaluated on their economic advantages and disadvantages.

Class divisions by capacity were retained for each of the direct heating equipment categories. Current class divisions are necessary due to the way in which direct heating equipment is evaluated by the "short-cut" method of the DOE test procedure. The equation for determining AFUE is a function of, among other things, the pilot fraction. The pilot fraction is defined as the input rate to the pilot light divided by the steady-state input rate to the heater. As the pilot fraction decreases, the AFUE will increase. For each direct heating equipment category (fan-wall, gravity-wall, room, floor), the input rate to the pilot is constant. Thus, for two heaters within the same category and with different capacities but the same steady-state efficiency, the AFUE will always be higher for the larger capacity equipment. In order to account for the relationship between the AFUE and the pilot fraction, the division of classes by capacity is retained.

1.3 DESIGN OPTIONS

The design options are listed in Table 1.2. They are changes that can be incorporated into the design of a direct heater to improve its efficiency. Some of the options are found in existing products; others are being developed.

Table 1.2 Design Options for Direct Heating Equipment

-
1. Increased Heat Exchanger Surface Area
 2. Derate and Secondary Air Control
 3. Electronic Ignition Device
 4. Vent Damper
 5. Power Burner or Induced Draft
 6. Two-Stage or Modulating Operation
 7. Improved Blower Motor Efficiency
 8. Increased Insulation (Floor Furnaces Only)
 9. Condensation of Flue Gases
 10. Combustion Box Damper
 11. Air Circulation Fan (Room Heaters & Floor Furnaces Only)
-

As stated in the introduction, AFUE is the efficiency descriptor used to rate direct heating equipment. Because the current efficiency rating only accounts for the consumption of gas energy, designs that are intended to reduce only the heater's electrical energy consumption (e.g., improved blower motor efficiency) will not be reflected in the AFUE. But proposed changes have been made to the current test procedure in order to incorporate equations that calculate the annual gas and electricity consumption of direct heating equipment. A new energy descriptor, the annual efficiency (AE), has also been added which, unlike the AFUE, accounts for both the gas and electrical energy consumption of the heater. With the new proposed test procedure, it is now possible to evaluate the economic justifiability of design options that effect the electrical

as well as the gas energy consumption. A more detailed description of the proposed test procedure is included later in the section on Energy-Use Data.

As mentioned earlier, the AFUE is a seasonal rating that accounts for both on-cycle and off-cycle losses. Both the on-cycle and off-cycle losses are composed of sensible and infiltration losses. (The tracer gas method of AFUE measurement explicitly measures each of these losses.) The effect that design options have on a direct heater are to reduce one or more of the following modes of heat loss.

The on-cycle sensible heat loss represents the energy needed to heat the air leaving the building up the stack (dilution and combustion air) from room temperature to stack temperature. The on-cycle infiltration loss is directly related to the on-cycle sensible heat loss. Outside air infiltrates into the room in order to make up for the loss of room air that is required for both dilution and combustion. The on-cycle infiltration loss is equivalent to the amount of air that is heated from the outdoor temperature to the room temperature.

The off-cycle sensible heat loss is equal to the amount of heat that has been stored in the heat exchanger during the burner-on time and is lost up the stack during the burner-off time. The off-cycle infiltration loss is directly related to the off-cycle sensible heat loss. Outside air infiltrates into the room to make up for the loss of room air that travels up the stack during the burner-off time. The infiltration heat loss is equal to the amount of air that is heated during the burner-off time from outside temperature to room temperature.

The following discussion describes each design option. Comments of manufacturers, suppliers, and gas utilities on the feasibility of each design are included.

Increased Heat Exchanger Surface Area

The performance of the heat exchanger can be improved by simply increasing its size. This can be done by either making it longer or higher. With the heat-transfer surface area increased, more heat can be extracted from the flue gases. This in turn increases the steady-state efficiency of the unit, and thus, the AFUE.

Manufacturers' data were used to determine the increase in AFUE due to increasing the heat exchanger size. Notes provided with the data indicated that efficiency increases were estimated based on a 50% increase in the heat exchanger. In order to accommodate the larger heat exchanger, the heater's cabinet had to be increased as well. For gravity units, the heat exchanger size increase results in an AFUE increase of 3 percentage points. For forced-air units, an AFUE increase of 2 percentage points was determined to result from the heat exchanger size increase.

An alternative to increasing the size of the heat exchanger is enhancing the inside and outside heat-transfer coefficients of the heat exchanger. Designing a new heat exchanger with higher heat-transfer coefficients is a very complex problem that no manufacturer or research organization has attempted to solve. Thus, increasing the performance of heat exchangers has been restricted to increasing its size.

With a larger heat exchanger, the heater would become bulkier than before and would incur higher production costs. Manufacturing costs are further increased because of the need to increase the cabinet size to accommodate the larger heat exchanger.

Derate and Secondary Air Control

Increasing both steady-state and seasonal efficiencies can be accomplished by derating the fuel input to the heater, along with controlling the quantity of secondary combustion air. Derating the fuel input increases the ratio of heat exchanger area to burner input, thus increasing the efficiency of the heater. However, simply derating without excess air control has been shown to be of no value in improving efficiency. Thus, the flue exit is baffled in order to reduce excess aeration.

Increases in efficiency were estimated from test results taken from a 1984 report published by the Gas Research Institute (3). In the report, tests were performed to determine the efficiency increases due to derating both a gravity type and forced-air type room heater. The tests conducted in the report were performed under an old DOE test procedure for direct heating equipment (4). This test procedure is essentially the same as the current test procedure for central furnaces and boilers where a cycle time of 17.2 minutes (3.83 minutes burner-on and 13.33 minutes burner-off) is used to determine the AFUE of the heating equipment. The results from derating the forced-air room heater 20% are presented in Table 1.3. The results from derating the gravity room heater 20% and 40% are presented in Table 1.4.

Table 1.3 Results from Derating Forced-Air Room Heater

Design Option	Q_{in} (Btu/h)	LS, on	LS, off	LI, on	LI, off	n_{ss}	n_u	AFUE
Baseline	44,100	12.9%	6.4%	2.2%	4.8%	76%	65.3%	62.4%
Derate 20%	34,400	10.3%	5.3%	2.9%	5.9%	79%	66.7%	63.0%

Q_{in} - input rate to the heater

LS - sensible heat loss during on and off portions of the cycle

LI - infiltration heat loss during on and off portions of the cycle

n_{ss} - steady-state efficiency

n_u - part-load fuel utilization efficiency

AFUE - annual fuel utilization efficiency

Table 1.4 Results from Derating Gravity Room Heater

Design Option	Q_{in} (Btu/h)	LS, on	LS, off	LI, on	LI, off	η_{ss}	η_u	AFUE
Baseline	34,600	17.4%	16.2%	2.1%	4.9%	66%	52.1%	49.5%
Derate 20%	26,900	11.2%	13.1%	2.2%	5.3%	74%	60.7%	57.0%
Derate 40%	21,100	8.4%	12.9%	2.4%	6.1%	77%	63.0%	58.5%

The resulting increase in steady-state efficiency and AFUE seems to be dependent on the efficiency of the baseline equipment. In the case of the gravity room heater, derating by 20% yields significant efficiency gains in both the steady-state efficiency and AFUE. Although derating the equipment by another 20% also results in an efficiency increase, it is much less than that resulting from the initial 20% derating.

Since there are significant differences between the current and past DOE test procedures for rating direct heating equipment, the results presented in Tables 1.3 and 1.4 must somehow be converted so that they are applicable for estimating the efficiency increases associated with derating direct heating equipment under the current test procedure. Although a conversion method can be derived, several assumptions are required to carry out the conversions. This method relies on establishing a percentage difference between the sum of the sensible and infiltration heat losses as measured according to the current and past DOE test procedures. An explanation of how this conversion method was developed follows.

As a way of demonstrating the differences between the current and old test procedures, the 1984 GRI report measured the efficiency of the forced-air room heater according to the tracer gas method (i.e. the current DOE test procedure). Using the tracer gas method, the AFUE was determined to be 67.8% (as compared to an AFUE of 62.4% measured according to the old test procedure). Assuming that the steady-state efficiencies and latent heat losses measured by the current and past test procedures are equal, the difference in the measured AFUEs can be used to calculate the percentage difference between the sum of the sensible and infiltration heat losses. Table 1.5 summarizes the differences between the old and current test procedures for the forced-air room heater tested in the 1984 GRI report.

Table 1.5 Forced-Air Heater: Summary of Results of Old and Current DOE Test Procedures

DOE	Q _{in}	Q _p									Total
Test	(Btu/h)	(Btu/h)	LS, on	LS, off	LI, on	LI, off	n _{ss}	n _u	L _{L,A}	AFUE	LS/LI
Old	44,100	750	12.9%	6.4%	2.2%	4.8%	76%	65.3%	9.87%	62.4%	26.3%
Current	44,100	750	-	-	-	-	76%	70.6%	9.87%	67.8%	19.9%

Old DOE Test - 17.2 minute cycle time; 3.87 minutes burner-on (t_{ON}), 13.33 minutes burner-off (t_{OFF}).

Current DOE Test (tracer gas method) - 40 minutes cycle time; 20 minutes burner-on, 20 minutes burner-off.

Q_p - input rate to the pilot.

All of the data presented in Table 1.5 for the old DOE test procedure, with the exception of the latent heat loss (L_{L,A}), are provided by the 1984 GRI report. The latent heat loss was calculated by using Eq. 1 from the old test procedure.

$$n_u = 100 \frac{-L_{L,A} - [t_{ON} / (t_{ON} + (Q_P / Q_{in}) * t_{OFF})] * [LS, on + LS, off + LI, on + LI, off]}{(1)} \quad (1)$$

As stated previously, the steady-state efficiency and the latent heat loss are assumed to remain constant, regardless of what test procedure is used. Thus, knowing the latent heat loss, steady-state efficiency, and AFUE, the part-load fuel utilization efficiency (n_u) can be calculated. The equation for calculating the AFUE in the current test procedure (i.e., the tracer gas method) can be manipulated so as to solve for n_u. This equation is presented below as Eq. 2.

$$AFUE = 4400 n_{ss} n_u Q_{in} / [(4400 n_{ss} Q_{in}) + (2.5(4600)n_u Q_P)] \quad (2)$$

Knowing the part-load fuel utilization efficiency, the sum of the sensible and infiltration heat losses can be determined by using Eq. 1. Eq. 1 is also used by the current DOE test procedure for calculating the part-load fuel utilization efficiency. As presented in Table 1.5, the sum of the sensible and infiltration heat losses for the current and past test procedures are 26.3% and 19.9%, respectively. Based on these results, it is assumed that the sum of the heat losses will decrease 24.5% when testing any direct heater according to the current rather than the old DOE test procedure. With this assumption, as well as the assumption regarding constant steady-state efficiency and latent heat loss, the results presented in Tables 1.3 and 1.4 can be converted to estimate the efficiency increases that would result from testing the direct heaters according to the current DOE test procedure.

Tables 1.6 and 1.7 summarize the results from using the conversion method discussed above on the forced-air and gravity room heaters tested in the 1984 GRI report.

Table 1.6 Forced-Air Heater: Comparison of Test Procedure Efficiency Increase Estimates

Design	Q_{in}	Q_p	LS/LI	LS/LI	n_{ss}	$L_{L,A}$	n_u	n_u	AFUE	AFUE
Option	(Btu/h)	(Btu/h)	Old	Current			Old	Current	Old	Current
Baseline	44,100	750	26.3%	19.9%	76%	9.87%	65.3%	70.6%	62.4%	67.8%
Derate 20%	34,400	750	24.4%	18.4%	79%	10.62%	66.7%	71.3%	63.0%	67.9%

Table 1.7 Gravity Heater: Comparison of Test Procedure Efficiency Increase Estimates

Design	Q_{in}	Q_p	LS/LI	LS/LI	n_{ss}	$L_{L,A}$	n_u	n_u	AFUE	AFUE
Option	(Btu/h)	(Btu/h)	Old	Current			Old	Current	Old	Current
Baseline	34,600	750	40.6%	30.7%	66%	10.15%	52.1%	59.8%	49.5%	56.9%
Derate 20%	26,900	750	31.8%	24.0%	74%	10.31%	60.7%	66.3%	57.0%	62.3%
Derate 40%	21,100	750	29.8%	22.5%	77%	10.48%	63.0%	67.8%	58.5%	62.7%

As evidenced by the above results, derating direct heating equipment will yield lower AFUE increases when tested according to the current DOE test procedure as opposed to the old test procedure.

For the purpose of analyzing the design option of derating direct heating equipment, the results presented in Tables 1.6 and 1.7 will be used. For direct heaters incorporating an air circulation fan, the steady-state efficiency and AFUE increases resulting from a 20% derating are based on the results presented in Table 1.6 (as long as the heater has a steady-state efficiency of at least 76%). According to these results, the steady-state efficiency will increase by 3.95% and the AFUE by only 0.15%. Both these efficiency increases are not absolute percentage point increases, but rather percentage increases.

For gravity direct heating equipment, the steady-state efficiency and AFUE increases resulting from a 20% derating are based on the results presented in Table 1.7. For gravity heaters with a steady-state efficiency less than or equal to 66%, the steady-state efficiency is assumed to increase by 12.12% and the AFUE by 9.49%. For heaters with a steady-state efficiency greater than or equal to 74%, the steady-state efficiency is assumed to increase by 4.05% and the AFUE by only 0.64%. For gravity heaters with an existing steady-state efficiency that is greater than 66% but less than 74%, a linear interpolation between the 20% and 40% derating results is used to estimate the efficiency increases resulting from a 20% derating. Eqs. 3 and 4 represent the straight-line forms of the equations used to establish the efficiency increases for the steady-state efficiency (n_{ss}) and AFUE when the existing steady-state efficiency is greater than 66% but less than 74%. The efficiency increases determined by Eqs. 3 and 4 are not absolute percentage point increases, but rather percentage increases.

$$\begin{aligned} n_{ss} \text{ percent increase} &= [(12.12\% - 4.05\%) / (66\% - 74\%)] \\ * n_{ss} + 78.6975\% &= (-1.00875)n_{ss} + 78.6975\% \end{aligned} \quad (3)$$

where n_{ss} is the existing steady-state efficiency and is expressed in percent.

$$\begin{aligned} \text{AFUE percent increase} &= [(9.49\% - 0.64\%) / (66\% - 74\%)] \\ * n_{ss} + 82.5025\% &= (-1.10625)n_{ss} + 82.5025\% \end{aligned} \quad (4)$$

Electronic Ignition Device

All gravity-type heaters and the majority of fan-type heaters are equipped with a standing pilot ignition system. In direct heating equipment, standing pilots continuously burn gas at a rate of 350 to 500 Btu/hour. The efficiency of the heater can be improved by simply replacing the standing pilot ignition system with an electronic ignition device. Two types of electronic ignition devices are considered for direct heating equipment: intermittent pilot ignition systems and hot surface ignition systems. In either case, the need for the standing pilot is eliminated. The empirical equation that is found in the "short-cut" method of the DOE test procedure is used for establishing the AFUE increase that can be expected from eliminating the standing pilot. (5) This empirical equation is represented by Eq. 5.

$$\text{AFUE} = 0.968n_{SS-WT} - 1.78D_F - 1.89D_S - 129P_F - 2.8L_J + 1.81 \quad (5)$$

In the above equation, the pilot fraction (P_F) accounts for the energy consumption of the standing pilot. Elimination of this term from the above equation yields the AFUE increase that occurs from eliminating the standing pilot. The other terms in the equation are weighted-average steady-state efficiency (n_{SS-WT}), off-cycle flue gas draft factor (D_F), off-cycle stack gas draft factor (D_S), and jacket loss for floor furnaces (L_J).

In assessing the impact on energy consumption, it is important to account for the added electrical energy consumption of the electronic ignition device in addition to the reduction in gas energy use that results from eliminating the standing pilot.

Standing pilot ignition systems for gravity heaters do not require an outside source of electricity to operate. There are two types of standing pilot ignition systems for gravity heaters: an hydraulic system and a millivolt system. Because an outside source of electricity is not required, these gas valves are more complex and more costly than those for a 24-volt ignition system. For both the hydraulic and millivolt systems, the small amount of electricity that is required is generated by either a thermocouple or thermopile.

Since forced-air wall furnaces already require an outside source of electricity to operate the fan, the standing pilot ignition system is powered off of a 24-volt power supply. The valve components in the gas valve draw approximately 0.5 amps resulting in a power consumption of 12 watts (6). The gas valve consumes power only during a call for heat. The power draw of the 24-volt transformer is approximately 0.6 watts and occurs continually (7).

Both types of electronic ignition devices considered here, hot surface and intermittent pilot, are 24-volt systems that require an outside source of electricity to operate it. As in the 24-volt standing pilot system, the gas valve for each of the electronic ignition systems only consumes power during a call for heat. The power draw of the gas valve is approximately 10.8 watts (8). Each electronic ignition system also requires a control module to operate it. The control module houses the electronic circuitry required to control the entire ignition system. The control module, which only consumes power during a call for heat, draws approximately 0.15 amps resulting in a power draw of 3.6 watts (9). Each electronic ignition system usually comes equipped with an electronic thermostat that draws power both when heat is or is not being called for. The thermostat's power draw during a call for heat is approximately 1.2 watts, while its draw during standby is 0.4 watts (10). The power draw of the 24-volt transformer is approximately 0.6 watts and occurs continually (11).

Vent Damper

In direct heating equipment, vent dampers are installed between the draft hood and the vent pipe. Vent dampers improve efficiency primarily by reducing both off-cycle infiltration and off-cycle sensible heat losses. There are two types of vent dampers: thermal and electrical.

Thermal vent dampers are activated by a pair of bi-metal coil springs. Heat created by combustion gases causes the two coil springs to contract and open the damper blade. When the demand for heat has been satisfied, the decreasing temperature allows the springs to cool and expand, returning the damper blade to the original closed position. The response time of thermal vent dampers is relatively slow as it takes the damper approximately four minutes to both fully open and close. Thermal vent dampers can be installed on units using either a standing pilot or an electronic ignition system. In their closed position, thermal vent dampers allow for some by-pass to ensure that during start up combustion gases will not be trapped within the heat exchanger. The by-pass also allows flue gases from a standing pilot to be vented. Because a by-pass is required, the reduction in off-cycle losses is not as great as is if the damper were allowed to completely seal the heater from the vent system.

Electrical vent dampers are operated by an outside source of electricity. Sensors indicate when the burner is off allowing for fast closure of the damper. Because of this, there is a greater reduction in off-cycle losses compared to thermally activated vent dampers. Electric vent dampers are designed to prevent burner operation when the damper is in other than a fully open position. Unlike thermal dampers, electric dampers do not allow for by-pass as they can open immediately upon burner operation. Electric vent dampers can be installed on units using either a standing pilot or electronic ignition system. In the case of a standing pilot system, a knockout

is provided on the damper allowing the standing pilot's flue gases to be vented when the damper is fully closed.

Energy savings resulting from thermal vent dampers were estimated from a paper that discusses their effect on the AFUE of direct heating equipment (12). Two different types of vent dampers were tested on three different heater types (i.e., one forced-air room heater, one gravity room heater, and one forced-air wall furnace). AFUE and steady-state efficiency increases for gravity direct heating equipment were derived from tests performed on the gravity room heater operating with a single-stage thermostat. It was demonstrated that, on average, a 3.75% increase in AFUE and a 2.83% steady-state efficiency increase could be expected. To establish the efficiency increases that could be expected from adding a thermal vent damper to a forced-air heater, the tests performed on the forced-air wall furnace with a single-stage thermostat were used. It was demonstrated that, on average, a 3.05% increase in AFUE and a 0.86% steady-state efficiency increase could be expected. The efficiency increases listed above for gravity and forced-air heaters are not absolute percentage point increases, but rather percentage increases.

Electrical vent dampers were not included as a design option for two reasons: high cost and lack of data. According to vent damper manufacturers, the cost of electric vent dampers is significantly more than that of thermal dampers, making them cost-prohibitive for direct heating equipment. In addition, no data were provided by either manufacturers or research reports to estimate the energy savings that would result by incorporating electrical vent dampers into direct heating equipment.

Power Burner or Induced Draft

Fan-assisted combustion systems consist of two types: power burners and induced draft systems. Power burners use blowers upstream of the combustion zone to supply a more efficient fuel-air mixture to the burner. Induced draft fans are located downstream of the combustion zone (at the exit of the heat exchanger) and regulate the amount of primary air at the burner, resulting in a higher combustion efficiency. Both power burners and induced draft systems also significantly reduce off-cycle losses. Since induced draft fans are located at the exit of the heat exchanger, they tend to reduce off-cycle infiltration losses more than power burners. The induced draft fan essentially acts as a vent damper to prevent room air from being drawn up the stack.

In applying fan-assisted combustion systems to room heaters and floor furnaces, only induced draft fans were considered. The space allocated for the draft hood is large enough to accommodate an induced draft fan. By simply replacing the draft hood with an induced draft fan, an AFUE increase of eight percentage points is expected (13). The accompanying steady-state efficiency increase is assumed to be five percentage points and results from increasing the amount of primary air to the burner. This increase is accomplished without further design modifications to the heater. Because the induced draft fan can be designed to overcome relatively large pressure drops within the heat exchanger, further increases in steady-state efficiency can be attained by redesigning the induced draft/heat exchanger system. The heat

exchanger can be redesigned to be more compact with more restrictions so that a greater amount of heat can be extracted from the flue gases. For room heaters and floor furnaces, the redesign of the induced draft/heat exchanger system included the addition of an air circulation fan. With redesign, the AFUE could be increased to 78%. Increases beyond 78% were not allowed as condensation of flue gases within the vent system would then be likely. Condensation of flue gases should be avoided unless the system is specifically designed to be a fully condensing furnace.

Induced draft systems were the only type of fan-assisted combustion system considered for wall furnaces. Since space allocation for the draft hood in wall furnaces is not as great as in room heaters or floor furnaces, the cabinet would likely have to be enlarged to accommodate an induced draft fan. Because of this, the cost of incorporating an induced draft fan into a wall furnace is significantly greater than that for either a room heater or floor furnace. For gravity wall furnaces, as for room heaters and floor furnaces, an increase of eight percentage points in the AFUE is expected by simply replacing the draft hood with an induced draft fan. The corresponding increase in the steady-state efficiency is assumed to be five percentage points. Redesign of the gravity wall furnace to attain 78% AFUE does not include the addition of an air-circulation fan. Because the baseline efficiency of fan wall furnaces is already high (73% or 74% AFUE), the addition of an induced draft fan is not expected to achieve an increase of eight percentage points in the AFUE. This would result in an AFUE beyond 78%.

Whether installed in a room heater, floor furnace, or wall furnace, the electrical power consumption of the fan motor in the induced draft system was assumed to be 50 watts.

Two-Stage and Modulating Operation

Two-stage or modulating operation allows a direct heater to better satisfy heating-load requirements. When low heating-load conditions exist, the heater has the capability to operate at a reduced burner rate. This reduces cycling of the unit, which in turn reduces large fluctuations in room temperature.

Two-stage or modulating burners attempt to reduce cycling of the heater by reducing the flow rate of gas at lower heating loads. Two-stage or modulating burners, which are currently manufactured, regulate the gas flow but not the air flow. Excess air is induced at lower gas-flow rates resulting in lower combustion efficiencies when compared to a normal or maximum gas-flow rate. Because of this, heaters equipped with two-stage or modulating burners will always have a lower energy efficiency, as measured by the DOE test procedure, than heaters equipped with single stage burners.

There are no known two-stage and modulating burners that regulate both the gas and air flow. So in order to achieve efficient two-stage or modulating operation, a two-stage or modulating burner must be incorporated into an induced-draft or forced-draft system that uses a two-speed or variable-speed combustion fan. With the multi-speed combustion fan, the excess air drawn into the burner at low gas-flow rates can be reduced so that there is no decrease in the

steady-state efficiency of the heater. On forced-air two-stage and modulating direct heaters, the air-circulation fan must also be capable of two-stage or variable-speed operation.

In order to estimate the efficiency increases resulting from incorporating two-stage or modulating operation into a direct heater, results are taken from the Mobile Home Furnaces analysis. The Mobile Home Furnaces analysis can be found in Volume I of this this Technical Support Document. AFUE efficiency increases for both the two-stage and modulating operation cases are based on a reduced-to-maximum input rate ratio of 50%. For two-stage operation, an AFUE increase of 1.3 percentage points is expected. For modulating operation, an AFUE increase of 1.95 percentage points is expected. In both two-stage and modulating operation, efficiency increases are a result of reducing off-cycle heat losses.

Improved Fan or Blower Motor Efficiency

In heaters that come equipped with air-circulation fans, the fan or blower motor efficiency can be increased to reduce the electrical energy consumption of the unit. As mentioned earlier, reducing the electrical energy consumption of the unit will have no effect on the AFUE. But because the new proposed DOE test procedure will take the electrical energy consumption into account, manufacturers will now have the incentive to improve the efficiency of the fan motor.

Typical fan motor sizes are 1/20 horsepower. Since the motor is so small, increases in efficiency would yield extremely small electrical energy savings. Presently, direct heating manufacturers are believed to use permanent split capacitor (PSC) fan motors. The next significant jump in motor efficiency would be to use a permanent magnet brushless dc motor. Since brushless dc technology is relatively new, this motor type is costly to produce. In addition, brushless dc motors are produced in low volume, further increasing their cost. Because of the extremely high cost of brushless dc motors and the small effect they have on reducing energy consumption, they were not included as a design option for direct heating equipment.

Increased Insulation

Since floor furnaces are the only heater types that are installed directly within an unconditioned space, increasing or improving the insulation of a heater was considered only for this equipment. Since room heaters and wall furnaces are installed within the conditioned space, insulation within the cabinet would only serve to minimize cabinet hot spots and reduce the amount of radiated heat coming off the heater. The DOE test procedure calls for the measurement of jacket losses when testing floor furnaces. Increased or improved insulation would reduce the jacket losses of this type of equipment. The installation of insulation in a floor furnace is at the perimeter of the cabinet.

Estimates of energy savings were provided by manufacturers. Jacket losses are relatively small compared to the on-cycle and off-cycle losses that occur in a floor furnace. Because of this, an increase in the AFUE of approximately one percentage point can be expected from increasing or improving the insulation. Jacket losses are measured independently of the

steady-state efficiency and, according to the DOE test procedure, have no effect on the measured steady-state efficiency of the heater. Thus, there is no accompanying steady-state efficiency increase from adding or improving the insulation.

Condensation of Flue Gases

Heaters designed with high steady-state efficiencies permit condensation within the heat exchanger by allowing enough heat to be extracted from the flue gases. This type of heater is typically termed a condensing heater and AFUEs generally exceed 90%. Typical condensing designs use either pulse combustion or a high-efficiency fan-assisted combustion system with additional heat exchanger area.

Only one condensing furnace has been designed for direct heating equipment and it is a pulse-combustion wall furnace. This pulse combustion system, like a direct-vent type heater, draws its combustion air from the outside. Once ignition is accomplished, the pulse combustion process is self-sustaining. The turbulent nature of the pulse-combustion process requires no mechanical devices (e.g., induced draft fans or power burners) to vent the flue products to the outside atmosphere. Unlike a typical direct-vent heater, combustion air and flue products are not drawn and exhausted through the same vent. This pulse-combustion design uses a secondary heat exchanger and an air-circulation fan to increase its steady-state efficiency. The secondary heat exchanger is usually located at the forced-air blower outlet, upstream of the primary heat exchanger. Part of the efficiency gain comes from capturing the heat of vaporization of the flue gases before they are expelled to the outside. Combustion gases condense because the temperature of the vented gases falls to about 130 °F. A condensate drain is needed to route the condensed moisture into a floor drain. More details on this heater can be found in the Gas Research Institute (GRI) report that details its development (14).

Condensing heaters that utilize fan-assisted combustion systems are only being designed for ducted furnaces. As mentioned previously in the discussion of fan-assisted combustion systems, this heater system can be designed to achieve high efficiencies. In that discussion, AFUEs were held at 78% in order to prevent condensation of the flue gases within the vent system. Since condensation is now desired, the fan-assisted system is designed to extract as much heat as possible from the flue gases. Fan-assisted combustion systems exhaust their flue gases through a direct vent. As in a pulse-combustion system, positive pressure is maintained within the vent system to exhaust the low-temperature flue gases. As in pulse-combustion systems, fan-assisted systems have some means to collect and drain the condensate that develops within the heat exchangers. Fan-assisted systems are also usually designed to use secondary heat exchangers and air-circulation fans.

The AFUE of the previously mentioned pulse-combustion wall furnace is 91.4% (15). This AFUE was used to establish the increase in AFUE that could be expected from a condensing direct heater. It was assumed that gravity wall heaters could not attain an AFUE this high. Since they cannot incorporate an air-circulation fan (otherwise they would be classified as a fan wall furnace), a maximum AFUE of 85% was assumed.

Combustion Box Damper

A manufacturer of ducted furnaces has developed a heater design incorporating a combustion box damper to help achieve an AFUE of 78%. The combustion box damper essentially acts as a vent damper. Although located upstream of the combustion zone, the flow of heat through the hot heat exchanger is still stopped at the end of the burner cycle. In this way, heat generated during the burner cycle is retained within the heat exchanger. Unlike a vent damper system, off-cycle infiltration losses are substantially reduced without having to seal off the vent system from the heat exchanger. Because the combustion box damper is located upstream of the burner, standing pilot ignition systems can still be used. In the case of direct-vent wall furnaces, the equivalent to a combustion box damper would be an inlet damper at the vent to prevent any outside combustion air from being drawn into the heat exchanger. An inlet damper for direct-vent systems is assumed to have the same effect on efficiency as the combustion box damper has on conventional-vent systems.

Tests have been conducted at the National Institute of Standards and Technology (NIST) on a ducted furnace incorporating a combustion box damper. The furnace was demonstrated to have, on average, a part-load fuel utilization efficiency (n_u) of 79.6% and a steady-state efficiency (n_{ss}) of 81.0%. In order to assess the damper's effect on the AFUE of direct heating equipment, the ducted furnace's part-load fuel utilization efficiency to steady-state efficiency ratio is used. Thus, if the steady-state efficiency of the heater is known, the ratio of 79.6% to 81.0% can be used to establish the part-load fuel-utilization efficiency. (Since a combustion box damper does not have any effect on the steady-state efficiency, the steady-state efficiency of a heater equipped with a combustion box damper is simply equal to the steady-state efficiency of the same heater equipped without a damper.) With both the steady-state and part-load fuel-utilization efficiencies known, Eq. 2 (repeated here from the discussion on the derating design option) can be used to calculate the AFUE.

$$AFUE = 4400 n_{ss} n_u Q_{in} / [(4400 n_{ss} Q_{in}) + (2.5 (4600) n_u Q_p)]$$

The above method for calculating the AFUE will be used to establish the AFUE increase that results from adding a combustion box damper to a direct heater. Typical AFUE increases are on the order of 7.10%.

Air-Circulation Fan

Air-circulation fans improve the steady-state efficiency of gravity heaters by circulating air in a counter-current mode to the flow of flue products. In gravity heaters, room air circulates co-current with the flue products, driven only by the thermal buoyant forces. Counter-current heat exchangers are inherently more efficient than co-flowing types. In addition, the higher air-flow rates that occur in forced-air heaters result in heat-transfer coefficients that are higher than can be obtained in gravity units.

Though no formal testing of direct heaters has been done to determine what AFUE increase could be expected from an air-circulation fan, it is believed that an AFUE increase of five percentage points could be obtained (16). This AFUE increase is due solely from improving the steady-state efficiency of the heater. This design option was only considered for room heaters and floor furnaces. Air-circulation fans are known to be easily incorporated into currently available room heater models as manufacturers already provide consumers with the option of purchasing fans for these units. Though floor furnaces do not currently have the option of adding a circulation fan, the cabinet size is believed to be large enough to incorporate a fan without having to enlarge the cabinet. Air-circulation fans were not analyzed for gravity wall furnaces as their incorporation would cause them to be classified as fan wall units. The electrical power consumption of the air circulation fan motor was assumed to be 60 watts.

1.4 ENERGY-USE DATA

The baseline efficiencies were set equal to the minimum allowable AFUEs established by NAECA for 1990. The October 1990 Gas Appliance Manufacturer Association (GAMA) directory for residential heating and water-heating equipment was used to verify that most models of direct heating equipment were produced at the NAECA minimum efficiency levels (17). Because gravity wall furnaces and room heaters comprise over 85% of all direct heaters shipped (Table 1.8), only the largest shipped product classes within these two direct heater categories are used for verification purposes. The efficiency distribution of available models in the largest shipped product classes (i.e., gravity wall 27,000 to 46,000 Btu/h, gravity wall over 46,000 Btu/h, room over 46,000 Btu/h) are provided in Figures 1.2 through 1.4. As evidenced by the figures, most models are produced at the NAECA minimum efficiency.

AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

4 of 6

Table 1.8 1989 Direct Heating Equipment Domestic Shipments

Product Class	% of Total Shipments
Fan Wall Furnaces	
Up to 42,000 Btu/hour	0.7%
Over 42,000 Btu/hour	8.1%
Gravity Wall Furnaces	
Up to 19,000 Btu/hour	4.2%
Over 19,000 up to 27,000 Btu/hour	13.5%
Over 27,000 up to 46,000 Btu/hour	21.9%
Over 46,000 Btu/hour	16.9%
Floor Furnaces	
Up to 37,000 Btu/hour	1.3%
Over 37,000 Btu/hour	4.7%
Room Heaters	
Up to 27,000 Btu/hour	0.9%
Over 27,000 up to 46,000 Btu/hour	4.9%
Over 46,000 Btu/hour	22.9%

Figure 1.2 Distribution of Models by AFUE: Gravity Wall Furnaces over 27,000⁶ up to 46,000 Btu/h

Figure 1.3 Distribution of Models by AFUE: Gravity Wall Furnaces over 46,000 Btu/h

Figure 1.4 **Distribution of Models by AFUE: Room Heaters over 46,000 Btu/h**

The input ratings that were selected for each of the representative baseline units were chosen to be typical of a majority of the models listed in the 1990 GAMA directory. According to the directory, models were not manufactured for three of the 16 product classes. Those classes were gravity wall furnaces, over 15,000 and up to 19,000 Btu/h; room heaters, up to 18,000 Btu/h; room heaters, over 20,000 and up to 27,000 Btu/h. Representative input ratings for these classes were selected according to comparable product classes.

Each baseline unit was assumed to use a standing pilot ignition system. The standing pilot gas consumption for each of the baseline units was determined from manufacturers' data provided by GAMA. Baseline units were determined to have the following standing pilot gas consumptions: 300 Btu/h for room heaters up to 46,000 Btu/h, 350 Btu/h for room heaters over 46,000 Btu/h, 400 Btu/h for all wall furnaces and floor furnaces up to 37,000 Btu/h, and 450 Btu/h for floor furnaces over 37,000 Btu/h. It is critical to pick an accurate gas consumption for the standing pilot, as it determines how much gas energy can be saved by replacing it with an electronic ignition device.

With the representative AFUE, fuel input rate, pilot input rate, and jacket loss (applicable to floor furnaces only) known for each of the baseline units, the steady-state efficiency can be determined. As discussed earlier, the "short-cut" method for determining the AFUE provides an empirical equation for calculating the AFUE. This equation (Eq. 6) was presented in the discussion of the electronic ignition device design option and is once again presented below.

$$\text{AFUE} = 0.968n_{\text{SS-WT}} - 1.78D_F - 1.89D_S - 129P_F - 2.8L_J + 1.81 \quad (6)$$

The pilot fraction (P_F) is defined as the ratio of the pilot light input rate to the fuel input rate. For all baseline direct heating equipment (i.e., heaters equipped with a atmospheric burner and draft hood), the values of both the off-cycle flue gas draft factor (D_F) and the off-cycle stack gas draft factor (D_S), as provided by the DOE test procedure, are equal to one. Thus by knowing the AFUE, pilot fraction, and jacket loss (if applicable), the above equation can easily be solved for the steady-state efficiency.

Proposed DOE Test Procedure

As mentioned earlier in the discussion of design options for direct heating equipment, the current DOE test procedure establishes an energy efficiency descriptor (AFUE) that takes into account only the fuel energy consumption of the heater. In order to account for the electrical energy consumption as well, DOE has proposed changes to the current test procedure that establish a new energy efficiency descriptor to rate direct heating equipment.

This new energy descriptor, the annual efficiency (AE), is represented by Eq. 7.

$$AE = 100 * [(E_F) (AFUE / 100) + 3413 (P_E) (BOH)] / [E_F + 3413 (F) (E_{AE})] \quad (7)$$

where

- E_{AE} = average annual auxiliary electrical consumption, *kWh*,
- E_F = average annual fuel energy consumption, *Btu*,
- AFUE = Annual Fuel Utilization Efficiency, *percent*,
- P_E = auxiliary electrical energy input rate, *kW*,
- BOH = national average number of burner operating hours, *hours*, and
- F = the ratio of the energy consumed at the source of electrical generation to the electrical energy delivered at the direct heater, 3.37.

Appendix A.1 of this volume provides details of the method to calculate the average annual auxiliary electrical consumption (E_{AE}), the average annual fuel energy consumption (E_F), and the burner operating hours (BOH).

As evidenced by Eq. 7, the annual efficiency (AE) is a function of the AFUE. The DOE test procedure provides three different methods for determining the AFUE (these methods were described in the introduction section of this chapter). The latter two methods of AFUE measurement (i.e., the method used for heaters equipped with manual controls and the tracer-gas method) rely on the following equation to calculate the AFUE:

$$AFUE = 4400 n_{ss} n_u Q_{in} / [(4400 n_{ss} Q_{in}) + (2.5 (4600) n_u Q_p)] \quad (8)$$

Climate Adjustment

In Eq. 8, the value of 4,400 represents the average number of heating degree days that direct heating equipment typically must satisfy during the course of a year. The 1987 Residential Energy Consumption Survey (RECS) (18) was used to confirm whether this value for the number of heating degree days is truly representative of the climate in which direct heaters are typically found. RECS was developed and conducted by the Energy Information Administration (EIA) to provide information concerning energy consumption within the residential sector of the United States. Data concerning actual energy consumption are obtained from fuel records maintained by the household's fuel suppliers. The sample size surveyed is large enough to provide representative energy information about the residential sector. From the 1987 RECS it was determined that 2,950 heating degree days, rather than 4,400, are more representative of the climate in which direct heaters are found. Thus, DOE has modified the equation used for calculating the AFUE (i.e., the method used for heaters equipped with manual controls and the

tracer gas method) so that it is based upon 2,950 heating degree days. Eq. 9 represents this modification.

$$AFUE = 2950 \, n_{ss} \, n_u \, Q_{in} / [(2950 \, n_{ss} \, Q_{in}) + (2.083 (4600) \, n_u \, Q_P)] \quad (9)$$

The value of 2.5 in the denominator of Eq. 8 has been changed to 2.083 in Eq. 9. This value is a function of the outdoor design temperature that direct heaters typically must be sized for. The value of 2.5 is based on an outdoor design temperature of 5 °F while the value of 2.083 is based on 15 °F. The design temperature of 15°F was found to be more representative of the temperature for which direct heating equipment must typically be designed, and DOE modified the equation for calculating the AFUE to reflect this change.

Calculation Approach

With the proposed DOE test procedure providing equations to calculate both the annual fuel (E_F) and electrical energy (E_{AE}) consumptions (refer to Appendix A.1 for details), the effect that prospective design options have on the overall energy consumption of direct heating equipment can now be determined. In the previous section on design options, information was presented on how each design option impacted the AFUE, the steady-state efficiency (n_{ss}), and the electrical power consumption (P_E). (It is important to note that the AFUE referred to here is the one based on 4,400 heating degree days (Eq. 7). In order to account for the changes made by the proposed DOE test procedure, the AFUE will be recalculated based on 2,950 heating degree days before the annual efficiency (AE) is calculated.) Knowing the AFUE, the steady-state efficiency, and the electrical power consumption allows for the calculation of the annual efficiency and annual energy consumptions.

The first step in determining the annual efficiency and annual energy consumptions is to establish the output capacity (Q_{OUT}) of the heater. With the exception of floor furnaces, the output capacity is simply equal to the fuel input rate to the heater (Q_{in}) multiplied by the steady-state efficiency (n_{ss}). For more details regarding the calculation of the output capacity, refer to Appendix A.1. Once the output capacity is determined, the typical design heating requirement (DHR) is established. The DHR is a function of the output capacity and is determined by "Table 4" of the proposed DOE test procedure. "Table 4" establishes a DHR based on a range of output capacities. The DHR only needs to be established for the baseline unit. Although each design option effects the output capacity of the heater, the DHR is assumed to be established according to the specifications of the baseline unit and remains constant regardless of how the output capacity is affected. The part-load fuel utilization efficiency (n_u) is established next, and is calculated by using Eq. 9. (The combustion box damper design option is the only exception to establishing n_u in this manner. Here the ratio of n_u -to- n_{ss} is known and is used to determine n_u . With n_u established, Eq. 8 is used for calculating the AFUE.) For design options that do not require a standing pilot, the part-load fuel utilization efficiency is simply equal to the AFUE. Once both the DHR and the part-load fuel utilization efficiency are established, the burner operating hours (BOH) are calculated. Once the BOH are established,

both the annual fuel (E_F) and auxiliary electrical energy (E_{AE}) consumptions are calculated. For more details regarding the calculation of the BOH and the annual energy consumptions, refer to Appendix A.1 of this volume.

As mentioned previously, design options were analyzed for how they impacted the AFUE based on 4,400 heating degree days. In order to account for the changes that have been made to the AFUE equation by the proposed DOE test procedure (i.e., calculation based on 2,950 heating degree days instead of 4,400), the AFUE is recalculated before establishing the AE. The various quantities that were calculated based on the "4,400 heating degree day" AFUE (i.e., n_u and BOH) are used to establish the "2,950 heating degree day" AFUE. With the new AFUE established, the annual efficiency is then calculated.

The results of the energy-use analysis are presented in Tables 1.9 to 1.24. Included in the tables are costs for manufacturing, maintenance, and installation. These costs will be explained in the next section on Cost-Efficiency Data. In addition to the cost data, the following quantities are presented in each table: the standard level, the design number, the design option, the fuel input rate (Q_{in}), the pilot light input rate (Q_p), the auxiliary electrical energy input rate (P_E), the AFUE based on 4,400 heating degree days, the steady-state efficiency (n_{ss}), the output capacity (Q_{OUT}), the DHR, the part-load fuel utilization efficiency (n_u), the BOH, the annual fuel energy consumption (E_F), the annual auxiliary electrical energy consumption (E_{AE}), the AFUE based on 2,950 heating degree days, and the annual efficiency (AE). Notes accompany each design option to explain how it was analyzed.

Tables 1.9 to 1.24 consist of two primary branches and three secondary branches. Design options within the branches are ordered so that those that are easiest to carry out and that are relatively more cost-effective are listed first. The first branch appearing in each of the tables (i.e., the first primary branch) consists of three relatively low-cost design options. Of the three design options listed in the first primary branch, one is always an electronic ignition device. The other two options consist of a damper design option (i.e., either a vent damper or combustion box damper) and a design option that improves the performance of the heat exchanger (i.e., either derating by 20% or increasing the heat exchanger size). Of the two pairs of design options presented, selection is based on which option of the pair is more cost-effective. The most cost-effective design option is included in the primary branch while the least cost-effective of the pair is presented as a secondary branch. The secondary branches are included to demonstrate that additional design options were considered in the analysis.

The second primary branch consists of design options that yield the maximum technologically feasible design. The design options which constitute the "max-tech" design, include the following: an electronic ignition device, an induced draft system, a redesign of the induced draft system, an air-circulation fan (not applicable to gravity wall furnaces), and a design that yields condensation of the flue gases.

With the exception of the gravity wall furnace over 46,000 Btu/h product class (i.e., Table 1.24), multi-stage operation (i.e., two-stage or modulating operation) results in a less energy-efficient design. The AE actually decreases by incorporating two-stage or modulating operation.

Table 1.9 Cost-Efficiency Table for Fan Wall Furnaces up to 42,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	η _{ss}	Q _{out} Btu/h	DHR Btu/h	η _u	BOH [*] hours	E _F MBtu	E _{AE} kWh	AFUE'	AE'
1,2,3	0	Baseline	(1)	184.90	500.00	29.50	40,000	400	72.6	73.0%	78.7%	31,467	26,500	75.3%	814.6	35.76	59.1	73.0%	72.2%
	1	0 + Electronic Ignition	(2)	208.80	500.00	55.00	40,000	0	76.2	74.3%	78.7%	31,467	26,500	74.3%	858.5	34.34	65.4	74.3%	73.3%
4	2	1 + Vent Damper ^{***}	(3)	230.40	510.00	55.00	40,000	0	76.2	76.6%	79.3%	31,738	26,500	76.6%	833.3	33.33	63.5	76.6%	75.6%
	3	2 + Increase HX Size	(4)	278.30	510.00	55.00	40,000	0	76.2	78.6%	81.3%	32,538	26,500	78.6%	812.2	32.49	61.9	78.6%	77.5%
	4	2 + Derate 20%	(5)	239.20	510.00	55.00	32,000	0	76.2	76.6%	82.5%	26,393	26,500	76.6%	1038.6	33.24	79.1	76.6%	75.4%
	5	1 + Combustion Box Damper ^{**}	(6)	248.50	500.00	90.50	40,000	0	76.2	77.3%	78.7%	31,467	26,500	77.3%	825.3	33.01	62.9	77.3%	76.3%
	6	1 + Induced Draft	(7)	311.50	500.00	112.20	40,000	0	126.2	78.0%	81.0%	32,387	26,500	78.0%	813.7	32.55	102.7	78.0%	76.3%
5	7	6 + Condense Flue Gases	(8)	405.90	600.00	161.20	40,000	0	126.2	91.4%	92.5%	37,017	26,500	91.4%	695.8	27.83	87.8	91.4%	89.2%
	8	7 + Two-Stage Operation	(9)	479.70	600.00	183.20	40,000	0	164.1	92.7%	-	-	26,500	92.7%	708.0/326.7	27.23	169.8	92.7%	87.8%
	9	7 + Modulating Operation	(10)	611.90	600.00	205.20	40,000	0	214.5	93.3%	-	-	26,500	93.3%	693.7/320.2	26.68	217.5	93.3%	87.0%

* Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

** Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

*** Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

1 Baseline: NAECA = 73%

2 Electronic Ignition: AFUE increase = 129 * (Q_p / Q_{out}); η_{ss} increase = 0%

3 Vent Damper: AFUE increase = 3.05%; η_{ss} increase = 0.86%

4 Increase HX Size: AFUE increase = 2 percentage points; η_{ss} increase = 2 percentage points

5 Derate 20%: AFUE increase = 0.64%; η_{ss} increase = 4.05%

6 Combustion Box Damper: η_u = η_{ss} * (79.6% / 81.0%); η_{ss} increase = 0%

7 Induced Draft: AFUE increase = 8 percentage points; η_{ss} increase = 5 percentage points

8 Condense Flue Gases: AFUE = 91.4%; η_{ss} = (AFUE - 1.81) / 0.968 (equation from DOE "short-cut" method where D_p, D_s, and P_F are equal to zero)

9 Two-Stage Operation: AFUE increase = 1.3 percentage points; η_{ss} is unknown

10 Modulating Operation: AFUE increase = 1.95 percentage points increase; η_{ss} is unknown

Table 1.10 Cost-Efficiency Table for Fan Wall Furnaces over 42,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH* hours	E _F MBtu	E _{AB} kWh	AFUE'	AE'
1,2,3	0	Baseline	(1)	205.60	500.00	29.50	55,000	400	72.6	74.0%	79.3%	43,635	36,500	75.7%	822.5	48.41	59.7	74.0%	73.4%
	1	0 + Vent Damper***	(2)	227.20	510.00	29.50	55,000	400	72.6	76.3%	80.0%	44,011	36,500	78.0%	797.0	47.02	57.9	76.3%	75.6%
4	2	1 + Electronic Ignition	(3)	251.20	510.00	55.00	55,000	0	76.2	77.2%	80.0%	44,011	36,500	77.2%	829.8	45.64	63.2	77.2%	76.4%
	3	2 + Increase HX Size	(4)	301.30	510.00	55.00	55,000	0	76.2	79.2%	82.0%	45,111	36,500	79.2%	808.9	44.49	61.6	79.2%	78.4%
	4	2 + Derate 20%	(5)	261.00	510.00	55.00	44,000	0	76.2	77.3%	83.2%	36,599	36,500	77.3%	1034.8	45.53	78.9	77.3%	76.3%
	5	0 + Combustion Box Damper**	(6)	247.30	500.00	65.00	55,000	400	72.6	76.2%	79.3%	43,635	36,500	78.0%	797.5	47.05	57.9	76.2%	75.5%
	6	0 + Electronic Ignition	(3)	229.60	500.00	55.00	55,000	0	76.2	74.9%	79.3%	43,635	36,500	74.9%	854.6	47.00	65.1	74.9%	74.2%
	7	6 + Induced Draft	(7)	334.30	500.00	112.20	55,000	0	126.2	78.0%	81.3%	44,702	36,500	78.0%	817.6	44.97	103.2	78.0%	76.8%
5	8	7 + Condense Flue Gases	(8)	439.30	600.00	161.20	55,000	0	126.2	91.4%	92.6%	50,925	36,500	91.4%	698.8	38.43	88.2	91.4%	89.9%
	9	8 + Two-Stage Operation	(9)	513.10	600.00	183.20	55,000	0	164.1	92.7%	-	-	36,500	92.7%	712.5/328.9	37.68	170.9	92.7%	89.1%
	10	8 + Modulating Operation	(10)	645.30	600.00	205.20	55,000	0	214.5	93.4%	-	-	36,500	93.4%	700.7/323.4	37.06	219.7	93.4%	88.7%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

- 1 Baseline: NAECA = 74%
- 2 Vent Damper: AFUE increase = 3.05%; n_{ss} increase = 0.86%
- 3 Electronic Ignition: AFUE increase = 129 * (Q_p / Q_{out}); n_{ss} increase = 0%
- 4 Increase HX Size: AFUE increase = 2 percentage points; n_{ss} increase = 2 percentage points
- 5 Derate 20%: AFUE increase = 0.64%; n_{ss} increase = 4.05%
- 6 Combustion Box Damper: n_u = n_{ss} * (79.6% / 81.0%); n_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Condense Flue Gases: AFUE = 91.4%; n_{ss} = (AFUE - 1.81) / 0.968 (equation from DOE "short-cut" method where D_p, D_S, and P_P are equal to zero)
- 9 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 10 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.11 Cost-Efficiency Table for Gravity Wall Furnaces up to 10,000 Btu/h

Std.	Design	Design		Mfg.	Install.	Maint.	Q _{in}	Q _p	P _E	AFUE	η _{ss}	Q _{out}	DHR	η _u	BOH ^o	E _F	E _{AB}	AFUE'	AE'
Level	No.	Options		1990\$	1990\$	1990\$	Btu/h	Btu/h	Watts			Btu/h	Btu/h		hours	MBtu	kWh		
1,2	0	Baseline	(1)	97.10	500.00	29.50	10,000	400	0.0	59.0%	68.2%	6,820	5,000	66.5%	587.6	9.14	0.0	59.0%	59.0%
	1	0 + Electronic Ignition	(2)	107.70	500.00	55.00	10,000	0	16.2	64.2%	68.2%	6,820	5,000	64.2%	750.3	7.50	12.2	64.2%	63.5%
3,4	2	1 + Derate 20%	(3)	118.10	500.00	55.00	8,000	0	16.2	68.6%	75.0%	5,996	5,000	68.6%	875.5	7.00	14.2	68.6%	67.7%
	3	2 + Combustion Box Damper ^{**}	(4)	150.60	500.00	90.50	8,000	0	16.2	73.7%	75.0%	5,996	5,000	73.7%	816.3	6.53	13.2	73.7%	72.7%
	4	1 + Increase HX Size	(5)	136.40	500.00	55.00	10,000	0	16.2	67.2%	71.2%	7,120	5,000	67.2%	717.1	7.17	11.6	67.2%	66.5%
	5	2 + Vent Damper ^{***}	(6)	139.71	510.00	55.00	8,000	0	16.2	71.2%	77.1%	6,166	5,000	71.2%	844.1	6.75	13.7	71.2%	70.3%
	6	1 + Induced Draft	(7)	232.80	500.00	112.20	10,000	0	66.2	78.0%	79.0%	7,900	5,000	78.0%	605.3	6.05	40.1	78.0%	74.5%
5	7	6 + Condense Flue Gases	(8)	267.90	600.00	161.20	10,000	0	66.2	85.0%	85.9%	8,590	5,000	85.0%	556.7	5.57	36.9	85.0%	81.0%
	8	7 + Two-Stage Operation	(9)	341.70	600.00	183.20	10,000	0	86.1	86.3%	-	-	5,000	86.3%	560.6/258.7	5.39	70.5	86.3%	77.5%
	9	7 + Modulating Operation	(10)	473.90	600.00	205.20	10,000	0	112.5	86.9%	-	-	5,000	86.9%	540.4/249.4	5.20	88.9	86.9%	75.8%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

- 1 Baseline: NAECA = 59%
- 2 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; η_{ss} increase = 0%
- 3 Derate 20%: AFUE increase = $η_{ss} * (-1.10625) + 82.5025\%$; η_{ss} increase = $η_{ss} * (-1.00875) + 78.6975\%$; η_{ss} is the steady-state efficiency of the previous design option
- 4 Combustion Box Damper: η_u = $η_{ss} * (79.6\% / 81.0\%)$; η_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; η_{ss} increase = 3 percentage points
- 6 Vent Damper: AFUE increase = 3.75%; η_{ss} increase = 2.83%
- 7 Induced Draft efficiency increase due to the following components:
 - Induced Draft Fan: AFUE increase = 8 percentage points; η_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, η_{ss} increase = directly proportional to AFUE increase
- 8 Condense Flue Gases: AFUE = 85.0%; η_{ss} = $(AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_p, D_s, and P_p are equal to zero)
- 9 Two-Stage Operation: AFUE increase = 1.3 percentage points; η_{ss} is unknown
- 10 Modulating Operation: AFUE increase = 1.95 percentage points increase; η_{ss} is unknown

Table 1.12 Cost-Efficiency Table for Gravity Wall Furnaces over 10,000 up to 12,000 Btu/h

Std.	Design	Design		Mfg.	Install.	Maint.	Q _{in}	Q _p	P _E	AFUE	n _{ss}	Q _{out}	DHR	n _u	BOH*	E _F	E _{AE}	AFUE'	AE'
Level	No.	Options		1990\$	1990\$	1990\$	Btu/h	Btu/h	Watts			Btu/h	Btu/h		hours	MBtu	kWh		
	0	Baseline	(1)	103.40	500.00	29.50	12,000	400	0.0	60.0%	68.3%	8,202	7,500	66.3%	803.5	12.82	0.0	60.0%	60.0%
1,2	1	0 + Derate 20%	(2)	111.60	500.00	29.50	9,600	400	0.0	64.1%	75.0%	7,201	7,500	72.5%	911.5	11.89	0.0	64.1%	64.1%
3	2	1 + Electronic Ignition	(3)	122.10	500.00	55.00	9,600	0	16.2	68.4%	75.0%	7,201	7,500	68.4%	1100.0	10.56	17.8	68.4%	67.7%
4	3	2 + Combustion Box Damper**	(4)	152.40	500.00	90.50	9,600	0	16.2	73.7%	75.0%	7,201	7,500	73.7%	1021.2	9.80	16.5	73.7%	72.9%
	4	0 + Increase HX Size	(5)	129.90	500.00	29.50	12,000	400	0.0	63.0%	71.3%	8,562	7,500	69.7%	757.9	12.30	0.0	63.0%	63.0%
	5	2 + Vent Damper***	(6)	143.70	510.00	55.00	9,600	0	16.2	71.0%	77.1%	7,405	7,500	71.0%	1060.6	10.18	17.2	71.0%	70.2%
	6	0 + Electronic Ignition	(3)	113.90	500.00	55.00	12,000	0	16.2	64.3%	68.3%	8,202	7,500	64.3%	937.2	11.25	15.2	64.3%	63.8%
	7	6 + Induced Draft	(7)	236.80	500.00	112.20	12,000	0	66.2	78.0%	79.0%	9,486	7,500	78.0%	759.8	9.12	50.3	78.0%	75.1%
5	8	7 + Condense Flue Gases	(8)	270.60	600.00	161.20	12,000	0	66.2	85.0%	85.9%	10,313	7,500	85.0%	698.6	8.38	46.2	85.0%	81.7%
	9	8 + Two-Stage Operation	(9)	344.40	600.00	183.20	12,000	0	86.1	86.3%	-	-	7,500	86.3%	705.4/325.6	8.14	88.7	86.3%	78.9%
	10	8 + Modulating Operation	(10)	476.60	600.00	205.20	12,000	0	112.5	87.0%	-	-	7,500	87.0%	683.2/315.3	7.88	112.4	87.0%	77.5%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

- 1 Baseline: NAECA=60%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 4 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 7 Induced Draft efficiency increase due to the following components:
 - Induced Draft Fan: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 8 Condense Flue Gases: AFUE = 85.0%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_p, D_s, and P_p are equal to zero)
- 9 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 10 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.13 Cost-Efficiency Table for Gravity Wall Furnaces over 12,000 up to 15,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH* hours	E _P MBtu	E _{AE} kWh	AFUE'	AE'
	0	Baseline	(1)	109.90	500.00	29.50	14,000	400	0.0	61.0%	68.7%	9,624	7,500	66.5%	683.3	12.80	0.0	61.0%	61.0%
1,2	1	0 + Derate 20%	(2)	116.00	500.00	29.50	11,200	400	0.0	64.9%	75.2%	8,419	7,500	72.1%	781.0	11.94	0.0	64.9%	64.9%
3	2	1 + Electronic Ignition	(3)	126.50	500.00	55.00	11,200	0	16.2	68.6%	75.2%	8,419	7,500	68.6%	941.4	10.54	15.3	68.6%	67.9%
4	3	2 + Combustion Box Damper**	(4)	154.70	500.00	90.50	11,200	0	16.2	73.9%	75.2%	8,419	7,500	73.9%	874.4	9.79	14.2	73.9%	73.2%
	4	0 + Increase HX Size	(5)	134.30	500.00	29.50	14,000	400	0.0	64.0%	71.7%	10,044	7,500	69.8%	645.1	12.28	0.0	64.0%	64.0%
	5	2 + Vent Damper***	(6)	148.10	510.00	55.00	11,200	0	16.2	71.2%	77.3%	8,658	7,500	71.2%	907.6	10.17	14.7	71.2%	70.5%
	6	0 + Electronic Ignition	(3)	120.40	500.00	55.00	14,000	0	16.2	64.7%	68.7%	9,624	7,500	64.7%	799.4	11.19	12.9	64.7%	64.2%
	7	6 + Induced Draft	(7)	241.30	500.00	112.20	14,000	0	66.2	78.0%	79.0%	11,066	7,500	78.0%	653.6	9.15	43.3	78.0%	75.5%
5	8	7 + Condense Flue Gases	(8)	283.50	600.00	161.20	14,000	0	66.2	85.0%	85.9%	12,030	7,500	85.0%	600.7	8.41	39.8	85.0%	82.1%
	9	8 + Two-Stage Operation	(9)	357.30	600.00	183.20	14,000	0	86.1	86.3%	-	-	7,500	86.3%	607.8/280.5	8.18	76.5	86.3%	79.8%
	10	8 + Modulating Operation	(10)	489.50	600.00	205.20	14,000	0	112.5	86.9%	-	-	7,500	86.9%	590.7/272.6	7.95	97.2	86.9%	78.6%

* Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

** Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

*** Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

1 Baseline: NAECA=61%

2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option

3 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%

4 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%

5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points

6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%

7 Induced Draft efficiency increase due to the following components:

Induced Draft Fan: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points

Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase

8 Condense Flue Gases: AFUE = 85.0%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_F , D_S , and P_P are equal to zero)

9 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown

10 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.14 Cost-Efficiency Table for Gravity Wall Furnaces over 15,000 up to 19,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH ^o hours	E _F MBtu	E _{AE} kWh	AFUE'	AE'
	0	Baseline	(1)	128.90	500.00	29.50	19,000	400	0.0	62.0%	68.8%	13,068	10,000	66.1%	700.7	16.54	0.0	62.0%	62.0%
1,2	1	0 + Derate 20%	(2)	137.50	500.00	29.50	15,200	400	0.0	65.9%	75.2%	11,428	10,000	71.3%	808.1	15.46	0.0	65.9%	65.9%
3	2	1 + Electronic Ignition	(3)	148.10	500.00	55.00	15,200	0	16.2	68.7%	75.2%	11,428	10,000	68.7%	925.7	14.07	15.0	68.7%	68.2%
	3	2 + Combustion Box Damper**	(4)	179.70	500.00	90.50	15,200	0	16.2	73.9%	75.2%	11,428	10,000	73.9%	860.4	13.08	13.9	73.9%	73.4%
	4	0 + Increase HX Size	(5)	160.80	500.00	29.50	19,000	400	0.0	65.0%	71.8%	13,638	10,000	69.3%	664.0	15.85	0.0	65.0%	65.0%
	5	2 + Vent Damper***	(6)	169.70	510.00	55.00	15,200	0	16.2	71.2%	77.3%	11,752	10,000	71.2%	892.4	13.56	14.5	71.2%	70.7%
	6	0 + Electronic Ignition	(3)	139.50	500.00	55.00	19,000	0	16.2	64.7%	68.8%	13,068	10,000	64.7%	786.2	14.94	12.7	64.7%	64.4%
4	7	6 + Induced Draft	(7)	274.70	500.00	112.20	19,000	0	66.2	78.0%	79.1%	15,025	10,000	78.0%	645.3	12.26	42.7	78.0%	76.2%
5	8	7 + Condense Flue Gases	(8)	329.50	600.00	161.20	19,000	0	66.2	85.0%	86.0%	16,332	10,000	85.0%	592.9	11.26	39.2	85.0%	82.9%
	9	8 + Two-Stage Operation	(9)	403.30	600.00	183.20	19,000	0	86.1	86.3%	-	-	10,000	86.3%	601.8/277.8	10.99	75.7	86.3%	81.4%
	10	8 + Modulating Operation	(10)	535.50	600.00	205.20	19,000	0	112.5	87.0%	-	-	10,000	87.0%	588.0/271.4	10.74	96.7	87.0%	80.6%

Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

- 1 Baseline: NAECA=62%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 4 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 7 Induced Draft efficiency increase due to the following components:
 - Induced Draft Fan: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 8 Condense Flue Gases: AFUE = 85.0%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_F, D_S, and P_F are equal to zero)
- 9 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 10 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.15 Cost-Efficiency Table for Gravity Wall Furnaces over 19,000 up to 27,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH* hours	E _F MBtu	E _{AE} kWh	AFUE' AE'
	0	Baseline	(1)	148.10	500.00	29.50	25,000	400	0.0	63.0%	69.1%	17,284	15,000	66.1%	827.7	23.87	0.0	63.0% 63.0%
1	1	0 + Derate 20%	(2)	159.00	500.00	29.50	20,000	400	0.0	66.8%	75.3%	15,066	15,000	70.8%	964.3	22.41	0.0	66.8% 66.8%
2	2	1 + Electronic Ignition	(3)	169.80	500.00	55.00	20,000	0	16.2	68.8%	75.3%	15,066	15,000	68.8%	1054.1	21.08	17.1	68.8% 68.5%
3	3	2 + Combustion Box Damper**	(4)	204.50	500.00	90.50	20,000	0	16.2	74.0%	75.3%	15,066	15,000	74.0%	980.2	19.60	15.9	74.0% 73.6%
	4	0 + Increase HX Size	(5)	187.00	500.00	29.50	25,000	400	0.0	66.0%	72.1%	18,034	15,000	69.3%	786.9	22.86	0.0	66.0% 66.0%
	5	2 + Vent Damper***	(6)	191.40	510.00	55.00	20,000	0	16.2	71.4%	77.5%	15,492	15,000	71.4%	1016.2	20.32	16.5	71.4% 71.0%
	6	0 + Electronic Ignition	(3)	158.90	500.00	55.00	25,000	0	16.2	65.1%	69.1%	17,284	15,000	65.1%	892.5	22.31	14.5	65.1% 64.8%
4	7	6 + Induced Draft	(7)	307.90	500.00	112.20	25,000	0	66.2	78.0%	79.0%	19,759	15,000	78.0%	738.8	18.47	48.9	78.0% 76.5%
5	8	7 + Condense Flue Gases	(8)	374.90	600.00	161.20	25,000	0	66.2	85.0%	85.9%	21,476	15,000	85.0%	678.5	16.96	44.9	85.0% 83.3%
	9	8 + Two-Stage Operation	(9)	448.70	600.00	183.20	25,000	0	86.1	86.3%	-	-	15,000	86.3%	690.2/318.6	16.59	86.8	86.3% 82.5%
	10	8 + Modulating Operation	(10)	580.90	600.00	205.20	25,000	0	112.5	86.9%	-	-	15,000	86.9%	676.9/312.4	16.27	111.3	86.9% 82.0%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

1 Baseline: NAECA = 63%

2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option

3 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%

4 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%

5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points

6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%

7 Induced Draft efficiency increase due to the following components:

Induced Draft Fan: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points

Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase

8 Condense Flue Gases: AFUE = 85.0%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_F , D_S , and P_F are equal to zero)

9 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown

10 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.16 Cost-Efficiency Table for Gravity Wall Furnaces over 27,000 up to 46,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH* hours	E _F MBtu	E _{AE} kWh	AFUE'	AE'
	0	Baseline	(1)	154.20	500.00	29.50	35,000	400	0.0	64.0%	69.6%	24,346	20,500	66.3%	820.2	31.88	0.0	64.0%	64.0%
1	1	0 + Derate 20%	(2)	162.80	500.00	29.50	28,000	400	0.0	67.5%	75.5%	21,138	20,500	70.4%	963.7	30.10	0.0	67.5%	67.5%
2	2	1 + Electronic Ignition	(3)	173.30	500.00	55.00	28,000	0	16.2	69.0%	75.5%	21,138	20,500	69.0%	1027.6	28.77	16.6	69.0%	68.7%
3	3	2 + Combustion Box Damper**	(4)	206.00	500.00	90.50	28,000	0	16.2	74.2%	75.5%	21,138	20,500	74.2%	955.8	26.76	15.5	74.2%	73.9%
	4	0 + Increase HX Size	(5)	191.10	500.00	29.50	35,000	400	0.0	67.0%	72.6%	25,396	20,500	69.4%	781.2	30.53	0.0	67.0%	67.0%
	5	2 + Vent Damper***	(6)	194.89	510.00	55.00	28,000	0	16.2	71.6%	77.6%	21,736	20,500	71.6%	990.6	27.74	16.0	71.6%	71.3%
	6	0 + Electronic Ignition	(3)	164.70	500.00	55.00	35,000	0	16.2	65.5%	69.6%	24,346	20,500	65.5%	866.6	30.33	14.0	65.5%	65.3%
4	7	6 + Induced Draft	(7)	311.80	500.00	112.20	35,000	0	66.2	78.0%	79.1%	27,671	20,500	78.0%	723.5	25.32	47.9	78.0%	76.9%
5	8	7 + Condense Flue Gases	(8)	381.90	600.00	161.20	35,000	0	66.2	85.0%	85.9%	30,070	20,500	85.0%	664.3	23.25	44.0	85.0%	83.8%
	9	8 + Two-Stage Operation	(9)	455.70	600.00	183.20	35,000	0	86.1	86.3%	-	-	20,500	86.3%	677.1/312.5	22.79	85.2	86.3%	83.5%
	10	8 + Modulating Operation	(10)	587.90	600.00	205.20	35,000	0	112.5	86.9%	-	-	20,500	86.9%	666.2/307.5	22.42	109.6	86.9%	83.3%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

- 1 Baseline: NAECA = 64%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 4 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 7 Induced Draft efficiency increase due to the following components:
 - Induced Draft Fan: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 8 Condense Flue Gases: AFUE = 85.0%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_p, D_s, and P_F are equal to zero)
- 9 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 10 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.17 Cost-Efficiency Table for Gravity Wall Furnaces over 46,000 Btu/h

Std.	Design	Design		Mfg.	Install.	Maint.	Q _{in}	Q _p	P _E	AFUE	n _{ss}	Q _{out}	DHR	n _u	BOH [*]	E _F	E _{AB}	AFUE'	AE'
Level	No.	Options		1990\$	1990\$	1990\$	Btu/h	Btu/h	Watts			Btu/h	Btu/h		hours	MBtu	kWh		
1	0	Baseline	(1)	206.20	500.00	29.50	50,000	400	0.0	65.0%	70.1%	35,068	30,000	66.6%	848.3	45.58	0.0	65.0%	65.0%
	1	0 + Derate 20%	(2)	215.30	500.00	29.50	40,000	400	0.0	68.2%	75.7%	30,284	30,000	70.2%	1005.7	43.33	0.0	68.2%	68.2%
	2	1 + Vent Damper ^{***}	(3)	236.90	510.00	29.50	40,000	400	0.0	70.7%	77.9%	31,141	30,000	72.9%	967.6	41.82	0.0	70.7%	70.7%
2	3	2 + Electronic Ignition	(4)	247.70	510.00	55.00	40,000	0	16.2	71.8%	77.9%	31,141	30,000	71.8%	1013.1	40.52	16.4	71.8%	71.6%
	4	0 + Increase HX Size	(5)	245.10	500.00	29.50	50,000	400	0.0	68.0%	73.1%	36,568	30,000	69.7%	809.3	43.65	0.0	68.0%	68.0%
3	5	1 + Electronic Ignition	(4)	226.10	500.00	55.00	40,000	0	16.2	69.2%	75.7%	30,284	30,000	69.2%	1050.5	42.02	17.0	69.2%	69.0%
	6	5 + Burner Box Damper ^{**}	(6)	265.40	500.00	90.50	40,000	0	16.2	74.4%	75.7%	30,284	30,000	74.4%	977.1	39.08	15.8	74.4%	74.2%
	7	0 + Electronic Ignition	(4)	217.00	500.00	55.00	50,000	0	16.2	66.0%	70.1%	35,068	30,000	66.0%	880.9	44.05	14.3	66.0%	65.9%
4	8	7 + Induced Draft	(7)	329.30	500.00	112.20	50,000	0	66.2	74.0%	75.1%	37,568	30,000	74.0%	782.3	39.11	51.8	74.0%	73.4%
	9	8 + Induced Draft Redesign	(8)	395.20	500.00	112.20	50,000	0	66.2	78.0%	79.1%	39,568	30,000	78.0%	742.4	37.12	49.1	78.0%	77.3%
5	10	9 + Condense Flue Gases	(9)	494.10	600.00	161.20	50,000	0	66.2	85.0%	86.0%	42,987	30,000	85.0%	681.6	34.08	45.1	85.0%	84.2%
	11	10 + Two-Stage Operation	(10)	567.90	600.00	183.20	50,000	0	86.1	86.3%	-	-	30,000	86.3%	695.7/321.1	33.45	87.5	86.3%	84.4%
	12	10 + Modulating Operation	(11)	700.10	600.00	205.20	50,000	0	112.5	87.0%	-	-	30,000	87.0%	686.3/316.8	33.00	112.9	87.0%	84.4%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

**Inlet Damper is used instead of a Combustion Box Damper on Direct Venting Furnaces

***Vent Dampers are only applicable to Non-Direct Venting Furnaces

NOTES

- 1 Baseline: NAECA=65%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 4 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 9 Condense Flue Gases: AFUE = 85.0%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_p , D_s , and P_p are equal to zero)
- 10 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 11 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.18 Cost-Efficiency Table for Floor Furnaces up to 37,000 Btu/h

Std. Level	Design No.	Design Options	Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH* hours	E _F MBtu	E _{AB} kWh	AFUE' AE'
	0	Baseline	(1)	154.10	705.00	29.50	30,000	400	0.0	56.0% 64.4%	18,493	15,000	58.2%	789.5	26.87	0.0	56.0% 56.0%
1	1	0 + Derate 20%	(2)	164.70	705.00	29.50	24,000	400	0.0	61.3% 72.3%	16,669	15,000	64.2%	890.9	24.53	0.0	61.3% 61.3%
2	2	1 + Electronic Ignition	(3)	175.60	705.00	55.00	24,000	0	16.2	63.0% 72.3%	16,669	15,000	63.0%	960.3	23.05	15.6	63.0% 62.7%
3	3	2 + Combustion Box Damper	(4)	210.00	705.00	90.50	24,000	0	16.2	71.0% 72.3%	16,669	15,000	71.0%	852.0	20.45	13.8	71.0% 70.7%
	4	0 + Increase HX Size	(5)	195.80	705.00	29.50	30,000	400	0.0	59.0% 67.4%	19,393	15,000	61.3%	746.3	25.59	0.0	59.0% 59.0%
	5	2 + Vent Damper	(6)	197.20	715.00	55.00	24,000	0	16.2	65.3% 74.3%	17,159	15,000	65.3%	925.7	22.22	15.0	65.3% 65.1%
	6	0 + Electronic Ignition	(3)	165.00	705.00	55.00	30,000	0	16.2	57.7% 64.4%	18,493	15,000	57.7%	838.5	25.16	13.6	57.7% 57.5%
	7	6 + Induced Draft	(7)	208.10	705.00	112.20	30,000	0	66.2	65.7% 69.4%	19,993	15,000	65.7%	730.4	21.91	48.4	65.7% 64.8%
4	8	7 + Induced Draft Redesign	(8)	330.70	705.00	112.20	30,000	0	126.2	78.0% 81.7%	23,683	15,000	78.0%	611.1	18.33	77.1	78.0% 75.8%
	9	8 + Increase Insulation	(9)	342.70	705.00	112.20	30,000	0	126.2	79.0% 81.7%	23,983	15,000	79.0%	603.5	18.10	76.2	79.0% 76.7%
5	10	9 + Condense Flue Gases	(10)	429.90	805.00	161.20	30,000	0	126.2	91.4% 92.6%	27,232	15,000	91.4%	522.9	15.69	66.0	91.4% 88.6%
	11	10 + Two-Stage Operation	(11)	503.70	805.00	183.20	30,000	0	164.1	92.7% -	-	15,000	92.7%	530.7/245.0	15.31	127.3	92.7% 86.3%
	12	10 + Modulating Operation	(12)	635.90	805.00	205.20	30,000	0	214.5	93.4% -	-	15,000	3.4%	517.8/239.0	14.94	162.4	93.4% 85.2%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA=56%
- 2 Derate 20%: AFUE increase = 9.49%; n_{ss} increase = 12.12%
- 3 Electronic Ignition: AFUE increase = 129 * (Q_p / Q_{out}); n_{ss} increase = 0%
- 4 Combustion Box Damper: n_u = n_{ss} * (79.6% / 81.0%); n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Induced Draft Redesign efficiency increase due to the following components:
 - Air Circulation Fan: AFUE increase = 5 percentage points; n_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 9 Increased Insulation: AFUE increase = 1 percentage point; n_{ss} increase = 0 percentage point
- 10 Condense Flue Gases: AFUE = 91.4%; n_{ss} = (AFUE - 1.81) / 0.968 (equation from DOE "short-cut" method where D_p, D_s, and P_F are equal to zero)
- 11 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 12 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.19 Cost-Efficiency Table for Floor Furnaces over 37,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	η _{ss}	Q _{out} Btu/h	DHR Btu/h	η _u	BOH* hours	E _F MBtu	E _{AB} kWh	AFUE'	AE'
1 2,3	0	Baseline	(1)	196.30	705.00	29.50	65,000	450	0.0	57.0%	64.6%	40,184	33,500	58.2%	837.6	58.01	0.0	57.0%	57.0%
	1	0 + Derate 20%	(2)	212.30	705.00	29.50	52,000	450	0.0	62.3%	72.5%	36,220	33,500	63.9%	951.4	52.99	0.0	62.3%	62.3%
	2	1 + Combustion Box Damper	(3)	251.90	705.00	65.00	52,000	450	0.0	69.3%	72.5%	36,220	33,500	71.2%	850.0	47.76	0.0	69.3%	69.3%
	3	2 + Electronic Ignition	(4)	262.70	705.00	90.50	52,000	0	16.2	70.2%	72.5%	36,220	33,500	70.2%	890.1	46.28	14.4	70.2%	70.0%
	4	0 + Increase HX Size	(5)	243.60	705.00	29.50	65,000	450	0.0	60.0%	67.6%	42,134	33,500	61.2%	794.2	55.21	0.0	60.0%	60.0%
4 5	5	1 + Vent Damper	(6)	233.90	715.00	29.50	52,000	450	0.0	64.7%	74.5%	37,286	33,500	66.3%	915.5	51.14	0.0	64.7%	64.7%
	6	0 + Induced Draft	(7)	226.20	705.00	86.70	65,000	450	62.6	65.0%	69.6%	43,434	33,500	66.4%	726.4	50.83	45.5	65.0%	64.6%
	7	6 + Induced Draft Redesign	(8)	359.40	705.00	86.70	65,000	450	122.6	78.0%	82.6%	51,884	33,500	79.7%	598.5	42.58	73.4	78.0%	77.1%
	8	7 + Electronic Ignition	(4)	383.70	705.00	112.20	65,000	0	126.2	78.9%	82.6%	51,884	33,500	78.9%	629.1	40.89	79.4	78.9%	77.8%
	9	8 + Increase Insulation	(9)	395.70	705.00	112.20	65,000	0	126.2	79.9%	82.6%	52,534	33,500	79.9%	621.3	40.38	78.4	79.9%	78.8%
	10	9 + Condense Flue Gases	(10)	525.60	805.00	161.20	65,000	0	126.2	91.4%	92.5%	58,984	33,500	91.4%	543.7	35.34	68.6	91.4%	90.0%
	11	10 + Two-Stage Operation	(11)	599.40	805.00	183.20	65,000	0	164.1	92.7%	-	-	33,500	92.7%	554.8/256.1	34.68	133.0	92.7%	89.6%
	12	10 + Modulating Operation	(12)	731.60	805.00	205.20	65,000	0	214.5	93.3%	-	-	33,500	93.3%	546.4/252.2	34.15	171.3	93.3%	89.3%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA = 57%
- 2 Derate 20%: AFUE increase = 9.49%; n_{ss} increase = 12.12%
- 3 Combustion Box Damper: n_u = n_{ss} * (79.6% / 81.0%); n_{ss} increase = 0%
- 4 Electronic Ignition: AFUE increase = 129 * (Q_p / Q_{out}); n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Induced Draft Redesign efficiency increase due to the following components:
 - Air Circulation Fan: AFUE increase = 5 percentage points; n_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 9 Increased Insulation: AFUE increase = 1 percentage point; n_{ss} increase = 0 percentage point
- 10 Condense Flue Gases: AFUE = 91.4%; n_{ss} = (AFUE - 1.81) / 0.968 (equation from DOE "short-cut" method where D_F, D_S, and P_F are equal to zero)
- 11 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 12 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.20 Cost-Efficiency Table for Room Heaters up to 18,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	η _{ss}	Q _{out} Btu/h	DHR Btu/h	η _u	BOH ^o hours	E _F MBtu	E _{AB} kWh	AFUE'	AE'
1	0	Baseline	(1)	125.70	385.00	29.50	15,000	300	0.0	57.0%	63.5%	9,521	7,500	60.5%	733.6	13.41	0.0	57.0%	57.0%
	1	0 + Derate 20%	(2)	135.20	385.00	29.50	12,000	300	0.0	62.3%	71.2%	8,540	7,500	67.1%	820.7	12.23	0.0	62.3%	62.3%
	2,3	2	1 + Electronic Ignition	(3)	146.20	385.00	55.00	12,000	0	16.2	64.9%	71.2%	8,540	7,500	64.9%	928.2	11.14	15.0	64.9%
4	3	2 + Vent Damper	(4)	167.80	395.00	55.00	12,000	0	16.2	67.4%	73.2%	8,781	7,500	67.4%	894.9	10.74	14.5	67.4%	66.8%
	4	0 + Increase HX Size	(5)	168.60	385.00	29.50	15,000	300	0.0	60.0%	66.5%	9,971	7,500	63.7%	692.4	12.81	0.0	60.0%	60.0%
	5	2 + Combustion Box Damper	(6)	182.90	385.00	90.50	12,000	0	16.2	69.9%	71.2%	8,540	7,500	69.9%	862.2	10.35	14.0	69.9%	69.3%
5	6	0 + Electronic Ignition	(3)	136.70	385.00	55.00	15,000	0	16.2	59.6%	63.5%	9,521	7,500	59.6%	809.9	12.15	13.1	59.6%	59.2%
	7	6 + Induced Draft	(7)	180.10	385.00	112.20	15,000	0	66.2	67.6%	68.5%	10,271	7,500	67.6%	702.8	10.54	46.5	67.6%	65.7%
	8	7 + Induced Draft Redesign	(8)	306.00	385.00	112.20	15,000	0	126.2	78.0%	78.9%	11,831	7,500	78.0%	600.5	9.01	75.8	78.0%	73.7%
	9	8 + Condense Flue Gases	(9)	367.30	485.00	161.20	15,000	0	126.2	91.4%	92.5%	13,880	7,500	91.4%	515.2	7.73	65.0	91.4%	85.9%
	10	9 + Two-Stage Operation	(10)	441.10	485.00	183.20	15,000	0	164.1	92.7%	-	-	7,500	92.7%	517.7/239.0	7.47	124.1	92.7%	80.9%
	11	9 + Modulating Operation	(11)	573.30	485.00	205.20	15,000	0	214.5	93.3%	-	-	7,500	93.3%	496.9/229.3	7.17	155.8	93.3%	78.6%

* Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA=57%
- 2 Derate 20%: AFUE increase = 9.49%; η_{ss} increase = 12.12%
- 3 Electronic Ignition: AFUE increase = $129 \cdot (Q_p / Q_{out})$; η_{ss} increase = 0%
- 4 Vent Damper: AFUE increase = 3.75%; η_{ss} increase = 2.83%
- 5 Increase HX Size: AFUE increase = 3 percentage points; η_{ss} increase = 3 percentage points
- 6 Combustion Box Damper: $\eta_u = \eta_{ss} \cdot (79.6\% / 81.0\%)$; η_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; η_{ss} increase = 5 percentage points
- 8 Induced Draft Redesign efficiency increase due to the following components:
 - Air Circulation Fan: AFUE increase = 5 percentage points; η_{ss} increase = 5 percentage points
 - Induced Draft Redesign: AFUE = 78% maximum, η_{ss} increase = directly proportional to AFUE increase
- 9 Condense Flue Gases: AFUE = 91.4%; $\eta_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_P, D_S, and P_F are equal to zero)
- 10 Two-Stage Operation: AFUE increase = 1.3 percentage points; η_{ss} is unknown
- 11 Modulating Operation: AFUE increase = 1.95 percentage points increase; η_{ss} is unknown

Table 1.21 Cost-Efficiency Table for Room Heaters over 18,000 and up to 20,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _a	BOH* hours	E _F MBtu	E _{AE} kWh	AFUE' AE'
	0	Baseline	(1)	135.00	385.00	29.50	20,000	300	0.0	58.0%	63.8%	12,768	10,000	60.7%	748.9	17.38	0.0	58.0% 58.0%
	1	0 + Derate 20%	(2)	145.31	385.00	29.50	16,000	300	0.0	63.4%	71.6%	11,452	10,000	67.1%	842.9	15.86	0.0	63.4% 63.4%
1	2	1 + Electronic Ignition	(3)	156.31	385.00	55.00	16,000	0	16.2	65.4%	71.6%	11,452	10,000	65.4%	923.5	14.78	15.0	65.4% 65.0%
2	3	2 + Vent Damper	(4)	177.90	395.00	55.00	16,000	0	16.2	67.8%	73.6%	11,776	10,000	67.8%	890.3	14.24	14.4	67.8% 67.4%
	4	0 + Increase HX Size	(5)	179.10	385.00	29.50	20,000	300	0.0	61.0%	66.8%	13,368	10,000	63.8%	708.8	16.59	0.0	61.0% 61.0%
3	5	2 + Combustion Box Damper	(6)	193.81	385.00	90.50	16,000	0	16.2	70.3%	71.6%	11,452	10,000	70.3%	858.7	13.74	13.9	70.3% 69.9%
	6	0 + Electronic Ignition	(3)	146.00	385.00	55.00	20,000	0	16.2	59.9%	63.8%	12,768	10,000	59.9%	806.4	16.13	13.1	59.9% 59.7%
	7	6 + Induced Draft	(7)	189.40	385.00	112.20	20,000	0	66.2	67.9%	68.8%	13,768	10,000	67.9%	703.0	14.06	46.5	67.9% 66.5%
4	8	7 + Induced Draft Redesign	(8)	317.10	385.00	112.20	20,000	0	126.2	78.0%	78.9%	15,788	10,000	78.0%	605.5	12.11	76.4	78.0% 74.8%
5	9	8 + Condense Flue Gases	(9)	387.90	485.00	161.20	20,000	0	126.2	91.4%	92.6%	18,518	10,000	91.4%	518.8	10.38	65.5	91.4% 87.3%
	10	9 + Two-Stage Operation	(10)	461.70	485.00	183.20	20,000	0	164.1	92.7%	-	-	10,000	92.7%	524.0/241.8	10.08	125.6	92.7% 83.6%
	11	9 + Modulating Operation	(11)	593.90	485.00	205.20	20,000	0	214.5	93.4%	-	-	10,000	93.4%	507.0/234.0	9.75	159.0	93.4% 81.7%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA = 58%
- 2 Derate 20%: AFUE increase = 9.49%; n_{ss} increase = 12.12%
- 3 Electronic Ignition: AFUE increase = 129 * (Q_p / Q_{out}); n_{ss} increase = 0%
- 4 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Combustion Box Damper: n_a = n_{ss} * (79.6% / 81.0%); n_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Induced Draft Redesign efficiency increase due to the following components:
 Air Circulation Fan: AFUE increase = 5 percentage points; n_{ss} increase = 5 percentage points
 Induced Draft Redesign: AFUE = 78% maximum, n_{ss} increase = directly proportional to AFUE increase
- 9 Condense Flue Gases: AFUE = 91.4%; n_{ss} = (AFUE - 1.81) / 0.968 (equation from DOE "short-cut" method where D_p, D_s, and P_p are equal to zero)
- 10 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 11 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.22 Cost-Efficiency Table for Room Heaters over 20,000 and up to 27,000 Btu/h

Std. Level	Design No.	Design Options	Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _B Watts	AFUE	η _{ss}	Q _{out} Btu/h	DHR Btu/h	η _u	BOH ^a hours	E _F MBtu	E _{AB} kWh	AFUE'	AE'	
1,2,3	0	Baseline	(1)	145.70	385.00	29.50	25,000	300	0.0	63.0%	68.6%	17,151	15,000	65.3%	852.0	23.67	0.0	63.0%	63.0%
	1	0 + Derate 20%	(2)	156.84	385.00	29.50	20,000	300	0.0	67.1%	75.1%	15,023	15,000	70.2%	990.3	22.14	0.0	67.1%	67.1%
	2	1 + Electronic Ignition	(3)	167.44	385.00	55.00	20,000	0	16.2	68.7%	75.1%	15,023	15,000	68.7%	1056.4	21.13	17.1	68.7%	68.3%
	3	2 + Vent Damper	(4)	189.04	395.00	55.00	20,000	0	16.2	71.2%	77.2%	15,448	15,000	71.2%	1018.4	20.37	16.5	71.2%	70.9%
	4	0 + Increase HX Size	(5)	191.30	385.00	29.50	25,000	300	0.0	66.0%	71.6%	17,901	15,000	68.5%	810.9	22.66	0.0	66.0%	66.0%
	5	2 + Combustion Box Damper	(6)	205.84	385.00	90.50	20,000	0	16.2	73.8%	75.1%	15,023	15,000	73.8%	983.0	19.66	15.9	73.8%	73.4%
	6	0 + Electronic Ignition	(3)	156.30	385.00	55.00	25,000	0	16.2	64.5%	68.6%	17,151	15,000	64.5%	899.6	22.49	14.6	64.5%	64.3%
4	7	6 + Induced Draft	(7)	199.70	385.00	112.20	25,000	0	66.2	72.5%	73.6%	18,401	15,000	72.5%	793.2	19.83	52.5	72.5%	71.3%
	8	7 + Air Circulation Fan	(8)	253.00	385.00	112.20	25,000	0	126.2	77.5%	78.6%	19,651	15,000	77.5%	735.0	18.38	92.8	77.5%	74.9%
5	9	8 + Condense Flue Gases	(9)	334.10	485.00	161.20	25,000	0	126.2	91.4%	92.6%	23,150	15,000	91.4%	625.4	15.63	78.9	91.4%	88.1%
	10	9 + Two-Stage Operation	(10)	407.90	485.00	183.20	25,000	0	164.1	92.7%	-	-	15,000	92.7%	633.5/292.4	15.23	151.9	92.7%	85.2%
	11	9 + Modulating Operation	(11)	540.10	485.00	205.20	25,000	0	214.5	93.4%	-	-	15,000	93.4%	616.0/284.3	14.81	193.1	93.4%	83.8%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA = 63%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 4 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Air Circulation Fan: AFUE increase = 5 percentage points; n_{ss} increase = 5 percentage points
- 9 Condense Flue Gases: AFUE = 91.4%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_F , D_S , and P_F are equal to zero)
- 10 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 11 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.23 Cost-Efficiency Table for Room Heaters over 27,000 and up to 46,000 Btu/h

Std. Level	Design No.	Design Options		Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _o	BOH* hours	E _F MBtu	E _{AE} kWh	AFUE'	AE'
	0	Baseline	(1)	156.50	385.00	29.50	35,000	300	0.0	64.0%	69.2%	24,213	20,500	65.7%	837.4	31.68	0.0	64.0%	64.0%
1	1	0 + Derate 20%	(2)	168.40	385.00	29.50	28,000	300	0.0	67.8%	75.3%	21,097	20,500	70.0%	982.0	29.83	0.0	67.8%	67.8%
	2	1 + Vent Damper	(3)	190.00	395.00	29.50	28,000	300	0.0	70.3%	77.5%	21,694	20,500	72.6%	944.6	28.79	0.0	70.3%	70.3%
2,3	3	2 + Electronic Ignition	(4)	200.60	395.00	55.00	28,000	0	16.2	71.4%	77.5%	21,694	20,500	71.4%	992.6	27.79	16.1	71.4%	71.2%
	4	0 + Increase HX Size	(5)	202.50	385.00	29.50	35,000	300	0.0	67.0%	72.2%	25,263	20,500	68.8%	798.2	30.32	0.0	67.0%	67.0%
	5	1 + Combustion Box Damper	(6)	207.70	385.00	65.00	28,000	300	0.0	72.1%	75.3%	21,097	20,500	74.0%	925.6	28.27	0.0	71.6%	71.6%
	6	0 + Electronic Ignition	(4)	167.10	385.00	55.00	35,000	0	16.2	65.1%	69.2%	24,213	20,500	65.1%	871.5	30.50	14.1	65.1%	64.9%
	7	6 + Induced Draft	(7)	210.40	385.00	112.20	35,000	0	66.2	73.1%	74.2%	25,963	20,500	73.1%	771.2	26.99	51.1	73.1%	72.2%
4	8	7 + Air Circulation Fan	(8)	264.10	385.00	112.20	35,000	0	126.2	78.1%	79.2%	27,713	20,500	78.1%	716.9	25.09	90.5	78.1%	76.2%
5	9	8 + Condense Flue Gases	(9)	355.80	485.00	161.20	35,000	0	126.2	91.4%	92.6%	32,395	20,500	91.4%	614.0	21.49	77.5	91.4%	88.9%
	10	9 + Two-Stage Operation	(10)	429.60	485.00	183.20	35,000	0	164.1	92.7%	-	-	20,500	92.7%	624.1/288.0	21.00	149.6	92.7%	87.2%
	11	9 + Modulating Operation	(11)	561.80	485.00	205.20	35,000	0	214.5	93.4%	-	-	20,500	93.4%	610.4/281.7	20.54	191.4	93.4%	86.2%

*Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA=64%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 4 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Combustion Box Damper: $n_o = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Air Circulation Fan: AFUE increase = 5 percentage points; n_{ss} increase = 5 percentage points
- 9 Condense Flue Gases: AFUE = 91.4%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_p , D_s , and P_F are equal to zero)
- 10 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 11 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

Table 1.24 Cost-Efficiency Table for Room Heaters over 46,000 Btu/h

Std. Level	Design No.	Design Options	Mfg. 1990\$	Install. 1990\$	Maint. 1990\$	Q _{in} Btu/h	Q _p Btu/h	P _E Watts	AFUE	n _{ss}	Q _{out} Btu/h	DHR Btu/h	n _u	BOH * hours	E _p MBtu	E _{AE} kWh	AFUE'	AE'
	0	Baseline	(1) 196.90	385.00	29.50	50,000	350	0.0	65.0%	70.0%	35,002	30,000	66.4%	854.3	45.48	0.0	65.0%	65.0%
1	1	0 + Derate 20%	(2) 212.20	385.00	29.50	40,000	350	0.0	68.3%	75.7%	30,264	30,000	70.1%	1012.1	43.20	0.0	68.3%	68.3%
	2	1 + Vent Damper	(3) 233.80	395.00	29.50	40,000	350	0.0	70.8%	77.8%	31,121	30,000	72.7%	974.0	41.68	0.0	70.8%	70.8%
2,3	3	2 + Electronic Ignition	(4) 244.40	395.00	55.00	40,000	0	16.2	71.7%	77.8%	31,121	30,000	71.7%	1013.6	40.54	16.4	71.7%	71.5%
	4	0 + Increase HX Size	(5) 247.20	385.00	29.50	50,000	350	0.0	68.0%	73.0%	36,502	30,000	69.5%	815.3	43.54	0.0	68.0%	68.0%
	5	1 + Combustion Box Damper	(6) 254.70	385.00	65.00	40,000	350	0.0	72.7%	75.7%	30,264	30,000	74.4%	951.5	40.79	0.9	72.3%	72.3%
	6	0 + Induced Draft	(7) 226.90	385.00	86.70	50,000	350	62.6	73.0%	75.0%	37,502	30,000	74.7%	752.3	40.42	47.1	73.0%	72.4%
	7	6 + Electronic Ignition	(4) 251.00	385.00	112.20	50,000	0	66.2	73.9%	75.0%	37,502	30,000	73.9%	783.6	39.18	51.9	73.9%	73.2%
4	8	7 + Air Circulation Fan	(8) 309.00	385.00	112.20	50,000	0	126.2	78.9%	80.0%	40,002	30,000	78.9%	730.5	36.52	92.2	78.9%	77.5%
5	9	8 + Condense Flue Gases	(9) 441.20	485.00	161.20	50,000	0	126.2	91.4%	92.6%	46,277	30,000	91.4%	631.5	31.58	79.7	91.4%	89.7%
	10	9 + Two-Stage Operation	(10) 515.00	485.00	183.20	50,000	0	164.1	92.7%	-	-	30,000	92.7%	643.6/297.0	30.94	154.3	92.7%	88.7%
	11	9 + Modulating Operation	(11) 647.20	485.00	205.20	50,000	0	214.5	93.4%	-	-	30,000	93.4%	632.2/291.9	30.40	198.2	93.4%	88.2%

* Burner Operating Hours for Two-Stage and Modulating Operation: 1st value listed is BOH_R; 2nd value listed is BOH_H

NOTES

- 1 Baseline: NAECA=65%
- 2 Derate 20%: AFUE increase = $n_{ss} * (-1.10625) + 82.5025\%$; n_{ss} increase = $n_{ss} * (-1.00875) + 78.6975\%$; n_{ss} is the steady-state efficiency of the previous design option
- 3 Vent Damper: AFUE increase = 3.75%; n_{ss} increase = 2.83%
- 4 Electronic Ignition: AFUE increase = $129 * (Q_p / Q_{out})$; n_{ss} increase = 0%
- 5 Increase HX Size: AFUE increase = 3 percentage points; n_{ss} increase = 3 percentage points
- 6 Combustion Box Damper: $n_u = n_{ss} * (79.6\% / 81.0\%)$; n_{ss} increase = 0%
- 7 Induced Draft: AFUE increase = 8 percentage points; n_{ss} increase = 5 percentage points
- 8 Air Circulation Fan: AFUE increase = 5 percentage points; n_{ss} increase = 5 percentage points
- 9 Condense Flue Gases: AFUE = 91.4%; $n_{ss} = (AFUE - 1.81) / 0.968$ (equation from DOE "short-cut" method where D_p, D_s, and P_p are equal to zero)
- 10 Two-Stage Operation: AFUE increase = 1.3 percentage points; n_{ss} is unknown
- 11 Modulating Operation: AFUE increase = 1.95 percentage points increase; n_{ss} is unknown

1.5 COST-EFFICIENCY DATA

In this section, cost and efficiency data are presented for all 16 product classes. The cost data consist of manufacturer, maintenance, and installation costs. The manufacturer cost is the cost to the manufacturer of producing products with the design options shown and does not include markups to wholesalers or retailers.

The maintenance cost is the net present value (NPV) to the consumer of maintaining the operation of the heater. Design options that incur a maintenance cost are electronic ignition devices, induced draft systems, condensing heaters, combustion box dampers, two-stage operation, and modulating operation. In addition, the standing pilot ignition system of the baseline unit also incurs a maintenance cost. Maintenance costs consist of replacement parts and labor. Estimates of these costs were provided by technicians who service heating equipment. With the exception of electronic ignition devices, the calculation of the maintenance cost is based on replacing the particular component once in a lifetime of the appliance. The specific year of failure, or time of replacement, was based on estimates provided by technicians who service heating equipment. For direct heating equipment, the lifetime is assumed to be 15 years (19). For electronic ignition devices, a retirement function was constructed for two of the device's components: the control module and the sensor. All other electronic ignition components were assumed to last the lifetime of the appliance. The retirement function is a curve of component lifetime versus the year of component failure. The function was constructed from information provided by electronic ignition manufacturers. Table 1.25 summarizes the maintenance costs (calculated at a 6% discount rate) that were used in the cost and efficiency analysis. For more details regarding the development of maintenance costs for direct heating equipment, refer to Volume A, Appendix E, of this Technical Support Document.

Table 1.25 Direct Heating Equipment Maintenance Costs

Maintenance Item	Maintenance Cost NPV @ 1990%
Standing Pilot Ignition Systems	30.00
Electronic Ignition Systems	55.00
Induced Draft Systems	57.00
Combustion Box Dampers	36.00
Condensing Furnace Systems	49.00
Two-Stage Operation	22.00
Modulating Operation	44.00

The installation cost is the added first cost of having a contractor install a direct heater into a home. It does not include the retail cost of the direct heater. The cost includes work necessary to bring the installation up to current building codes. Estimates of these costs were provided by contractors familiar with the installation of direct heating equipment. Following are the

installation costs for direct heating equipment: \$385 for room heaters, \$500 for wall furnaces, and \$705 for floor furnaces. Only vent dampers and condensing heaters were assumed to increase installation costs. The additional \$10 for the installation of vent dampers covers the additional time necessary to carefully install the damper between the draft hood and the vent. The additional \$100 for condensing heaters is required to provide adequate drainage of the condensate away from the heater.

The cost and efficiency data were combined and are presented in the 16 tables referred to in the previous section on "Energy-Use Data" (Tables 1.9 to 1.24). Appendix A.2 of this volume contains disaggregated manufacturer costs for all 16 product classes. Total manufacturer costs are divided into material, labor, tooling, shipping, and indirect costs. Indirect costs include expenses such as general and administrative costs, research and development, rent, utility costs, and certification tests and fees. Several sources were used in establishing the costs. GAMA supplied manufacturers' cost estimates for the following design options: electronic ignition with vent damper, derating, increasing the heat exchanger, induced draft systems, and condensation of flue gases. Independent estimates of materials costs were obtained from suppliers for the following design options: electronic ignition devices, thermal vent dampers, and induced draft systems. A report by ADM Associates, Inc., a subcontractor to LBL, was also used to help estimate the cost of thermal vent dampers and induced draft-systems (20). The costs provided by ADM were from the analysis done on small gas furnaces. ADM cost estimates for incorporating these designs into small gas furnaces were assumed to be equal to those for direct heating equipment.

For the derating, increased heat exchanger size, and condensing flue gas design options, cost estimates were based on manufacturers' cost data supplied by GAMA.

Vent damper material costs were based on estimates from suppliers and ADM. Other manufacturing costs (i.e., labor, tooling, shipping, indirect) were assumed to be zero for thermal vent dampers as installation does not require design changes to the heater.

The material cost of replacing a standing pilot ignition system with an electronic ignition system depends on whether electricity is required to operate the standing pilot system. For standing pilot systems requiring no outside source of electricity to operate, the material cost of the electronic ignition system is essentially the same as the standing pilot's system. The additional cost of the control module in the electronic system is offset by the less expensive gas valve it uses. Standing pilot gas valves, which operate without an outside electricity source, are more complex and more expensive than 24-volt gas valves. The only additional cost incurred by the electronic system is for the 24-volt transformer, wiring harness, and terminal block. As for 24-volt standing pilot systems, they use the same type of gas valve as those found in electronic systems. Thus, because they do not require a control module to operate, 24-volt standing pilot control systems cost approximately half as much as electronic systems. The material costs associated with both standing pilot and electronic ignition system components were estimated by suppliers of these systems. The manufacturers' data provided by GAMA were used to estimate other costs (i.e., labor, tooling, indirect).

The costs associated with induced draft systems depend on the type of direct heater in which it is installed. For floor furnaces and room heaters, since the draft hood can simply be replaced without having to enlarge the cabinet, material and labor cost estimates from ADM were solely used. ADM cost estimates were lower than those indicated by the manufacturers' data. However, indirect costs (i.e., expenses such as general and administrative costs, research and development, rent, utility costs, and certification tests and fees) were taken from the GAMA data. For wall furnaces, since the assumption was made that the cabinet had to be enlarged, cost estimates from manufacturers were used. Costs for the redesign of the induced draft system to attain a direct heater efficiency of 78% AFUE were derived from manufacturers' estimates for the induced draft design option.

The increased insulation design option involved only an additional material cost and was estimated from manufacturers' cost data.

The combustion box damper, air circulation fan, and two-stage and modulating operation design options were not listed in the Advanced Notice of Proposed Rulemaking. Because of this, manufacturers did not provide cost data for these design options. The combustion box damper and air-circulation fan design options were assumed to require similar design changes to those associated with increasing the size of the heat exchanger. Because of this, the labor, tooling, shipping, and indirect costs for the combustion box damper and air-circulation fan design options were assumed to be equal to the manufacturers' cost estimates for increasing the size of the heat exchanger. (The combustion box damper incurred no additional shipping cost.) The material cost for the combustion box damper was determined from estimates provided by ducted furnace manufacturers. The air-circulation fan material cost was derived from retail list prices for an optional air-circulation fan using a manufacturer-to-retail markup of three. Costs for the two-stage and modulating operation design options are identical to those used for the Mobile Home Furnace analysis (See Volume I). These costs were provided by mobile home furnace manufacturers.

1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN

As previously stated, the maximum technologically feasible design for all 16 product classes is obtained by condensing the flue gases. The efficiency of the "max tech" design was derived from data given by manufacturers plus a variety of other sources. All of the efficiency values (and manufacturing costs as well) in Tables 1.9 through 1.24 have some uncertainty associated with them.

With the exception of the fan wall furnace product classes, the range of the 95% confidence interval for each of the maximum technologically feasible designs is approximately the same. The low end of the interval is, on average, 5.6% lower than the "max tech" design's annual efficiency (AE) rating. The high end of the interval is, on average, 2.8% higher than the "max tech" design's AE rating. For the two fan wall furnace product classes, the low end of the 95% confidence interval is 1.2% lower than the "max tech" design's AE rating while the high end of the interval is 1.3% higher than the "max tech" design's AE rating. Volume A provides a general discussion of how the 95% confidence interval is established for "max tech" designs.

CHAPTER 2. BASE CASE FORECASTS: DIRECT HEATING EQUIPMENT

Analyzing impacts of federal energy-efficiency standards requires comparing projected U.S. residential energy consumption with and without the standards. The cases without standards are referred to as *base case projections*. These base case projections are compared to projections of conditions that would be likely to prevail if standards were enacted (see Chapter 3). The difference between the two projections is defined as the incremental impact of standards.

Projections are made for a number of demographic, economic, and energy variables, including energy prices, household income, housing stock, housing starts, mix of house types (single-family, multifamily, mobile homes), building shell thermal characteristics, appliance purchases, equipment prices, unit energy consumption, and aggregate residential energy consumption by fuel type.

2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS

The demographic and economic assumptions are described in Volume A, Chapter 5 of this Technical Support Document.

2.2 AVERAGE EQUIPMENT LIFETIME

Average lifetimes are assumed to be 15 years for all direct heating equipment (see Table 2.1).

Table 2.1 Average Equipment Lifetime (Years) of Direct Heating Equipment

	Years	Source
Electric	15.0	LBL
Gas	15.0	LBL
Oil	15.0	LBL

2.3 BASE CASE PROJECTIONS

This section contains projections of unit energy consumption of new appliances, annual appliance installations, annual residential energy consumption, and price of purchased appliances.

2.3.1 New Appliance Unit Energy Consumptions

Annual unit energy consumption (UEC) of new appliances is projected based upon a set of designs available (each design characterized by a purchase price and an energy-efficiency factor or UEC), and a market discount rate (derived from implicit decision-making in recent purchase decisions for the product). The LBL-REM produces projections of annual energy consumption of new appliances after 1980. Table 2.2 shows the trends in efficiency and annual UEC.

Table 2.2 Base Case Projection of Unit Energy Consumption for New Gas Room Heaters

Year	Average AE	UEC (MMBtu/year)
1981	0.645	36.44
1990	0.648	36.24
1996	0.675	34.94
2000	0.676	34.94
2030	0.732	32.15

Source: LBL-REM (1980-2030).

2.3.1.1 Efficiency Distributions

Because this product is not part of the federal appliance-labeling program, no distribution is available; instead, all shipments in each year are taken to be of a single design option.

2.3.1.2 Usage

The relative usage expressing hours of operation per year as a relative index with a value of 1.0 in the base year (1980) is shown in Table 2.3. Usage is assumed to vary as a function of operating cost, which is in turn a function of gas prices and equipment efficiency and building shell efficiency.

Table 2.3 Projected Average Usage of Gas Room Heaters

Year	Usage Factor
1981	0.994
1990	1.045
1996	1.073
2000	1.070
2030	0.905

Source: LBL-REM.

2.3.2 Annual U.S. Appliance Installations

The market for appliances is seen as having two segments: new construction and existing housing. All new households are considered eligible to purchase each appliance. The pool of potential purchasers among existing households each year is defined as households that retired a unit that year, plus a fraction of households that did not previously own the product.

The initial (1980) fraction of new (and of existing) households expected to purchase each product and fuel type is specified as input to LBL-REM. LBL-REM produces projected fractions, for each year, of new households (and of existing households) that purchase the product. The projection is based on market share elasticities with respect to income, equipment price, and annual operating expense. Market share elasticities are given in Appendix B of this volume.

The projection for the period 1981-1990 is calibrated to reasonable agreement with available data, including domestic shipments (from published trade association data) and surveys of appliance ownership (e.g., from DOE/EIA RECS and the Bureau of the Census).

Tables 2.4 and 2.5 show the significant trends in the installation and saturation of this product.

Table 2.4 Annual Installations of Room Heaters in U.S. Households (Thousands)

Year	Electric	Gas	Other	Total
1981	562	624	89	1276
1990	436	466	72	974
1996	450	478	58	986
2000	460	467	56	983
2030	538	189	50	777

Table 2.5 Percent of Occupied U.S. Housing Units Having Room Heaters

Year	Electric	Gas	Other	Total
1980	4	19	2	25
1990	8	9	2	18
1996	7	7	1	15
2000	7	6	1	14
2030	6	3	1	9

Source: LBL-REM.

2.3.3 U.S. Residential Energy Consumption

U.S. residential energy consumption for this product is calculated each year as the product of: number of occupied households, fraction of households owning the appliance, average unit energy consumption (engineering estimate), and usage behavior factor.

Table 2.6 shows the U.S. energy consumption, expressed in quadrillion Btu of primary energy using a conversion factor for electricity of one kWh per 11,500 Btu.

Table 2.6 U.S. Residential Energy Consumption for Room Heaters (Quadrillion Btu, Primary Energy)

Year	Electric	Gas	Other	Total
1981	0.44	0.53	0.08	1.05
1990	0.73	0.27	0.09	1.08
1996	0.76	0.21	0.08	1.06
2000	0.74	0.21	0.07	1.01
2030	0.73	0.08	0.05	0.86

Source: LBL-REM.

2.3.4 Price of Purchased Appliances

Prices of new units increase over time as energy-efficiency improvements are incorporated. Table 2.7 shows projected shipment-weighted average prices.

Table 2.7 Average Price of New Gas Room Heaters in U.S. Households (1990 Dollars)

Year	Average Price
1981	1024
1990	1025
1996	1057
2000	1058
2030	1213

Source: LBL-REM.

2.4 SENSITIVITY ANALYSIS OF THE BASE CASE

The sensitivity cases selected are defined as follows:

1. *Lower Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level is decreased by the estimated uncertainty interval.
2. *Higher Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level is increased by the estimated uncertainty interval.
3. *Lower Energy Price.* Assume lower energy prices. Starting from 1992 to 2030, electricity prices are 3% lower while gas and distillate prices are 5% lower than those in the AEO 1991 forecast (21).
4. *Higher Energy Price.* Assume higher energy prices. Starting from 1992 to 2030, electricity prices are 3% higher while gas and distillate prices are 5% higher than those in the AEO 1991 forecast.
5. *High Equipment Efficiency.* Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.
6. *Market Discount Rates Decline.* Assume that market discount rates used to determine future efficiency choices are declining over time by 2% per year, i.e., efficiency improvements appear in the marketplace sooner.

The results of these six sensitivity cases are presented in the following tables. Tables 2.8 shows how the average price varies. Table 2.9 shows the differences in unit energy consumption or efficiency. The first line of these tables gives the results of the reference case described in the previous section; the rest of the lines give the corresponding results of the sensitivity cases listed above.

Table 2.8 Average Purchase Price of New Gas Room Heaters (1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	1024	1025	1057	1058	1213
1	798	826	841	859	976
2	1434	1435	1437	1452	1588
3	1024	1025	1026	1057	1211
4	1024	1025	1057	1058	1222
5	1024	1041	1246	1456	1826
6	1024	1025	1057	1062	1421

Table 2.9 Average Unit Consumption of New Gas Room Heaters (MMBtu/Year)

Year:	1981	1990	1996	2000	2030
Reference	36.4	36.2	34.9	34.9	32.2
1	36.4	35.0	34.8	34.1	31.3
2	36.4	36.2	36.2	35.8	32.9
3	36.4	36.2	36.2	34.9	32.2
4	36.4	36.2	34.9	34.9	32.0
5	36.4	35.7	31.7	29.1	26.3
6	36.4	36.2	34.9	34.9	29.1

Source: LBL-REM.

CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: DIRECT HEATING EQUIPMENT

The LBL Residential Energy Model (LBL-REM) projects a number of economic and energy-use variables that are used to assess the impact of proposed standards on consumers, electric utilities, and appliance manufacturers. This chapter presents projections from the model, which assume various trial standards.

The principal outputs from the LBL-REM for each year are:

- unit equipment price and operating expense by product,
- projected annual shipments of residential appliances,
- energy consumption by end use and fuel, and
- differences in these quantities between a base case and each trial standards case.

These outputs are provided annually (or for selected years) and cumulatively over a period of time, i.e., 1996-2030. Energy savings are given for each year from implementation of standards to the end of the period. Net present value of the standards is evaluated for each regulated product and for the end use(s) comprising the regulated and competing products. The sensitivity of the outputs to the key assumptions and data is analyzed; the results of this analysis are also presented.

Section 3.1 presents the trial standards levels analyzed. Section 3.2 presents the historical and projected energy consumption, including unit energy consumption for new purchases, and total national energy consumption. Section 3.3 presents historical and projected annual installations. Section 3.4 presents purchase prices. Section 3.5 presents net present value and Section 3.6 discusses the results of the sensitivity analyses.

An overview of the general LBL-REM methodology and demographic assumptions is in Volume A of this Technical Support Document. Product-specific input data are described in Appendix C of this volume.

3.1 STANDARDS LEVELS

Table 3.1 shows the correspondence between the trial standards levels, the engineering design levels, and the associated energy consumption.

Table 3.1 Trial Standards Levels for Direct Heating Equipment

	Trial Standard Level				
	1	2	3	4	5
Engineering design option:					
Fan wall heater up to 42 kBtu	0	0	0	2	7
Fan wall heater over 42 kBtu	0	0	0	2	8
Floor furnace up to 37 kBtu	1	2	3	8	10
Floor furnace over 37 kBtu	2	3	3	9	10
Gravity wall heater up to 10 kBtu	0	0	2	2	7
Gravity wall heater 10 to 12 kBtu	1	1	2	3	8
Gravity wall heater 12 to 15 kBtu	1	1	2	3	8
Gravity wall heater 15 to 19 kBtu	1	1	2	7	8
Gravity wall heater 19 to 27 kBtu	1	2	3	7	8
Gravity wall heater 27 to 46 kBtu	1	2	3	7	8
Gravity wall heater over 46 kBtu	1	3	6	8	11
Room heater up to 18 kBtu	1	2	2	5	9
Room heater 18 to 20 kBtu	2	3	5	8	9
Room heater 20 to 27 kBtu	1	1	1	8	9
Room heater 27 to 46 kBtu	1	3	3	8	9
Room heater over 46 kBtu	1	3	3	8	9
Maximum annual energy consumption (MMBtu)					
Fan wall heater up to 42 kBtu	35.8	35.8	35.8	33.3	27.8
Fan wall heater over 42 kBtu	48.4	48.4	48.4	45.6	38.4
Floor furnace up to 37 kBtu	24.5	23.1	20.5	18.3	15.7
Floor furnace over 37 kBtu	47.8	46.3	46.3	40.4	35.3
Gravity wall heater up to 10 kBtu	9.1	9.1	7.0	7.0	5.6
Gravity wall heater 10 to 12 kBtu	11.9	11.9	10.6	9.8	8.4
Gravity wall heater 12 to 15 kBtu	11.9	11.9	10.5	9.8	8.4
Gravity wall heater 15 to 19 kBtu	15.5	15.5	14.1	12.3	11.3
Gravity wall heater 19 to 27 kBtu	22.4	21.1	19.6	18.5	17.0
Gravity wall heater 27 to 46 kBtu	30.1	28.8	26.8	25.3	23.3
Gravity wall heater over 46 kBtu	43.3	40.5	39.1	39.1	33.5
Room heater up to 18 kBtu	12.2	11.1	11.1	10.4	7.7
Room heater 18 to 20 kBtu	14.8	14.2	13.7	12.1	10.4
Room heater 20 to 27 kBtu	22.1	22.1	22.1	18.4	15.6
Room heater 27 to 46 kBtu	29.8	27.8	27.8	25.1	21.5
Room heater over 46 kBtu	43.2	40.5	40.5	36.5	31.6

3.2 ENERGY CONSUMPTION

Table 3.2 shows the past and projected average energy use of new direct heating equipment. The weighted-average is obtained by taking the product of UEC of each class times a class-specific weighting factor, then summing over the classes. The weighting factors are:

Fan wall heater up to 42 kBtu	0.007
Fan wall heater over 42 kBtu	0.081
Floor furnace up to 37 kBtu	0.047
Floor furnace over 37 kBtu	0.013
Gravity wall heater up to 10 kBtu	0.010
Gravity wall heater 10 to 12 kBtu	0.010
Gravity wall heater 12 to 15 kBtu	0.010
Gravity wall heater 15 to 19 kBtu	0.010
Gravity wall heater 19 to 27 kBtu	0.136
Gravity wall heater 27 to 46 kBtu	0.219
Gravity wall heater over 46 kBtu	0.168
Room heater up to 18 kBtu	0.001
Room heater 18 to 20 kBtu	0.001
Room heater 20 to 27 kBtu	0.009
Room heater 27 to 46 kBtu	0.049
Room heater over 46 kBtu	0.228

The UEC of average, new direct heating equipment is projected to decrease from 36.2 MMBtu/yr for units bought from 1990 to 34.9 MMBtu/yr in 1996 in the absence of amended standards.

Table 3.2 Unit Energy Consumption for New Direct Heating Equipment (Weighted-Average Million Btu/Year)

Year	Trial Standard Level					
	Base	1	2	3	4	5
1981	36.4					
1990	36.2					
1996	34.9	34.7	33.1	32.1	30.1	26.3
2000	34.9	34.7	33.1	32.1	30.1	26.3
2015	34.1	34.0	32.8	31.8	30.1	26.3
2030	32..2	32.1	31.2	30.4	29.5	26.3

Source: LBL-REM.

Table 3.3a to Table 3.3d present projections of energy savings in: (a) electricity (b) gas, (c) oil, and (d) all fuel types. Standards (affecting only gas equipment) are projected to produce cumulative energy savings ranging from a loss of 0.23 Quads for standards level 5 to a saving of 0.38 Quads for standards level 3, during the period 1996-2030. At standards levels 4 and 5, gas savings are offset by increased consumption of electricity and oil due to fuel switching.

Table 3.3a U.S. Electricity Consumption for Room Heat (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level				
		1	2	3	4	5
1981	0.440					
1990	0.725					
1996	0.762	0.762	0.761	0.761	0.764	0.771
2000	0.735	0.734	0.734	0.734	0.743	0.766
2015	0.689	0.688	0.685	0.683	0.699	0.738
2030	0.730	0.729	0.726	0.722	0.730	0.745
1996-2030	24.82	24.80	24.72	24.64	25.10	26.16
Cumulative Savings:		0.02	0.10	0.18	-0.28	-1.34
Percent of Base:		0.1%	0.4%	0.7%	-1.1%	-5.4%

Table 3.3b U.S. Gas Consumption for Direct Heating Equipment (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level				
		1	2	3	4	5
1981	0.531					
1990	0.271					
1996	0.214	0.214	0.212	0.211	0.207	0.200
2000	0.211	0.210	0.207	0.204	0.194	0.175
2015	0.142	0.142	0.140	0.137	0.124	0.096
2030	0.084	0.084	0.084	0.083	0.076	0.061
1996-2030	5.35	5.34	5.26	5.17	4.78	3.97
Cumulative Savings:		0.01	0.09	0.18	0.57	1.38
Percent of Base:		0.2%	1.7%	3.4%	10.7%	25.8%

Table 3.3c U.S. Oil Consumption for Direct Heating Equipment (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level				
		1	2	3	4	5
1981	0.080					
1990	0.087					
1996	0.080	0.080	0.080	0.080	0.080	0.082
2000	0.069	0.069	0.069	0.069	0.071	0.076
2015	0.050	0.050	0.049	0.049	0.052	0.060
2030	0.045	0.045	0.045	0.044	0.046	0.048
1996-2030	1.92	1.91	1.90	1.90	1.98	2.19
Cumulative Savings:		0.01	0.02	0.02	-0.06	-0.27
Percent of Base:		0.5%	1.0%	1.0%	-3.1%	-14.1%

Table 3.3d Total U.S. Energy Consumption for Room Heat (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level				
		1	2	3	4	5
1981	1.05					
1990	1.08					
1996	1.06	1.06	1.05	1.05	1.05	1.05
2000	1.02	1.01	1.01	1.01	1.01	1.02
2015	0.88	0.88	0.87	0.87	0.88	0.89
2030	0.86	0.86	0.86	0.85	0.85	0.85
1996-2030	32.09	32.05	31.88	31.71	31.86	32.32
Cumulative Savings:		0.04	0.21	0.38	0.23	-0.23
Percent of Base:		0.1%	0.7%	1.2%	0.7%	-0.7%

Source: LBL-REM.

3.3 ANNUAL INSTALLATIONS

As shown in Table 3.4, installations¹ of direct heating equipment are affected by standards. This result is a function of the change in operating expense, change in equipment price, and market share elasticities. The projection shows a change of between -11.9% and 1.6% for cumulative shipments of gas direct heating equipment from 1996 to 2030 for the various standard levels.

¹ If there are no imports or exports, annual installations are equivalent to domestic shipments. Domestic shipments can be calculated as annual installations, less imports, plus exports.

Table 3.4 Cumulative Installations of Direct Heating Equipment (Millions)

1996-2030	Trial Standard Level					
	Base	1	2	3	4	5
Electric	16.51	16.50	16.44	16.36	16.68	17.39
Gas	11.23	11.26	11.37	11.49	10.80	9.26
Oil	1.82	1.81	1.80	1.79	1.88	2.10
Total	29.56	29.57	29.61	29.64	29.36	28.75
Change from Base:						
Electric		-0.01	-0.07	-0.15	0.17	0.88
Gas		0.03	0.14	0.26	-0.43	-1.97
Oil		-0.01	-0.02	-0.03	0.06	0.28
Total		0.01	0.05	0.08	-0.20	-0.81
Percent Change:						
Electric		-0.1%	-0.4%	-0.9%	1.0%	5.3%
Gas		0.2%	0.8%	1.6%	-2.6%	-11.9%
Oil		-0.1%	-0.1%	-0.2%	0.4%	1.7%
Total		0.1%	0.3%	0.5%	-1.2%	-4.9%

Source: LBL-REM.

3.4 APPLIANCE PRICES

Projections of the purchase prices for new direct heating equipment in 1990 dollars are shown in Table 3.5. The prices typically increase when standards come into effect.

Table 3.5 Average Purchase Price for New Direct Heating Equipment (1990 Dollars Per Unit)

Year	Trial Standard Level					
	Base	1	2	3	4	5
1981	1024					
1990	1025					
1996	1057	1062	1122	1175	1381	1826
2000	1058	1063	1122	1175	1381	1826
2015	1100	1103	1144	1196	1389	1826
2030	1213	1214	1245	1290	1442	1826

Source: LBL-REM.

3.5 NET PRESENT VALUE

The net present value (NPV) of standards for any product is calculated by first determining the difference in present value of unit life-cycle costs between the base case and standards case each year. That difference is then multiplied by the standards case shipments for the year. The net present value for the period (1996-2030) is the sum over the years of the annual values. A positive net present value of standards results when the new units in the standards case have lower present value of life-cycle cost than do new units in the base case. Table 3.6 shows the NPV to consumers of the trial standards levels. Standards levels 1 through 3 show positive net present value and benefit/cost ratio greater than 1.

Table 3.6 Net Present Value for Direct Heating Equipment Purchased from 1996-2030
1990 (Billion 90\$ Discounted at 7%)²

	Trial Standard Level				
	1	2	3	4	5
Fuel costs savings:					
Electricity	0.001	0.004	0.006	-0.006	-0.036
Gas	0.023	0.256	0.490	0.772	1.228
Oil	0.000	0.000	0.000	-0.002	-0.006
TOTAL benefit (energy):	0.023	0.259	0.497	0.765	1.185
Equipment costs:					
Electric	0.000	0.000	0.000	0.000	0.000
Gas	0.014	0.197	0.384	1.023	2.116
Oil	0.000	0.000	0.000	0.000	0.000
TOTAL cost (equipment):	0.014	0.197	0.384	1.023	2.116
NET = benefit - cost:					
Electric	0.001	0.004	0.006	-0.006	-0.036
Gas	0.009	0.059	0.106	-0.251	-0.888
Oil	0.000	0.000	0.000	-0.002	-0.006
TOTAL net present value:	0.009	0.063	0.113	-0.259	-0.930
Ratio: Benefit/cost:	1.65	1.32	1.29	0.75	0.56

²Normalized to standards case shipments.

3.6 SENSITIVITY ANALYSIS

The base case and standards levels as described above constitute a reference case against which the impacts of standards under different assumptions may be compared. The sensitivity analysis is performed by running the LBL-REM for the base case and *trial standards level 3* for direct heating equipment. For each sensitivity case, the results for the trial standards level are compared to the corresponding base-case run and the differences are tabulated.

The assumptions in the sensitivity cases are described in Section 2.4 and listed in Table 3.7. Table 3.8 shows results for cumulative energy consumption. The sensitivity analysis of product shipments is given in Table 3.9. Table 3.10 shows the net present values. The first line of these tables gives the results of the reference case (base case, standards level, and difference). The rest of the lines each give the results corresponding to one of the sensitivity cases, including the base case, standards case, and difference. Note that the changes in the impact of standards as a function of the changed assumptions (difference between the base and standards cases) are the principal results of the sensitivity analysis.

Table 3.7 Sensitivity Analysis Cases

Case	Description
1	Lower Equipment Prices
2	Higher Equipment Prices
3	Lower Energy Price
4	Higher Energy Price
5	High Equipment Efficiency
6	Market Discount Rates Decline

Table 3.8 Cumulative Energy Consumption of Gas Room Heaters During the Period 1996-2030 (Quadrillion Btu, Primary)

	Trial Standard		
	Base	Level 3	Difference
Reference	5.35	5.17	0.18
1	5.26	5.11	0.15
2	5.40	5.25	0.15
3	5.57	5.36	0.21
4	5.14	4.99	0.15
5	4.34	4.21	0.13
6	5.29	5.12	0.17

Table 3.9 Cumulative Shipments of Gas Room Heaters During the Period 1996-2030 (Millions)

	Base	Trial Standard Level 3	Difference
Reference	11	11	0
1	11	11	0
2	11	12	0
3	12	12	0
4	11	11	0
5	10	10	0
6	11	11	0

Table 3.10 Total Net Present Value to Consumers for Units Sold During the Period 1996-2030 (Discounted to 1990 at 7% Real)

Case	Net Present Value (Billion 1990\$) Trial Standard Level 3
Reference	0.113
1	0.095
2	0.242
3	0.127
4	0.127
5	-0.146
6	0.080

Source: LBL-REM.

CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS

The effect of standards on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The net effect is analyzed by calculating the life-cycle cost, using the engineering data (Chapter 1) for energy consumption and equipment price, and assuming the energy price projected for 1996. Section 4.1 presents the life-cycle costs (LCC) for each design option. The results are displayed as graphs and as tables of values. Sections 4.2 through 4.4 show the impacts of standards on consumers. Section 4.5 presents the effect of different assumptions on the life-cycle cost calculations.

The *difference* due to standards is calculated (Sections 4.2 to 4.4) after a base case forecast is made (see Chapter 2). The base case forecast accounts for market-based shifts in efficiency and usage that are projected to occur independently of standards. Then only those appliance purchasers who are impacted by standards (i.e., those who would have chosen a design eliminated by standards) are included in calculating the impact of standards on consumers. The impact of standards is expressed by three measures:

- Section 4.2: Payback Period (PBP),
- Section 4.3: Change in Life-Cycle Cost (LCC), and
- Section 4.4: Cost of Conserved Energy (CCE).

4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS

The LCC is the sum of the purchase price (PC) and the operating expense (OC) discounted over the lifetime (N) of the appliance.

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

If operating expenses are constant over time, Eq. 1 simplifies to:

$$LCC = PC + PWF \cdot OC \quad (2)$$

where we have defined the present worth factor:

$$PWF = \sum_{t=1}^N \frac{1}{(1+r)^t} = \frac{1}{r} \left[1 - \frac{1}{(1+r)^N} \right] \quad (3)$$

The LCC is calculated for each class in the year standards are imposed, using a discount rate, r .

4.1.1 LCC Data Inputs

The purchase price is based on the factory costs in the Engineering Analysis (Chapter 1) and includes a factory markup plus distributor and retailer markups, calculated by LBL-MIM. Installation and maintenance costs are also from the Engineering Analysis. Purchase price and installation costs are added to the present value of operating expenses (including maintenance, if applicable), discounted, and summed over the life of the product. Expenses in future years are discounted to the year of purchase, 1996. For the residential sector, the discount rate is 6% real, with sensitivity analysis performed at 2% and 10% real.

The energy price is the projected 1996 average residential energy price times an end-use factor of 0.90 (electricity) or 0.98 (gas). (See discussions in Volume A, Section 5.1.5 of this Technical Support Document.)

4.1.2 LCC Results

Figures 4.1 through 4.16 show the LCCs by design option. The values used to produce these figures are presented in Tables 4.1 to 4.16.

Figure 4.1 Life-Cycle Cost for a Fan Wall Heater up to 42K Btuh

Table 4.1 Life-Cycle Costs of Fan Wall Heater up to 42K Btuh

Standard Design Level	Design No.	Design Option	Equip-			Annual Energy Use			Annual	Life-Cycle Costs		
			Install & Maint	Retail Price	ment Price	Gas (MMBtu)	Elec (kWh)	Energy Cost	4%	6%	10%	
1,2,3	0	Baseline	529.47	619.65	1149.12	72.2%	35.76	59.10	220.72	3609.49	3292.81	2818.66
4	1	0 + Electronic Ignition	554.97	698.98	1253.95	73.3%	34.34	65.40	212.70	3632.01	3319.74	2853.47
	2	1 + Vent Damper	564.97	774.58	1339.55	75.6%	33.33	63.50	206.45	3648.08	3344.61	2891.50
	3	2 + Increase HX Size	564.97	876.54	1441.51	77.5%	32.49	61.90	201.24	3692.19	3396.03	2953.89
	4	2 + Derate 20%	564.97	782.71	1347.68	75.4%	33.24	79.10	207.25	3665.11	3360.51	2905.72
5	5	1 + Burner Box Damper	590.51	778.32	1368.83	76.3%	33.01	62.90	204.46	3662.78	3354.64	2894.71
	6	1 + Induced/Forced Draft	612.06	980.14	1592.20	76.3%	32.55	102.70	205.12	3899.40	3584.36	3114.80
	7	6 + Condense Flue Gases	761.10	1216.10	1977.20	89.2%	27.83	87.80	175.37	3961.44	3680.47	3261.40
	8	7 + Two-Stage Operation	783.09	1421.66	2204.75	87.8%	27.23	169.80	178.82	4232.55	3941.46	3507.82
	9	7 + Modulating Operation	805.07	1788.51	2593.58	87.0%	26.68	217.50	179.61	4635.45	4337.98	3895.35

Notes: This class represents 0.7% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.2 Life-Cycle Cost for a Fan Wall Heater over 42K Btuh

Table 4.2 Life-Cycle Costs of Fan Wall Heater over 42K Btuh

Standard Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1,2,3	0	Baseline	529.47	691.74	1221.21	73.4%	48.41	59.70	297.05	4530.25	4106.24	3471.33
	1	0 + Vent Damper	539.47	766.97	1306.44	75.6%	47.02	57.90	288.51	4520.57	4108.56	3491.63
	2	1 + Electronic Ignition	564.97	827.50	1392.47	76.4%	45.64	63.20	280.65	4526.01	4118.20	3508.81
4	3	2 + Increase HX Size	564.97	956.00	1520.97	78.4%	44.49	61.60	273.58	4575.88	4178.01	3583.52
	4	2 + Derate 20%	564.97	833.51	1398.48	76.3%	45.53	78.90	281.34	4539.68	4130.90	3520.06
	5	0 + Burner Box Damper	565.01	816.94	1381.95	75.5%	47.05	57.90	288.69	4605.54	4185.82	3557.51
	6	0 + Electronic Ignition	554.97	772.42	1327.39	74.2%	47.00	65.10	289.01	4553.93	4134.36	3507.35
5	7	6 + Induced/Forced Draft	612.06	1060.92	1672.98	76.8%	44.97	103.20	280.05	4813.34	4392.92	3765.54
	8	7 + Condense Flue Gases	761.10	1318.19	2079.29	89.9%	38.43	88.20	239.33	4774.57	4403.68	3849.91
	9	8 + Two-Stage Operation	783.09	1526.75	2309.84	89.1%	37.68	170.90	241.92	5039.29	4659.47	4092.91
	10	8 + Modulating Operation	905.07	1898.24	2703.31	88.7%	37.06	219.70	242.39	5443.20	5057.45	4482.99

Notes: This class represents 8.1% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.3 Life-Cycle Cost for a Floor Heater up to 37K Btuh

Table 4.3 Life-Cycle Costs of Floor Heater up to 37K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE*	Annual Energy Use			Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)	Annual Energy Cost	4%	6%	10%
	0	Baseline	734.47	603.36	1337.83	56.0%	26.87	0.00	162.02	3145.60	2911.45	2560.93
1	1	0 + Derate 20%	734.47	653.92	1388.39	61.3%	24.53	0.00	147.91	3039.28	2824.97	2504.17
2	2	1 + Electronic Ignition	759.97	685.06	1445.03	62.7%	23.05	15.60	140.33	3018.49	2807.98	2494.12
3	3	2 + Burner Box Damper	795.51	769.27	1564.78	70.7%	20.45	13.80	124.50	2969.66	2773.96	2482.44
	4	0 + Increase HX Size	734.47	745.40	1479.87	59.0%	25.59	0.00	154.31	3201.83	2978.53	2644.26
	5	2 + Vent Damper	769.97	750.17	1520.14	65.1%	22.22	15.00	135.28	3037.38	2833.98	2530.77
	6	0 + Electronic Ignition	759.97	661.63	1421.60	57.5%	25.16	13.60	152.88	3134.61	2906.45	2566.16
	7	6 + Induced Draft	817.06	779.42	1596.48	64.8%	21.91	48.40	136.28	3138.35	2920.10	2595.52
4	8	7 + Induced Draft Redesign	817.06	1148.73	1965.79	75.8%	18.33	77.10	117.17	3295.13	3103.75	2819.44
	9	8 + Increase Insulation	817.06	1188.52	2005.58	76.7%	18.10	76.20	115.70	3318.64	3129.32	2848.09
5	10	9 + Condense Flue Gases	966.10	1465.52	2431.62	88.6%	15.69	66.00	100.29	3581.09	3405.69	3144.75
	11	10 + Two-Stage Operation	988.09	1673.09	2661.18	86.3%	15.31	127.30	103.28	3849.13	3664.26	3389.71
	12	10 + Modulating Operation	1010.07	2097.43	3107.50	85.2%	14.94	162.40	104.07	4309.53	4118.28	3834.74

Notes: This class represents 4.7% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.4 Life-Cycle Cost for a Floor Heater over 37K Btuh

Table 4.4 Life-Cycle Costs of Floor Heater over 37K Btuh

Standard Design Level	No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	AE*	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
	0	Baseline	734.47	693.41	1427.88	57.0%	58.01	0.00	349.80	5323.38	4825.20	4079.19
	1	0 + Derate 20%	734.47	747.79	1482.26	62.3%	52.99	0.00	319.53	5041.20	4585.58	3903.33
1	2	1 + Burner Box Damper	770.01	838.03	1608.04	69.3%	47.76	0.00	287.99	4823.80	4405.07	3778.24
2,3	3	2 + Electronic Ignition	795.51	856.01	1651.52	70.0%	46.28	14.40	280.31	4788.70	4373.92	3754.25
	4	0 + Increase HX Size	734.47	835.59	1570.06	60.0%	55.21	0.00	332.91	5277.84	4803.40	4092.95
	5	1 + Vent Damper	744.47	914.40	1658.87	64.7%	51.14	0.00	308.37	5093.78	4653.85	3995.09
	6	0 + Induced Draft	791.56	881.81	1673.37	64.6%	50.83	45.50	310.42	5144.50	4688.24	4005.93
	7	6 + Induced Draft Redesign	791.56	1194.84	1986.40	77.1%	42.58	73.40	263.08	4931.14	4541.45	3958.85
	8	7 + Electronic Ignition	817.06	1236.82	2053.88	77.8%	40.89	79.40	253.40	4897.92	4514.98	3943.73
4	9	8 + Increase Insulation	817.06	1270.46	2087.52	78.8%	40.38	78.40	250.24	4896.41	4517.91	3953.32
5	10	9 + Condense Flue Gases	966.10	1624.83	2590.93	90.0%	35.34	68.60	219.01	5060.28	4717.96	4206.99
	11	10 + Two-Stage Operation	988.09	1862.14	2850.23	89.6%	34.68	133.00	220.57	5342.26	4992.47	4470.88
	12	10 + Modulating Operation	1010.07	2151.79	3161.86	89.3%	34.15	171.30	220.67	5660.31	5305.10	4775.98

Notes: This class represents 1.3% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.5 Life-Cycle Cost for a Gravity Wall Heater up to 10K Btuh

Table 4.5 Life-Cycle Costs of Gravity Wall Heater up to 10K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1,2	0	Baseline	529.47	370.37	899.84	59.0%	9.14	0.00	55.11	1518.94	1435.12	1309.77
	1	0 + Electronic Ignition	554.97	421.49	976.46	63.5%	7.50	12.20	46.28	1504.15	1425.90	1310.14
3,4	2	1 + Derate 20%	554.97	448.21	1003.18	67.7%	7.00	14.20	43.43	1499.26	1425.01	1315.24
	3	2 + Burner Box Damper	590.51	520.27	1110.78	72.7%	6.53	13.20	40.51	1581.84	1504.24	1389.62
	4	1 + Increase HX Size	554.97	611.27	1166.24	66.5%	7.17	11.60	44.23	1741.75	1652.93	1522.23
	5	2 + Vent Damper	564.97	509.03	1074.00	70.3%	6.75	13.70	41.88	2140.90	2047.64	1909.71
5	6	1 + Induced/Forced Draft	612.06	787.94	1400.00	74.5%	6.05	40.10	39.93	2340.94	2245.15	2104.01
	7	6 + Condense Flue Gases	761.10	879.77	1640.87	81.0%	5.57	36.90	36.76	2084.00	1997.93	1870.79
	8	7 + Two-Stage Operation	783.09	1074.21	1857.30	77.5%	5.39	70.50	38.57	2325.80	2231.92	2093.65
	9	7 + Modulating Operation	805.07	3296.48	4101.55	75.8%	5.20	88.90	39.01	4580.21	4480.44	4333.93

Notes: This class represents 1.0% of the direct heating equipment sold in 1989
Average life time for all direct heating equipment is 15 years
All costs are in 1990 dollars.
Electricity rate is 8.61 cent/kWh (1996)
Gas rate is 6.030 \$/MMBtu (1996)
Equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.6 Life-Cycle Cost for a Gravity Wall Heater 10K to 12K Btuh

Table 4.6 Life-Cycle Costs of Gravity Wall Heater 10K to 12K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use			Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)	Annual Energy Cost	4%	6%	10%
1,2	0	Baseline	529.47	370.24	899.71	60.0%	12.82	0.00	77.30	1765.53	1650.51	1478.42
	1	0 + Derate 20%	529.47	402.13	931.60	64.1%	11.89	0.00	71.70	1735.07	1627.93	1467.65
3	2	1 + Electronic Ignition	554.97	434.51	989.48	67.7%	10.56	17.80	65.21	1727.68	1622.81	1467.17
4	3	2 + Burner Box Damper	590.51	514.87	1105.38	72.9%	9.80	16.50	60.51	1798.84	1693.11	1536.36
5	4	0 + Increase HX Size	529.47	554.71	1084.18	63.0%	12.30	0.00	74.17	1915.13	1804.52	1639.04
	5	2 + Vent Damper	564.97	495.52	1060.49	70.2%	10.18	17.20	62.87	1772.64	1671.06	1520.36
6	6	0 + Electronic Ignition	554.97	419.95	974.92	63.8%	11.25	15.20	69.15	1756.89	1646.48	1482.55
	7	6 + Induced/Forced Draft	612.06	759.75	1371.81	75.1%	9.12	50.30	59.32	2058.02	1947.98	1785.49
7	8	7 + Condense Flue Gases	761.10	844.37	1605.47	81.7%	8.38	46.20	54.51	2245.89	2134.88	1970.36
	9	8 + Two-Stage Operation	783.09	1028.55	1811.64	78.9%	8.14	88.70	56.72	2481.93	2362.53	2186.04
10	10	8 + Modulating Operation	805.07	3103.32	3908.39	77.5%	7.88	112.40	57.19	4589.22	4463.89	4279.08

Notes: This class represents 1.0% of the direct heating equipment sold in 1989
Average life time for all direct heating equipment is 15 years
All costs are in 1990 dollars.
Electricity rate is 8.61 cent/kWh (1996)
Gas rate is 6.030 \$/MMBtu (1996)
Equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.7 Life-Cycle Cost for a Gravity Wall Heater 12K to 15K Btuh

Table 4.7 Life-Cycle Costs of Gravity Wall Heater 12K to 15K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
	0	Baseline	529.47	370.77	900.24	61.0%	12.80	0.00	77.18	1764.72	1649.87	1478.03
1,2	1	0 + Derate 20%	529.47	392.72	922.19	64.9%	11.94	0.00	72.00	1729.01	1621.45	1460.54
3	2	1 + Electronic Ignition	554.97	425.35	980.32	67.9%	10.54	15.30	64.87	1714.79	1610.38	1455.45
4	3	2 + Burner Box Damper	590.51	498.79	1089.30	73.2%	9.79	14.20	60.26	1779.88	1674.52	1518.31
	4	0 + Increase HX Size	529.47	448.71	978.18	64.0%	12.28	0.00	74.05	1807.79	1697.35	1532.12
	5	2 + Vent Damper	564.97	581.74	1146.71	70.5%	10.17	14.70	62.59	1855.80	1754.60	1604.48
	6	0 + Electronic Ignition	554.97	416.15	971.12	64.2%	11.19	12.90	68.59	1746.87	1637.24	1474.49
	7	6 + Induced/Forced Draft	612.06	735.93	1347.99	75.5%	9.15	43.30	58.90	2029.51	1920.06	1758.46
5	8	7 + Condense Flue Gases	761.10	833.16	1594.26	82.1%	8.41	39.80	54.14	2230.57	2120.07	1956.33
	9	8 + Two-Stage Operation	783.09	1053.37	1836.46	79.8%	8.18	76.50	55.91	2497.75	2379.49	2204.70
10	10	8 + Modulating Operation	805.07	3038.03	3843.10	78.6%	7.95	97.20	56.31	4514.07	4389.98	4207.04

Notes: This class represents 1.0% of the direct heating equipment sold in 1989
Average life time for all direct heating equipment is 15 years
All costs are in 1990 dollars.
Electricity rate is 8.61 cent/kWh (1996)
Gas rate is 6.030 \$/MMBtu (1996)
Equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.8 Life-Cycle Cost for a Gravity Wall Heater 15K to 19K Btuh

Table 4.8 Life-Cycle Costs of Gravity Wall Heater 15K to 19K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1,2	0	Baseline	529.47	371.75	901.22	62.0%	16.54	0.00	99.74	2016.44	1869.88	1650.54
	1	0 + Derate 20%	529.47	399.40	928.87	65.9%	15.46	0.00	93.22	1971.68	1834.28	1628.66
3	2	1 + Electronic Ignition	554.97	425.59	980.56	68.2%	14.07	15.00	86.13	1951.40	1817.11	1617.40
	3	2 + Burner Box Damper	590.51	483.09	1073.60	73.4%	13.08	13.90	80.07	1984.47	1851.24	1653.31
4	4	0 + Increase HX Size	529.47	573.39	1102.86	65.0%	15.85	0.00	95.57	2171.82	2031.11	1820.54
	5	2 + Vent Damper	564.97	474.31	1039.28	70.7%	13.56	14.50	83.01	1975.45	1845.54	1652.40
6	6	0 + Electronic Ignition	554.97	412.87	967.84	64.4%	14.94	12.70	91.18	1994.81	1853.41	1643.07
	7	6 + Induced/Forced Draft	612.06	710.27	1322.33	76.2%	12.26	42.70	77.60	2211.78	2076.04	1875.05
5	8	7 + Condense Flue Gases	761.10	840.53	1601.63	82.9%	11.26	39.20	71.27	2428.43	2293.85	2094.02
	9	8 + Two-Stage Operation	783.09	1003.87	1786.96	81.4%	10.99	75.70	72.79	2635.88	2493.89	2283.56
	10	8 + Modulating Operation	805.07	2929.76	3734.83	80.6%	10.74	96.70	73.09	4592.38	4444.69	4226.41

Notes: This class represents 1.0% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.9 Life-Cycle Cost for a Gravity Wall Heater 19K to 27K Btuh

Table 4.9 Life-Cycle Costs of Gravity Wall Heater 19K to 27K Btuh

Standard Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cy. Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
	0	Baseline	529.47	371.91	901.38	63.0%	23.87	0.00	143.93	2508.02	2299.31	1986.89
1	1	0 + Derate 20%	529.47	405.56	935.03	66.8%	22.41	0.00	135.13	2443.79	2247.46	1953.58
2	2	1 + Electronic Ignition	554.97	424.87	979.84	68.5%	21.08	17.10	128.58	2422.66	2228.68	1939.56
3	3	2 + Burner Box Damper	590.51	475.87	1066.38	73.6%	19.60	15.90	119.56	2416.28	2227.53	1946.43
	4	0 + Increase HX Size	529.47	809.24	1338.71	66.0%	22.86	0.00	137.84	2877.64	2677.49	2377.89
	5	2 + Vent Damper	564.97	466.52	1031.49	71.0%	20.32	16.50	123.95	2422.79	2235.32	1955.96
	6	0 + Electronic Ignition	554.97	408.85	963.82	64.8%	22.31	14.50	135.78	2486.62	2282.52	1978.25
4	7	6 + Induced/Forced Draft	612.06	698.49	1310.55	76.5%	18.47	48.90	115.58	2622.27	2433.13	2152.15
5	8	7 + Condense Flue Gases	761.10	819.67	1580.77	83.3%	16.96	44.90	106.13	2795.18	2611.57	2338.32
	9	8 + Two-Stage Operation	783.09	971.60	1754.69	82.5%	16.59	86.80	107.51	2989.68	2798.86	2515.40
	10	8 + Modulating Operation	805.07	1242.62	2047.69	82.0%	16.27	111.30	107.69	3289.96	3093.62	2802.46

Notes: This class represents 13.6% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.10 Life-Cycle Cost for a Gravity Wall Heater 27K to 46K Btuh

Table 4.10 Life-Cycle Costs of Gravity Wall Heater 27K to 46K Btuh

Standard Design Level	Design Option No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use			Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)	Annual Energy Cost	4%	6%	10%
	0	Baseline										
1	1	0 + Derate 20%	529.47	394.05	923.52	64.0%	31.88	0.00	192.23	3067.18	2790.55	2376.40
2	2	1 + Electronic Ignition	529.47	418.98	948.45	67.5%	30.10	0.00	181.50	2972.77	2711.24	2319.69
3	3	2 + Burner Box Damper	554.97	442.15	997.12	68.7%	28.77	16.60	174.91	2955.03	2695.90	2309.21
	4	0 + Increase HX Size	529.47	504.35	1094.86	73.9%	26.76	15.50	162.70	2924.41	2675.00	2303.04
	5	2 + Vent Damper	564.97	549.51	1078.98	67.0%	30.53	0.00	184.09	3132.13	2866.95	2469.94
	6	0 + Electronic Ignition	554.97	485.71	1050.68	71.3%	27.74	16.00	168.65	2938.96	2688.64	2315.14
4	7	6 + Ind/For Draft Redesign	612.06	430.64	985.61	65.3%	30.33	14.00	184.09	3045.62	2773.57	2367.55
5	8	7 + Condense Flue Gases	761.10	853.37	1614.47	83.8%	23.25	47.90	156.80	3096.07	2848.97	2481.17
	9	8 + Two-Stage Operation	783.09	1008.67	1791.76	83.5%	22.79	44.00	143.99	3249.72	3012.89	2659.92
	10	8 + Modulating Operation	805.07	1285.65	2090.72	83.3%	22.42	85.20	144.76	3440.89	3197.69	2835.78
								109.60	144.63	3743.68	3495.40	3126.44

Notes: This class represents 21.9% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.11 Life-Cycle Cost for a Gravity Wall Heater over 46K Btuh

Table 4.11 Life-Cycle Costs of Gravity Wall Heater over 46K Btuh

Standard Design Level	Design Option	Equip-				Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
		Install & Maint	Retail Price	ment Price	AE'	Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1	0 Baseline	529.47	515.33	1044.80	65.0%	45.58	0.00	274.84	4106.95	3714.16	3126.02
	1 0 + Derate 20%	529.47	542.64	1072.11	68.2%	43.33	0.00	261.28	3983.42	3609.70	3050.14
2	2 1 + Vent Damper	539.47	590.23	1129.70	70.7%	41.82	0.00	252.17	3939.77	3578.86	3038.47
	3 2 + Electronic Ignition	564.97	609.75	1174.72	71.6%	40.52	16.40	245.75	3920.19	3561.46	3025.58
3	4 0 + Increase HX Size	529.47	686.85	1216.32	68.0%	43.65	0.00	263.21	4149.08	3772.65	3209.02
	5 1 + Electronic Ignition	554.97	563.29	1118.26	69.0%	42.02	17.00	254.84	3975.51	3593.35	3046.37
4	6 5 + Burner Box Damper	590.51	658.00	1248.51	74.2%	39.08	15.80	237.01	3861.33	3550.41	2997.40
	7 0 + Electronic Ignition	554.97	552.49	1107.46	65.9%	44.05	14.30	266.85	4158.11	3699.18	3156.69
5	8 7 + Induced/Forced Draft	612.06	784.48	1396.54	73.4%	39.11	51.80	240.29	4083.45	3730.31	3186.87
	9 8 + Ind/For Draft Redesign	612.06	919.85	1531.91	77.3%	37.12	49.10	228.06	4094.18	3746.88	3229.01
12	10 9 + Condense Flue Gases	761.10	1105.86	1866.96	84.2%	34.08	45.10	209.38	4229.34	3900.55	3409.84
	11 10 + Two-Stage Operation	783.09	1241.71	2024.80	84.4%	33.45	87.50	209.24	4390.81	4056.95	3559.24
	12 10 + Modulating Operation	805.07	3334.21	4139.28	84.4%	33.00	112.90	208.71	6504.72	6166.33	5662.40

Notes: This class represents 16.8% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.12 Life-Cycle Cost for a Room Heater up to 18K Btuh

Table 4.12 Life-Cycle Costs of Room Heater up to 18K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1	0	Baseline	414.47	242.40	656.87	57.0%	13.41	0.00	80.86	1562.24	1442.22	1262.64
	1	0 + Derate 20%	414.47	263.50	677.97	62.3%	12.23	0.00	73.75	1504.23	1394.21	1229.62
	2,3	1 + Electronic Ignition	439.97	281.63	721.60	64.4%	11.14	15.00	68.47	1496.00	1386.55	1224.06
4	3	2 + Vent Damper	449.97	314.96	764.93	66.8%	10.74	14.50	66.01	1512.04	1406.04	1248.71
	4	0 + Increase HK Size	414.47	315.11	729.58	60.0%	12.81	0.00	77.24	1594.73	1479.79	1307.83
	5	2 + Burner Box Damper	475.51	333.58	809.09	69.3%	10.35	14.00	63.62	1537.03	1426.94	1263.66
5	6	0 + Electronic Ignition	439.97	270.69	710.66	59.2%	12.15	13.10	74.39	1550.96	1433.17	1258.20
	7	6 + Induced Draft	497.06	331.69	828.75	65.7%	10.54	46.50	67.56	1606.52	1484.90	1305.07
	8	7 + Induced Draft Redesign	497.06	521.52	1018.58	73.7%	9.01	75.80	60.86	1721.83	1609.64	1443.92
	9	8 + Condense Flue Gases	646.10	609.25	1255.35	85.9%	7.73	65.00	52.21	1870.19	1762.41	1602.74
	10	9 + Two-Stage Operation	668.09	729.15	1397.24	80.9%	7.47	124.10	55.73	2056.51	1938.50	1764.10
	11	9 + Modulating Operation	690.07	942.55	1632.62	78.6%	7.17	155.80	56.65	2307.41	2182.83	1999.17

Notes: This class represents 0.1% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.13 Life-Cycle Cost for a Room Heater 18K to 20K Btuh

Table 4.13 Life-Cycle Costs of Room Heater 18K to 20K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	Annual Energy Use AE' (MMBtu)	Gas (MMBtu)	Elec (kWh)	Annual Energy Cost	Life-Cycle Costs		
										4%	6%	10%
	0	Baseline	414.47	242.59	657.06	58.0%	17.38	0.00	104.80	1828.59	1674.91	1444.91
	1	0 + Derate 20%	414.47	264.18	678.65	63.4%	15.86	0.00	95.63	1748.28	1607.48	1396.79
1	2	1 + Electronic Ignition	439.97	280.46	720.43	65.0%	14.78	15.00	90.41	1738.87	1598.56	1389.83
2	3	2 + Vent Damper	449.97	311.09	761.06	67.4%	14.24	14.40	87.11	1742.72	1607.06	1405.30
	4	0 + Increase HX Size	414.47	311.72	726.19	61.0%	16.59	0.00	100.04	1844.76	1697.77	1477.81
3	5	2 + Burner Box Damper	475.51	325.19	800.70	69.9%	13.74	13.90	84.05	1755.82	1617.00	1410.68
	6	0 + Electronic Ignition	439.97	270.04	710.01	59.7%	16.13	13.10	98.39	1817.14	1665.61	1440.08
	7	6 + Induced Draft	497.06	325.59	822.65	66.5%	14.06	46.50	88.79	1836.42	1684.95	1460.41
4	8	7 + Induced Draft Redesign	497.06	503.69	1000.75	74.8%	12.11	76.40	79.60	1912.41	1773.86	1568.66
5	9	8 + Condense Flue Gases	646.10	621.02	1267.12	87.3%	10.38	65.50	68.23	2060.11	1929.80	1736.38
	10	9 + Two-Stage Operation	668.09	720.25	1388.34	83.6%	10.08	125.60	71.60	2224.03	2083.71	1875.88
	11	9 + Modulating Operation	690.07	904.69	1594.76	81.7%	9.75	159.00	72.48	2445.58	2298.74	2081.74

Notes: This class represents 0.1% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.14 Life-Cycle Cost for a Room Heater 20K to 27K Btuh

Table 4.14 Life-Cycle Costs of Room Heater 20K to 27K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1,2,3	0	Baseline	414.50	416.11	830.58	63.0%	23.67	0.00	142.73	2423.82	2216.80	1906.91
	1	0 + Derate 20%	414.50	455.92	870.39	67.1%	22.14	0.00	133.50	2361.05	2167.01	1876.55
	2	1 + Electronic Ignition	440.00	477.47	917.44	68.3%	21.13	17.10	128.89	2363.62	2169.21	1879.46
	3	2 + Vent Damper	450.00	525.79	975.76	70.9%	20.37	16.50	124.25	2370.41	2182.51	1902.53
	4	0 + Increase HX Size	414.50	528.80	943.27	66.0%	22.66	0.00	136.64	2468.79	2270.34	1973.28
	5	2 + Burner Box Damper	475.50	556.41	1031.92	73.4%	19.66	15.90	119.92	2385.85	2196.59	1914.73
	6	0 + Electronic Ignition	440.00	457.96	897.93	64.3%	22.49	14.60	136.87	2432.89	2227.25	1920.68
	7	6 + Induced Draft	497.10	549.15	1046.21	71.3%	19.83	52.50	124.09	2452.56	2251.44	1952.54
	8	7 + Air Circulation Fan	497.10	658.28	1155.34	74.9%	18.38	92.80	118.82	2503.06	2309.36	2021.56
4	9	8 + Condense Flue Gases	646.10	862.23	1508.33	88.1%	15.63	78.90	101.04	2666.12	2489.68	2227.15
	10	9 + Two-Stage Operation	668.10	1034.56	1702.65	85.2%	15.23	151.90	104.92	2908.79	2721.62	2443.62
	11	9 + Modulating Operation	690.10	1357.90	2047.97	83.8%	14.81	193.10	105.93	3270.68	3076.81	2789.35

Notes: This class represents 0.9% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.15 Life-Cycle Cost for a Room Heater 27K to 46K Btuh

Table 4.15 Life-Cycle Costs Room Heater 27K to 46K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	AE'	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
1	0	Baseline	414.47	398.92	813.39	64.0%	31.68	0.00	191.03	2943.64	2668.71	2257.10
	1	0 + Derate 20%	414.47	438.45	852.92	67.8%	29.83	0.00	179.87	2859.14	2599.90	2211.78
	2	1 + Vent Damper	424.47	482.46	906.93	70.3%	28.79	0.00	173.60	2843.43	2593.00	2218.09
2,3	3	2 + Electronic Ignition	449.97	498.18	948.15	71.2%	27.79	16.10	168.96	2839.88	2589.12	2214.97
	4	0 + Increase HX Size	414.47	500.09	914.56	67.0%	30.32	0.00	182.83	2953.63	2690.23	2295.89
	5	1 + Burner Box Damper	450.01	501.33	951.34	71.6%	28.27	0.00	170.47	2860.43	2606.95	2227.65
4	6	0 + Electronic Ignition	439.97	421.37	861.34	64.9%	30.50	14.10	185.13	2932.84	2659.34	2251.14
	7	6 + Induced Draft	497.06	515.67	1012.73	72.2%	26.99	51.10	167.15	2897.77	2636.11	2246.53
	8	7 + Air Circulation Fan	497.06	615.20	1112.26	76.2%	25.09	90.50	159.08	2907.64	2657.32	2284.72
5	9	8 + Condense Flue Gases	646.10	819.48	1465.58	88.9%	21.49	77.50	136.26	3014.91	2788.94	2452.25
	10	9 + Two-Stage Operation	668.09	976.15	1644.24	87.2%	21.00	149.60	139.51	3235.02	2999.20	2648.34
	11	9 + Modulating Operation	690.07	1256.21	1946.28	86.2%	20.54	191.40	140.34	3551.52	3309.27	2949.35

Notes: This class represents 4.6% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

Figure 4.16 Life-Cycle Cost for a Room Heater over 46K Btuh

Table 4.16 Life-Cycle Costs of Room Heater over 46K Btuh

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equipment Price	Annual Energy Use AE' (MMBtu)	Gas (MMBtu)	Elec (kWh)	Annual Energy Cost	Life-Cycle Costs		
										4%	6%	10%
1	0	Baseline	414.47	637.92	1052.39	65.0%	45.48	0.00	274.24	4107.84	3715.90	3129.02
	1	0 + Derate 20%	414.47	705.85	1120.32	68.3%	43.20	0.00	260.49	4022.91	3650.30	3092.38
	2	1 + Vent Damper	424.47	757.33	1181.80	70.8%	41.68	0.00	251.33	3982.48	3622.76	3084.15
2,3	3	2 + Electronic Ignition	449.97	769.97	1219.94	71.5%	40.54	16.40	245.87	3966.75	3607.85	3071.72
	4	0 + Increase HX Size	414.47	766.89	1181.36	68.0%	43.54	0.00	262.54	4106.74	3731.25	3169.02
	5	1 + Burner Box Damper	450.01	774.73	1224.74	72.3%	40.79	0.00	245.96	3973.21	3613.58	3075.27
4	6	0 + Induced/Forced Draft	471.56	762.16	1233.72	72.4%	40.42	47.10	247.79	4008.46	3640.28	3089.88
	7	6 + Electronic Ignition	497.06	786.39	1283.45	73.2%	39.18	51.90	240.72	3986.51	3621.40	3076.86
	8	7 + Air Circulation Fan	497.06	918.90	1415.96	77.5%	36.52	92.20	228.15	3979.27	3631.84	3113.77
5	9	8 + Condense Flue Gases	646.10	1252.67	1898.77	89.7%	31.58	79.70	197.29	4126.67	3814.88	3349.65
	10	9 + Two-Stage Operation	668.09	1478.30	2146.39	88.7%	30.94	154.30	199.85	4408.08	4087.41	3609.46
	11	9 + Modulating Operation	690.07	1808.87	2498.94	88.2%	30.40	198.20	200.38	4771.73	4445.06	3958.69

Notes: This class represents 22.8% of the direct heating equipment sold in 1989; average life time for all direct heating equipment is 15 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 6.030 \$/MMBtu (1996); equipment prices include installation costs and maintenance costs (present value at 6% real discount rate).

4.2 PAYBACK PERIODS BY STANDARD LEVEL

The payback period (PBP) measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. PBP is found by solving the equation:

$$\Delta PC + \sum_{i=1}^{PAY} \Delta OC_i = 0 \quad (4)$$

for *PAY*. In general, *PAY* is found by interpolating between the two years when the expression in Eq. 4 changes sign. If the operating cost is constant, the equation has the simple solution:

$$PAY = -\frac{\Delta PC}{\Delta OC} \quad (5)$$

Numerically, the PBP is the ratio of the increase in purchase (and installation) price from the base to the standards cases to the decrease in annual operating expenditures (including maintenance). PBPs are expressed in years. A PBP of three years means that the increased purchase price is equal to three times the value of reduced operating expenses achieved in the year of purchase, or that the increased purchase price is recovered in approximately three years because of lower operating expenses. PBPs greater than the life of the product mean that the increased purchase price is not recovered in reduced operating expenses.

4.2.1 PBP Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standards level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.2.2 PBP Results

The PBPs by standards level shown in Tables 4.17 through 4.33 are the weighted-averages. They compare that portion of the projected distribution of designs in the base case that are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts.

Tables 4.17 through 4.33 show the calculation of LCC differences, payback, and CCE. The tables are composed of several parts: (a) summarizes the equipment cost, operating cost, LCC, and energy use for each design option, (b) shows the distribution of units sold in 1996, according to the base case forecast. In the other columns, part of this distribution is expressed as the percent of eliminated units due to standards. That is, if 78% of units sold in the base case correspond to design 0, and standards level 1 (equivalent to design 1) eliminates only design 0, then the fraction of eliminated units due to standard level 1 is 100% for design 0.

Table (c) applies the weights in Table (b) to the values in Table (a) to obtain the weighted-average values shown. Table (d) shows the resulting LCC differences, PBPs, and CCE.

4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS

The impact of standards is calculated as the difference in LCC, base case minus standards case. If the LCC difference is greater than zero (positive savings), the standard provides a net decrease in expenses to the consumer. That is, the present value of decreased operating expenses offsets the increased purchase price. Conversely, if the LCC difference is negative, the standard causes a net increase in expenses to the consumer.

4.3.1 Data Inputs for Change in LCC

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.3.2 Results for Change in LCC

Tables 4.17 through 4.32 show the LCC differences by standard level, one table for each class. The results are the weighted-average of LCC differences comparing that portion of the projected distribution of designs in the base case that are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts. These LCCs are calculated at a 6% discount rate; a higher discount rate (e.g., 10%) gives a smaller difference.

Tables 4.17.d to 4.32.d show higher LCC (negative LCC difference) for most standard levels for most classes. Lower LCC (positive LCC difference) is found:

for floor furnaces up to 37 kBtu, standards levels 1, 2, and 3,

for floor furnaces over 37 kBtu, standards levels 1 through 4,

for gravity wall heaters up to 10 kBtu, standards levels 3 and 4,

for gravity wall heaters 10 over 46 kBtu, standards levels 1, 2, and 3, and

for room heaters up to 27 kBtu, standards levels, 1, 2, and 3.

4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS

The CCE is the increase in purchase price amortized over the lifetime of the appliance at the consumer discount rate divided by the annual energy savings:

$$CCE = -\frac{CRF \cdot \Delta PC}{\Delta E}, \quad (6)$$

where the capital recovery factor $CRF = 1/PWF$ is used to annualize the capital costs. Note that although the CCE can be measured in cents per kWh, it does not depend on current or future energy prices. The consumer will benefit whenever the cost of conserved energy is less than the price of energy for that end use.

4.4.1 CCE Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.4.2 CCE Results

Tables 4.17 through 4.32 show the cost of conserved energy at site of the standards levels as compared to the base case. Note that the current (1990) and projected (1996) average residential electricity prices are 8.11 and 8.29 cents per kWh respectively (22). These are equivalent to 23.74 and 24.28 dollars per million Btu, respectively, where one kWh is taken as 3,412 Btu site energy. The residential price of natural gas was \$5.69 per million Btu in 1990 and is projected to be \$6.15 in 1996 (20).

Standard levels with CCEs less than projected (1996) costs of energy supply include:

for floor furnaces up to 37 kBtu, standards levels 1, 2, and 3,

for floor furnaces over 37 kBtu, standards levels 1 through 4,

for gravity wall heaters up to 10 kBtu, standards levels 3 and 4,

for gravity wall heaters 10 over 46 kBtu, standards levels 1, 2, and 3,
for room heaters up to 27 kBtu, standards levels, 1, 2, and 3, and

for room heaters 27 to over 46 kBtu, standards levels 1, 2, 3, and 4.

Standard levels with CCEs greater than the projected costs of energy supply include all others.

Table 4.17.a Cost and Energy-Use Summary, Fan Wall Heater up to 42 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	1149.12	220.72	3292.81	35.96
1	1253.95	212.70	3319.74	34.56
2	1339.55	206.45	3344.61	33.55
6	1592.20	205.12	3584.36	32.90
7	1977.20	175.37	3680.47	28.13

Table 4.17.b Distribution of Units Sold Below Standards, Fan Wall Heater up to 42 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	46.14%	<Standard>	<Standard>	<Standard>	49.74%	47.65%
1	46.63%				50.26%	48.15%
2	3.38%				<Standard>	3.49%
6	0.69%					0.71%
7	3.16%					<Standard>

Table 4.17.c Weighted-Averages of Units Sold Below Standards, Fan Wall Heater up to 42 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	NA	NA	NA	1201.81	1209.40
Operating Cost (1990 \$)	NA	NA	NA	216.69	216.25
Life-Cycle Cost (1990 \$)	NA	NA	NA	3306.35	3309.66
Energy Use (MMBtu/yr)	NA	NA	NA	35.26	35.18

Table 4.17.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Fan Wall Heater up to 42 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	NA	NA	NA	-38.3	-370.8
Payback	NA	NA	NA	13.5	18.8
CCE (\$/MMBtu)	NA	NA	NA	8.3	11.2

Table 4.18.a Cost and Energy Use Summary, Fan Wall Heater over 42 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	1221.21	297.05	4106.24	48.61
1	1306.44	288.51	4108.56	47.22
6	1327.39	289.01	4134.36	47.22
2	1392.47	280.65	4118.20	45.86
7	1672.98	280.05	4392.92	45.32
8	2079.29	239.33	4403.68	38.73

Table 4.18.b Distribution of Units Sold Below Standards, Fan Wall Heater over 42 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	65.66%	<Standard>	<Standard>	<Standard>	68.26%	65.66%
1	22.91%				23.82%	22.91%
6	7.62%				7.92%	7.62%
2	3.81%				<Standard>	3.81%
7	0.00%					0.00%
8	0.00%					<Standard>

Table 4.18.c Weighted-Averages of Units Sold Below Standards, Fan Wall Heater over 42 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	NA	NA	NA	1249.92	1255.35
Operating Cost (1990 \$)	NA	NA	NA	294.38	293.86
Life-Cycle Cost (1990 \$)	NA	NA	NA	4109.02	4109.37
Energy Use (MMBtu/yr)	NA	NA	NA	48.17	48.08

Table 4.18.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Fan Wall Heater over 42 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	NA	NA	NA	-9.2	-294.3
Payback	NA	NA	NA	10.4	15.1
CCE (\$/MMBtu)	NA	NA	NA	6.4	9.1

Table 4.19.a Cost and Energy-Use Summary, Floor Furnace up to 37 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	1337.83	162.02	2911.45	26.87
1	1388.39	147.91	2824.97	24.53
2	1445.03	140.33	2807.98	23.10
7	1596.48	136.28	2920.10	22.08
3	1564.78	124.50	2773.96	20.50
8	1965.79	117.17	3103.75	18.59
9	2005.58	115.70	3129.32	18.36
10	2431.62	100.29	3405.69	15.92

Table 4.19.b Distribution of Units Sold Below Standards, Floor Furnace up to 37 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	3.63%	100.00%	3.83%	3.63%	3.63%	3.63%
1	91.26%	<Standard>	96.17%	91.25%	91.25%	91.25%
2	5.12%		<Standard>	5.12%	5.12%	5.12%
7	0.00%			0.00%	0.00%	0.00%
3	0.00%			<Standard>	0.00%	0.00%
8	0.00%				<Standard>	0.00%
9	0.00%					0.00%
10	0.00%					<Standard>

Table 4.19.c Weighted-Averages of Units Sold Below Standards, Floor Furnace up to 37 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	1337.83	1386.46	1389.45	1389.46	1389.46
Operating Cost (1990 \$)	162.02	148.45	148.03	148.03	148.03
Life-Cycle Cost (1990 \$)	2911.45	2828.28	2827.24	2827.24	2827.24
Energy Use (MMBtu/yr)	26.87	24.62	24.54	24.54	24.54

Table 4.19.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Floor Furnace up to 37 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	86.5	20.3	53.3	-276.5	-578.4
Payback	3.6	7.2	7.4	18.7	21.8
CCE (\$/MMBtu)	2.2	4.0	4.5	10.0	12.4

Table 4.20.a Cost and Energy-Use Summary, Floor Furnace over 37 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	1427.88	349.80	4825.20	58.01
1	1482.26	319.53	4585.58	52.99
2	1608.04	287.99	4405.07	47.76
3	1651.52	280.31	4373.92	46.33
7	1986.40	263.08	4541.45	42.83
8	2053.88	253.40	4514.98	41.16
9	2087.52	250.24	4517.91	40.65
10	2590.93	219.01	4717.96	35.57

Table 4.20.b Distribution of Units Sold Below Standards, Floor Furnace over 37 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	8.05%	8.60%	8.05%	8.05%	8.05%	8.05%
1	85.59%	91.40%	85.59%	85.59%	85.59%	85.59%
2	6.36%	<Standard>	6.36%	6.36%	6.36%	6.36%
3	0.00%		<Standard>	<Standard>	0.00%	0.00%
7	0.00%				0.00%	0.00%
8	0.00%				0.00%	0.00%
9	0.00%				<Standard>	0.00%
10	0.00%					<Standard>

Table 4.20.c Weighted-Averages of Units Sold Below Standards, Floor Furnace over 37 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	1477.59	1485.88	1485.88	1485.88	1485.88
Operating Cost (1990 \$)	322.13	319.96	319.96	319.96	319.96
Life-Cycle Cost (1990 \$)	4606.18	4593.39	4593.39	4593.39	4593.39
Energy Use (MMBtu/yr)	53.42	53.06	53.06	53.06	53.06

Table 4.20.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Floor Furnace over 37 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	201.1	219.5	219.5	75.5	-124.6
Payback	3.8	4.2	4.2	8.6	10.9
CCE (\$/MMBtu)	2.4	2.5	2.5	5.0	6.5

Table 4.21.a Cost and Energy-Use Summary, Gravity Wall Heater up to 10 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	899.84	55.11	1435.12	9.14
1	976.46	46.28	1425.90	7.54
2	1003.18	43.43	1425.01	7.05
6	1400.00	39.93	2245.15	6.19
7	1640.87	36.76	1997.93	5.70

Table 4.21.b Distribution of Units Sold Below Standards, Gravity Wall Heater up to 10 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	0.00%	<Standard>	<Standard>	0.00%	0.00%	0.00%
1	100.00%			100.00%	100.00%	100.00%
2	0.00%			<Standard>	<Standard>	0.00%
6	0.00%					0.00%
7	0.00%					<Standard>

Table 4.21.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater up to 10 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	NA	NA	976.46	976.46	976.46
Operating Cost (1990 \$)	NA	NA	46.28	46.28	46.28
Life-Cycle Cost (1990 \$)	NA	NA	1425.90	1425.90	1425.90
Energy Use (MMBtu/yr)	NA	NA	7.54	7.54	7.54

Table 4.21.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater up to 10 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	NA	NA	0.9	0.9	-572.0
Payback	NA	NA	9.4	9.4	69.8
CCE (\$/MMBtu)	NA	NA	5.6	5.6	37.2

Table 4.22.a Cost and Energy-Use Summary, Gravity Wall Heater 10 to 12 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	899.71	77.30	1650.51	12.82
1	931.60	71.70	1627.93	11.89
6	974.92	69.15	1646.48	11.30
2	989.48	65.21	1622.81	10.62
3	1105.38	60.51	1693.11	9.86
7	1371.81	59.32	1947.98	9.29
8	1605.47	54.51	2134.88	8.54

Table 4.22.b Distribution of Units Sold Below Standards, Gravity Wall Heater 10 to 12 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	0.00%	100.00%	100.00%	0.00%	0.00%	0.00%
1	100.00%	<Standard>	<Standard>	100.00%	100.00%	100.00%
6	0.00%			0.00%	0.00%	0.00%
2	0.00%			<Standard>	0.00%	0.00%
3	0.00%				<Standard>	0.00%
7	0.00%					0.00%
8	0.00%					<Standard>

Table 4.22.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 10 to 12 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	899.71	899.71	931.60	931.60	931.60
Operating Cost (1990 \$)	77.30	77.30	71.70	71.70	71.70
Life-Cycle Cost (1990 \$)	1650.51	1650.51	1627.93	1627.93	1627.93
Energy Use (MMBtu/yr)	12.82	12.82	11.89	11.89	11.89

Table 4.22.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), And Costs of Conserved Energy (at 6% real) Gravity Wall Heater 10 to 12 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	22.6	22.6	5.1	-65.2	-506.9
Payback	5.7	5.7	8.9	15.5	39.2
CCE (\$/MMBtu)	3.5	3.5	4.7	8.8	20.7

Table 4.23.a Cost and Energy-Use Summary, Gravity Wall Heater 12 to 15 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	900.24	77.18	1649.87	12.80
1	922.19	72.00	1621.45	11.94
6	971.12	68.59	1637.24	11.23
2	980.32	64.87	1610.38	10.59
3	1089.30	60.26	1674.52	9.84
7	1347.99	58.90	1920.06	9.30
8	1594.26	54.14	2120.07	8.55

Table 4.23.b Distribution of Units Sold Below Standards, Gravity Wall Heater 12 to 15 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	9.42%	100.00%	100.00%	9.42%	9.42%	9.42%
1	80.50%	<Standard>	<Standard>	80.50%	80.50%	80.50%
6	10.08%			10.08%	10.08%	10.08%
2	0.00%			<Standard>	0.00%	0.00%
3	0.00%				<Standard>	0.00%
7	0.00%					0.00%
8	0.00%					<Standard>

Table 4.23.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 12 to 15 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	900.24	900.24	925.05	925.05	925.06
Operating Cost (1990 \$)	77.18	77.18	72.14	72.14	72.14
Life-Cycle Cost (1990 \$)	1649.87	1649.87	1625.72	1625.72	1625.72
Energy Use (MMBtu/yr)	12.80	12.80	11.95	11.95	11.95

Table 4.23.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 12 to 15 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	28.4	28.4	15.3	-48.8	-494.4
Payback	4.2	4.2	7.6	13.8	37.2
CCE (\$/MMBtu)	2.6	2.6	4.2	8.0	20.3

Table 4.24.a Cost and Energy-Use Summary, Gravity Wall Heater 15 to 19 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	901.22	99.74	1869.88	16.54
1	928.87	93.22	1834.28	15.46
6	967.84	91.18	1853.41	14.98
2	980.56	86.13	1817.11	14.12
7	1322.33	77.60	2076.04	12.41
8	1601.63	71.27	2293.85	11.39

Table 4.24.b Distribution of Units Sold Below Standards, Gravity Wall Heater 15 to 19 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	0.00%	100.00%	100.00%	0.00%	0.00%	0.00%
1	100.00%	<Standard>	<Standard>	100.00%	100.00%	100.00%
6	0.00%			0.00%	0.00%	0.00%
2	0.00%			<Standard>	0.00%	0.00%
7	0.00%				<Standard>	0.00%
8	0.00%					<Standard>

Table 4.24.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 15 to 19 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	901.22	901.22	928.87	928.87	928.87
Operating Cost (1990 \$)	99.74	99.74	93.22	93.22	93.22
Life Cycle Cost (1990 \$)	1869.88	1869.88	1834.28	1834.28	1834.28
Energy Use (MMBtu/yr)	16.54	16.54	15.46	15.46	15.46

Table 4.24.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 15 to 19 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	35.6	35.6	17.2	-241.8	-459.6
Payback	4.2	4.2	7.3	25.2	30.6
CCE (\$/MMBtu)	2.6	2.6	4.0	13.3	17.0

Table 4.25.a Cost and Energy-Use Summary, Gravity Wall Heater 19 to 27 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	901.38	143.93	2299.31	23.87
1	935.03	135.13	2247.46	22.41
6	963.82	135.78	2282.52	22.36
2	979.84	128.58	2228.68	21.14
3	1066.38	119.56	2227.53	19.65
7	1310.55	115.58	2433.13	18.64
8	1580.77	106.13	2611.57	17.11

Table 4.25.b Distribution of Units Sold Below Standards, Gravity Wall Heater 19 to 27 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	9.39%	100.00%	10.25%	9.43%	9.39%	9.39%
1	68.66%	<Standard>	74.97%	68.98%	68.65%	68.65%
6	13.53%		14.77%	13.59%	13.53%	13.53%
2	7.96%		<Standard>	8.00%	7.96%	7.96%
3	0.47%			<Standard>	0.47%	0.47%
7	0.00%				<Standard>	0.00%
8	0.00%					<Standard>

Table 4.25.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 19 to 27 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	901.38	935.83	939.35	939.95	939.95
Operating Cost (1990 \$)	143.93	136.13	135.52	135.45	135.45
Life-Cycle Cost (1990 \$)	2299.31	2257.96	2255.61	2255.48	2255.48
Energy Use (MMBtu/yr)	23.87	22.55	22.44	22.43	22.43

Table 4.25.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 19 to 27 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	51.9	29.3	28.1	-177.6	-356.1
Payback	3.8	5.8	8.0	18.7	21.9
CCE (\$/MMBtu)	2.4	3.2	4.7	10.1	12.4

Table 4.26.a Cost and Energy-Use Summary, Gravity Wall Heater 27 to 46 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	923.52	192.23	2790.55	31.88
1	948.45	181.50	2711.24	30.10
2	997.12	174.91	2695.90	28.83
3	1094.86	162.70	2675.00	26.81
7	1326.06	156.80	2848.97	25.48
8	1614.47	143.99	3012.89	23.40

Table 4.26.b Distribution of Units Sold Below Standards, Gravity Wall Heater 27 to 46 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	8.89%	100.00%	9.98%	8.90%	8.89%	8.89%
1	80.17%	<Standard>	90.02%	80.30%	80.16%	80.16%
2	10.78%		<Standard>	10.80%	10.78%	10.78%
3	0.17%			<Standard>	0.17%	0.17%
7	0.00%				<Standard>	0.00%
8	0.00%					<Standard>

Table 4.26.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater 27 to 46 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	923.52	945.96	951.49	951.73	951.73
Operating Cost (1990 \$)	192.23	182.57	181.74	181.71	181.71
Life-Cycle Cost (1990 \$)	2790.55	2719.16	2716.65	2716.57	2716.58
Energy Use (MMBtu/yr)	31.88	30.28	30.12	30.12	30.12

Table 4.26.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater 27 to 46 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	79.3	23.3	41.6	-132.4	-296.3
Payback	2.3	6.7	7.5	15.0	17.6
CCE (\$/MMBtu)	1.4	3.6	4.5	8.3	10.2

Table 4.27.a Cost and Energy-Use Summary, Gravity Wall Heater over 46 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	1044.80	274.84	3714.16	45.58
1	1072.11	261.28	3609.70	43.33
5	1118.26	254.84	3593.35	42.08
2	1129.70	252.17	3578.86	41.82
3	1174.72	245.75	3561.46	40.58
8	1396.54	240.29	3730.31	39.29
6	1248.51	237.01	3550.41	39.13
9	1531.91	228.06	3746.88	37.29
10	1866.96	209.38	3900.55	34.23
11	2024.80	209.24	4056.95	33.75

Table 4.27.b Distribution of Units Sold Below Standards, Gravity Wall Heater over 46 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	0.77%	100.00%	0.77%	0.77%	0.77%	0.77%
1	97.95%	<Standard>	97.95%	97.95%	97.95%	97.95%
5	1.28%		1.28%	1.28%	1.28%	1.28%
2	0.00%		0.00%	0.00%	0.00%	0.00%
3	0.00%		<Standard>	0.00%	0.00%	0.00%
8	0.00%			0.00%	<Standard>	0.00%
6	0.00%			<Standard>		0.00%
9	0.00%					0.00%
10	0.00%					0.00%
11	0.00%					<Standard>

Table 4.27.c Weighted-Averages of Units Sold Below Standards, Gravity Wall Heater over 46 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	1044.80	1072.49	1072.49	1072.49	1072.49
Operating Cost (1990 \$)	274.84	261.30	261.30	261.30	261.30
Life-Cycle Cost (1990 \$)	3714.16	3610.30	3610.30	3610.30	3610.30
Energy Use (MMBtu/yr)	45.58	43.33	43.33	43.33	43.33

Table 4.27.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Gravity Wall Heater over 46 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	104.5	48.8	59.9	-120.0	-446.7
Payback	2.0	6.6	7.2	15.4	18.3
CCE (\$/MMBtu)	1.2	3.8	4.3	8.3	10.2

Table 4.28.a Cost and Energy-Use Summary, Room Heater up to 18 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	656.87	80.86	1442.22	13.41
1	677.97	73.75	1394.21	12.23
6	710.66	74.39	1433.17	12.19
2	721.60	68.47	1386.55	11.19
5	809.09	63.62	1426.94	10.40
8	1018.58	60.86	1609.64	9.27
9	1255.35	52.21	1762.41	7.95

Table 4.28.b Distribution of Units Sold Below Standards, Room Heater up to 18 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%
1	100.00%	<Standard>	100.00%	100.00%	100.00%	100.00%
6	0.00%		0.00%	0.00%	0.00%	0.00%
2	0.00%		<Standard>	<Standard>	0.00%	0.00%
5	0.00%				<Standard>	0.00%
8	0.00%					0.00%
9	0.00%					<Standard>

Table 4.28.c Weighted-Averages of Units Sold Below Standards, Room Heater up to 18 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	656.87	677.97	677.97	677.97	677.97
Operating Cost (1990 \$)	80.86	73.75	73.75	73.75	73.75
Life-Cycle Cost (1990 \$)	1442.22	1394.21	1394.21	1394.21	1394.21
Energy Use (MMBtu/yr)	13.41	12.23	12.23	12.23	12.23

Table 4.28.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater up to 18 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	48.0	7.7	7.7	-32.7	-368.2
Payback	3.0	8.3	8.3	12.9	26.8
CCE (\$/MMBtu)	1.8	4.3	4.3	7.4	13.9

Table 4.29.a Cost and Energy-Use Summary, Room Heater 18 to 20 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	657.06	104.80	1674.91	17.38
1	678.65	95.63	1607.48	15.86
2	720.43	90.41	1598.56	14.83
3	761.06	87.11	1607.06	14.29
5	800.70	84.05	1617.00	13.79
8	1000.75	79.60	1773.86	12.37
9	1267.12	68.23	1929.80	10.60

Table 4.29.b Distribution of Units Sold Below Standards, Room Heater 18 to 20 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	20.74%	24.18%	23.70%	22.53%	20.74%	20.74%
1	65.05%	75.82%	74.34%	70.68%	65.05%	65.05%
2	1.71%	<Standard>	1.95%	1.86%	1.71%	1.71%
3	4.54%		<Standard>	4.93%	4.54%	4.54%
5	7.96%			<Standard>	7.96%	7.96%
8	0.00%				<Standard>	0.00%
9	0.00%					<Standard>

Table 4.29.c Weighted-Averages of Units Sold Below Standards, Room Heater 18 to 20 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	673.43	674.35	678.63	688.34	688.34
Operating Cost (1990 \$)	97.85	97.70	97.18	96.13	96.13
Life-Cycle Cost (1990 \$)	1623.78	1623.29	1622.49	1622.05	1622.05
Energy Use (MMBtu/yr)	16.23	16.20	16.11	15.92	15.92

Table 4.29.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater 18 to 20 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	25.2	16.2	5.5	-151.8	-307.7
Payback	6.3	8.2	9.3	18.9	20.7
CCE (\$/MMBtu)	3.5	4.7	5.4	9.1	11.2

Table 4.30.a Cost and Energy-Use Summary, Room Heater 20 to 27 kBtu

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	830.58	142.73	2216.80	23.67
1	870.39	133.50	2167.01	22.14
6	897.93	136.87	2227.25	22.54
7	1046.21	124.09	2251.44	20.01
8	1155.34	118.82	2309.36	18.70
9	1508.33	101.04	2489.68	15.90

Table 4.30.b Distribution of Units Sold Below Standards, Room Heater 20 to 27 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	0.00%	100.00%	100.00%	100.00%	0.00%	0.00%
1	100.00%	<Standard>	<Standard>	<Standard>	100.00%	100.00%
6	0.00%				0.00%	0.00%
7	0.00%				0.00%	0.00%
8	0.00%				<Standard>	0.00%
9	0.00%					<Standard>

Table 4.30.c Weighted-Averages of Units Sold Below Standards, Room Heater 20 to 27 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	830.58	830.58	830.58	870.39	870.39
Operating Cost (1990 \$)	142.73	142.73	142.73	133.50	133.50
Life-Cycle Cost (1990 \$)	2216.80	2216.80	2216.80	2167.01	2167.01
Energy Use (MMBtu/yr)	23.67	23.67	23.67	22.14	22.14

Table 4.30.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater 20 to 27 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	49.8	49.8	49.8	-142.3	-322.7
Payback	4.3	4.3	4.3	19.4	19.7
CCE (\$/MMBtu)	2.7	2.7	2.7	8.5	10.5

Table 4.31.a Cost and Energy-Use Summary, Room Heater 27 to 46 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	813.39	191.03	2668.71	31.68
1	852.92	179.87	2599.90	29.83
2	906.93	173.60	2593.00	28.79
3	948.15	168.96	2589.12	27.84
7	1012.73	167.15	2636.11	27.16
8	1112.26	159.08	2657.32	25.40
9	1465.58	136.26	2788.94	21.75

Table 4.31.b Distribution of Units Sold Below Standards, Room Heater 27 to 46 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	10.54%	100.00%	10.73%	10.73%	10.54%	10.54%
1	74.13%	<Standard>	75.47%	75.47%	74.14%	74.14%
2	13.56%		13.80%	13.80%	13.56%	13.56%
3	1.76%		<Standard>	<Standard>	1.76%	1.76%
7	0.00%				0.00%	0.00%
8	0.00%				<Standard>	0.00%
9	0.00%					<Standard>

Table 4.31.c Weighted-Averages of Units Sold Below Standards, Room Heater 27 to 46 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	813.39	856.13	856.13	857.75	857.75
Operating Cost (1990 \$)	191.03	180.20	180.20	180.00	180.00
Life-Cycle Cost (1990 \$)	2668.71	2606.33	2606.33	2606.03	2606.03
Energy Use (MMBtu/yr)	31.68	29.88	29.88	29.85	29.85

Table 4.31.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Room Heater 27 to 46 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	68.8	17.2	17.2	-51.3	-182.9
Payback	3.5	8.2	8.2	12.2	13.9
CCE (\$/MMBtu)	2.2	4.6	4.6	5.9	7.7

Table 4.32.a Cost and Energy-Use Summary, Room Heater over 46 kBtu

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	1052.39	274.24	3715.90	45.48
1	1120.32	260.49	3650.30	43.20
2	1181.80	251.33	3622.76	41.68
3	1219.94	245.87	3607.85	40.60
6	1233.72	247.79	3640.28	40.58
7	1283.45	240.72	3621.40	39.36
8	1415.96	228.15	3631.84	36.83
9	1898.77	197.29	3814.88	31.85

Table 4.32.b Distribution of Units Sold Below Standards, Room Heater over 46 kBtu

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
0	12.51%	100.00%	12.69%	12.69%	12.51%	12.51%
1	71.37%	<Standard>	72.41%	72.41%	71.38%	71.38%
2	14.69%		14.90%	14.90%	14.69%	14.69%
3	1.42%		<Standard>	<Standard>	1.42%	1.42%
6	0.00%				0.00%	0.00%
7	0.00%				0.00%	0.00%
8	0.00%				<Standard>	0.00%
9	0.00%					<Standard>

Table 4.32.c Weighted-Averages of Units Sold Below Standards Room Heater over 46 kBtu

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
Equip. Price (1990 \$)	1052.39	1120.86	1120.86	1122.27	1122.27
Operating Cost (1990 \$)	274.24	260.87	260.87	260.66	260.66
Life-Cycle Cost (1990 \$)	3715.90	3654.52	3654.52	3653.86	3653.86
Energy Use (MMBtu/yr)	45.48	43.26	43.26	43.23	43.23

Table 4.32.d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real) Room heater over 46 kBtu

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5
LCC difference	65.6	46.7	46.7	22.0	-161.0
Payback	4.9	6.6	6.6	9.0	12.3
CCE (\$/MMBtu)	3.1	3.8	3.8	4.7	7.0

4.5 LCC SENSITIVITY ANALYSIS

The sensitivity of the national LCC results were tested by varying assumptions about energy prices and equipment prices. These tables should be compared to the first set of tables in Section 4.1.

Low and high energy prices were defined as the minimum and maximum, respectively, of states' energy prices. Projected (1992) state energy prices (23) relative to the national average were applied to the projected 1996 national average price from the *Annual Energy Outlook 1991* to obtain state prices for 1996. (This represents a wider range of prices than analyzed in previous analyses, which used the average across Census regions.)

Low and high equipment prices were defined as one standard deviation below and above, respectively, the equipment prices used elsewhere in this chapter (from the Engineering Analysis). Note that the uncertainty in the baseline price is a percent of the total price, while the uncertainty in the price of other designs is applied to the incremental price of that design.

The following sensitivity cases were analyzed:

- (1) low (state) energy prices,
- (2) high equipment prices,
- (3) low (state) energy prices and high equipment prices,
- (4) high (state) energy prices,
- (5) low equipment prices, and
- (6) high (state) energy prices and low equipment prices.

Figure 4.17 and Table 4.33 summarize the results of the sensitivity analysis. They include:

- graph of highest and lowest LCC sensitivity, and reference case, and
- table of LCCs for all sensitivity cases. The table also shows the number of sensitivity cases for which each design option is the minimum LCC.

Figure 4.17 Life-Cycle Cost for a Gravity Wall Heater 27K to 46K Btuh

Table 4.33 Sensitivity Summary of Life-Cycle Costs of Gravity Wall Heater, 27K to 46K Btuh

Standard Level	1	2	3	4	5		Std Level @	Design Option
Design Option	0	1	2	3	6	7	8	min LCC @ min LCC
Reference	2791	2711	2696	2675	2774	2849	3013	3
1	2229	2181	2193	2207	2242	2414	2614	1
2	3275	3199	3193	3193	3269	3402	3681	2
3	2694	2646	2666	2689	2716	2904	3197	1
4	5800	5553	5417	5206	5641	5253	5220	3
5	2605	2526	2497	2464	2574	2625	2731	3
6	5615	5367	5218	4995	5442	5028	4939	5
# of cases as min LCC	2	1	3				1	

CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF DIRECT HEATING EQUIPMENT

5.1 LONG-RUN IMPACTS

The analysis shows that compared to the 1996 base case, the direct heating equipment industry is likely to experience a ROE increase at trial standards levels 1 and 2 and an ROE decrease at levels 3 through 5. At standards level 1, there is approximately a 73% chance that ROE will increase, with an expected increase of 0.02%. At standards level 2, there is approximately a 72% chance ROE will increase with a expected increase of 0.01%. At standards level 3, there is approximately a 54% chance of a decrease in ROE with an expected decrease of 0.05%. At standards level 4, there is approximately a 61% chance of an increase in ROE with an expected decrease of 0.02%. At standards level 5, there is approximately a 58% chance of a decrease in ROE with a expected increase of 0.27%. These results are based on Table 5.1. The probabilities of change are computed from the expected change, the standard error of this estimate, and the assumption of a normal distribution.

5.1.1 Qualitative Analysis

According to reports from within the industry, direct heating equipment manufacturing is characterized by economies of scale; this means that for the purposes of price determination, there are fixed costs. These vary depending on the standards level under consideration, but are estimated to be in the range of 10% of total costs. Increases in fixed costs cannot be passed on, which implies that the markup over variable cost must be approximately 10% if the typical firm is to have a near-average ROE. To the extent that this markup is the same after standards are imposed, and to the extent that standards induce an increase in variable costs, such costs will be more than completely passed on in the form of a price increase, which in itself is profitable, but which also tends to reduce profit because of the effect of a price increase on sales. If standards induce an increase in fixed costs, this cost cannot be passed on and will negatively influence profit. Because of the mandated increase in efficiency, operating costs will necessarily decline, which will tend to increase profit by making direct heating equipment more attractive and thereby increasing demand. (However, this effect is smaller for direct heating equipment than for most other appliances.) Also, demand is specified as a function of purchase price and operating cost (i.e., life-cycle cost) under constant life-cycle cost elasticity. Therefore, as price changes, so does price elasticity, and consequently, markup. (For instance, as price rises, price elasticity rises and markup falls.) The model calculates that these effects, when combined, are more likely to increase economic profits than decrease them at levels 1 and 2 and are more likely to reduce economic profits than increase them at standards levels 3 through 5.

5.1.2 Quantitative Analysis

Table 5.1 summarizes all essential outputs from the LBL-MIM simulations using the primary scenario for direct heating equipment. Six other scenarios are summarized and discussed in the sensitivity section, Section 5.4.

Once the above interpretations are understood, the results of the model concerning the long-run impact of standards on the direct heating equipment manufacturing industry can be read from the output table.

Table 5.1 Direct Heating Equipment Output Table: Primary Scenario - Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.07	0.07	0.07	0.07	0.07	0.06
% change		0.31%	0.38%	0.82%	-7.81%	-16.14%
S.E.		1.51%	8.59%	16.66%	17.56%	45.80%
Price	\$220.16	\$221.65	\$238.16	\$249.73	\$332.65	\$453.66
% change		0.68%	8.17%	13.43%	51.10%	106.06%
S.E.		0.70%	3.19%	4.59%	16.33%	35.25%
Revenue (in \$M)	16.30	0.68%	17.70	18.64	22.70	28.16
% change		0.70%	8.59%	14.36%	39.29%	72.80%
S.E.		1.51%	9.21%	18.65%	25.05%	89.70%
Net Income (in \$M)	0.56	0.57	0.57	0.57	0.53	0.48
Difference		0.00	0.00	0.01	-0.04	-0.09
S.E.		0.04	0.27	0.31	0.33	1.39
ROE	7.38%	7.39%	7.38%	7.32%	7.35%	7.10%
Difference		0.02%	0.01%	-0.05%	-0.02%	-0.27%
S.E.		0.17%	0.69%	1.04%	4.33%	7.00%

5.2 SHORT-RUN IMPACTS

The business cycle presents the direct heating equipment industry with fairly sharp periodic fluctuations in demand, much larger than the fluctuations predicted for any of the standards levels. These normal demand fluctuations present the same types of opportunities for price competition that will accompany fluctuations resulting from a change in standards. Regressing price on demand and a time trend for the past 18 years shows that a 10% fall in demand typically leads to a 0.3% fall in the price of direct heating equipment; a 10% demand increase has the reverse effect. This effect is taken into account as described in Volume A, Chapter 3, Section 3.2.4, and is used to produce a short-run version of the output table that is

displayed in Table 5.2. Note that at each standards level analyzed for the direct heating equipment manufacturing industry, the short run ROE results are generally lower than the long-run results. For reasons that are explained in the above reference, the short-run change has been overestimated. Thus the values for change in Table 5.2 should generally be viewed as somewhat too large in the absolute value.

Table 5.2 Direct Heating Equipment Output Table: Primary Scenario - Short-Run

	1996.BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.07	0.07	0.07	0.07	0.07	0.06
% change		0.20%	0.25%	0.66%	-7.38%	-14.57%
Price	\$220.16	\$222.45	\$239.03	\$250.81	\$329.81	\$444.56
% change		1.04%	8.57%	13.92%	49.81%	101.93%
Revenue (in \$M)	16.30	16.50	17.74	18.69	22.61	28.12
% change		1.24%	8.85%	14.68%	38.75%	72.52%
Net Income (in \$M)	0.56	0.59	0.59	0.59	0.37	0.06
Difference		0.02	0.03	0.03	-0.19	-0.50
ROE	7.38%	7.64%	7.66%	7.60%	5.17%	0.92%
Difference		0.27%	0.29%	0.23%	-2.20%	-6.45%
S.E.		3.17%	4.08%	6.97%	1337.49%	154.89%

5.3 IMPACT AS A FUNCTION OF FIRM SIZE

In this industry, average cost decreases with firm size, which means that the industry has economies of scale, and large firms (to the extent that their facilities are up-to-date) have lower average costs than small firms. This fact, coupled with the increasing competitiveness of the national market and competition from other products (e.g., central heating equipment) probably accounts for the continuing consolidation that has been occurring for several decades. The fact that the consolidation has been producing larger firms strongly corroborates the finding that large firms have a cost advantage.

A principal implication of consolidation is that the smaller of the major firms will be, on average, in more danger of failing or being bought out than will the larger firms. Because of the greater precariousness of smaller firms, any decrease in average profitability is more likely to seriously damage a smaller firm, and an increase in average profitability is more likely to mean the difference between success and failure for a smaller firm.

From the point of view of competitiveness, a decrease in average profitability could speed up the process of consolidation, producing a less competitive industry, and an increase in average profitability could help maintain the current level of competition. Either effect might

well be temporary because in the long run the number of firms should be determined by the industry's cost structure and by the way a single firm's elasticity of demand relates to the number of competing firms. Of course, if standards are technologically difficult to meet, they may hurt selected smaller firms the most because smaller firms have less sophisticated research and development capabilities.

5.4 SENSITIVITY ANALYSIS FOR DIRECT HEATING EQUIPMENT

The three following subsections discuss different aspects of the sensitivity analysis conducted by LBL-MIM. The first subsection, on sensitivity charts, shows the implications of the uncertainty of each control variable for the prediction of ROE. The next subsection shows six alternative scenarios that are of particular importance and deserve a more detailed analysis than those randomly generated by Monte Carlo runs. The last subsection shows the use of Monte Carlo runs to find combinations of errors that would cause the change in ROE to be considerably more negative than is predicted.

5.4.1 Sensitivity Charts

Table 5.3 lists the sensitivity of ROE to changes in control panel inputs. The variables analyzed are industry price-elasticity of demand (IPE), discount rate (RD), the equity cost of capital (ECC), economic profit (EP), the fixed part of costs (FCA), the fixed part of one-time costs (F1X), one-time capital costs (CC.N), one-time variable costs (dVC.N), and the shape parameter of the demand curve (ro.N).

Table 5.3 Direct Heating Equipment Sensitivity Chart: Primary Scenario (Sensitivity of ROE to 1 S.E. Change in Control Variable)

Control Variables			Possible Standards Levels				
Name	Value	Changed	1	2	3	4	5
IPE	-0.300	-0.690	0.06%	0.07%	0.15%	-1.65%	-4.27%
RD	50.00%	114.96%	0.00%	0.15%	0.22%	1.32%	2.81%
ECC	0.068	0.075	0.00%	0.00%	0.00%	-0.01%	-0.04%
EP	0.008	0.018	-0.01%	-0.01%	-0.02%	0.07%	0.15%
FCA	0.098	0.157	0.00%	0.00%	-0.01%	0.06%	0.13%
F1X	0.200	0.348	-0.09%	-0.10%	-0.14%	-0.17%	-0.30%
CC.N	0.394	0.480	-0.02%	-0.03%	-0.04%	-0.07%	-0.16%
dVC.N	5.124	6.872	0.00%	0.01%	0.01%	0.05%	0.01%
ro.N	0.000	0.100	0.01%	0.01%	0.02%	-0.26%	-0.63%

As can be seen from the table, three control variables account for nearly all of the uncertainty in the determination of ROE. These are (1) consumer discount rate (RD), (2) the industry elasticity of demand with respect to price (IPE), and (3) fixed one-time costs (F1X). The reasons that these three variables are important are discussed below.

5.4.2 Alternative Scenarios

The sensitivity analysis shows that both price and operating cost elasticities (the latter being derived from the discount rate) play crucial roles in determining the model's output. These are both *industry* elasticities as opposed to single-firm elasticities; this means they measure the effect on demand of a change in price by all firms and a change in operating cost of all pool heaters. The estimates of standard errors that are calculated by the Monte Carlo analysis fully acknowledge the uncertainties of these two variables. However, in order to show in detail all of the ramifications of changing one or both of them, six alternative scenarios have been run. The six scenarios include low and high price-elasticity scenarios, a constant-shipments scenario (i.e., industry price and operating cost elasticity set to zero), high- and low-discount-rate scenarios (i.e., high and low operating cost scenarios), and a low-discount-rate and high price-elasticity scenario. Tables 5.4 through 5.9 show the results of running these six scenarios for the direct heating equipment manufacturing industry.

In these alternative scenarios, note the impact of a change in the discount rate. A high RD input value lowers ROE, and a lower RD value increases ROE. Because markup is determined by price elasticity, it will tend to change as the ratio of price to operating cost changes. Standards will always increase this ratio, which decreases markup. This effect is strongest when appliance demand is relatively elastic with respect to operating cost. That is, a more elastic operating cost elasticity will result in a greater decrease in markup under standards, resulting in a greater decrease in profitability.

Tables 5.4 through 5.10 show that increasing price elasticity also tends to lower ROE. This effect is probably due to the greater decline in shipments when price elasticity is greater.

The percentage of one-time fixed costs (F1X) is important because of its role in the model. It determines the LBL-MIM's estimate of the markup over variable cost, which, in turn, determines the firm's ability to pass on various combinations of fixed and variable costs for each standards level. For a more detailed explanation, see Volume A, Appendix C.

5.4.3 Monte Carlo Analysis

The Monte Carlo approach is described in Volume A, Chapter 3, Section 3.2.4, and the standard errors it generates are reported in the output tables. Table 5.10 shows the control panels from two Monte Carlo runs, which were selected because they show a decrease in long-run ROE. Both Monte Carlo runs were done on standards level 2. In both runs, increases in price elasticity coupled with increases in the percentage of fixed one-time costs (which are not passed through via prices) and the discount rate are the primary factors in reducing ROE.

Table 5.4 Direct Heating Equipment Output Table: Low-Price Elasticity Scenario

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.07	0.07	0.07	0.07	0.07	0.07
% change		0.00%	0.00%	0.00%	0.00%	-0.01%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%
Price	\$220.16	\$221.65	\$238.15	\$249.73	\$332.65	\$453.67
% change		0.68%	8.17%	13.43%	51.10%	106.06%
S.E.		0.79%	3.29%	4.65%	17.18%	35.22%
Revenue (in \$M)	15.96	16.07	17.27	18.11	24.12	32.90
% change		0.68%	8.18%	13.43%	51.09%	106.05%
S.E.		0.79%	3.29%	4.65%	17.18%	35.21%
Net Income (in \$M)	0.52965	0.53	0.53	0.52	0.63	0.75
Difference		-0.00	-0.01	-0.01	0.09	0.22
S.E.		0.01	0.02	0.03	0.11	0.20
ROE	7.08%	7.06%	7.03%	6.91%	8.28%	9.69%
Difference		-0.03%	-0.05%	-0.18%	1.20%	2.61%
S.E.		0.11%	0.22%	0.33%	1.48%	2.64%

Table 5.5 Direct Heating Equipment Output Table: High-Price Elasticity Scenario

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.08	0.08	0.08	0.08	0.06	0.05
% change		0.62%	0.76%	1.65%	-15.02%	-29.68%
S.E.		0.45%	1.99%	3.22%	7.29%	11.20%
Price	\$220.16	\$221.65	\$238.16	\$249.73	\$332.65	\$453.66
% change		0.68%	8.17%	13.43%	51.10%	106.06%
S.E.		0.72%	3.20%	5.18%	15.59%	33.42%
Revenue (in \$M)	16.64	16.86	18.14	19.18	21.37	24.11
% change		1.30%	9.00%	15.30%	28.41%	44.90%
S.E.		0.27%	1.01%	1.41%	1.69%	2.89%
Net Income (in \$M)	0.60	0.61	0.61	0.62	0.43	0.24
Difference		0.01	0.01	0.02	-0.16	-0.35
S.E.		0.01	0.02	0.04	0.11	0.23
ROE	7.66%	7.72%	7.72%	7.73%	6.38%	4.16%
Difference		0.06%	0.06%	0.07%	-1.28%	-3.51%
S.E.		0.10%	0.18%	0.29%	1.36%	4.51%

Table 5.6 Direct Heating Equipment Output Table: Constant-Shipments Scenario

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.07	0.07	0.07	0.07	0.07	0.07
% change		0.00%	0.00%	0.00%	0.00%	0.00%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%
Price	\$220.16	\$221.65	\$238.15	\$249.73	\$332.65	\$453.67
% change		0.68%	8.17%	13.43%	51.10%	106.06%
S.E.		0.74%	3.11%	4.55%	17.20%	34.37%
Revenue (in \$M)	15.96	16.07	17.27	18.11	24.12	32.90
% change		0.68%	8.17%	13.43%	51.10%	106.06%
S.E.		0.74%	3.11%	4.55%	17.20%	34.37%
Net Income (in \$M)	0.59	0.53	0.53	0.52	0.63	0.75
Difference		-0.00	-0.00	-0.01	0.10	0.22
S.E.		0.01	0.02	0.02	0.11	0.22
ROE	7.08%	7.06%	7.03%	6.91%	8.28%	9.69%
Difference		-0.03%	-0.05%	-0.18%	1.20%	2.61%
S.E.		0.10%	0.20%	0.31%	1.40%	2.78%

Table 5.7 Direct Heating Equipment Output Table: Low-Discount Rate Scenario

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.09	0.09	0.11	0.12	0.13	0.18
% change		3.66%	21.12%	39.65%	49.21%	105.91%
S.E.		0.26%	1.47%	3.11%	8.45%	24.43%
Price	\$219.81	\$221.21	\$237.03	\$248.09	\$328.50	\$445.58
% change		0.64%	7.84%	12.87%	49.45%	102.72%
S.E.		0.71%	2.95%	4.77%	15.97%	30.72%
Revenue (in \$M)	19.13	19.95	24.98	30.15	42.65	79.85
% change		4.32%	30.61%	57.62%	122.99%	317.42%
S.E.		0.50%	2.36%	4.37%	11.73%	24.09%
Net Income (in \$M)	0.82	0.89	1.17	1.47	1.63	2.59
Difference		0.06	0.34	0.65	0.80	1.76
S.E.		0.02	0.11	0.21	0.28	0.67
ROE	9.25%	9.61%	10.86%	11.86%	12.30%	14.15%
Difference		0.36%	1.61%	2.61%	3.04%	4.90%
S.E.		0.20%	0.86%	1.42%	1.65%	2.61%

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

5 of 6

Table 5.8 Direct Heating Equipment Output Table: High-Discount-Rate Scenario

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.07	0.07	0.07	0.07	0.06	0.06
% change		-0.14%	-2.11%	-3.37%	-12.12%	-20.93%
S.E.		0.24%	0.86%	1.36%	3.30%	4.46%
Price	\$220.76	\$222.41	\$240.09	\$252.55	\$339.81	\$467.59
% change		0.75%	8.75%	14.40%	53.93%	111.81%
S.E.		0.81%	3.09%	5.18%	18.10%	35.18%
Revenue (in \$M)	15.98	16.08	17.01	17.66	21.62	26.76
% change		0.60%	6.46%	10.55%	35.27%	67.47%
S.E.		0.56%	2.06%	3.38%	10.17%	17.69%
Net Income (in \$M)	0.56	0.56	0.58	0.59	0.72	0.87
Difference		0.00	0.03	0.04	0.16	0.32
S.E.		0.01	0.03	0.05	0.24	0.46
ROE	7.44%	7.49%	7.93%	8.15%	10.70%	14.07%
Difference		0.05%	0.49%	0.71%	3.26%	6.63%
S.E.		0.12%	0.42%	0.76%	3.96%	8.01%

Table 5.9 Direct Heating Equipment Output Table: Low-Discount-Rate and High-Price Elasticity Scenario

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5
Shipments (in Mil)	0.10	0.11	0.15	0.20	0.23	0.44
% change		7.45%	46.70%	95.02%	122.62%	323.96%
S.E.		0.62%	4.97%	12.80%	30.04%	140.27%
Price	\$219.81	\$221.21	\$237.03	\$248.09	\$328.50	\$445.59
% change		0.64%	7.84%	12.87%	49.45%	102.72%
S.E.		0.78%	3.11%	4.87%	15.75%	34.21%
Revenue (in \$M)	22.96	24.82	36.32	50.53	76.37	197.29
% change		8.14%	58.20%	120.12%	232.70%	759.45%
S.E.		0.45%	3.94%	11.59%	24.74%	199.28%
Net Income (in \$M)	1.20	1.36	2.18	3.19	3.78	8.08
Difference		0.16	0.98	1.99	2.58	6.88
S.E.		0.05	0.33	0.72	1.04	3.42
ROE	11.28%	11.93%	14.07%	15.56%	16.15%	18.23%
Difference		0.65%	2.79%	4.28%	4.87%	6.95%
S.E.		0.36%	1.58%	2.66%	3.00%	3.90%

Table 5.10 Direct Heating Equipment Monte Carlo Runs: Searching for Low ROE

		Scenario: Primary		Standard Level = 2	
DIRECT HEATING EQMT		Input		Vari-	Progrm
CONTROL FACTORS		Value	Cntrl	ation	Value
Price Elasticity		-0.300	2.08	100%	-1.691
Consumer Discount Rate		50.0%	0.63	100%	84.17%
Equity Cost of Capital		0.068	-1.80	10%	0.057
Economic Profit		0.008	0.97	1%	0.017
L-R Fixed Part of Costs & Assets		0.098	-0.60	50%	0.074
L-R Fixed Part of 1-X Cap. Cost		0.200	0.86	60%	0.322
One-Time Capital Costs		0.428	-0.51	20%	0.387
Unit Variable Cost Increase		\$21.58	2.06	30%	39.552
Elasticity Curve Parameter		0.000	0.34	10%	0.034
Short Run Price Response to Demand		0.157	0.63	76%	0.363
	NAECA	NEW		PRVIOUS	NEW
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments	0.08	0.06	-17.22%	0.31%	0.07
Price	\$220.39	\$257.05	16.63%	0.68%	\$251.00
Revenue (in \$M)	16.88	16.30	-3.45%	0.99%	17.02
Net Income	0.61	0.40	-0.21	0.00	0.19
ROE	7.70%	6.01%	-1.68%	0.02%	2.87%
08-Sep-92		16:24	Trys =		34.00
		Scenario: Primary		Standard Level = 2	
DIRECT HEATING EQMT		Input		Vari-	Progrm
CONTROL FACTORS		Value	Cntrl	ation	Value
Price Elasticity		-0.300	2.26	100%	-1.963
Consumer Discount Rate		50.0%	1.22	100%	138.47%
Equity Cost of Capital		0.068	0.06	10%	0.068
Economic Profit		0.008	1.83	1%	0.026
L-R Fixed Part of Costs & Assets		0.098	1.78	50%	0.228
L-R Fixed Part of 1-X Cap. Cost		0.200	-0.87	60%	0.124
One-Time Capital Costs		0.428	1.64	20%	0.592
Unit Variable Cost Increase		\$21.58	0.07	30%	22.013
Elasticity Curve Parameter		0.000	-0.92	10%	-0.092
Short Run Price Response to Demand		0.157	0.33	76%	0.243
	NAECA	NEW		PRVIOUS	NEW
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments	0.07	0.07	-12.05%	0.38%	0.07
Price	\$220.06	\$241.89	9.92%	8.17%	\$238.42
Revenue (in \$M)	16.40	15.86	-3.32%	8.59%	16.27
Net Income	0.75	0.50	-0.25	0.00	0.43
ROE	9.76%	7.25%	-2.51%	0.01%	6.32%
08-Sep-92		16:26	Trys =		44.00

CHAPTER 6. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES: DIRECT HEATING EQUIPMENT

6.1 INTRODUCTION

Appliance efficiency standards have four principal effects on electric utilities: (1) they allow utilities to avoid fuel and other operating costs because less electricity needs to be generated, (2) they may allow utilities to defer construction of new generating capacity, (3) they may allow utilities to defer construction of new or upgraded T&D capacity, and (4) they reduce revenues from electricity sales. The second section of this chapter presents the results of the avoided cost calculations. The third section presents the expected peak load and reliability savings for the analyzed standardS levels. The fourth section presents the results of the revenue loss calculation. More details on methodology may be found in Appendix E of Volume A.

6.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS

Figure 6.1 shows avoided energy and reliability costs for electricity savings from direct heating equipment.³ These figures show the sum of avoided costs for the base-, high-, and low-energy-price cases.⁴ The value per million Btu (MMBtu) of avoided reliability costs is zero in all three energy-price cases, because capacity savings only have value in summer (see Appendix G of Volume A). The avoided fuel and capital component depends on fuel prices and varies among the three cases. As explained in Appendix E of Volume A, this component implicitly contains the costs avoided when baseload power plants are deferred or canceled (it also contains avoided transmission and distribution capital costs). These avoided costs represent a simple summary of the utility analysis, and they are a measure of the societal benefit of the electricity saved in each year. They are used in the LBL-REM to value electricity savings from the societal perspective.

³The total avoided costs for televisions varies slightly by policy case because the conservation load factors vary depending on the percentage of total energy savings attributable to standby losses. We only show one graph here because the variation in avoided costs over the policy cases is around 1%. See Appendix G in Volume A for more details.

⁴ Fuel price forecasts for the period 1990 to 2000 are taken from the DOE/EIA *Annual Energy Outlook 1991* (DOE/EIA-0383(91)). The forecasts for years after 2000 were linearly extrapolated using the methodology described in Volume A. The high (low) energy price case is derived by increasing (decreasing) the reference case AEO fuel price forecasts for gas and coal by 5%.

6.3 PEAK LOAD AND CAPACITY REDUCTIONS

Because peak savings only have value in summer, any shifts in electricity use caused by standards on fuel-fired direct heating equipment have no peak demand savings or capacity savings.

6.4 REVENUE LOSSES

Appliance standards allow utilities to avoid the variable costs of generating electricity, but standards also reduce electricity sales. In a rate case, the utility and the regulators agree on the revenue requirements and rates based on some estimate of future sales. If the effects of appliance efficiency standards are not included in this forecast, actual sales will be less than forecasted sales, which implies that the utility will not be able to recover some of the fixed costs that were included in the original revenue-requirements calculation. This effect can be eliminated if electric utilities and regulators, when calculating rates, use the most current information on the impacts of appliance efficiency standards.

Utilities routinely petition regulators for changes in rates. In the course of such a petition, the utility's forecasted sales can be adjusted to account for the appliance efficiency standards and hence eliminate these "lost" revenues. Those revenues lost as a result of time lags in regulation are not a true economic cost, but are a transfer payment from the utility to utility customers. The size of this transfer payment depends on regulatory behavior and on the net change in revenues, which is equal to the difference between sales reductions and avoided costs.

Since the magnitude of these losses is dependent on assumptions about regulatory behavior, and because this behavior is so varied among states, it is difficult to do this calculation for the nation. An additional complication is that unanticipated sales growth from other sectors may compensate for the revenue shortfall. Two cases are presented here, one that assumes that regulators adjust the rates to reflect the reduced sales in five years, and one that assumes that they never adjust the rates. These cases also assume that there is no unanticipated sales growth. These results are presented both on a year-by-year and a present-value basis.

It is possible that the regulators could adjust the rates in anticipation of the new standards, in which case there would be no revenue impact at all. It is also possible that the regulators would not grant rate relief for several years after the standards go into effect, which is approximated by the five-year-lag case. While it is unlikely that regulators would never adjust the rates to reflect the post-standard sales forecast, this case is included as an absolute upper bound. Figure 6.2 shows annual revenue losses and avoided costs over time for level 3 standards, and Table 6.1 shows net revenue losses for all standards levels. Cumulative net revenue losses for direct heating equipment range from \$1.4 to 6.9 billion.

Figure 6.1 Utility Avoided Costs for Direct Heating Equipment

Figure 6.2 Revenue Reductions and Avoided Costs for Direct Heating Equipment

Table 6.1 Net Revenue Losses - Direct Heating Equipment (Million 1990 Dollars)

Year	Net Revenue Losses				
	Level 1	Level 2	Level 3	Level 4	Level 5
1996	2	3	3	-8	-35
1997	2	3	3	-14	-54
1998	2	3	4	-19	-72
1999	2	3	4	-24	-89
2000	3	4	4	-29	-105
2001	3	4	5	-32	-118
2002	2	4	5	-36	-129
2003	3	5	6	-38	-137
2004	2	5	6	-39	-144
2005	2	5	6	-41	-149
2006	2	5	7	-41	-152
2007	2	5	7	-42	-154
2008	2	5	8	-41	-153
2009	2	5	8	-40	-150
2010	1	5	8	-38	-146
2011	1	5	9	-36	-138
2012	1	5	9	-32	-128
2013	1	6	9	-29	-118
2014	1	6	9	-25	-107
2015	1	6	10	-22	-95
2016	1	5	10	-19	-85
2017	1	5	10	-16	-75
2018	1	5	10	-13	-66
2019	1	5	9	-11	-58
2020	1	5	9	-9	-51
2021	0	4	9	-7	-44
2022	0	4	8	-6	-37
2023	0	4	7	-4	-32
2024	0	3	7	-3	-27
2025	0	3	6	-3	-22
2026	0	3	5	-2	-18
2027	0	2	5	-1	-14
2028	0	2	4	-1	-11
2029	0	1	3	0	-8
2030	0	1	2	0	-5
Total	44	147	234	-721	-2927

The figures show utility revenue losses, assuming no regulatory adjustment. When this adjustment is made, rates will be increased over the base case forecast, and utilities will cease to lose revenue. Total residential rates would not change in 2000 and 2005, respectively, if direct heating equipment is subject to level 3 standards and regulators only change commercial rates to compensate for any loss in revenue.

Table 6.2 shows the present value of net revenue losses at a 5% real utility discount rate for all standard levels and for the two assumptions about regulatory behavior. This discount rate is based on an assumed average utility capital structure and current rates of return.

Table 6.2 Present Value of Revenue Losses - Direct Heating Equipment (Million 1990 Dollars)

Regulatory Lag	Level 1	Level 2	Level 3	Level 4	Level 5
None	0	0	0	0	0
1996-2001	8	11	12	-62	-235
1996-2030	21	55	80	-315	-1230

For direct heating equipment, the present value of net lost revenues may range from \$0.1 to \$0.5 billion for a five-year lag, and would be as large as \$2.7 billion if the regulators did not make adjustments. The present values over the period 1996 to 2030 also represent the rate increases needed over this period to compensate for lost revenues, assuming that regulators adjust immediately.

6.5 SENSITIVITY ANALYSIS

Table 6.3 shows the present value of net lost revenues for the sensitivity cases. The assumptions for the sensitivity cases are the same as those for previous tables.

Table 6.3 Present Value of Net Lost Revenues (Million 1990 \$) - Direct Heating Equipment (Sensitivity Cases)

Regulatory Lag	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
None	0	0	0	0	0	0
1996-2001	10	47	26	9	0	4
1996-2030	68	218	109	99	0	55

CHAPTER 7. ENVIRONMENTAL EFFECTS

7.1 INTRODUCTION

The environmental effects from a range of new candidate energy-conservation standards for direct heating equipment are presented here. The results are presented for each potential standard level. Each measure of possible environmental change is an alternative action, and it is compared to what is expected to happen if no new standards for direct heating equipment were finalized, i.e., the "no action" alternative.

The main environmental concern addressed is emissions from fossil-fueled electricity generation. Although direct heating equipment consists overwhelmingly of fuel-burning space-heating appliances, design options for direct heaters have the effect of impacting the sales of electric space-heating equipment. This ultimately results in either an increase or decrease in electricity use and, therefore, changes in the amount of power plant emissions. The greatest changes in air pollution will generally be for sulfur oxides, listed in equivalent weight of sulfur dioxide, or SO_2 . Reductions of nitrogen oxides and carbon dioxide also occur and are listed by weight of NO_x and CO_2 , respectively. Carbon dioxide (CO_2) emissions from fossil-fuel burning is considered an environmental hazard because it contributes to the "greenhouse effect" by trapping heat energy from the earth that is emitted as infrared radiation. The "greenhouse effect" is expected to gradually raise the mean global temperature. Since direct heating equipment consists almost entirely of fuel-burning space heating appliances, design options will also reduce in-home fuel consumption, resulting in lower emissions from these fuel-burning appliances.

For a detailed description of the methodology that was used in estimating the environmental impacts, refer to the Environmental Assessment in Appendix D of Volume A.

7.2 RESULTS

The following tabular results indicate what changes can be brought about in the amounts of emitted CO_2 , SO_2 , and NO_x by imposing efficiency standards for direct heating equipment. A table is presented for each of the appliance's trial standards levels. Each table details the changes that occur to each of the three emissions (i.e., CO_2 , SO_2 , and NO_x) through the imposition of an appliance's specific trial standard level. Each table includes the following information for a specific year between 1996 and 2030: the amount of emission abated from power plant generation, the amount abated from in-home generation, the net change in the emissions, and the percent the net change comprises of total U.S. power plant emissions. Also included are the cumulative changes of each pollutant (between the years 1996 and 2030).

Changes in the amounts of CO₂, SO₂, and NO_x emitted at trial standards levels 1 through 5 are summarized in Tables 7.1 through 7.5.

7.2.1 Sulfur and Nitrogen Oxide Emissions

Sulfur dioxide emissions would be increased by a cumulative total of up to 0.32 million tons between 1996 and 2030 in the level 5 scenario. In the year 1996, increases in sulfur dioxide will represent about 0.04% of the SO₂ emissions estimated to come from power plants in that year. In the year 2030, increases in SO₂ emissions will represent about 0.04% of the SO₂ emissions estimated to come from power plants in that year. Although increased in the level 5 scenario, SO₂ emissions would be decreased between 1996 and 2030 in the level 1, 2, and 3 scenarios. However, because of provisions in the Clean Air Act Amendments (Pub. L. 101-549, November 15, 1990), the possible reductions of SO₂ that are caused by standards can be earned as credits by the utility realizing the reductions. To the extent SO₂ credits are used for future emissions, the net effect on SO₂ emissions from standards would be only a postponement of those SO₂ emissions.

Level 5 design changes to direct heating equipment would result in an estimated increase in NO_x emissions of 0.18 million tons between 1996 and 2030. NO_x increases would represent 0.03% and 0.01% of the NO_x emissions estimated to come from power plants in the years 1996 and 2030, respectively.

7.2.2 Carbon Dioxide Emissions

The cumulative increase in CO₂ emissions from level 5 design changes is 60 million tons of CO₂. For the year 1996, the estimated CO₂ increase is 173 thousand tons of CO₂, or about 0.01% of estimated U.S. total CO₂ emissions in 1996. For the year 2030, the estimated CO₂ increase is 285 thousand tons of CO₂, or about 0.01% of estimated U.S. total CO₂ emissions in 2030.

Table 7.1
Reduction of Pollutants for Mobile Home Furnaces - Level One

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	8	11	19	0.00%
2005	8	25	33	0.00%
2010	8	30	39	0.00%
2015	8	39	47	0.00%
2020	0	44	44	0.00%
2025	0	30	30	0.00%
2030	0	25	25	0.00%

Cumulative CO2 reduction, 1996-2030 = 1 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	30	0	30	0.00%
2005	26	16	41	0.00%
2010	22	16	38	0.00%
2015	18	31	49	0.00%
2020	0	31	31	0.00%
2025	0	16	16	0.00%
2030	0	16	16	0.00%

Cumulative SO2 reduction, 1996-2030 = 992 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	0	0	0	0.00%
2000	22	11	33	0.00%
2005	21	22	43	0.00%
2010	19	28	47	0.00%
2015	16	34	50	0.00%
2020	0	39	39	0.00%
2025	0	28	28	0.00%
2030	0	22	22	0.00%

Cumulative NOx reduction, 1996-2030 = 1,151 tons

Table 7.2
Reduction of Pollutants for Mobile Home Furnaces - Level Two

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	0	11	11	0.00%
2000	-8	47	38	0.00%
2005	-17	68	51	0.00%
2010	-34	87	53	0.00%
2015	-42	101	59	0.00%
2020	-51	98	47	0.00%
2025	-50	78	28	0.00%
2030	-58	67	10	0.00%

Cumulative CO2 reduction, 1996-2030 = 1 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	0	0	0	0.00%
2000	-30	-16	-46	0.00%
2005	-51	-47	-98	0.00%
2010	-89	-63	-151	0.00%
2015	-89	-78	-167	0.00%
2020	-86	-94	-179	0.00%
2025	-66	-110	-175	0.00%
2030	-58	-110	-157	0.00%

Cumulative SO2 reduction, 1996-2030 = -4,696 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	0	10	10	0.00%
2000	-22	46	24	0.00%
2005	-41	70	28	0.00%
2010	-77	90	12	0.00%
2015	-82	104	22	0.00%
2020	-86	103	17	0.00%
2025	-72	86	14	0.00%
2030	-71	75	4	0.00%

Cumulative NOx reduction, 1996-2030 = 541 tons

Table 7.3
Reduction of Pollutants for Mobile Home Furnaces - Level Three

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	-17	30	12	0.00%
2000	-59	92	33	0.00%
2005	-127	137	10	0.00%
2010	-204	174	-30	0.00%
2015	-254	183	-70	0.00%
2020	-278	169	-109	0.00%
2025	-267	125	-142	0.00%
2030	-240	90	-150	0.00%

Cumulative CO2 reduction, 1996-2030 = -2 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	-97	-47	-144	0.00%
2000	-211	-157	-367	0.00%
2005	-385	-297	-682	-0.01%
2010	-532	-423	-955	-0.01%
2015	-534	-548	-1,081	-0.01%
2020	-470	-626	-1,096	-0.02%
2025	-350	-626	-976	-0.02%
2030	-240	-579	-819	-0.02%

Cumulative SO2 reduction, 1996-2030 = -28,747 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	-61	33	-28	0.00%
2000	-157	103	-54	0.00%
2005	-310	160	-150	0.00%
2010	-463	208	-255	0.00%
2015	-495	229	-266	0.00%
2020	-470	223	-247	0.00%
2025	-384	181	-203	0.00%
2030	-295	143	-152	0.00%

Cumulative NOx reduction, 1996-2030 = -6,507 tons

Table 7.4
Reduction of Pollutants for Mobile Home Furnaces - Level Four

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	-34	37	3	0.00%
2000	-117	95	-22	0.00%
2005	-245	153	-92	0.00%
2010	-365	172	-194	-0.01%
2015	-465	172	-294	-0.01%
2020	-506	140	-366	-0.01%
2025	-476	82	-393	-0.01%
2030	-414	37	-377	-0.01%

Cumulative CO2 reduction, 1996-2030 = -8 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	-193	-94	-287	0.00%
2000	-422	-313	-735	-0.01%
2005	-745	-563	-1,308	-0.02%
2010	-954	-845	-1,799	-0.02%
2015	-978	-1,080	-2,058	-0.03%
2020	-855	-1,221	-2,076	-0.03%
2025	-624	-1,205	-1,829	-0.03%
2030	-414	-1,096	-1,509	-0.03%

Cumulative SO2 reduction, 1996-2030 = -54,358 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	-121	45	-76	0.00%
2000	-314	122	-192	0.00%
2005	-599	202	-397	-0.01%
2010	-829	248	-581	-0.01%
2015	-907	271	-636	-0.01%
2020	-855	254	-601	-0.01%
2025	-684	198	-486	-0.01%
2030	-508	144	-365	-0.01%

Cumulative NOx reduction, 1996-2030 = -15,781 tons

Table 7.5
Reduction of Pollutants for Mobile Home Furnaces - Level Five

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	-77	111	34	0.00%
2000	-268	293	25	0.00%
2005	-558	449	-109	0.00%
2010	-841	527	-314	-0.01%
2015	-1,075	537	-537	-0.01%
2020	-1,164	420	-744	-0.02%
2025	-1,119	264	-854	-0.02%
2030	-1,035	147	-888	-0.02%

Cumulative CO2 reduction, 1996-2030 = -15 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	-435	-141	-576	0.00%
2000	-964	-579	-1,543	-0.02%
2005	-1,695	-1,158	-2,853	-0.03%
2010	-2,196	-1,737	-3,933	-0.05%
2015	-2,259	-2,301	-4,560	-0.06%
2020	-1,967	-2,723	-4,690	-0.07%
2025	-1,467	-2,848	-4,315	-0.07%
2030	-1,034	-2,801	-3,835	-0.08%

Cumulative SO2 reduction, 1996-2030 = -122,401 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	-273	120	-153	0.00%
2000	-717	337	-380	-0.01%
2005	-1,364	543	-821	-0.01%
2010	-1,908	675	-1,233	-0.02%
2015	-2,095	740	-1,354	-0.02%
2020	-1,967	670	-1,297	-0.02%
2025	-1,607	534	-1,074	-0.02%
2030	-1,271	417	-854	-0.01%

Cumulative NOx reduction, 1996-2030 = -33,753 tons

Table 7.6
Reduction of Pollutants for Mobile Home Furnaces - Level Six

CO2 Reduction (in Thousand Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. CO2 Power Plant Emissions
1996	-164	159	-5	0.00%
2000	-595	372	-223	-0.01%
2005	-1,217	544	-673	-0.02%
2010	-1,827	637	-1,190	-0.04%
2015	-2,310	607	-1,703	-0.05%
2020	-2,462	335	-2,127	-0.05%
2025	-2,379	45	-2,334	-0.05%
2030	-2,268	-196	-2,464	-0.05%

Cumulative CO2 reduction, 1996-2030 = -49 million tons of CO2

SO2 Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	% U.S. SO2 Power Plant Emissions
1996	-918	-297	-1,216	-0.01%
2000	-2,138	-1,330	-3,468	-0.04%
2005	-3,697	-2,676	-6,374	-0.07%
2010	-4,768	-3,881	-8,649	-0.10%
2015	-4,856	-5,071	-9,927	-0.13%
2020	-4,162	-6,025	-10,187	-0.15%
2025	-3,120	-6,370	-9,490	-0.16%
2030	-2,266	-6,479	-8,745	-0.18%

Cumulative SO2 reduction, 1996-2030 = -269,787 tons

NOx Reduction (in Tons)

Year	Abated from Power Plant Generation	Abated from In-Home Generation	Net Change	%U.S. NOx Power Plant Emissions
1996	-576	181	-395	0.00%
2000	-1,591	487	-1,104	-0.02%
2005	-2,975	784	-2,191	-0.03%
2010	-4,144	992	-3,152	-0.04%
2015	-4,502	1,081	-3,422	-0.05%
2020	-4,162	915	-3,246	-0.05%
2025	-3,419	673	-2,746	-0.04%
2030	-2,786	454	-2,332	-0.04%

Cumulative NOx reduction, 1996-2030 = -87,340 tons

APPENDIX A. ENGINEERING ANALYSIS - SUPPORTING DOCUMENTATION

A.1 CALCULATION METHOD FOR DETERMINING THE AVERAGE ANNUAL AUXILIARY ELECTRICAL CONSUMPTION (E_{AE}), THE AVERAGE ANNUAL FUEL ENERGY CONSUMPTION (E_F), AND THE BURNER OPERATING HOURS (BOH)

The new proposed DOE test procedure provides a new energy descriptor to rate direct heating equipment. The new energy descriptor, the annual efficiency (AE), is represented by Eq. 1.

$$AE = * [(E_F) (AFUE / 100) + 3413 (P_E) (BOH)] / [E_F + 3413 (F) (E_{AE})] \quad (1)$$

where E_{AE} = average annual auxiliary electrical consumption, *kWh*,
 E_F = average annual fuel energy consumption, *Btu*,
 $AFUE$ = Annual Fuel Utilization Efficiency, *percent*,
 P_E = auxiliary electrical energy input rate, *kW*,
 BOH = national average number of burner operating hours, *hours*, and
 F = the ratio of the energy consumed at the source of electrical generation to the electrical energy delivered at the direct heater, 3.37.

Before the annual efficiency can be established, the average annual fuel energy consumption (E_F) and the average annual auxiliary electrical energy consumption (E_{AE}) must first be determined. In order to calculate the annual gas and electrical energy consumptions, DOE has taken the equations that are used for determining these quantities from the DOE test procedure for central furnaces and boilers and modified them so that they are applicable to direct heating equipment. For determining the annual fuel energy consumption, Eq. 2 is used. For determining the annual auxiliary electrical energy consumption, Eq. 3 is used.

$$E_F = BOH (Q_{in} - Q_p) + 8760 (Q_p) \quad (2)$$

$$E_{AE} = BOH (P_E) \quad (3)$$

As evidenced by the above equations, the annual gas and electrical energy consumptions are a function of the burner operating hours (*BOH*). There are two different methods for calculating the *BOH* depending on whether the heater is equipped with single-stage or multi-stage (i.e., two-stage or modulating) controls. Most direct heating equipment is equipped with single-stage (or manual) controls and the *BOHs* are calculated by using the following equation.

$$BOH_{ss} = 1416 (A_F) (A) (DHR) - 1416 (B) \quad (4)$$

where

	1416	=	national average heating load hours for direct heaters based on 2,950 degree days and 15 °F outdoor design temperature,
A_F	=	0.6858, adjustment factor to adjust the calculated design heating requirement and heating load hours to the actual heating load experienced by the heating system,	
DHR	=	typical design heating requirements based on Q_{OUT} ,	
Q_{OUT}	=	$[(n_{ss} / 100) - C_J (L_J / 100)] (Q_{in})$,	
L_J	=	jacket loss for floor furnaces; $C_J = 2.8$, adjustment factor for jacket losses,	
A	=	$100000 / [341300 (P_E) + (Q_{in} - Q_P) (n_u)]$,	
B	=	$2.938 (Q_P) (n_u) (A) / 100000$, and	
2.938	=	$(4610/1416)$ = ratio of the average length of the heating season in hours to the average heating load hours.	

The part-load fuel-utilization efficiency (n_u) is necessary for calculating the factors "A" and "B" and is determined differently depending on which of the three methods in the DOE test procedure is used for establishing the AFUE. If the heater is tested according to the "short-cut" method, Eq. 5 is used for calculating n_u .

$$AFUE = 2950 n_{ss} n_u Q_{in} / [(2950 n_{ss} Q_{in}) + (2.083 (4600)n_u Q_P)] \quad (5)$$

Eq. 5 simply needs to be algebraically manipulated so that the part-load fuel utilization efficiency is being solved for instead of the AFUE. For the other two methods of establishing the AFUE (i.e., the method for heaters equipped with manual controls and the tracer gas method), the current DOE test procedure provides details on how n_u is measured (24).

For heaters equipped with two-stage or modulating controls, the *BOH* is the sum of the burner hours at the reduced operating mode (BOH_R) and the maximum operating mode (BOH_H). For the reduced operating mode, the burner operating hours are determined by using Eq. 6.

$$BOH_R = X_1 E_M / Q_{red-in} \quad (6)$$

The burner operating hours for the maximum operating mode are calculating by using Eq. 7.

$$BOH_H = X_2 E_M / Q_{in} \quad (7)$$

In the above equations, X_1 and X_2 represent the fraction of the heating load that occurs at the reduced and maximum operating modes, respectively. Tables are provided in the current DOE test procedure for establishing their values. The term E_M is the average annual energy used during the heating season and is represented by Eq. 8.

$$E_M = BOH_{ss} (Q_{in} - Q_p) + (8760 - 4600) (Q_p) \quad (8)$$

The single stage burner operating hours (BOH_{ss}) referred to in Eq. 8 are the same hours as defined in Eq. 4. In order to be applicable for the case of multi-stage burners, the term P_E in the factor "A" is increased by the factor "R." Thus, the equation for factor "A" is now represented by Eq. 9.

$$A = 100000 / [341300 (P_E) (R) + (Q_{in} - Q_p) (n_u)] \quad (9)$$

The factor "R" accounts for the additional hours of operation that occur as a result of having either two-stage or modulating capability. For two-stage controls, "R" is always equal to 1.3. For modulating controls, where the ratio of the reduced-to-maximum fuel input rate is 50%, "R" equals 1.7.

A.2 MANUFACTURER COST DATA FOR DIRECT HEATING EQUIPMENT

The following tables show the total manufacturing costs (1990\$) for several design options for 16 product classes of direct heating equipment. Total costs are divided into variable and capital costs. Variable costs consist of material costs, purchased parts, labor costs, shipping costs, and a portion of indirect costs. Capital costs consist of tooling costs and a portion of indirect costs. Indirect costs include expenses such as general and administrative costs, research and development, rent, utility costs, and certification tests and fees. With the exception of the baseline costs, the disaggregated costs and total incremental costs are always relative to the preceding design option. The incremental costs for each design option are per unit produced. The total costs at each design option, including the baseline, are cumulative. The estimated uncertainty (at a 95% confidence level) for the total costs are provided for each design option.

Table A.1 Total Manufacturing Costs for Direct Heating Equipment (by Design Option)

Fan Wall Heater up to 42,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
1,2,3	0	Baseline	124.20	20.00	0.00	5.20	35.50	-	184.90	-
	1	0 + Electronic Ignition	21.00	0.90	0.20	0.00	1.80	23.90	208.80	5%
4	2	1 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	230.40	15%
	3	2 + Increase HX Size	25.30	5.00	5.90	2.90	8.80	47.90	278.30	20%
	4	2 + Derate 20%	2.60	0.00	5.90	0.00	0.30	8.80	239.20	10%
	5	1 + Burner Box Damper	20.00	5.00	5.90	0.00	8.80	39.70	248.50	20%
	6	1 + Induced Draft	83.00	5.00	5.90	0.00	8.80	102.70	311.50	15%
5	7	6 + Condense Flue Gases	86.90	1.00	2.70	2.01	1.80	94.40	405.90	15%
	8	7 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	479.70	20%
	9	7 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	611.90	20%

Fan Wall Heater over 42,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
1,2,3	0	Baseline	138.00	22.50	0.00	5.80	39.30	-	205.60	-
	1	0 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	227.20	15%
4	2	1 + Electronic Ignition	21.00	0.90	0.30	0.00	1.80	24.00	251.20	5%
	3	2 + Increase HX Size	25.30	5.60	6.50	3.10	9.60	50.10	301.30	20%
	4	2 + Derate 20%	2.90	0.00	6.50	0.00	0.40	9.80	261.00	10%
	5	0 + Burner Box Damper	20.00	5.60	6.50	0.00	9.60	41.70	247.30	20%
	6	0 + Electronic Ignition	21.00	0.90	0.30	0.00	1.80	24.00	229.60	5%
	7	6 + Induced Draft	83.00	5.60	6.50	0.00	9.60	104.70	334.30	15%
5	8	7 + Condense Flue Gases	96.70	1.20	2.80	2.20	2.10	105.00	439.30	15%
	9	8 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	513.10	20%
	10	8 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	645.30	20%

Gravity Wall Heater up to 10,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
1,2	0	Baseline	66.10	10.40	0.00	2.10	18.50	-	97.10	-
	1	0 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	107.70	5%
3,4	2	1 + Derate 20%	1.79	0.00	8.30	0.00	0.32	10.40	118.10	10%
	3	2 + Burner Box Damper	20.00	1.60	8.30	0.00	2.60	32.50	150.60	20%
	4	1 + Increase HX Size	15.30	1.60	8.30	0.90	2.60	28.70	136.40	20%
	5	2 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	139.71	15%
	6	1 + Induced Draft	110.00	1.60	8.30	0.00	5.20	125.10	232.80	15%
5	7	6 + Condense Flue Gases	11.50	5.20	8.30	1.00	9.10	35.10	267.90	15%
	8	7 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	341.70	20%
	9	7 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	473.90	20%

Gravity Wall Heater over 10,000 up to 12,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	68.40	11.90	0.00	2.30	20.80	-	103.40	-
1,2	1	0 + Derate 20%	1.70	0.00	6.20	0.00	0.30	8.20	111.60	10%
3	2	1 + Electronic Ignition	7.50	0.90	0.30	0.00	1.80	10.50	122.10	5%
4	3	2 + Burner Box Damper	20.00	1.50	6.20	0.00	2.60	30.30	152.40	20%
	4	0 + Increase HX Size	15.30	1.50	6.20	0.90	2.60	26.50	129.90	20%
	5	2 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	143.70	15%
	6	0 + Electronic Ignition	7.50	0.90	0.30	0.00	1.80	10.50	113.90	5%
	7	6 + Induced Draft	110.00	1.50	6.20	0.00	5.20	122.90	236.80	15%
5	8	7 + Condense Flue Gases	12.30	5.10	6.20	1.00	9.20	33.80	270.60	15%
	9	8 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	344.40	20%
	10	8 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	476.60	20%

Gravity Wall Heater over 12,000 up to 15,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	70.80	13.10	0.00	2.80	23.20	-	109.90	-
1,2	1	0 + Derate 20%	1.70	0.00	4.10	0.00	0.30	6.10	116.00	10%
3	2	1 + Electronic Ignition	7.50	0.90	0.30	0.00	1.80	10.50	126.50	5%
4	3	2 + Burner Box Damper	20.00	1.40	4.10	0.00	2.70	28.20	154.70	20%
	4	0 + Increase HX Size	15.30	1.40	4.10	0.90	2.70	24.40	134.30	20%
	5	2 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	148.10	15%
	6	0 + Electronic Ignition	7.50	0.90	0.30	0.00	1.80	10.50	120.40	5%
	7	6 + Induced Draft	110.00	1.40	4.10	0.00	5.40	120.90	241.30	15%
5	8	7 + Condense Flue Gases	22.80	5.10	4.10	1.10	9.10	42.20	283.50	15%
	9	8 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	357.30	20%
	10	8 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	489.50	20%

Gravity Wall Heater over 15,000 up to 19,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	85.60	14.50	0.00	3.20	25.60	-	128.90	-
1,2	1	0 + Derate 20%	2.10	0.00	6.10	0.00	0.40	8.60	137.50	10%
3	2	1 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	148.10	5%
	3	2 + Burner Box Damper	20.00	1.90	6.10	0.00	3.60	31.60	179.70	20%
	4	0 + Increase HX Size	19.00	1.90	6.10	1.30	3.60	31.90	160.80	20%
	5	2 + Vent Damper	21.59	0.00	0.00	0.00	0.00	21.59	169.70	15%
	6	0 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	139.50	5%
4	7	6 + Induced Draft	120.00	1.90	6.10	0.00	7.20	135.20	274.70	15%
5	8	7 + Condense Flue Gases	34.50	4.60	6.10	1.30	8.30	54.80	329.50	15%
	9	8 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	403.30	20%
	10	8 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	535.50	20%

Gravity Wall Heater over 19,000 up to 27,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	100.50	16.10	0.00	3.50	28.00	-	148.10	-
1	1	0 + Derate 20%	2.50	0.00	8.00	0.00	0.40	10.90	159.00	10%
2	2	1 + Electronic Ignition	7.50	0.90	0.60	0.00	1.80	10.80	169.80	5%
3	3	2 + Burner Box Damper	20.00	2.40	8.00	0.00	4.30	34.70	204.50	20%
	4	0 + Increase HX Size	22.80	2.40	8.00	1.40	4.30	38.90	187.00	20%
	5	2 + Vent Damper	21.59	0.00	0.00	0.00	0.00	21.59	191.40	15%
	6	0 + Electronic Ignition	7.50	0.90	0.60	0.00	1.80	10.80	158.90	5%
4	7	6 + Induced Draft	130.00	2.40	8.00	0.00	8.60	149.00	307.90	15%
5	8	7 + Condense Flue Gases	46.00	4.10	8.00	1.60	7.30	67.00	374.90	15%
	9	8 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	448.70	20%
	10	8 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	580.90	20%

Gravity Wall Heater over 27,000 up to 46,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	103.00	17.20	0.00	3.90	30.10	-	154.20	-
1	1	0 + Derate 20%	2.60	0.00	5.70	0.00	0.30	8.60	162.80	10%
2	2	1 + Electronic Ignition	7.50	0.90	0.30	0.00	1.80	10.50	173.30	5%
3	3	2 + Burner Box Damper	20.00	2.60	5.70	0.00	4.40	32.70	206.00	20%
	4	0 + Increase HX Size	22.80	2.60	5.70	1.40	4.40	36.90	191.10	20%
	5	2 + Vent Damper	21.59	0.00	0.00	0.00	0.00	21.59	194.89	15%
	6	0 + Electronic Ignition	7.50	0.90	0.30	0.00	1.80	10.50	164.70	5%
4	7	6 + Induced Draft	130.00	2.60	5.70	0.00	8.80	147.10	311.80	15%
5	8	7 + Condense Flue Gases	51.40	4.10	5.70	1.70	7.20	70.10	381.90	15%
	9	8 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	455.70	20%
	10	8 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	587.90	20%

Gravity Wall Heater over 46,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	121.90	28.30	0.00	6.10	49.90	-	206.20	-
1	1	0 + Derate 20%	3.00	0.00	5.50	0.00	0.60	9.10	215.30	15%
	2	1 + Vent Damper	21.59	0.00	0.00	0.00	0.00	21.59	236.90	15%
2	3	2 + Electronic Ignition	7.50	0.90	0.60	0.00	1.80	10.80	247.70	5%
	4	0 + Increase HX Size	18.30	4.90	5.50	1.30	8.90	38.90	245.10	20%
	5	1 + Electronic Ignition	7.50	0.90	0.60	0.00	1.80	10.80	226.10	5%
3	6	5 + Burner Box Damper	20.00	4.90	5.50	0.00	8.90	39.30	265.40	20%
	7	0 + Electronic Ignition	7.50	0.90	0.60	0.00	1.80	10.80	217.00	5%
4	8	7 + Induced Draft	93.00	4.90	5.50	0.00	8.90	112.30	329.30	15%
	9	8 + Ind Draft Redesign	57.00	0.00	0.00	0.00	8.90	65.90	395.20	15%
	10	9 + Condense Flue Gases	86.70	1.60	5.50	2.20	2.90	98.90	494.10	15%
5	11	10 +Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	567.90	20%
	12	10 +Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	700.10	20%

Floor Heater up to 37,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	104.40	15.60	0.00	6.60	27.50	-	154.10	-
1	1	0 + Derate 20%	2.10	0.00	8.10	0.00	0.40	10.60	164.70	10%
2	2	1 + Electronic Ignition	7.50	0.90	0.70	0.00	1.80	10.90	175.60	5%
3	3	2 + Burner Box Damper	20.00	2.20	8.10	0.00	4.10	34.40	210.00	20%
	4	0 + Increase HX Size	25.30	2.20	8.10	2.00	4.10	41.70	195.80	20%
	5	2 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	197.20	15%
	6	0 + Electronic Ignition	7.50	0.90	0.70	0.00	1.80	10.90	165.00	5%
	7	6 + Induced Draft	36.00	3.00	0.00	0.00	4.10	43.10	208.10	15%
4	8	7 + Ind Draft Redesign	94.00	2.20	16.20	2.00	8.20	122.60	330.70	15%
	9	8 + Increase Insulation	12.00	0.00	0.00	0.00	0.00	12.00	342.70	10%
5	10	9 + Condense Flue Gases	71.90	1.30	8.00	2.20	3.80	87.20	429.90	15%
	11	10 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	503.70	20%
	12	10 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	635.90	20%

Floor Heater over 37,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	143.00	15.60	0.00	6.80	30.90	-	196.30	-
	1	0 + Derate 20%	2.80	0.00	12.80	0.00	0.40	16.00	212.30	10%
1	2	1 + Burner Box Damper	20.00	2.40	12.80	0.00	4.40	39.60	251.90	20%
2,3	3	2 + Electronic Ignition	7.50	0.90	0.60	0.00	1.80	10.80	262.70	5%
	4	0 + Increase HX Size	25.30	2.40	12.80	2.40	4.40	47.30	243.60	20%
	5	1 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	233.90	15%
	6	0 + Induced Draft	22.50	3.00	0.00	0.00	4.40	29.90	226.20	15%
	7	6 + Ind Draft Redesign	94.00	2.40	25.60	2.40	8.80	133.20	359.40	15%
	8	7 + Electronic Ignition	21.00	0.90	0.60	0.00	1.80	24.30	383.70	5%
4	9	8 + Increase Insulation	12.00	0.00	0.00	0.00	0.00	12.00	395.70	10%
5	10	9 + Condense Flue Gases	110.50	1.10	13.00	2.20	3.10	129.90	525.60	15%
	11	10 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	599.40	20%
	12	10 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	731.60	20%

Room Heater up to 18,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	65.60	20.90	0.00	2.40	36.80	-	125.70	-
1	1	0 + Derate 20%	1.60	0.00	7.40	0.00	0.50	9.50	135.20	10%
2,3	2	1 + Electronic Ignition	7.50	0.90	0.80	0.00	1.80	11.00	146.20	5%
	3	2 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	167.80	15%
	4	0 + Increase HX Size	25.30	2.50	9.90	0.90	4.30	42.90	168.60	20%
4	5	2 + Burner Box Damper	20.00	2.50	9.90	0.00	4.30	36.70	182.90	20%
	6	0 + Electronic Ignition	7.50	0.90	0.80	0.00	1.80	11.00	136.70	5%
	7	6 + Induced Draft	36.00	3.00	0.00	0.00	4.40	43.40	180.10	15%
	8	7 + Ind Draft Redesign	94.00	2.50	19.80	0.90	8.70	125.90	306.00	15%
5	9	8 + Condense Flue Gases	45.60	1.30	9.90	1.40	3.10	61.30	367.30	15%
	10	9 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	441.10	20%
	11	9 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	573.30	20%

Room Heater over 18,000 up to 20,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	73.90	21.20	0.00	3.00	36.90	-	135.00	-
	1	0 + Derate 20%	1.80	0.00	8.00	0.00	0.50	10.31	145.31	10%
1	2	1 + Electronic Ignition	7.50	0.90	0.80	0.00	1.80	11.00	156.31	5%
2	3	2 + Vent Damper	21.59	0.00	0.00	0.00	0.00	21.59	177.90	15%
	4	0 + Increase HX Size	25.30	2.60	10.50	1.30	4.40	44.10	179.10	20%
3	5	2 + Burner Box Damper	20.00	2.60	10.50	0.00	4.40	37.50	193.81	20%
	6	0 + Electronic Ignition	7.50	0.90	0.80	0.00	1.80	11.00	146.00	5%
	7	6 + Induced Draft	36.00	3.00	0.00	0.00	4.40	43.40	189.40	15%
4	8	7 + Ind Draft Redesign	94.00	2.60	21.00	1.30	8.80	127.70	317.10	15%
5	9	8 + Condense Flue Gases	54.30	1.20	10.70	1.50	3.10	70.80	387.90	15%
	10	9 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	461.70	20%
	11	9 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	593.90	20%

Room Heater over 20,000 up to 27,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	83.10	21.20	0.00	4.20	37.20	-	145.70	-
1,2,3	1	0 + Derate 20%	2.03	0.00	8.60	0.00	0.51	11.14	156.84	10%
	2	1 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	167.44	5%
	3	2 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	189.04	15%
	4	0 + Increase HX Size	25.30	2.50	11.50	1.90	4.40	45.60	191.30	20%
	5	2 + Burner Box Damper	20.00	2.50	11.50	0.00	4.40	38.40	205.84	20%
	6	0 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	156.30	5%
	7	6 + Induced Draft	36.00	3.00	0.00	0.00	4.40	43.40	199.70	15%
4	8	7 + Air Circulation Fan	33.00	2.50	11.50	1.90	4.40	53.30	253.00	15%
5	9	8 + Condense Flue Gases	63.80	1.20	11.50	1.60	3.00	81.10	334.10	15%
	10	9 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	407.90	20%
	11	9 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	540.10	20%

Room Heater over 27,000 up to 46,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	92.60	21.10	0.00	5.20	37.60	-	156.50	-
1	1	0 + Derate 20%	2.30	0.00	9.20	0.00	0.40	11.90	168.40	10%
	2	1 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	190.00	15%
2,3	3	2 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	200.60	5%
	4	0 + Increase HX Size	25.30	2.60	12.40	1.40	4.30	46.00	202.50	20%
	5	1 + Burner Box Damper	20.00	2.60	12.40	0.00	4.30	39.30	207.70	20%
	6	0 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	167.10	5%
	7	6 + Induced Draft	36.00	3.00	0.00	0.00	4.30	43.30	210.40	15%
4	8	7 + Air Circulation Fan	33.00	2.60	12.40	1.40	4.30	53.70	264.10	15%
5	9	8 + Condense Flue Gases	73.70	1.20	12.20	1.80	2.80	91.70	355.80	15%
	10	9 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	429.60	20%
	11	9 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	561.80	20%

Room Heater over 46,000 Btu/h

Std. Level	Design No.	Design Options	Mat. Cost	Labor Cost	Tool. Cost	Ship. Cost	Ind. Cost	Total Incr.	Total Cost	Uncert
	0	Baseline	128.80	26.30	0.00	6.20	35.60	-	196.90	-
1	1	0 + Derate 20%	3.30	0.00	11.60	0.00	0.40	15.30	212.20	10%
	2	1 + Vent Damper	21.60	0.00	0.00	0.00	0.00	21.60	233.80	15%
2,3	3	2 + Electronic Ignition	7.50	0.90	0.40	0.00	1.80	10.60	244.40	5%
	4	0 + Increase HX Size	25.30	2.60	15.40	2.50	4.50	50.30	247.20	20%
	5	1 + Burner Box Damper	20.00	2.60	15.40	0.00	4.50	42.50	254.70	20%
	6	0 + Induced Draft	22.50	3.00	0.00	0.00	4.50	30.00	226.90	15%
	7	6 + Electronic Ignition	21.00	0.90	0.40	0.00	1.80	24.10	251.00	5%
4	8	7 + Air Circulation Fan	33.00	2.60	15.40	2.50	4.50	58.00	309.00	15%
5	9	8 + Condense Flue Gases	110.70	1.10	15.40	2.10	2.90	132.20	441.20	15%
	10	9 + Two-Stage Operation	55.00	17.60	1.20	0.00	0.00	73.80	515.00	20%
	11	9 + Modulating Operation	204.00	2.00	0.00	0.00	0.00	206.00	647.20	20%

APPENDIX B. LBL-REM INPUT DATA: DIRECT HEATING EQUIPMENT

The complete input listing is available on electronic medium in ASCII format. The input database includes demographic, economic, and engineering data.

The following is the regular LBL-REM input for direct heating equipment.

For standards cases, simply replace the input values for two variables in each class of each product regulated. The two variables are labelled: "first year for standard" and "UEC of standard." For example, for room heater standards taking effect in 1996, change the lines "first year for standard = 2031" to "first year for standard = 1996" and enter the appropriate maximum UEC values in the lines "UEC of standard" for each class.

ROOM HEAT

```
total saturation      = 1.00
elec price multiplier = 0.90
gas price multiplier  = 0.98
ncalc                = 2
ndr1 (1, read drate & curve) = 1
nv1 (# of eun inputs) = 1
nv5 (# of cap inputs) = 0
nv2 (# of peq inputs) = 0
nv4 (# of usage inputs) = 0
ndis (year to forecast eff) = 11
nv3 (# of ti inputs)  = 3
```

----- UEC of stock unit in base year by fuel type i (MMBTU/yr) -----

1	2	3	4	5	
115.88	38.19	60.75	0.00	0.00	** SF **
115.88	38.19	60.75	0.00	0.00	** MF **
115.88	38.19	60.75	0.00	0.00	** MB **

----- Purchase price of a reference unit (\$1990) -----

1	2	3	4	5	
985.02	1014.42	1477.55	0.00	0.00	** SF **
985.02	1014.42	1477.55	0.00	0.00	** MF **
985.02	1014.42	1477.55	0.00	0.00	** MB **

----- Relative UEC and Capacity of a reference unit to a stock unit -----

1	2	3	4	5	
1.0000	1.0000	1.0000	1.0000	1.0000	** re **
1.0000	1.0000	1.0000	1.0000	1.0000	** recap**

```

----- Base Year Saturations - c70 -----
      1      2      3      4      5      6
    0.130  0.700  0.070  0.000  0.000  0.100      ** SF **
    0.240  0.700  0.025  0.000  0.000  0.035      ** MF **
    0.220  0.000  0.130  0.000  0.000  0.650      ** MB **

----- Marginal Saturations for Replacement Units - cn(m=1) -----
      1      2      3      4      5      6
    0.200  0.340  0.070  0.000  0.000  0.390      ** SF **
    0.560  0.340  0.015  0.000  0.000  0.085      ** MF **
    0.240  0.000  0.130  0.000  0.000  0.630      ** MB **

----- Marginal Saturations for New Houses - cn(m=2) -----
      1      2      3      4      5      6
    0.400  0.100  0.030  0.000  0.000  0.470      ** SF **
    0.800  0.120  0.000  0.000  0.000  0.080      ** MF **
    0.150  0.000  0.080  0.000  0.000  0.770      ** MB **

----- Historical Shipments (from 1980 to 30 years back) -----
1 Electric Room Heater (large)
    0.655  0.550  0.356  0.469  0.429  0.346  0.245  0.155  0.140  0.140
    0.140  0.140  0.140  0.090  0.090  0.090  0.090  0.090  0.050  0.050
    0.050  0.050  0.050  0.030  0.030  0.030  0.030  0.030  0.020  0.020
2 Gas Room Heater (large)
    0.426  0.409  0.384  0.409  .4229  .4438  .5624  .7485  .8451  .5799
    0.781  1.043  0.974  0.920  1.034  0.994  1.190  1.324  1.161  1.067
    1.211  1.446  1.485  1.440  1.699  1.729  1.432  1.674  1.786  1.897
3 Oil Room Heater (large)
    0.043  0.045  0.037  0.041  0.055  0.060  0.053  0.048  0.048  0.047
    0.045  0.047  0.049  0.046  0.035  0.033  0.034  0.042  0.047  0.047
    0.050  0.060  0.064  0.057  0.056  0.043  0.021  0.025  0.013  0.009

----- Retirement Function (from age 1 to 30 years) -----
for i 1 2
    .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0380
    .0690  .0930  .1110  .1210  .1240  .1210  .1110  .0930  .0690  .0380
    .0120  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000
for i 3
    .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0380
    .0700  .0950  .1120  .1230  .1260  .1230  .1120  .0950  .0700  .0360
    .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000  .0000

----- Average Life Times (by fuel type i) -----
      1      2      3      4      5
    15.0  15.0  15.0   0.0   0.0

----- Operating Cost Elasticities (for 5 fuel types and income) -----
      1      2      3      4      5      6
    -1.00  0.20  0.10  0.00  0.00  0.00      ** j=1 **
     0.25 -0.65  0.55  0.00  0.00  0.00      ** j=2 **
     0.25  0.20 -0.60  0.00  0.00  0.00      ** j=3 **

```

0.25	0.00	0.15	0.00	0.00	0.00	** j=4 **
0.00	0.00	0.00	0.00	0.00	0.00	** j=5 **
0.15	0.25	-0.20	0.00	0.00	-0.90	** j=6 **

----- Real Interest Rate for calc of Price Elast. (for 5 fuel types) -----

1	2	3	4	5	
0.08	0.11	0.11	0.00	0.00	** j=1 **
0.11	0.08	0.11	0.00	0.00	** j=2 **
0.11	0.11	0.08	0.00	0.00	** j=3 **
0.11	0.11	0.11	0.00	0.00	** j=4 **
0.00	0.00	0.00	0.00	0.00	** j=5 **

----- Usage Elasticities (for 5 fuel types and income) -----

1	2	3	4	5	
-0.30	0.00	0.00	0.00	0.00	** j=1 **
0.00	-0.30	0.00	0.00	0.00	** j=2 **
0.00	0.00	-0.30	0.00	0.00	** j=3 **
0.00	0.00	0.00	0.00	0.00	** j=4 **
0.00	0.00	0.00	0.00	0.00	** j=5 **
0.10	0.10	0.10	0.00	0.00	** j=6 **

----- Discount Rates for Replacement Units (m=1) -----

1	2	3	4	5	
0.0000	1.4800	3.3230	0.0000	0.0000	** SF **
0.0000	1.2390	4.8800	0.0000	0.0000	** MF **
0.0000	1.1740	2.6110	0.0000	0.0000	** MB **

----- Discount Rates for New Units (m=2) -----

1	2	3	4	5	
0.0000	1.2610	3.3230	0.0000	0.0000	** SF **
0.0000	1.1030	3.8610	0.0000	0.0000	** MF **
0.0000	0.8680	1.6830	0.0000	0.0000	** MB **

----- Cost-Efficiency Curve Parameters -----

1	2	3	4	5	
0.6133	0.6846	0.7522	0.0000	0.0000	** einf **
2.9350	4.5210	11.9680	0.0000	0.0000	** calfa **

----- Thermal Integrity of Stock Units in base year -----

1	2	3	4	5	
0.957	0.971	0.972	1.000	1.000	** SF **
0.983	0.994	0.992	1.000	1.000	** MF **
0.807	0.968	0.987	1.000	1.000	** MB **

----- Historical Relative Energy Use (eun) for New Units -----

i	1	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

of products in direct heat = 1


```
=====
product type id#      = 11
product name          = DH (Direct Heating)
end-use id#           = 2
fuel type id#         = 2
number of classes     = 16
```

```
----- the 1st class -----
class id#             = 51
class name             = W<42 (Fan wall heater up to 42 kBtu)
discount rate         = .07
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard       = 287.91
conversion (Kwh-MMBTU&usage) = 1.000
```

```
----- Historical energy factors
1981  1982  1983  1984  1985  1986  1987  1988  1989
0.722 0.722 0.722 0.722 0.722 0.722 0.722 0.722 0.722
```

```
----- Adjusted volumes (1981-2030) (35.76*.722/365)
0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074
0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074
0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074 0.07074
0.07074 0.07074 0.07074 0.07074 0.07074
```

```
----- Fraction of market share (1981-2030)
l = 1 2 3
.0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070
.0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070
.0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070 .0070
.0070 .0070 .0070 .0070 .0070
```

```
----- UEC (Kwh) & Purchase Price ($1990) data
Price MMBtu MMBtu
1149.12 35.76 0.2031
1253.95 34.34 0.2231
1339.55 33.33 0.2167
1592.20 32.55 0.3504
1977.20 27.83 0.2996
```

```
----- Shipment Distribution
EFF Units
73.0 3.0
73.3 4.0
74.6 1.0
74.8 3.0
75.4 3.0
75.5 1.0
75.6 6.0
76.5 2.0
```

77.0	1.0
77.5	1.0
91.4	1.0

----- the 2nd class -----

class id# = 52
class name = W>42 (Fan wall heater over 42 kBtu)
discount rate = .07
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734	0.734

----- Adjusted volumes (1981-2030) (48.41*.734/365)

0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735
0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735
0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735
0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735	0.09735

----- Fraction of market share (1981-2030)

1 = 1 2 3

.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810
.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810
.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810	.0810
.0810	.0810	.0810	.0810	.0810					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
1221.21	48.41	0.2037
1306.44	47.02	0.1976
1327.39	47.00	0.2221
1392.47	45.64	0.2156
1672.98	44.97	0.3521
2079.29	38.43	0.3009

----- Shipment Distribution

EFF	Units
74.0	7.0
74.1	4.0
74.2	4.0
74.3	6.0
75.0	4.0
76.0	6.0
76.5	2.0
77.5	2.0

----- the 3rd class -----

class id# = 53
class name = F<37 (Floor Furnace up to 37 kBtu)
discount rate = .26
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.560	0.560	0.560	0.560	0.560	0.560	0.560	0.560	0.560

----- Adjusted volumes (1981-2030) (26.87*.56/365)

0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123
0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123
0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123
0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123	0.04123

----- Fraction of market share (1981-2030)

1	2	3
.0470	.0470	.0470
.0470	.0470	.0470
.0470	.0470	.0470
.0470	.0470	.0470

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
1337.83	26.87	0.0000
1388.39	24.53	0.0000
1445.03	23.05	0.0532
1596.48	21.91	0.1651
1564.78	20.45	0.0471
1965.79	18.33	0.2631
2005.58	18.10	0.2600
2431.62	15.69	0.2252

----- Shipment Distribution

EFF	Units
56.0	4.0
56.8	2.0

----- the 4th class -----

class id# = 54
class name = F>37 (Floor furnace over 37 kBtu)
discount rate = .53
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570

----- Adjusted volumes (1981-2030) (58.01*.57/365)

0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059
0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059
0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059
0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059	0.09059

----- Fraction of market share (1981-2030)

1 = 1 2 3

.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130
.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130
.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130	.0130
.0130	.0130	.0130	.0130	.0130					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
1427.88	58.01	0.0000
1482.26	52.99	0.0000
1608.04	47.76	0.0000
1651.52	46.28	0.0491
1986.40	42.58	0.2504
2053.88	40.89	0.2709
2087.52	40.38	0.2675
2590.93	35.34	0.2341

----- Shipment Distribution

EFF	Units
57.0	11.0
58.1	2.0
60.0	2.0

----- the 5th class -----

class id# = 55
class name = G<10 (Gravity wall heater up to 10 kBtu)
discount rate = .07
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.590	0.590	0.590	0.590	0.590	0.590	0.590	0.590	0.590

----- Adjusted volumes (1981-2030) (9.14*.59/365)

0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477
 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477
 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477 0.01477
 0.01477 0.01477 0.01477 0.01477 0.01477

----- Fraction of market share (1981-2030)

l = 1 2 3

.0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
 .0100 .0100 .0100 .0100 .0100

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
899.84	9.14	0.0000
976.46	7.50	0.0416
1003.18	7.00	0.0485
1400.00	6.05	0.1368
1640.87	5.57	0.1259

----- Shipment Distribution

EFF	Units
59.0	1.0

----- the 6th class -----

class id# = 56
 class name = G<12 (Gravity wall heater 10 to 12 kBtu)
 discount rate = .14
 first year to forecast UEC = 1989
 first year for standard = 2031
 UEC of standard = 287.91
 conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600

----- Adjusted volumes (1981-2030) (12.82*.60/365)

0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107
 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107
 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107 0.02107
 0.02107 0.02107 0.02107 0.02107 0.02107

----- Fraction of market share (1981-2030)

l = 1 2 3

.0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
 .0100 .0100 .0100 .0100 .0100

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
899.71	12.82	0.0000
931.60	11.89	0.0000
974.92	11.25	0.0519
989.48	10.56	0.0607
1105.38	9.80	0.0563
1371.81	9.12	0.1716
1605.47	8.38	0.1576

----- Shipment Distribution

EFF	Units
60.0	1.0

----- the 7th class -----

class id# = 57
class name = G<15 (Gravity wall heater 12 to 15 kBTu)
discount rate = .21
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.610	0.610	0.610	0.610	0.610	0.610	0.610	0.610	0.610

----- Adjusted volumes (1981-2030) (12.80*.61/365)

0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139
0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139
0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139 0.02139
0.02139 0.02139 0.02139 0.02139 0.02139

----- Fraction of market share (1981-2030)

l = 1 2 3
.0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
.0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
.0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100 .0100
.0100 .0100 .0100 .0100 .0100

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
900.24	12.80	0.0000
922.19	11.94	0.0000
971.12	11.19	0.0440
980.32	10.54	0.0522
1089.30	9.79	0.0485
1347.99	9.15	0.1477
1594.26	8.41	0.1358

----- Shipment Distribution

EFF	Units
61.0	2.0
62.0	2.0
63.1	5.0

----- the 8th class -----

class id# = 58
class name = G<19 (Gravity wall heater 15 to 19 kBtu)
discount rate = .21
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.620	0.620	0.620	0.620	0.620	0.620	0.620	0.620	0.620

----- Adjusted volumes (1981-2030) (16.54*.62/365)

0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810
0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810
0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810	0.02810
0.02810	0.02810	0.02810	0.02810	0.02810					

----- Fraction of market share (1981-2030)

1 = 1 2 3

.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100
.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100
.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100
.0100	.0100	.0100	.0100	.0100					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
901.22	16.54	0.0000
928.87	15.46	0.0000
967.84	14.94	0.0433
980.56	14.07	0.0512
1322.33	12.26	0.1457
1601.63	11.26	0.1338

----- Shipment Distribution

EFF	Units
62.0	1.0

----- the 9th class -----

class id# = 59
class name = G<27 (Gravity wall heater 19 to 27 kBtu)
discount rate = .24
first year to forecast UEC = 1989
first year for standard = 2031

UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630

----- Adjusted volumes (1981-2030) (23.87*.63/365)

0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120
0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120
0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120
0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120	0.04120

----- Fraction of market share (1981-2030)

1 = 1 2 3

.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360
.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360
.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360	.1360
.1360	.1360	.1360	.1360	.1360					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
901.38	23.87	0.0000
935.03	22.41	0.0000
963.82	22.31	0.0495
979.84	21.08	0.0583
1066.38	19.60	0.0543
1310.55	18.47	0.1668
1580.77	16.96	0.1532

----- Shipment Distribution

EFF	Units
63.0	15.0
63.2	8.0
63.3	9.0
64.8	5.0
65.0	3.0
68.4	1.0

----- the 10th class -----

class id# = 60
class name = G<46 (Gravity wall heater 27 to 46 kBtu)
discount rate = .41
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640

----- Adjusted volumes (1981-2030) (31.88*.64/365)

0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590
 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590
 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590 0.05590
 0.05590 0.05590 0.05590 0.05590 0.05590

----- Fraction of market share (1981-2030)

l = 1 2 3

.2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190
 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190
 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190 .2190
 .2190 .2190 .2190 .2190 .2190

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
923.52	31.88	0.0000
948.45	30.10	0.0000
997.12	28.77	0.0566
1094.86	26.76	0.0529
1326.06	25.32	0.1634
1614.47	23.25	0.1501

----- Shipment Distribution

EFF	Units
64.0	14.0
64.1	9.0
65.0	3.0
65.6	5.0
67.6	1.0

----- the 11th class -----

class id# = 61
 class name = G>46 (Gravity wall heater over 46 kBtu)
 discount rate = .47
 first year to forecast UEC = 1989
 first year for standard = 2031
 UEC of standard = 287.91
 conversion (Kwh-MMBTU&usage) = 1.000
 640

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.650

----- Adjusted volumes (1981-2030) (45.58*.65/365)

0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742
 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742
 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742 0.07742
 0.07742 0.07742 0.07742 0.07742 0.07742

----- Fraction of market share (1981-2030)

l = 1 2 3

.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680
.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680
.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680	.1680
.1680	.1680	.1680	.1680	.1680					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
1044.80	45.58	0.0000
1072.11	43.33	0.0000
1118.26	42.02	0.0580
1129.70	41.82	0.0000
1174.72	40.52	0.0560
1396.54	39.11	0.1767
1248.51	39.08	0.0539
1531.91	37.12	0.1675
1866.96	34.08	0.1539
2024.80	33.45	0.2986

----- Shipment Distribution

EFF	Units
65.0	11.0
65.1	9.0

----- the 12th class -----

class id# = 62
class name = R<18 (Room heater up to 18 kBtu)
discount rate = .31
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570	0.570

----- Adjusted volumes (1981-2030) (13.41*.57/365)

0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094
0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094
0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094	0.02094
0.02094	0.02094	0.02094	0.02094	0.02094					

----- Fraction of market share (1981-2030)

l = 1 2 3

.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
.0010	.0010	.0010	.0010	.0010					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
656.87	13.41	0.0000
677.97	12.23	0.0000
710.66	12.15	0.0447
721.60	11.14	0.0512
764.93	10.74	0.0495
809.09	10.35	0.0478
1018.58	9.01	0.2586
1255.35	7.73	0.2218

----- Shipment Distribution

EFF	Units
57.0	1.0

----- the 13th class -----

class id# = 63
class name = R<20 (Room heater 18 to 20 kBtu)
discount rate = .40
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580

----- Adjusted volumes (1981-2030) (17.38*.58/365)

0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762
0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762
0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762
0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762	0.02762

----- Fraction of market share (1981-2030)

l = 1 2 3

.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010	.0010
.0010	.0010	.0010	.0010	.0010					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
657.06	17.38	0.0000
678.65	15.86	0.0000
720.43	14.78	0.0512
761.06	14.24	0.0491
800.70	13.74	0.0474
1000.75	12.11	0.2607
1267.12	10.38	0.2235

----- Shipment Distribution

EFF	Units
58.0	6.0
60.0	1.0
67.5	1.0

----- the 14th class -----

class id# = 64
class name = R<27 (Room heater 20 to 27 kBtu)
discount rate = .21
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630

----- Adjusted volumes (1981-2030) (23.67*.63/365)

0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086
0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086
0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086
0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086

----- Fraction of market share (1981-2030)

l = 1 2 3

.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090
.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090
.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090	.0090
.0090	.0090	.0090	.0090	.0090					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
830.58	23.67	0.0000
870.39	22.14	0.0000
897.93	22.49	0.0498
917.44	21.13	0.0583
975.76	20.37	0.0563
1046.21	19.83	0.1791
1155.34	18.38	0.3166
1508.33	15.63	0.2692

----- Shipment Distribution

EFF	Units
63.0	1.0

----- the 15th class -----

class id# = 65
class name = R<46 (Room heater 27 to 46 kBtu)
discount rate = .26
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640	0.640

----- Adjusted volumes (1981-2030) (31.68*.64/365)

0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555
0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555
0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555
0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555	0.05555

----- Fraction of market share (1981-2030)

1 = 1 2 3

.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490
.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490
.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490	.0490
.0490	.0490	.0490	.0490	.0490					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
813.39	31.68	0.0000
852.92	29.83	0.0000
906.93	28.79	0.0000
948.15	27.79	0.0549
1012.73	26.99	0.1744
1112.26	25.09	0.3088
1465.58	21.49	0.2644

----- Shipment Distribution

EFF	Units
64.0	17.0
65.0	1.0
67.1	3.0

----- the 16th class -----

class id# = 66
class name = R>46 (Room heater over 46 kBtu)
discount rate = .17
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 287.91
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.650	0.650

----- Adjusted volumes (1981-2030) (45.48*.65/365)

0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099
0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099
0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099	0.08099
0.08099	0.08099	0.08099	0.08099	0.08099					

----- Fraction of market share (1981-2030)

l = 1 2 3

.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290
.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290
.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290	.2290
.2290	.2290	.2290	.2290	.2290					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	MMBtu
1052.39	45.48	0.0000
1120.32	43.20	0.0000
1181.80	41.68	0.0000
1219.94	40.54	0.0560
1233.72	40.42	0.1607
1283.45	39.18	0.1771
1415.96	36.52	0.3146
1898.77	31.58	0.2719

----- Shipment Distribution

EFF	Units
65.0	34.0
66.4	1.0
66.5	2.0
66.9	1.0
67.4	3.0
68.3	3.0

APPENDIX C. LBL MANUFACTURER IMPACT MODEL: DIRECT HEATING EQUIPMENT

C.1 INTRODUCTION

The Lawrence Berkeley Laboratory Manufacturer Impact Model (LBL-MIM) collects all the calculations necessary to determine the impact of a change in appliance efficiency standards on an industry's profitability and scale of operation into one spreadsheet. Volume A, Appendix C, of this Technical Support Document, provides an overview and description of the LBL-MIM. There is a description of the economic theory and a discussion of each of the model's modules. In this appendix, the LBL-MIM input data and model runs for direct heating equipment are described together.

C.1.1 Engineering Cost Data

The source of the engineering data is the Engineering Analysis performed in Chapter 1 of this volume. The data came from manufacturers of these products and/or discussions with industry consultants and other studies. The engineering data used as inputs to the model consist of several components:

1. The incremental unit variable cost incurred by the manufacturer for each of the design options that increases the efficiency of the appliance, such as raw materials, direct labor, purchased parts, and increased transportation costs. The incremental variable cost is listed for each design option for each product class.
2. The annual unit energy consumption (UEC) associated with each design option for each product class.
3. Some of the design options also require additional capital investment in the form of retooling, new tooling, or other capital expenditures. These expenses are listed as one figure for each design option requiring capital expenditures; the single figure covers all of the product classes.

The engineering input data are also listed for each standards level being analyzed (a 1990 calibration case, a 1996 base case using the 1990 standards, and standards levels 1, 2, 3, etc., which are the new levels being analyzed). The figures used are exactly the same as those used for the design options, but are calculated for standards levels instead. The engineering data used as inputs to the LBL-MIM are listed on the engineering data page of the model, which follows this section. The actual data are listed there rather than here since there are several tables of

data. For a thorough description of the collection and meaning of the engineering data, see the Engineering Analysis.

C.1.2 Industry Market Data

Industry Shipments

These data include annual industry shipments for the 1990 calibration case, the 1996 base case (using the 1990 standards), and the 1996 shipments for each of the standards levels. The 1990 shipments figure is based on statistics from the industry and GAMA.

Elasticities

Price and operating cost elasticities determine the effect on shipments of changes in appliance price and operating cost. For direct heating equipment, the price elasticity is estimated to be -0.33 and the operating cost elasticity -0.20. The source is LBL. Because these elasticities are very important, a sensitivity analysis using different elasticities is done.

Product Class Market Share

Each of the product classes has a share of the total direct heating equipment market, and the market share, or unit sales, for each product class is an input to the model. For direct heating equipment, the market shares range from less than 1% for the smaller capacity room heaters to greater than 20% for the larger capacity wall and room heaters. The data are based on estimates by an industry consultant and are for 1989.

Markups

Manufacturers charge different markups over variable cost for different product classes, resulting in different profit margins for different product classes. For direct heating equipment, the estimated markups range from 1.25 to 1.31 with an average of 1.27. The different markups used in the model are based on data supplied by the industry.

Initial Prices

The 1990 baseline manufacturer's selling price is used as a base to which are added incremental costs of reaching the higher efficiency levels. The unit price quoted for each product class refers to the most inexpensive, fewest-frills model produced by the manufacturer. The source of the baseline manufacturer's price for each product class is research by the Manufacturer Analysis team with review by industry consultants.

Energy Price

This figure is the ratio of the price of a 1990 kWh to a 1996 kWh. The source is the LBL-REM. Industry market data appear on the Cost, Sales, and Revenues page of the model.

C.1.3 Financial Input Data

Financial Inputs

The financial inputs for direct heating equipment are summarized in Tables C.1 to C.4.

Table C.1 Rates of Financial Costs

Variable	Value	Source
After-tax equity cost of capital ¹	6.8%	MIM calc. from public financial data ²
Interest rate on debt ¹	2.5%	MIM calc. from public financial data
Interest lost in cash ¹	1.0%	MIM calc. from public financial data
Rate of depreciation	17.7%	Public financial data
Tax rate	34.0%	Tax law

¹Cost of capital and interest rate are *real* rather than nominal.

²Public financial data include data from Value Line, Standard and Poor's, Moody's, individual company annual reports, and economic reports.

Table C.2 Other Financial Inputs

Variable	Value	Source
Cash	4.6%	Public financial data
Inventory and receivables	30.7%	Public financial data
Net depreciable assets	15.1%	Public financial data
General and administrative expenses	13.9%	Public financial data
Engineering expense	1.2%	Public financial data and industry sources ¹

¹Industry sources include consultants under contract to LBL and discussions with industry representatives.

Table C.3 Fixed, Variable, and Revenue-Related Cost Split

Variable	Value	Source
Fixed part of all costs and depr. assets	10.0%	Industry sources
Fixed part of one-time capital costs	15.0%	Industry sources
Economic profit	0.0%	MIM est. from financial data
Debt/equity ratio	112.6%	Public financial data
Markup on typical model	1.37	Industry sources
Ratio of highest to lowest markup	1.00	Industry sources

Table C.4 One-Time Costs

Variable	Value	Source
One-time capital cost's life	8 years	Industry sources
One-time capital cost's tax life	8 years	MIM calculation
Percent additional 1-X capital	100%	MIM estimate
Age of replaced capital	6 years	Public financial data

The expenditure schedule above lists the costs incurred over time for preparations to meet the new standards. A percentage of the total cost is attributed to each year before the standards go into effect since that is when these expenses will occur.

C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO

Table C.5 Direct Heating Equipment Version of LBL-MIM

Control Panel

		Scenario: Primary		Standard Level = 1	
DIRECT HEATING EQMT		Input		Vari-	Progrm
CONTROL FACTORS		Value	Cntrl	ation	Value Name
Price Elasticity		-0.300	0.00	100%	-0.300 IPB
Consumer Discount Rate		50.0%	0.00	100%	50.00% RD
Equity Cost of Capital		0.068	0.00	10%	0.068 ECC
Economic Profit		0.008	0.00	1%	0.008 EP
L-R Fixed Part of Costs & Assets		0.098	0.00	50%	0.098 FCA
L-R Fixed Part of 1-X Cap. Cost		0.200	0.00	60%	0.200 FIX
One-Time Capital Costs		0.394	0.00	20%	0.394 CC.N
Unit Variable Cost Increase		\$5.12	0.00	30%	5.124 dVC.N
Elasticity Curve Parameter		0.000	0.00	10%	0.000 ro.N
Short Run Price Response to Demand		0.157	0.00	76%	0.157 SRPR
SUMMARY		NAECA	NEW	PRVIOUS	NEW
		BASE	L-RUN	CHANGE	S-RUN
Shipments	0.07	0.07	0.31%	0.31%	0.07
Price	\$220.16	\$221.65	0.68%	0.68%	\$222.45
Revenue (in \$M)	16.30	16.46	0.99%	0.99%	16.50
Net Income	0.56	0.57	0.00	0.00	0.59
ROE	7.38%	7.39%	0.02%	0.02%	7.64%
		Trys =		2.00	

Table C.6 Direct Heating Equipment Version of LBL-MIM

The Monte Carlo Module

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.

				Secnds/iteration =	1.90	time
				Iterations to go =	0.00	nn
DIRECT HEATING EQMT				Sample Size =	400.00	
	%dQ	%dP	%dR	dNI	dROE.N	dROE.S
Value	0.31%	0.68%	0.99%	0.44%	0.02%	0.27%
Means	-7.99%	112.78%	91.81%	12.01%	-0.27%	18.36%
Std. Dev	45.80%	35.25%	89.70%	138.90%	7.00%	154.89%
History	0.06	1.49	1.65	0.13	0.01	0.06
...	-0.61	1.54	0.00	-0.81	-0.15	1.85
Range	-0.32	1.24	0.52	-0.47	-0.05	-0.19
Name	-0.55	1.30	0.04	-0.34	0.00	-0.48
Is	-0.12	0.86	0.63	-0.12	-0.01	-0.04
Carlo	-0.04	0.62	0.56	0.03	0.00	-0.01
	0.84	0.87	2.45	2.45	0.07	-0.26
	-0.28	0.94	0.40	-0.24	-0.02	-0.05
	-0.09	0.73	0.57	-0.17	-0.02	-0.03
	-0.14	1.44	1.10	0.18	0.04	-0.15
	-0.17	0.94	0.61	-0.16	-0.01	-0.05
	-0.36	1.07	0.32	-0.21	0.00	-0.06
	-0.11	0.65	0.47	-0.17	-0.01	-0.05
	-0.07	0.87	0.74	0.03	0.01	-0.01
	-0.09	0.87	0.71	-0.10	-0.01	-0.07
	-0.19	1.58	1.09	0.16	0.04	-0.11
	-0.04	0.80	0.72	0.17	0.02	0.01
	-0.15	1.43	1.07	0.02	0.02	-0.02
	-0.01	1.27	1.25	0.02	0.00	0.00
	-0.11	1.63	1.33	0.41	0.07	-0.02
	-0.11	0.82	0.62	-0.05	0.00	-0.05
	-0.26	1.11	0.56	-0.04	0.02	-0.01
	0.40	1.57	2.59	1.31	0.07	0.06
	-0.26	1.22	0.65	-0.06	0.01	-0.14
	-0.05	1.10	1.00	0.30	0.04	0.02
	-0.37	1.15	0.35	-0.27	-0.01	-0.08
	-0.28	1.53	0.84	0.98	0.19	0.11
	-0.20	1.68	1.13	0.32	0.07	0.01
	-0.11	1.78	1.47	0.72	0.11	0.06
	-0.37	1.76	0.73	-0.26	-0.02	-0.07
	-0.23	1.10	0.62	-0.22	-0.02	-0.27
	-0.07	1.24	1.09	0.15	0.02	0.00
	-0.35	1.17	0.40	-0.10	0.01	-0.02

Table C.7 Direct Heating Equipment Version of LBL-MIM

The Accounting Module

(All units are millions or millions of \$ unless labeled with \$ or %.)

	1990	BASE '96	NEW '96	CHANGE
Revenue	15.69	16.30	16.46	1.0%
Expenses				
Cost of Goods Sold	12.16	12.70	12.84	1.1%
Selling & G & A	1.93	1.97	1.97	0.2%
Engineering	0.17	0.17	0.17	0.2%
Depreciation	0.54	0.54	0.54	NA
1-X Depreciation	0.00	0.04	0.05	NA
Total Expenses	14.80	15.42	15.57	1.0%
Earnings Before Interest & Taxes	0.89	0.88	0.89	0.9%
Interest	0.04	0.02	0.02	0.1%
Earnings Before Taxes	0.85	0.86	0.87	1.0%
Taxes	0.29	0.30	0.31	1.6%
Net Income	0.56	0.56	0.56	0.6%
Gross Margin	22.48%	22.10%	22.02%	-0.38%
Return on Sales	3.56%	3.42%	3.41%	-0.4%
Total Assets	9.26	9.53	9.59	0.5%
Return on Assets (w/interest taxed)	6.34%	6.01%	6.02%	0.0
Equity	7.41	7.63	7.67	0.5%
Return on Equity	7.55%	7.32%	7.32%	0.0
ECONOMIC ANALYSIS				
	1990	BASE '96	NEW '96	CHANGE
Shipments	0.07	0.07	0.07	0.3%
Price	\$216.36	\$220.16	\$221.65	0.7%
Revenue	15.69	16.30	16.46	1.0%
Fixed Costs	1.54	1.54	1.54	-9.2%
Variable Costs (w/ Q)	13.30	13.86	0.11	-11.5%
Total Expenses	14.84	15.40	1.65	-10.9%
Cash	1.57	1.60	1.61	-10.8%
Inventories	4.71	4.81	4.82	0.3%
Depreciable	-898.45	-865.27	-771.23	-10.9%
Total Assets	9.26	9.53	9.59	0.5%

Table C.8 Direct Heating Equipment Version of LBL-MIM

The Engineering Inputs Module

Increment in Additional UVC by Level and Class													
Baseline	0	1	2	3	4	5	6	7	8	9	10	11	12
FW<42k	174.2	23.16	21.60	39.36	2.81	31.16	94.16	91.16	72.60	206.00			
FW>42k	193.8	21.60	23.16	40.72	3.18	32.32	23.16	95.32	101.57	72.60	206.00		
FF<37k	145.9	2.38	9.66	25.07	32.37	21.60	9.66	41.87	103.94	12.00	78.06	72.60	206.00
FF>37k	187	3.08	25.48	9.66	33.18	21.60	28.58	104.96	23.16	12.00	115.97	72.60	206.00
GW<10k	91.55	9.66	2.01	23.42	19.62	21.60	115.24	24.07	72.60	206.00			
GW10-12k	97.16	1.91	9.66	23.32	19.52	21.60	9.66	115.14	24.84	72.60	206.00		
GW12-15k	102.9	1.91	9.66	23.29	19.49	21.60	9.66	115.18	35.37	72.60	206.00		
GW15-19k	121.2	2.38	9.66	24.42	24.72	21.59	9.66	126.94	46.21	72.60	206.00		
GW19-27k	139.7	2.78	9.66	25.41	29.61	21.59	9.66	138.42	56.81	72.60	206.00		
GW27-46k	145.2	2.78	9.66	25.68	29.88	21.59	9.66	138.76	62.24	72.60	206.00		
GW>46k	191.23	3.42	21.59	9.66	30.73	9.66	31.13	9.66	104.13	63.23	92.53	72.60	206.00
RH<18k	114.7	1.95	9.66	21.60	31.71	25.51	9.66	42.08	103.49	50.47	72.60	206.00	
RH18-20k	123.9	2.15	9.66	21.59	32.28	25.68	9.66	42.08	104.06	59.17	72.60	206.00	
RH20-27k	134.5	2.39	9.66	21.60	32.78	25.58	9.66	42.08	40.48	68.70	72.60	206.00	
RH27-46k	145.2	2.58	21.60	9.66	32.31	25.61	9.66	42.01	40.01	78.66	72.60	206.00	
RH>46k	186.2	3.58	21.60	9.66	33.55	25.75	28.65	23.16	41.25	115.93	72.60	206.00	
VCSE Additional UVC. (Above Level 0 cost.) - There are many branches													
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
FW<42k	0	23	45	84	48	54	117	208	281	414	414	414	414
FW>42k	0	22	45	85	48	32	23	118	220	293	426	426	426
FF<37k	0	2	12	37	32	34	10	52	155	167	246	318	452
FF>37k	0	3	29	38	33	25	29	134	157	169	285	357	491
GW<10k	0	10	12	35	29	33	125	149	222	355	355	355	355
GW10-12k	0	2	12	35	20	33	10	125	150	222	356	356	356
GW12-15k	0	2	12	35	19	33	10	125	160	233	366	366	366
GW15-19k	0	2	12	36	25	34	10	137	183	255	389	389	389
GW19-27k	0	3	12	38	30	34	10	148	205	277	411	411	411
GW27-46k	0	3	12	38	30	34	10	148	211	283	417	417	417
GW>46k	0	3	25	35	31	13	44	10	114	177	270	342	476
RH<18k	0	2	12	33	32	37	10	52	155	206	278	412	412
RH18-20k	0	2	12	33	32	37	10	52	156	215	288	421	421
RH20-27k	0	2	12	34	33	38	10	52	92	161	234	367	367
RH27-46k	0	3	24	34	32	28	10	52	92	170	243	376	376
RH>46k	0	4	25	35	34	29	29	52	93	209	282	415	415

Table C.8 Direct Heating Equipment Version of LBL-MIM

The Engineering Inputs Module (continued)

Energy Consumption - Natural Gas (Primary) in MBTUs													
	0	1	2	3	4	5	6	7	8	9	10	11	12
FW<42k	36	34	33	32	33	33	33	28	27	27			
FW>42k	48	47	46	44	46	47	47	45	38	38	37		
FF<37k	27	25	23	20	26	22	25	22	18	18	16	15	15
FF>37k	58	53	48	46	55	51	51	43	41	40	35	35	34
GW<10k	9	8	7	7	7	7	6	6	5	5			
GW10-12k	13	12	11	10	12	10	11	9	8	8	8		
GW12-15k	13	12	11	10	12	10	11	9	8	8	8		
GW15-19k	17	15	14	13	16	14	15	12	11	11	11		
GW19-27k	24	22	21	20	23	20	22	18	17	17	16		
GW27-46k	32	30	29	27	31	28	30	25	23	23	22		
GW>46k	46	43	42	41	44	42	39	44	39	37	34	33	32.9975
RH<18k	13	12	11	11	13	10	12	11	9	8	7	7	
RH18-20k	17	16	15	14	17	14	16	14	12	10	10	10	
RH20-27k	24	22	21	20	23	20	22	20	18	16	15	15	
RH27-46k	32	30	29	28	30	28	31	27	25	21	21	21	
RH>46k	45	43	42	41	44	41	40	39	37	32	31	30	

Energy Consumption - Electricity (Secondary - in KwHr)												
	0	1	2	3	4	5	6	7	8	9	10	11
FW<42k	59	65	63	62	79	63	103	88	170	218		
FW>42k	60	58	63	62	79	58	65	103	88	171	220	
FF<37k	0	0	16	14	0	15	14	48	77	76	66	127
FF>37k	0	0	0	14	0	0	45	73	79	78	69	133
GW<10k	0	12	14	13	12	14	40	37	71	89		
GW10-12k	0	0	18	17	0	17	15	50	46	89	112	
GW12-15k	0	0	15	14	0	15	13	43	40	76	97	
GW15-19k	0	0	15	14	0	14	13	43	39	76	97	
GW19-27k	0	0	17	16	0	16	14	49	45	87	111	
GW27-46k	0	0	17	15	0	16	14	48	44	85	110	
GW>46k	0	0	0	16	0	17	16	14	52	49	45	88
RH<18k	0	0	15	14	0	14	13	47	76	65	124	156
RH18-20k	0	0	15	14	0	14	13	47	76	65	126	159
RH20-27k	0	0	17	16	0	16	15	53	93	79	152	193
RH27-46k	0	0	0	16	0	0	14	51	90	77	150	191
RH>46k	0	0	0	16	0	0	47	52	92	80	154	198

Table C.8 Direct Heating Equipment Version of LBL-MIM

The Engineering Inputs Module (continued)

Capital cost / unit / 7													
	0	1	2	3	4	5	6	7	8	9	10	11	12
FW<42k	10.65	0.74	0.00	8.54	5.99	8.54	8.54	3.24	1.20	0.00			
FW>42k	11.79	0.00	0.84	9.38	6.62	9.38	0.84	9.38	3.43	1.20	0.00		
FF<37k	8.25	8.22	1.24	9.33	9.33	0.00	1.24	1.23	18.66	0.00	9.14	1.20	0.00
FF>37k	9.27	12.92	14.12	1.14	14.12	0.00	1.32	28.24	1.14	0.00	13.93	1.20	0.00
GW<10k	5.55	0.94	8.40	9.08	9.08	0.00	9.86	11.03	1.20	0.00			
GW10-12k	6.24	6.29	0.84	6.98	6.98	0.00	0.84	7.76	8.96	1.20	0.00		
GW12-15k	6.96	4.19	0.84	4.91	4.91	0.00	0.84	5.72	6.83	1.20	0.00		
GW15-19k	7.68	6.22	0.94	7.18	7.18	0.00	0.94	8.26	8.59	1.20	0.00		
GW19-27k	8.40	8.12	1.14	9.29	9.29	0.00	1.14	10.58	10.19	1.20	0.00		
GW27-46k	9.03	5.82	0.84	7.02	7.02	0.00	0.84	8.34	7.86	1.20	0.00		
GW>46k	14.97	5.68	0.00	1.14	8.17	1.14	8.17	1.14	8.17	2.67	6.37	1.20	0.00
RH<18k	11.04	7.55	1.34	0.00	11.19	11.19	1.34	1.32	22.41	10.83	1.20	0.00	
RH18-20k	11.07	8.15	1.34	0.00	11.82	11.82	1.34	1.32	23.64	11.63	1.20	0.00	
RH20-27k	11.16	8.75	0.94	0.00	12.82	12.82	0.94	1.32	12.82	12.40	1.20	0.00	
RH27-46k	11.28	9.32	0.00	0.94	13.69	13.69	0.94	1.29	13.69	13.04	1.20	0.00	
RH>46k	10.68	11.72	0.00	0.94	16.75	16.75	1.35	0.94	16.75	16.27	1.20	0.00	
CC.E	Additional CC. (Above Level 0 cost.): Lots of Branches												
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
FW<42k	0	1	1	9	7	9	9	13	14	13	13	13	13
FW>42k	0	0	1	10	7	9	1	10	14	15	14	14	14
FF<37k	0	8	9	19	9	9	1	2	21	21	30	31	30
FF>37k	0	13	27	28	14	13	1	30	31	31	45	46	45
GW<10k	0	1	9	18	10	9	11	22	23	22	22	22	22
GW10-12k	0	6	7	14	7	7	1	9	18	19	18	18	18
GW12-15k	0	4	5	10	5	5	1	7	13	15	13	13	13
GW15-19k	0	6	7	14	7	7	1	9	18	19	18	18	18
GW19-27k	0	8	9	19	9	9	1	12	22	23	22	22	22
GW27-46k	0	6	7	14	7	7	1	9	17	18	17	17	17
GW>46k	0	6	6	7	8	7	15	1	9	12	18	20	18
RH<18k	0	8	9	9	11	20	1	3	25	36	37	36	36
RH18-20k	0	8	9	9	12	21	1	3	26	38	39	38	38
RH20-27k	0	9	10	10	13	23	1	2	15	27	29	27	27
RH27-46k	0	9	9	10	14	23	1	2	16	29	30	29	29
RH>46k	0	12	12	13	17	28	1	2	19	35	37	35	35

Table C.9 Direct Heating Equipment Version of LBL-MIM

The Standards Level Module

Levl'n prev	LEV.B	lev.N	Eng:	0 ...	27	"F _{max}	
-1	0	1	REM:	-1 ...	5	"S _{max}	
1	1	1		1 ==> Stndrds	0 ==> Eng.		
SIE	SIE.B	SIE.N	Esc = QUIT				
VCSR							
Additional UVC by Level and Class. (Above Base cost.)							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5
FW<42k	9.88	19.71	19.71	19.71	19.71	50.44	208.48
FW>42k	5.68	8.42	8.42	8.42	8.42	44.76	220.05
FF<37k	0.08	2.78	2.87	12.04	37.11	155.47	245.53
FF>37k	0.23	4.45	28.56	38.22	38.22	168.70	284.67
GW<10k	0.01	9.66	9.66	9.66	11.67	11.67	148.97
GW10-12k	0.00	1.91	1.91	1.91	11.57	34.89	149.64
GW12-15k	0.17	2.51	2.69	2.69	11.57	34.86	160.21
GW15-19k	0.00	2.38	2.38	2.38	12.04	136.60	182.81
GW19-27k	0.41	4.39	4.65	12.56	37.85	148.08	204.89
GW27-46k	0.23	3.64	3.88	12.48	38.12	148.42	210.66
GW>46k	3.19	3.52	3.55	34.68	44.21	113.79	342.15
RH<18k	0.00	1.95	1.95	11.61	11.61	37.12	205.70
RH18-20k	0.93	6.10	14.84	33.73	37.49	155.80	214.97
RH20-27k	0.00	2.39	2.39	2.39	2.39	92.22	160.92
RH27-46k	0.26	5.79	6.06	33.84	33.84	91.68	170.34
RH>46k	0.43	6.75	7.20	34.84	34.84	93.06	208.99
KWS.R							
Kw Hrs /Yr							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5
FW<42k	218	215	215	215	215	205	175
FW>42k	295	294	294	294	294	280	239
FF<37k	162	148	148	140	124	117	100
FF>37k	348	320	288	280	280	250	219
GW<10k	55	46	46	46	43	43	37
GW10-12k	77	72	72	72	65	60	54
GW12-15k	77	72	72	72	65	60	54
GW15-19k	100	93	93	93	86	77	71
GW19-27k	143	135	135	128	120	115	106
GW27-46k	191	182	181	175	163	157	144
GW>46k	262	261	261	246	237	240	209
RH<18k	81	74	74	68	68	64	52
RH18-20k	103	96	90	87	84	79	68
RH20-27k	143	133	133	133	133	118	101
RH27-46k	190	180	179	169	169	159	136
RH>46k	273	261	259	246	246	228	197

Table C.9 Direct Heating Equipment Version of LBL-MIM

The Standards Level Module (continued)

CC.R							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5
FW<42k	0.54	0.83	0.83	0.83	0.83	1.18	12.52
FW>42k	0.05	0.10	0.10	0.10	0.10	0.84	13.65
FF<37k	0.27	7.99	8.28	9.46	18.79	21.13	30.27
FF>37k	0.95	12.78	27.04	28.18	28.18	30.70	44.63
GW<10k	0.00	0.94	0.94	0.94	9.34	9.34	21.83
GW10-12k	0.02	6.29	6.29	6.29	7.13	14.11	17.56
GW12-15k	0.37	3.46	3.85	3.85	5.03	9.94	13.39
GW15-19k	0.00	6.22	6.22	6.22	7.16	9.20	17.79
GW19-27k	0.54	6.55	7.32	9.30	18.55	11.72	21.91
GW27-46k	0.49	5.41	5.92	6.67	13.68	9.18	17.04
GW>46k	5.30	5.65	5.69	6.82	14.99	9.31	19.55
RH<18k	0.01	7.55	7.55	8.89	8.89	20.08	35.90
RH18-20k	1.21	7.59	10.43	10.43	21.31	26.30	37.93
RH20-27k	0.00	8.75	8.75	8.75	8.75	15.08	27.48
RH27-46k	0.92	8.35	9.34	10.26	10.26	15.92	28.96
RH>46k	1.39	10.27	11.73	12.66	12.66	19.04	35.31
ADDITIONAL CC *7							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5
FW<42k	0.04	0.04	0.04	0.04	0.04	0.04	0.08
FW>42k	0.48	0.48	0.48	0.48	0.48	0.49	0.53
FF<37k	0.06	0.08	0.09	0.09	0.12	0.13	0.17
FF>37k	0.22	0.27	0.32	0.32	0.32	0.33	0.38
GW<10k	0.03	0.03	0.03	0.03	0.06	0.06	0.11
GW10-12k	0.03	0.06	0.06	0.06	0.06	0.08	0.10
GW12-15k	0.04	0.05	0.05	0.05	0.06	0.07	0.09
GW15-19k	0.04	0.06	0.06	0.06	0.07	0.07	0.11
GW19-27k	0.58	0.60	0.60	0.61	0.65	0.62	0.66
GW27-46k	1.00	1.02	1.02	1.03	1.05	1.04	1.06
GW>46k	1.30	1.30	1.30	1.31	1.33	1.31	1.35
RH<18k	0.00	0.03	0.03	0.04	0.04	0.08	0.13
RH18-20k	0.01	0.03	0.04	0.04	0.08	0.10	0.14
RH20-27k	0.05	0.08	0.08	0.08	0.08	0.10	0.15
RH27-46k	0.28	0.31	0.31	0.32	0.32	0.34	0.38
RH>46k	1.24	1.28	1.28	1.28	1.28	1.31	1.37
CCEE.R							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5
Cumltv CC	0	0	5	5	5	61	71
	5	6	6	6	6	6	7
	1990	1996	NEW96	1990	1996	NEW96	
	VC89	VCB	VCN	KW87	KWB	KWN	
FW<42k	9.882	19.71	19.71	218.1	214.8	214.8	
FW>42k	5.68	8.42	8.42	294.7	293.7	293.7	

Table C.9 Direct Heating Equipment Version of LBL-MIM

The Standards Level Module (continued)

FF<37k	0.078	2.784	2.87	161.6	148	147.5
FF>37k	0.227	4.453	28.56	347.6	319.9	288
GW<10k	0.014	9.66	9.66	55.13	46.25	46.25
GW10-12k	0.005	1.907	1.907	77.32	71.69	71.69
GW12-15k	0.169	2.51	2.69	76.7	72.13	71.65
GW15-19k	0	2.384	2.384	99.72	93.24	93.24
GW19-27k	0.411	4.386	4.647	143.2	135.4	134.6
GW27-46k	0.233	3.635	3.883	191.4	181.7	180.8
GW>46k	3.192	3.52	3.546	262.2	261.3	261.2
RH<18k	0.002	1.948	1.948	80.87	73.75	73.75
RH18-20k	0.926	6.105	14.84	103.2	96.14	89.68
RH20-27k	0	2.385	2.385	142.8	133.5	133.5
RH27-46k	0.256	5.787	6.058	189.9	180	178.8
RH>46k	0.426	6.749	7.197	272.6	260.6	258.9
	1990	1996	NEW96	Weighted	Base Case	New Sids
	CPC89	CPCB	CPCN	Op Cost	Weighted	Weighted
					d P	d P
FW<42k	0.538	0.832	0.832	1.563	0.07	0.07
FW>42k	0.048	0.096	0.096	23.81	0.221	0.221
FF<37k	0.269	7.986	8.283	2.139	0.036	0.037
FF>37k	0.951	12.78	27.04	16.31	0.198	1.33
GW<10k	0.001	0.94	0.94	0.578	0.101	0.101
GW10-12k	0.015	6.29	6.29	0.81	0.02	0.02
GW12-15k	0.371	3.459	3.853	0.804	0.025	0.026
GW15-19k	0	6.221	6.221	1.045	0.025	0.025
GW19-27k	0.539	6.554	7.316	19.41	0.539	0.574
GW27-46k	0.488	5.406	5.923	41.87	0.744	0.799
GW>46k	5.298	5.651	5.694	44.17	0.055	0.06
RH<18k	0.006	7.55	7.55	0.053	0.001	0.001
RH18-20k	1.206	7.592	10.43	0.067	0.003	0.009
RH20-27k	0	8.752	8.752	1.25	0.021	0.021
RH27-46k	0.925	8.354	9.337	9.218	0.268	0.282
RH>46k	1.394	10.27	11.73	62.29	1.445	1.547
Wgt Fuel Cost: F				225.4	3.774	5.124
					dVC.B0	dVC.N0
---OUTPUT---						
	CC.87	CCB	CCN	CC.B0	CC.N0	dVC.B.CV
	5.418	5.733	5.811	0.315	0.394	25.00%

Table C.10 Direct Heating Equipment Version of LBL-MIM

The Costs, Sales, and Revenue Module

						bb	-325
						aa	1885
Ratio of highest to lowest markup:				ratio.0	1.30	ratio.cv	0.20
Typical markup over UVC				mid.0	0.31	mid.cv	0.20
Size of firm as % of industry				size.0	0.17		
CALIBRATION CASE (1990)							
	Indst	Relatv	----- Firm -----				
	Ship.	Ship.	Ship.	Price	Rev.		Weighted
		Q%	Q.1	P.1/Range	R.1	m.1	UVC.1
FW<42k	0.00	0.01	0.00	227.40	0.12	1.29	175.83
FW>42k	0.04	0.08	0.01	252.92	1.48	1.31	193.55
FF<37k	0.01	0.01	0.00	190.33	0.18	1.27	149.45
FF>37k	0.02	0.05	0.00	244.07	0.83	1.30	187.45
GW<10k	0.00	0.01	0.00	119.47	0.09	1.24	96.66
GW10-12k	0.00	0.01	0.00	126.79	0.10	1.24	102.26
GW12-15k	0.00	0.01	0.00	134.34	0.10	1.24	108.00
GW15-19k	0.00	0.01	0.00	158.19	0.12	1.26	125.90
GW19-27k	0.06	0.14	0.01	182.31	1.79	1.27	143.63
GW27-46k	0.10	0.22	0.02	189.45	3.01	1.27	148.81
GW>46k	0.07	0.17	0.01	249.56	3.05	1.31	191.23
RH<18k	0.00	0.00	0.00	149.63	0.01	1.25	119.51
RH18-20k	0.00	0.00	0.00	161.73	0.01	1.26	128.52
RH20-27k	0.00	0.01	0.00	175.57	0.11	1.27	138.71
RH27-46k	0.02	0.05	0.00	189.51	0.67	1.27	148.85
RH>46k	0.10	0.23	0.02	243.02	4.03	1.30	186.72
TOTAL S	0.44	20.00%	0.07	\$216	15.69	1.29	20.00%
	"TS.0	"Q.CV	Q.0	P.0	R		"P.CV
							UVC

Table C.10 Direct Heating Equipment Version of LBL-MIM

The Costs, Sales and Revenue Module (continued)

BASE CASE (1996)								
	Rule-of- Thb d P	Rule-of- Thb Price		Pi.B	Op Cost Ratio	Weightd OpCst-R	Qi.B	Ri.B
FW<42k	12.98	0.13	0	\$232	0.98	0.01	0.0005	0.12
FW>42k	3.62	1.53	0	\$256	1.00	0.08	0.0060	1.53
FF<37k	10.39	0.20	0	\$196	0.92	0.01	0.0010	0.19
FF>37k	16.38	0.91	1	\$248	0.92	0.04	0.0035	0.86
GW<10k	12.74	0.10	0	\$125	0.84	0.01	0.0008	0.10
GW10-12k	7.85	0.10	0	\$132	0.93	0.01	0.0008	0.10
GW12-15k	5.62	0.11	0	\$138	0.94	0.01	0.0008	0.11
GW15-19k	8.52	0.13	0	\$163	0.94	0.01	0.0008	0.13
GW19-27k	10.44	1.93	1	\$188	0.95	0.13	0.0100	1.88
GW27-46k	8.75	3.21	1	\$195	0.95	0.21	0.0162	3.15
GW>46k	0.75	3.12	0	\$250	1.00	0.17	0.0125	3.12
RH<18k	9.11	0.01	0	\$155	0.91	0.00	0.0000	0.01
RH18-20k	12.19	0.01	0	\$167	0.93	0.00	0.0000	0.01
RH20-27k	10.84	0.12	0	\$181	0.94	0.01	0.0006	0.12
RH27-46k	13.72	0.73	1	\$194	0.95	0.05	0.0036	0.70
RH>46k	16.39	4.39	5	\$247	0.96	0.22	0.0169	4.17
	0.05	16.73	9	0.00				
	Alpha.B	Sum P (2)	Sum (3)	220.2 "P.B	16.30 Sum(Ri)	-0.04 OC%.B0 check=R.B	0.0740 "Q.B	16.298 "R.B
NEW STANDARDS CASE (1996)								
	Rule-of- Thb d P	Rule-of- Thb Price		Pi.N	% Chng Op Cost	Weightd OpCst-R	Qi.N	Ri.N
FW<42k	13.01	0.13	0	\$236.5	0.98	0.01	0.0005	0.13
FW>42k	3.63	1.54	0	\$256.2	1.00	0.08	0.0060	1.54
FF<37k	11.72	0.20	0	\$198.8	0.91	0.01	0.0010	0.20
FF>37k	64.07	1.07	14	\$212.3	0.83	0.04	0.0035	0.74
GW<10k	12.85	0.10	0	\$128.5	0.84	0.01	0.0008	0.10
GW10-12k	8.58	0.11	0	\$133.7	0.93	0.01	0.0008	0.10
GW12-15k	6.60	0.11	0	\$139.9	0.93	0.01	0.0008	0.11
GW15-19k	9.25	0.13	0	\$165.4	0.94	0.01	0.0008	0.13
GW19-27k	12.26	1.96	2	\$191.1	0.94	0.13	0.0101	1.92
GW27-46k	10.18	3.24	2	\$197.2	0.94	0.21	0.0162	3.20
GW>46k	0.88	3.13	0	\$250.4	1.00	0.17	0.0125	3.13
RH<18k	9.99	0.01	0	\$157.3	0.91	0.00	0.0000	0.01
RH18-20k	26.80	0.01	0	\$171.8	0.87	0.00	0.0000	0.01
RH20-27k	11.88	0.12	0	\$184.2	0.94	0.01	0.0007	0.12
RH27-46k	15.96	0.74	1	\$199.5	0.94	0.05	0.0036	0.72
RH>46k	19.58	4.46	7	\$253.6	0.95	0.22	0.0170	4.30
TOTAL	0.02	17.06	26	221.6	16.46	-0.05	0.0743	16.46
	Alpha.N	Sum P (2)	Sum (3)	"P.N	Sum(Ri)	OC%.N0 check=R.N	"Q.N	"R.N

Table C.11 Direct Heating Equipment Version of LBL-MIM

The Financial Module

INPUT	NAME	VALUE	NAME	C.V. or Control Factor
RATES of COST				
After Tax Equity Cost of Capital	ECC.0	0.07	ECC.CV	10%
Interest Rate on Debt	I.0	2.50%	LCV	100%
Interest Lost on Cash	ICash.0	0.01	ICASH.CV	100%
Rate of Depreciation	Dep.0	0.18		
Tax Rate	T.0	34.00%	T.CV	20%
ASSETS and COSTS as a PERCENT of REVENUE				
Cash	C:R.0	10%	C:R.CV	100.00%
Inventory & Receivables	IR:R.0	30%	IR:R.CV	27.19%
Depreciable Assets	DA:R.0	19%	DA:R.CV	36.89%
G & A	G&A.0	14%	G&A.CV	40.00%
Engineering	Eng	1.20%		
FIXED AND VARIABLE COST SPLIT				
Fixed Part of All Costs & Depr Assets	FDA.0	9.81%	FCA.CV	50.00%
Fixed Part of 1-X Capital Cost	F1X.0	20.00%	F1X.CV	60.00%
OTHER				
Economic Profit	EP.0	0.75%	EP.CV	1.00%
Debt to Equity ratio	DER.0	25.00%	DER.CV	43.36%
Markup on typical model	"mid	30.50%		
Ratio of highest to lowest markup	"ratio	130.00%		
OUTPUT				
Depreciation	DRR	3.5%		
G&A to Overhead Ratio	G:O	92.1%		
Engineering to Overhead Ratio	E:O	7.9%		
Debt Ratio	DR	20.0%		
Equity Ratio	ER	80.0%		
Pre-Tax Equity Cost of Capital*	PECC	10.3%		
Weighted Average Cost of Capital	WACC	8.7%		
After Tax WACC	ATWACC	5.8%		
Return on Equity	ROE	7.55%		
ROE - Input	ROE.0	7.00%		

All interest rates and costs of capital are "real".

*When Pre-Tax ECC is used, all costs are counted tax exempt.

Table C.12 Direct Heating Equipment Version of LBL-MIM

The One-Time Cost Amortization Module

INPUT		NAME	VALUE	
Economic life of existing capital		L	8.00	years
Tax life of existing capital		TL	6.00	years
Age of existing capital		AGE	1.00	years
Percent of 1X capital that is add-on (as opposed to replacement capital)		%NC	50%	
COMPUTATIONS				
DESCRIPTION		NAME	VALUE	
Continuous After-Tax WACC		ATR	5.61%	
Weighted CC Lead-Time Factors	0.00	0.29	0.54	0.26
Cumulative CC Lead-Time Factors		LTC.0	1.092	
$\exp(-ATR \cdot TL)$		EMRT	0.714	
$\exp(-ATR \cdot L)$		EMRL	0.638	
Rate of tax benefit	3.30	BN	0.057	
Remaining tax life		RTL	5.00	years
Tax Benefit Rate: $(1 - \%NC) \cdot BN$		BEN	0.028	
Discount factor: $@\exp(-ATR \cdot (L - (TL - RTL)))$		DIS	0.68	
Loss of tax benefit on portion of existing capital with remaining tax life		LEC1	0.124	
Loss of tax benefit on discounted existing capital expenditure in the future		LEC2	0.097	
LEVELIZED CC				
Initial Cost			GROSS CC	TAX EFF
			1.000	
Tax Benefit of Straight-Line Depreciation				0.289
Savings from not replacing existing Capital later			-0.338	
Loss of Tax Benefit from existing Capital				-0.221
Present Value of CC:			0.662	0.068
Adjusted for Capital Lead Time			0.723	0.074
Levelized Tax Benefit: 1-X dep. of existing Cap.				0.004
LEVELIZED CC FACTOR		CCLF	0.112	0.016
AVERAGE ASSET FACTOR				
Asset Factor for Any New Cap. or Asset		AFB	0.574	
Average Asset Factor for Add-on Capital		AAF	0.287	
INPUT				
NEW CAP. COST: 1990-96 (\$000)	CC.B0	0.32		
1996 CHANGE	CC.N	0.39		
COEFFICIENTS OF VARIATION	CCLCV	0.20		
OUTPUT				
	BASE CASE 1996		NEW STNDS 1996	
Levelized 1-X CC: Gross	LCC.B	0.04	LCC.N	0.04
Levelized 1-X CC: Tax Effects	LCC.TB	0.00	LCC.TN	0.01
Levelized 1-X CC: Net	LCC.NB	0.030377	LCC.NN	0.03794
Levelized 1-X Assets	LA.B	0.09	LA.N	0.11

Table C.13 Direct Heating Equipment Version of LBL-MIM

The Long-Run Model Module

1990 CASE		A:F	A:Q	A:R	A	
Assets -->		0.019	0.571	0.590	9	
Costs except taxes		TC:F	TC:Q	TC:R	TC	
and equity -->		0.098	0.848	0.946	15	
		EC:F	EC:Q	EC:R	EC	
Economic costs -->		0.066	0.591	0.996	16	
	Economic Income			EI:R	0.0035	
	Markup (mu - 1)			mu1	0.1173	
	Price Leader's elasticity of demand:				-9.5	
BASE 1996		A:BF	A:BQ		A:B	
Assets		0.29	123.62		9.53	
		TC:BF	TC:BQ		TC:B	
Costs except taxes		1.54	187.23		15	
		EC:BF	EC:BQ		EC:B	
Economic costs		1.04	130.64		16	
NEW 1996		A:NF	A:NQ		A:N	
Assets		0.29	123.62		9.59	
		TC:NF	TC:NQ		TC:N	
Costs except taxes		1.54	188.58		16	
		EC:NF	EC:NQ		EC:N	
Economic costs		1.04	131.68		16	
-----1990-----						
Assets			---BASE 1996---	---NEW 1996---		
Shipments	"Q	0.07	Q.B	0.07	Q.N	0.07
Price	"P	\$216.36	P.B	\$220.16	P.N	\$221.65
Revenue	"R	15.69	R.B	16.30	R.N	16.46
Unit Var. Cost	"UVC	\$167.72	UVC.B	\$171.50	UVC.N	\$172.85
V. Cost Goods Sold	VCGS	12.16	VCGS.B	12.70	VCGS.N	12.84
1X tax benefit			X1T.B	0.00	X1T.N	0.01
Pre-tax cost	PTC	14.84	PTC.B	15.44	PTC.N	15.59
Taxes	TAX	0.29	TAX.B	0.30	TAX.N	0.31
Net Income	NI	0.56	NLB	0.56	NLN	0.57
Economic Income	EI	0.06	ELB	0.04	ELN	0.05
Equity	EQ	7.41	EQ.B	7.63	EQ.N	7.67
Retm on Equity	"ROE	7.55%	ROE.B	7.38%	ROE.N	7.39%
ACCOUNTING PAGE CALCULATIONS						
-----1990-----						
Interest not 1X	IC	0.04	IC.B	0.02	IC.N	0.02
Pre-intrst cst	PIC	14.80	PIC.B	15.42	PIC.N	15.57
1X depreciation			X1D.B	0.04	X1D.N	0.05
1X interest			X1LB	0.00	X1LN	0.00
1X equity cost			X1E.B	0.00	X1E.N	0.01

Table C.14 Direct Heating Equipment Version of LBL-MIM

The Short-Run Model Module

Short-Run "Supply Elasticity of Price": (Q/P)*dP/dQ			SRQE.0	0.157
Standard Error of SRQE		.	SRQE.SD	0.120
Random Value selected for this run:			"SRQE	0.157
R.S	16.50		"P.N	\$221.65
UVC.S	\$172.85		"Q.N	0.07
VCGS.S	12.82			
TC.S	15.53			
TAX.S	0.34	P=a+bQ	ap	bp
PTC.S	15.58		186.85	479.89
NLS	0.59	Q=c+dP	0.99	cq
A.S	9.59		0.10	dq
EQ.S	7.67			0.00
ROE.S	7.64%		P.S	222.45
			Q.S	0.07
		Check P	\$221.72	
		Check Q		0.0741

Short-Run Assumptions:

The industry installs the long-run optimal level of capital

The industry produces to meet demand at the low short-run price

Table C.15 Direct Heating Equipment Version of LBL-MIM

The Charts Module

CHARTS OF SENSITIVITY AND PROFIT FOR DIRECT HEATING EQUIPMENT

Sensitivity of ROE to 1 S.E. change in Control Variable

Scenario = Primary

Control Variables		Possible Standards Levels					
Name	Value	Changed	1	2	3	4	5
IPE	-0.300	-0.690	0.06%	0.07%	0.15%	-1.65%	-4.27%
RD	50.00%	114.96%	0.00%	0.15%	0.22%	1.32%	2.81%
ECC	0.068	0.075	0.00%	0.00%	0.00%	-0.01%	-0.04%
EP	0.008	0.018	-0.01%	-0.01%	-0.02%	0.07%	0.15%
FCA	0.098	0.157	0.00%	0.00%	-0.01%	0.06%	0.13%
FIX	0.200	0.348	-0.09%	-0.10%	-0.14%	-0.17%	-0.30%
CC.N	0.394	0.480	-0.02%	-0.03%	-0.04%	-0.07%	-0.16%
dVC.N	5.124	6.872	0.00%	0.01%	0.01%	0.05%	0.01%
ro.N	0.000	0.100	0.01%	0.01%	0.02%	-0.26%	-0.63%
SRPR	0.157	0.594	0.00	0.00	0.00	0.00	0.00

Change in Long-Run ROE from 1996 NAECA Base Case by Engineering and Standards Levels

Scenario = Primary

Level	Engin	Standrds
1	-3.04%	0.02%
2	-3.12%	0.01%
3	-3.19%	-0.05%
4	-3.11%	-0.02%
5	-3.11%	-0.27%
6	-3.02%	
7	-3.13%	
8	-3.25%	
9	-3.27%	
10	-3.41%	
11	-3.41%	
12	-3.36%	

REFERENCES

1. U.S. Office of the Federal Register. 1990. *Code of Federal Regulations, Title 10, Energy, Part 430, Chapter 2: Energy Conservation Program for Consumer Products*, Washington, DC, 1990.
2. A.P. Sanghvi. 1990. *Cost-Benefit Analysis of Power System Reliability: Determination of Interruption Costs*. Prepared by RCG/Hagler/Bailly Inc., for Electric Power Research Institute, Arlington, VA EL-6791, Vol. 2, p 3-3 and Vol. 3, p 3-3.
3. T.S Zawacki, J.T. Cole, V. Huang, H. Banasiuk, and R.A. Macriss. 1984. *Efficiency and Emissions Improvement of Gas-Fired Space Heaters. Task 1: Efficiency Improvement of Vented Heaters*. Gas Research Institute, Chicago, IL, Report No. PB84-179761.
4. G.E. Kelly, J. Chi, and M.E. Kuklewicz. 1978. *Recommended Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers*. National Bureau of Standards, Washington, DC, NBSIR 78-1543, October 1978.
5. U.S. Office of the Federal Register, 1990. *Op. cit.*
6. D. Macintosh, F. Gary, and L. Spindler. 1991. *Personal communication*. Robertshaw Controls Company, Long Beach, CA and Holland, MI, July, 1991.
7. *Ibid.*
8. *Ibid.*
9. *Ibid.*
10. *Ibid.*
11. *Ibid.*
12. E.R. Kweiler, W.F. Mullis. 1981. "Determination of Annual Efficiency of Vented Heaters Equipped with Thermally Activated Vent Dampers." *ASHRAE Transactions*, 85(1): pp 753-768.
13. D. DeWerth. 1990. *Personal communication*. American Gas Association Laboratories, Cleveland, OH, October 1990.
14. R.A. Borgeson and W.H. Thrasher. 1987. *Development of a Pulse Combustion Space Heater*. Gas Research Institute, Chicago, IL, Report No. GRI-87/0142.

15. Gas Appliance Manufacturers Association (GAMA). 1990. *Consumer's Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment*. ETL Testing Laboratories, Cortland, NY, October 1990.
16. W.H. Thrasher. 1990. *Personal communication*. American Gas Association Laboratories, Cleveland, OH, October 1990.
17. GAMA. 1990. *Op. cit.*
18. U.S. DOE Energy Information Administration (EIA). 1989. *Household Energy Consumption and Expenditures 1987, Part 1: National Data*. Report No. DOE/EIA-0321(87), Washington, DC, October 1989.
19. *Appliance Magazine*. 1991. "The Life Expectancy/Replacement Picture." 48:9(62-63). September 1991.
20. ADM Associates Inc. 1987. *Costing Analysis of Design Options for Residential Appliances and Space Conditioning Equipment*. Prepared by ADM Associates Inc., Sacramento, CA, for Lawrence Berkeley Laboratory, Purchase No. 4541710, December 1987.
21. U.S. DOE, Energy Information Administration, 1991. *Annual Energy Outlook 1991*, DOE/EIA-0383(91).
22. *Ibid.*
23. U.S. DOE, Energy Information Administration, 1991. *State Energy Price Projections for the Residential Sector, 1991-1992*. Service Report SR/EMEU/91-04, November.
24. U.S. Office of the Federal Register, 1990. *Op. cit.*

Volume I

Table of Contents

CHAPTER 1. ENGINEERING ANALYSIS	1-1
1.1 INTRODUCTION	1-1
1.2 PRODUCT CLASSES	1-4
1.3 DESIGN OPTIONS	1-4
1.3.1 Baseline Furnaces	1-6
1.3.2 Improved Circulating Air Fan Motor Efficiency	1-7
1.3.3 Fan-Assisted Combustion with Electronic Ignition (EI)	1-7
1.3.4 Improved Heat Exchanger	1-8
1.3.5 Two-Stage Operation	1-8
1.3.6 Full Furnace Modulation	1-10
1.3.7 Condensing Flue Gas	1-10
1.3.8 Additional Cabinet Insulation	1-11
1.3.9 Fan-Assisted Combustion	1-11
1.3.10 Infrared Burner	1-11
1.3.11 Burner Box Damper	1-12
1.4 ENERGY-USE DATA	1-12
1.4.1 Parameters Used in Analysis	1-12
1.4.2 AFUE Values	1-14
1.4.3 Estimation of Steady-State Efficiencies for Design Options	1-14
1.4.4 Transformation of AFUE and Eff_{HS} Values from Existing Test Procedure to Proposed Test Procedure Values	1-16
1.4.5 Calculations for Gas-Fired Single-Stage Furnaces with Pilot Ignition	1-20
1.4.6 Calculations for Single-Stage Furnaces with Electronic Ignition	1-20
1.4.7 Calculations for Two-Stage Furnaces	1-20
1.4.8 Calculations for Full Modulating Furnaces	1-21
1.4.9 Energy-Usage Calculations	1-22
1.5 COST-EFFICIENCY DATA	1-23
1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGNS	1-29
CHAPTER 2. BASE CASE FORECASTS: MOBILE HOME FURNACES	2-1
2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS	2-1
2.2 AVERAGE EQUIPMENT LIFETIME	2-1
2.2 BASE CASE PROJECTIONS	2-1
2.2.1 New Appliance Unit Energy Consumptions	2-2
2.2.1.1 Efficiency Distributions	2-2
2.2.1.2 Usage	2-2
2.2.2 Annual U.S. Appliance Installations	2-3
2.2.3 U.S. Residential Energy Consumption	2-4
2.2.4 Price of Purchased Appliances	2-4
2.3 SENSITIVITY ANALYSIS OF THE BASE CASE	2-4

CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: MOBILE	
HOME FURNACES	3-1
3.1 STANDARD LEVELS	3-1
3.2 ENERGY CONSUMPTION	3-2
3.3 ANNUAL INSTALLATIONS	3-5
3.4 APPLIANCE PRICES	3-6
3.5 NET PRESENT VALUE (NPV)	3-7
3.6 SENSITIVITY ANALYSIS	3-7

CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS: MOBILE	
HOME FURNANCES	4-1
4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS	4-1
4.1.1 LCC Data Inputs	4-2
4.1.2 LCC Results	4-2
4.2 PAYBACK PERIODS BY STANDARD LEVEL	4-8
4.2.1 PBP Data Inputs	4-8
4.2.2 PBP Results	4-8
4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS	4-9
4.3.1 Data Inputs for Change in LCC	4-9
4.3.2 Results for Change in LCC	4-9
4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS	4-9
4.4.1 CCE Data Inputs	4-10
4.4.2 CCE Results	4-10
4.5 LCC SENSITIVITY ANALYSIS	4-13

CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF MOBILE HOME	
FURNACES	5-1
5.1 LONG-RUN IMPACTS	5-1
5.1.1 Qualitative Analysis	5-1
5.1.2 Quantitative Analysis	5-2
5.2 SHORT-RUN IMPACTS	5-2
5.3 IMPACT AS A FUNCTION OF FIRM SIZE	5-3
5.4 SENSITIVITY ANALYSIS FOR MOBILE HOME FURNACES	5-4
5.4.1 Sensitivity Charts	5-4
5.4.2 Alternative Scenarios	5-5
5.4.3 Monte Carlo Analysis	5-5

CHAPTER 6. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES: MOBILE	
HOME FURNACES	6-1
6.1 INTRODUCTION	6-1
6.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS	6-1
6.3 PEAK LOAD AND CAPACITY REDUCTIONS	6-1
6.4 REVENUE LOSSES	6-3
6.5 SENSITIVITY ANALYSIS	6-6

CHAPTER 7. ENVIRONMENTAL EFFECTS	7-1
7.1 INTRODUCTION	7-1
7.2 RESULTS	7-1
7.2.1 Sulfur and Nitrogen Oxide Emissions	7-2
7.2.2 Carbon Dioxide Emissions	7-2
APPENDIX A. ENGINEERING ANALYSIS NOMENCLATURE	A-1
APPENDIX B. LBL-REM INPUT DATA:	
CENTRAL SPACE HEATING	B-1
APPENDIX C. LBL MANUFACTURER IMPACT MODEL:	
MOBILE HOME FURNACES	C-1
C.1 INTRODUCTION	C-1
C.1.1 Engineering Cost Data	C-1
C.1.2 Industry Market Data	C-2
C.1.3 Financial Input Data	C-3
C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO	C-4

List of Tables

Table 1.1	Design Options and Standard Levels for Gas Mobile Home Furnaces	1-5
Table 1.2	Design Options and Standard Levels for Oil Mobile Home Furnaces	1-5
Table 1.3	Calculations to Determine Fan Power at Low Fan Speed	1-10
Table 1.4	Determination of DHR Values for Gas and Oil Furnaces	1-13
Table 1.5	Transformation of AFUE and Effy _{HS} Values from Existing Test Procedure to Proposed Test Procedure Values	1-17
Table 1.6	Efficiency Calculation Details for Gas MHFs	1-18
Table 1.7	Efficiency Calculation Details for Oil MHFs	1-19
Table 1.8	Sales Weighted-Average Annual Energy Consumption (Based on HLH = 1880 Hours) for Gas Furnaces	1-23
Table 1.9	Sales Weighted-Average Annual Energy Consumption (Based on HLH = 1880 Hours) for Oil Furnaces	1-23
Table 1.10	Gas Furnace Maintenance Cost Components and Installation Costs (1990 \$)	1-26
Table 1.11	Maintenance Cost Breakdown for Baseline Oil Furnace (1990\$)	1-27
Table 1.12	Oil Furnace Maintenance Cost Components and Installation Costs (1990 \$)	1-27
Table 1.13	Cost-Efficiency Data for Gas Mobile Home Furnaces	1-28
Table 1.14	Cost-Efficiency Data for Oil Mobile Home Furnaces	1-28
Table 2.1	Average Equipment Lifetime (Years) of Mobile Home Furnaces	2-1
Table 2.2	Base Case Projection of Unit Energy Consumption for New Mobile Home Furnaces	2-2
Table 2.3	Projected Average Usage of Mobile Home Furnaces	2-2
Table 2.4	Annual Installations of Mobile Home Furnaces in U.S. Households (Thousands)	2-3
Table 2.5	Percent of Occupied U.S. Housing Units Having Mobile Home Furnaces . .	2-3
Table 2.6	U.S. Residential Energy Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary Energy)	2-4
Table 2.7	Average Price of New Mobile Home Furnaces in U.S. Households (1990 dollars)	2-4
Table 2.8a	Average Purchase Price of New Gas-Fired Mobile Home Furnaces (1990 Dollars)	2-5
Table 2.8b	Average Purchase Price of New Oil-Fired Mobile Home Furnaces (1990 Dollars)	2-6
Table 2.9a	Average Unit Consumption of New Gas-Fired Mobile Furnaces (MMBtu/Year)	2-6
Table 2.9b	Average Unit Consumption of New Oil-Fired Mobile Furnaces (MMBtu/Year)	2-6
Table 3.1	Trial Standards Levels for Mobile Home Furnaces	3-2
Table 3.2a	Unit Energy Consumption for New Gas-Fired Mobile Home Furnaces (Million Btu/Year)	3-2

Table 3.2b	Unit Energy Consumption for New Oil-Fired Mobile Home Furnaces (Million Btu/Year)	3-3
Table 3.3a	U.S. Electricity Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary) (Includes Electric Heat, Fossil Furnaces, Heat Pumps)	3-3
Table 3.3b	U.S. Gas Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)	3-4
Table 3.3c	U.S. Oil Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)	3-4
Table 3.3d	U.S. Other Energy Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)	3-4
Table 3.3e	Total U.S. Energy Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)	3-5
Table 3.4	Cumulative Installations of Mobile Home Furnaces (Millions)	3-6
Table 3.5a	Average Purchase Price for New Gas-Fired Mobile Home Furnaces (1990 Dollars Per Unit)	3-7
Table 3.5b	Average Purchase Price for New Oil-Fired Mobile Home Furnaces (1990 Dollars Per Unit)	3-7
Table 3.6	Net Present Value for Mobile Home Furnaces Purchased from 1996-2030 (Billion 1990\$ Discounted at 7%	3-8
Table 3.7	Sensitivity Analysis Cases	3-9
Table 3.8a	Cumulative Energy Consumption of Gas Mobile Home Furnaces During the Period 1996-2030 (Quadrillion Btu, Primary)	3-9
Table 3.8b	Cumulative Energy Consumption of Oil Mobile Home Furnaces During the Period 1996-2030 (Quadrillion Btu, Primary)	3-9
Table 3.9a	Cumulative Shipments of Gas Mobile Home Furnaces During the Period 1996-2030 (Millions)	3-10
Table 3.9b	Cumulative Shipments of Oil Mobile Home Furnaces During the Period 1996-2030 (Millions)	3-10
Table 3.10	Total Net Present Value to Consumers for Units Sold During the Period 1996-2030 (Discounted to 1990 at 4% Real)	3-10
Table 4.1	Life-Cycle Costs of Gas-Fired Mobile Home Furnace (56 Mbth input)	4-7
Table 4.2	Life-Cycle Costs of Oil-Fired Mobile Home Furnace (81.6 Mbth input)	4-7
Table 4.3a	Cost and Energy-Use Summary Gas-Fired, Low-Capacity Mobile Home Furnaces	4-11
Table 4.3b	Distribution of Units Sold Below Standards, Gas-Fired, Low-Capacity Mobile Home Furnaces	4-11
Table 4.3c	Weighted-Averages of Units Sold Below Standards, Gas-Fired, Low-Capacity Mobile Home Furnaces	4-11
Table 4.4a	Cost and Energy-Use Summary, Oil-Fired, Low-Capacity Mobile Home Furnaces	4-12
Table 4.4b	Distribution of Units Sold Below Standards, Oil-Fired, Low-Capacity Mobile Home Furnaces	4-12
Table 4.4c	Weighted-Averages of Units Sold Below Standards, Oil-Fired, Low-Capacity Mobile Home Furnaces	4-13

Table 4.4d	Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Oil-Fired, Low Capacity Mobile Home Furnaces	4-13
Table 4.5	Sensitivity Summary of Life-Cycle Costs of Gas Mobile Home Furnaces	4-15
Table 5.1	Output Table: Primary Scenario – Long-Run	5-2
Table 5.2	Output Table: Primary Scenario – Short-Run	5-3
Table 5.3	Sensitivity Chart: Primary Scenario (Sensitivity of ROE to 1 S.E. Change in Control Variable	5-4
Table 5.4	Output Table: Low Industry Price Elasticity Scenario – Long-Run	5-6
Table 5.5	Output Table: High Industry Price Elasticity Scenario – Long-Run	5-7
Table 5.6	Output Table: Constant Shipments Scenario – Long-Run	5-7
Table 5.7	Output Table: Low Discount Rate Scenario – Long-Run	5-8
Table 5.8	Output Table: High Discount Rate Scenario – Long-Run	5-8
Table 6.1	Net Revenue Losses - Mobile Home Furnaces (Million 1990 Dollars)	6-5
Table 6.2	Present Value of Revenue Losses - Mobile Home Furnaces (Million 1990 Dollars)	6-6
Table 6.3	Present Value of Net Lost Revenues (Million 1990 \$) - Mobile Home Furnaces (Sensitivity Cases)	6-6
Table C.1	Rates of Financial Costs	C-3
Table C.2	Other Financial Inputs	C-3
Table C.3	Fixed, Variable, and Revenue-Related Cost Split	C-3
Table C.4	One-Time Costs	C-4
Table C.5	Mobile Home Furnaces Version of LBL-MIM	C-4
Table C.6	Mobile Home Furnaces Version of LBL-MIM	C-5
Table C.7	Mobile Home Furnaces Version of LBL-MIM	C-6
Table C.8	Mobile Home Furnaces Version of LBL-MIM	C-7
Table C.9	Mobile Home Furnaces Version of LBL-MIM	C-8
Table C.10	Mobile Home Furnaces Version of LBL-MIM	C-9
Table C.11	Mobile Home Furnaces Version of LBL-MIM	C-10
Table C.12	Mobile Home Furnaces Version of LBL-MIM	C-11
Table C.13	Mobile Home Furnaces Version of LBL-MIM	C-12
Table C.14	Mobile Home Furnaces Version of LBL-MIM	C-13
Table C.15	Mobile Home Furnaces Version of LBL-MIM	C-14

CHAPTER 1. ENGINEERING ANALYSIS

1.1 INTRODUCTION

Furnace Description

A mobile home furnace (MHF) is an air-heating appliance used for providing central space or comfort heating for mobile (manufactured) homes. Similar in most respects to central furnaces for site-built homes, MHFs incorporate an air-heating component, a fan to force air through air-distribution ducting, a thermostat and electrical controls to process signals from the thermostat, a combustion exhaust or flue system, a combustion air intake system, and a filter. Only fuel combustion furnaces are considered here. Also, it should be noted that heating appliances that are non-ducted are referred to as "direct-heating" appliances and are treated as a separate product type in Volume H.

There are two major respects in which MHFs are different from furnaces for most site-built homes:

- They are completely installed by the home manufacturer in the factory.
- They are required (by HUD's "Manufactured Home Construction and Safety Standards" (1) to have an isolated combustion system that completely separates furnace combustion air and flue products from the indoor air of the home¹(2).

The isolated combustion requirement dictates that MHFs must have direct-venting systems. For manufactured homes, the most common direct-vent configuration consists of a concentric flue gas/intake air assembly in which combustion products are exhausted through a flue duct surrounded by (or inside of) a concentric intake air duct. This configuration permits a single penetration through the roof of the home for the combined flue gas/intake air assembly and is important in maintaining cost control for the entire furnace installation. Some oil furnaces and convertible furnaces (i.e., furnaces that can be fitted with either a gas burner or oil burner) do not have the concentric vent arrangement and use separate ducts to floor or roof penetrations in order to obtain combustion supply air.

¹The HUD code applies to manufactured housing with a floor area greater than 400 square feet. Smaller homes are covered by ANSI standards as "park" models or trailers (2). A typical single-wide manufactured home might have floor dimensions of 14' by 66' (784 to 924 square feet). The requirement does not distinguish MHFs from *all* site-built home furnaces. There are some furnaces marketed for the site-built market that are equipped with a direct-vent type flue/supply air system.

Heating System Description

Central furnaces in manufactured houses are almost always located in a central closet that is equipped with a return-air door grill. Return air is drawn through the door grill into the closet, into the furnace to be heated, and then forced through supply ductwork into the home. The supply ductwork is almost exclusively located beneath the floor, so that the great majority of MHFs are of the downflow configuration, i.e., they draw return air into the furnace, then force the air in a downward direction into supply ductwork (as opposed to furnaces for site-built homes, which are available in upflow, downflow, and horizontal configurations). One source has stated that upflow furnaces are used only in Texas, Arizona, and California (where cooling needs have driven some manufacturers to incorporate attic spaces along with attic ducting), and that they constitute about 5% of the gas furnace market, or 2% to 3% of the total MHF market. These furnaces were not treated as a separate class for purposes of this analysis: the costs and efficiency increments for various design options should be approximately the same for both upflow and downflow furnaces.

MHF Market

In 1990 the total number of manufactured home shipments in the U.S. was about 190,000. This represented about 14% of privately owned housing units started, and about 26% of privately owned units sold during the year (3). A 1989 survey (4) indicates the following approximate percentages for heating system types in manufactured homes shipped in that year²:

Electric resistance:	46%
Heat pump:	1%
Gas:	45%
Oil:	8%

The furnaces shipped with new homes presently constitute about 90 to 95% of the total MHF market, and replacement furnaces constitute the balance of the market. Thus, the total MHF shipments for 1990 were approximately 200,000 to 210,000 units.

Furnace Manufacturing and Installation

Two manufacturers supply virtually all furnaces for the manufactured housing industry.

The furnace manufacturing process is dominated by sheet metal blanking, forming, and joining procedures, and by the assembly of subcomponents into the entire furnace package. The furnace cabinet, primary heat exchanger (which is cannister-shaped for the two major MHF manufacturers), flue/intake assembly, and gas burner assembly are all predominantly sheet metal.

²Virtually all of the manufactured homes were shipped with central space-conditioning equipment. There are no wall furnaces or other non-ducted heaters that are approved for manufactured home installation. Baseboard electric heaters, while approved, are seldom used.

While subcomponents such as the gas burner assembly and fan housing can be either purchased or manufactured by the furnace manufacturer, all other sheet metal components are typically fabricated and assembled at the factory. Components such as the gas valve/regulator, oil burner assembly, fan scrolls and motors, and electrical subcomponents are all purchased for assembly into the final package at the furnace factory. The furnace is then shipped along with the (separate) flue/intake assembly to the mobile home factory, where the furnace is placed and gas, electrical (including thermostat), and duct connections are made. The flue/intake assembly can be mounted at the house placement site by crews that specialize in manufactured home placement work. Mounting the flue/intake at this final point minimizes overall home height during transport.

DOE Test Procedure (5) (6)

Under the existing DOE test procedure,³ various steady-state and transient furnace operation characteristics are measured, then calculations are performed to estimate Annual Fuel Utilization Efficiency (AFUE, a measure of fuel efficiency) and Annual Efficiency (AE, a measure of combined fuel and electric efficiency). These calculations account for on-cycle thermal efficiency effects due to latent and sensible flue gas losses, furnace jacket conduction losses, and furnace-induced infiltration losses. Off-cycle effects include jacket and sensible flue losses. In addition to the listed losses, warm-up and cool-down transient effects are also considered. The calculations are based on a number of assumptions, among them: (a) that the furnace is placed in an indoor location, (b) that there are a fixed number of duty cycles per day during the heating season, and (c) that a furnace is sized at 70% greater than the calculated design (maximum instantaneous) heating load of the home.

The test procedure has changed over the years with respect to required assumptions about furnace placement. The procedure that is used for this analysis has only recently been proposed. Because it has not been formally approved, it is referred to here as the "proposed" test procedure to distinguish it from the "existing" procedure. The proposed procedure differs from the existing procedure in several major ways. The first change assumes that furnace placement is inside the conditioned space rather than outside. Test data in the analysis presented below are adjusted to reflect this change. The adjustment and associated calculations are discussed below in Section 1.4.4.

The second change involves the AFUE as a measure of furnace efficiency. The AFUE measure does not account for electric energy consumption, so circulating air and combustion fan power consumptions are not accounted for in AFUE ratings. However, the proposed DOE test procedure includes a methodology for generating an Annual Efficiency, or AE, value that incorporates electric energy consumption. The proposed procedure also includes a methodology

³Reference (5) presents the detailed calculations required to generate AFUE, AE, and other values related to furnace efficiency. However, it does not develop or give explanations regarding the calculations. Reference (6) presents background documentation for the development of much of the content in Reference (5).

for calculating yearly fuel and electric energy consumption specifically for mobile homes. This methodology is used below in Section 1.4.

Regardless of the test procedure, MHFs feature direct vent combustions systems and therefore do not induce home infiltration. Therefore, an option in the test procedure is used that does not include infiltration effects in the calculation of furnace efficiency.

1.2 PRODUCT CLASSES

The Energy Policy and Conservation Act (as ammended by the NAECA legislation) does not specify product classes for MHFs (7). However, the legislation requires that appliances in general be segregated into different product classes based on fuel type (8). For .HFs, the relevant fuel type product classes are gas and oil. No other product class subdivisions appear to be appropriate.⁴ For purposes of the present engineering analysis, the most important differences between gas and oil furnaces are:

- Gas furnaces are capable of using either pilot or intermittent ignition, while oil burners are only available with intermittent spark ignition. Thus, the baseline options and efficiencies for gas and oil furnaces are different from each other.
- The infrared burner design option for gas furnaces is not available for oil furnaces.
- For various design options, the incremental manufacturing costs for oil and gas furnaces are very different. This is particularly true of the two-stage and continuous-modulation design options.

Oil and gas furnaces, by virtue of their fuel type alone, have different combustion characteristics. However, the extent of these differences is unclear with respect to AFUE. For example, the convertible furnaces (which has the same features for both oil and gas burner configurations) of one MHF manufacturer have AFUE ratings for gas burners that are up to 1.2 AFUE points greater than the oil burner AFUEs (for furnaces with the same input Btu/hr rating). For the convertible furnace of the other manufacturer, oil burner AFUE values are up to about 4 percentage points greater than the gas burner AFUEs. These variations are probably due to a number of causes (air/fuel ratio, burner design, etc.) other than fuel type.

1.3 DESIGN OPTIONS

This section describes the data and assumptions used as inputs in the calculation of energy savings for all furnace design options. Data for all of the options were either obtained from one or both of the MHF manufacturers, from parts suppliers, or estimated as noted below.

⁴While upflow and downflow furnaces could be considered as distinct classes, the technical differences between them are small. Convertible furnaces (i.e., furnaces built to accept either gas or oil burners), since they are manufactured for the MHF market, could be considered a separate product class. However, these can be simply treated by the stipulation that they meet the appropriate standard with both gas and oil burners.

Tables 1.1 and 1.2 list the design options considered in this analysis. Calculations using the data and assumptions presented in this section are described in Section 1.4. Results of the calculations are shown in Tables 1.13 and 1.14.

Table 1.1 Design Options and Standard Levels for Gas Mobile Home Furnaces

Standard Level	Option Number	Design Option Description
0	0	Baseline
1	1	0 + Improved fan motor efficiency
4	2	1 + Fan-assisted combustion with electronic ignition (EI)
	3	2 + Improved heat exchanger
	4	3 + Two-stage operation
	5	4 + Infrared burner
2	6	1 + Burner box damper
3	7	6 + Improved heat exchanger
5	8	1 + Condensing flue gas
	9	8 + Two-stage operation
6	10	8 + Continuous furnace modulation
	11	0 + Cabinet insulation
	12	0 + Fan-assisted combustion

Table 1.2 Design Options and Standard Levels for Oil Mobile Home Furnaces

Standard Level	Option Number	Design Option Description
0	0	Baseline
1,2	1	0 + Improved fan motor efficiency
3,4	2	1 + Improved heat exchanger
5	3	1 + Condensing Flue Gas
6	4	3 + Full furnace modulation
	5	3 + Two-stage operation
	6	0 + Cabinet Insulation

Throughout the following discussion of design options, values to be used in the subsequent yearly energy calculations (presented in Section 1.4.1) will be typed in **boldface** and surrounded with brackets [...]. Nomenclature for these variables is in accord with the nomenclature used in the proposed DOE test procedure. Definitions of the nomenclature used in this volume are provided in Appendix A.

1.3.1 Baseline Furnaces

The NAECA legislation specifies that, as of September 1, 1990, the minimum efficiency for all MHFs (regardless of fuel type) must be 75 AFUE. The two MHF manufacturers were surveyed in order to determine baseline characteristics for gas and oil furnaces. Where there was any apparent difference between the two manufacturers in technology, the technology with the higher energy consumption (lower efficiency) was used for the baseline case.

Gas-Fueled Furnaces

Based on a survey of the manufacturers, a 56,000 Btu/hr input-rated furnace ($Q_{IN} = 56,000$ Btu/h) was chosen for the gas furnace baseline case analysis. The lowest efficiency gas furnace of this size supplied by the industry has the minimum efficiency allowed by the NAECA standard, i.e., 75% AFUE. The 75% AFUE efficiency was therefore chosen as the baseline for comparison of all gas furnace design options. Other features common to the 75% AFUE furnaces from both companies include:

- Flue gas/supply air configuration: Concentric direct vent.
- Draft: Natural.
- Air-side fan motor type: Shaded pole (350 watts input used in analysis [$BE = .35$ kW]).
- Ignition: Continuous pilot (525 Btu/hr input used in analysis [$Q_P = 525$ Btu/h]).

Oil-Fueled Furnaces

The oil furnaces of both MHF manufacturers have significantly higher efficiencies than the allowable minimum. The following baseline features were chosen based on information provided by the manufacturers and by GAMA (9).

- Efficiency: 80.4% AFUE (average of two manufacturers) [AFUE = 80.4].
- Fuel input rate: 81,600 Btu/hr (average of two manufacturers) [$Q_{IN} = 81,600$ Btu/h].
- Air-side fan motor: Shaded pole, 760 watts input [$BE = .76$ kW].
- Oil burner motor: Split-phase, 282 watts input [$PE = .282$ kW].
- Ignition type: Interrupted spark.

While both manufacturers did not use interrupted spark ignition (for which spark is present only until ignition is proved) at the time of this analysis, it was anticipated that both manufacturers would be using interrupted spark by the time that the standards based on this analysis are effective.

1.3.2 Improved Circulating Air⁵ Fan Motor Efficiency

This option characterizes the effect of changing from the baseline shaded pole fan motor (for both gas and oil furnaces) to a permanent split capacitor (psc) type motor for the circulating air fan. For gas furnaces, available data showed that a 200-watt input psc motor [Gas, Option 1: BE = .20 kW] could replace the baseline shaded pole (350-watt) motor. For the oil furnace, the psc motor input wattage was estimated on the following basis:

- Approximate efficiency of shaded pole motors: 45%.
- Approximate efficiency of psc motors: 69%.
- Given (baseline) shaded pole motor input wattage: 760 watts.
- Estimated psc input watts: $760 \text{ watts} \times (.45/.69) = 496 \text{ watts}$.
[Oil, Option 1: BE = .496 kW].

1.3.3 Fan-Assisted Combustion with Electronic Ignition (EI)

This option is applicable only to gas furnaces, since all oil furnaces feature fan-assisted combustion and spark ignition. The term "electronic ignition" refers to both spark and hot-surface systems. Both MHF manufacturers presently produce small numbers of furnaces with electronic ignition and fan-assisted combustion. The combustion air fan for each design is located on the upstream side of combustion and is sized at about 60 watts input [Gas furnace, Option 2: BE = .60 kW].

Due to safety considerations, the EI option for MHFs cannot be used without fan-assisted combustion. Since a MHF has an isolated combustion system, any gas injected into the combustion box during a failed ignition event would remain undiluted within the combustion box. This would constitute an explosion hazard during an attempt at reignition. It is essential, then, that a fan be available to purge the combustion box after failed combustion.

The EI system completely eliminates pilot energy consumption [$Q_p = 0$]. While electrical energy consumption for the EI system is small, the incremental electric power consumption over that of pilot systems is not insignificant compared with fan energy consumption. The following estimates give the magnitude of incremental electrical energy consumption due to EIs (10):

- Gas valve electrical energy consumption: EI gas valve energy consumption is virtually the same as that of pilot ignition gas valves.
- Ignition energy consumption: A typical hot-surface EI system consumes about 400 watts for 15 seconds, or 1.67 watt-hours for each ignition cycle. At 15,000 cycles per year, this amounts to about 8% of the calculated total fan energy consumption of 302 kWh per year (for the EI option). Hot-surface ignition cycle durations up to 50 seconds long are known to exist.

⁵The term "circulating" air fan is distinguished here from the "combustion" air fan. This nomenclature will be used throughout this report.

While EI energy consumption is included in the energy calculation procedure specified in the proposed DOE test procedure, the above estimate of EI energy consumption has not been used for energy calculations in the analysis presented here.

1.3.4 Improved Heat Exchanger

A wide range of heat exchanger improvements are available. For purposes of this analysis, a 2 percentage point increase in AFUE was chosen to be evaluated for both gas and oil furnaces. It was assumed that the associated steady-state efficiency (Effy_{SS}) increase for both gas and oil furnaces would also be about 2 percentage points. This increase in Effy_{SS} can be problematic with respect to possible flue gas condensation on the duct wall (which separates inlet and exhaust gas streams) in a concentric direct vent: in cold weather, incoming supply air can lower the temperature of the vent wall below the dew point of the flue gases. For gas furnaces, this phenomenon starts to occur for Effy_{SS} values above about 83%, while the corresponding critical efficiency for oil furnaces is about 85%. The baseline gas furnace selected for analysis (which both manufacturers produce) has a Effy_{SS} of about 84%. Both manufacturers currently report limited flue condensation in cold weather tests for this furnace, although they consider the magnitude and duration of the condensation to be within the limits of their current designs.

In order to limit corrosion due to the increased condensation associated with increased furnace Effy_{SS} values, vent system materials would have to be changed to the more exotic stainless steels. A cost adder (based on data supplied by the manufacturers) for these more exotic materials was therefore applied to the improved heat exchanger design option for gas furnaces.

A material cost adder was not applied to the improved heat exchanger option for the oil furnace. The baseline oil furnace steady-state efficiency is about 82%, and the incremental steady-state efficiency increase (about 2%) was not considered problematic with respect to the condensation limit, which is approximately 85%.

1.3.5 Two-Stage Operation

This option characterizes a furnace with two operation levels for the main furnace components: burner, air-side fan, and forced draft fan. Based on the importance of controlling air-fuel ratio for differing operation levels, this option was considered applicable only to furnaces with powered combustion. Two-stage operation could be achieved without varying circulating air-flow rate, but flue condensation problems at low fire would be more likely in that case, so changing speed for both fans was considered important for this option.

Two-stage operation for oil furnaces was assumed to be implemented by the use of two burner nozzles.

In order to perform an engineering analysis, the lower operating level for both gas and oil furnaces was characterized by an input at 50% of the maximum fuel input rate [$Q_{\text{IN,R}} = .5(Q_{\text{IN}})$], and 50% of the maximum rate for both combustion and circulating air-flow rates. The

50% level was chosen (in consultation with the furnace manufacturers) as a reasonable minimum firing level with respect to burner operation and the need to maintain condensation control. While it is unnecessary that air-flow reductions coincide exactly with the firing-rate reduction, the 50% levels were chosen as approximate values. In practice, limitations on turn-down ratios would come from the necessities to maintain both (1) a low enough $Effy_{SS}$ to prevent flue gas condensation and (2) a high enough burner firing rate to sustain stable and efficient combustion.

Also for analysis purposes, the $Effy_{SS}$ values for high and low firing rates were assumed to be identical [$Effy_{SS,R} = Effy_{SS}$].

Motor speed variation for two-stage operations can be achieved through various means. The most common techniques for AC motors involve either inverter power control or motor slip control through usage of multiple motor windings (or winding "taps"). For the engineering analysis, cost estimates for both of these methods were obtained and then averaged. Likewise, power reduction for the lower operating level was obtained by averaging results for both control methods. The fan input power at low speed (for both fans) was calculated as a fraction of the high-speed power by using the relationship:

$$\frac{P_{low}}{P_{high}} = \left(\frac{\eta_{low}}{\eta_{high}} \right)^{-1} \left(\frac{Q_{low}}{Q_{high}} \right)^3$$

where the ratio $(Q_{low}/Q_{high}) = 0.5$ is the ratio of the air-flow rates (cfms) for both circulating and combustion air flows, and the ratio of η values is the ratio of fan electric motor efficiencies at high and low speeds.

The fan power ratio, P_{low}/P_{high} , in the above equation was computed as the average for the two control methods, i.e., slip control and inverter control. Efficiency values were first evaluated for a multi-tapped, four-speed, 1/3 hp psc type motor, and an η ratio (η_{low}/η_{high}) of 0.21 was obtained. In order to obtain the η ratio for inverter control, it was assumed (according to the recommendation of one of the manufacturers) that the efficiency reduction from high to low speed would be approximately 80% of the reduction in efficiency incurred with motor slip control. Thus, for slip control, with the low-speed efficiency evaluated as 0.21 (= 1.0-0.79) times the high-speed efficiency, the reduction in efficiency was 79%. The low-speed efficiency for inverter control was evaluated at 80% of this reduction, or

$$\eta_{low} = [1 - (.8 \times .79)] \eta_{high} = .37 \eta_{high} .$$

Table 1.3 summarizes these calculations. Using the average of the two power ratios shown in the table (0.595 and 0.338), the value of P_{low} was calculated as 0.47 (approximated as 0.50) times P_{high} [$PE_R = .5(PE)$ and $BE_R = .5(BE)$].

Table 1.3 Calculations to Determine Fan Power at Low Fan Speed

Control Method	η_{low}/η_{high}	P_{low}/P_{high}
Slip Control (Multi-tapped motor)	$(1 - 0.79) = 0.21$	$(1/0.21)(0.125) = .595$
Inverter Control	$[1 - (0.8)(0.79)] = 0.37$	$(1/0.37)(0.125) = .338$
Average of Slip and Inverter Control	--	$0.47 \approx 0.5$

1.3.6 Full Furnace Modulation

The term "full furnace modulation" will be used in this report to refer to any furnace with more than two levels of operation. For the same reasons as those given above (for the two-stage option), a maximum turn-down of 50% was used to characterize the full modulation option [$Q_{IN,R} = .5(Q_{IN})$].

Furnace modulation can generally be implemented in either a continuous or step-wise manner. For purposes of this analysis, step-wise modulation was assumed. This made possible the assumption of either a multi-tap or inverter-controlled motor, and a corresponding motor-efficiency ratio identical to the one used for the two-stage operation option (i.e., the average of the efficiencies for motor slip control and inverter control as described above) [$PE_R = .5(PE)$ and $BE_R = .5(BE)$]. Implementation of full modulation for oil furnaces was assumed to be through the usage of multiple burner nozzles.

Similar to the case for two furnaces, the steady-state efficiency values for maximum fuel input and reduced input modulation were assumed to be identical [$Effy_{SS,R} = Effy_{SS}$].

1.3.7 Condensing Flue Gas

In order to achieve the increased efficiencies associated with condensing combustion gases, manufacturers use either finned-tube secondary heat exchangers or other supplemental heat exchanger configurations. The furnace design and installation must be further modified to incorporate condensate drainage.

Pulse combustion was not considered an economic solution for this design option. The efficiency ranges associated with pulse combustion are identical to the efficiencies of standard combustion systems, while the costs associated with pulse combustion were considered to be higher. Both MHF manufacturers would be required to spend extra money for either pulse combustion patent royalties or for the extensive development required to achieve independent pulse designs.

Several furnace condensate drainage configurations are possible for installation-costing purposes. Some present manufacturers of condensing furnaces include a venting kit designed to

interface condensate drainage with the furnace venting system, while other manufacturers leave more of the condensate drainage plumbing up to the installer. The final disposal of condensate can be into either a dry well or the house plumbing system. For purposes of costing the condensate drainage, the conservative assumption was made that condensate would be drained into the home plumbing system through a standard trap, and that the trap would be vented into a nearby plumbing vent.⁶ The vent and condensate pipes were assumed to be 1/2" PVC pipe, and were evaluated at approximately \$74 in cost to the home owner. This cost was obtained by first estimating material costs and then multiplying by the markup factor used to generate home owner costs from home manufacturer costs. For reasons presented in Section 1.5, the markup factor is not given in this document.

1.3.8 Additional Cabinet Insulation

The proposed DOE test procedure is based on furnace placement inside the conditioned space and furnace jacket (cabinet) losses are consequently considered to be zero. This is a reasonable assumption for MHFs, which are virtually all located inside a return air closet within the mobile home. Clearances from the furnace to surrounding walls are usually small and the MHFs presently must have insulated jackets in order to be approved for zero clearance to walls. In most cases, the furnace closet walls are not part of the outside shell of the home, so heat losses through the furnace jacket and the surrounding walls are completely captured within the heated space.

Because cabinet losses are considered to be zero, no efficiency benefit could be attributed to additional cabinet insulation. This option was therefore not considered.

1.3.9 Fan-Assisted Combustion

This option adds a combustion fan to the baseline furnace in the same way that a fan is added for Option 2 (EI with fan-assisted combustion). In this case, the AFUE improvement is an average value taken from the manufacturer questionnaire. The change in Eff_{ySS} from the preceding option is assumed to be the same as the Eff_{ySS} for design option 2. The Eff_{ySS} assumptions will be discussed below.

1.3.10 Infrared Burner

Infrared burners can be implemented through metal screens, porous ceramic matrices, or ceramic grids placed in the path of the combustion gas/air mixture. The incremental cost and performance values for this design option were obtained from the manufacturer questionnaires.

⁶Current manufacturers of condensing furnaces for site-built homes recommend the usage of condensate plumbing vents that merely open to the indoor environment, so the assumption here (of a vent connected into a central plumbing vent) is conservative. Heat-tracing tapes are also recommended for locations where freezing might be possible. The assumption for this analysis was that the home manufacturer would be able to route the condensate drain line within the insulated envelope of the home, thereby avoiding the need for heat tracing.

No specific implementation configurations or techniques were provided in the manufacturers' responses.

Infrared burner technology is generally considered to be very difficult (if not impossible) to implement for oil burners. It was therefore not considered in this analysis.

1.3.11 Burner Box Damper

Burner combustion air inlet dampers can be used to eliminate or significantly reduce off-cycle buoyancy-driven movement of air through the combustion gas passages of gas furnaces. This air movement removes heat from the heat exchanger during the post-firing cool-down time, and therefore scavenges heat (from the heat exchanger) that would otherwise be transferred to the circulating air stream.

Because mobile home furnaces feature the isolated combustion configuration, combustion air supply to the furnace is provided through a duct that is internal to the furnace. This duct can be fitted with an electrically actuated automatic damper in order to restrict or eliminate off-cycle air flow. Manufacturer cost estimates were obtained for this configuration.

For oil furnaces, the oil burner fan creates a significant restriction to off-cycle air flow, and there is a general belief that it serves to a significant extent the same function as a burner box damper. The burner box damper was therefore not considered for the oil furnace. There is no known data that characterizes the actual effect of a combustion damper for an oil mobile home furnace. While the effects of stack dampers are characterized by data for non-mobile home oil furnaces, that data is not considered applicable to mobile home furnaces.

1.4 ENERGY-USE DATA

The proposed DOE test procedure provides a methodology for determining annual fuel energy usage, electric energy usage, and annual efficiency (AE). This section describes the application of the test procedure calculations to each of the design options (described in the previous section). Results for all the calculations are presented in Tables 1.6 and 1.7.

The following conventions are used in referring to specific sections of test procedure documents: "ASHRAE standard" refers to ANSI/ASHRAE Standard 103-1988 (11), and "DOE" or "DOE test procedure" refers to the latest proposed version of the DOE test procedure, due to be published in the Federal Register in late 1993 or early 1994.

1.4.1 Parameters Used in Analysis

The calculations for fuel and electric energy usage are described in Paragraphs 10.19.1 through 10.19.7 of the proposed DOE test procedure. Many of the variables used in performing the calculations have been presented above in Section 1.3. The following are additional values necessary for performing the calculations as specified:

- Ratio of blower on-time to average burner on-time (y).
Single-stage furnaces with fan delay:

$$y = 1 + (t^+ - t^-)/3.87 = 1 + (3.0 - 1.5)/3.87 = 1.39$$

Two-stage or modulating furnaces with fan delay:

$$y = 1 + (t^+ - t^-)/10 = 1 + (3.0 - 1.5)/10 = 1.15$$

where the values for $t^+=3$ minutes and $t^-=1.5$ minutes are used.

- Ratio of forced draft blower on-time to average burner on-time (y_p). The value $y_p=1$ was used for all options in this analysis.
- Design heating requirement (DHR). The DHR is the actual heating load for a furnace application based on the maximum heating load (in Btu/hr) of a residence at the winter design temperature. Since the oversize factor used in the DOE test procedure is 0.7, the DHR for both gas and oil furnaces was established as the average output (of all options) divided by 1.7. Table 1.4 presents the calculations used to establish the DHR values for both oil and gas furnaces. The DHR values in the final column were calculated by dividing the "Average Output" values by 1.7.
- The factor R in the equation for determining the factor A. According to the proposed test procedure, the value $R = 1$ is used for single-stage furnaces and $R = 2.3$ for two-stage and modulating furnaces.

Table 1.4 Determination of DHR Values for Gas and Oil Furnaces

Product Class	<u>Minimum Output</u>		<u>Maximum Output</u>		Average Output (Btu/hr)	DHR (Btu/hr)
	Effy _{SS}	Output (Btu/hr)	Effy _{SS}	Output (Btu/hr)		
GAS (56,000 Btu/hr input)	.839	46984	.930	52080	49532	29136
OIL (81,600 Btu/hr input)	.820	66912	.925	75480	71196	41880

1.4.2 AFUE Values

Because the calculations for this analysis are based on the use of the proposed DOE test procedure, it is not possible here to use AFUE values from tests performed in recent years with the existing DOE test procedure. The proposed test procedure eliminates the jacket loss term previously used in calculating AFUE. However, the available AFUE data have been adjusted to eliminate the jacket loss term, thereby yielding values according to the proposed procedure. The paragraphs below (in this section and Section 1.4.3) present the available AFUE and steady-state efficiency Eff_{SS} data (generated on the basis of the existing test procedure). Section 1.4.4 describes the calculations used to transform AFUE values to the proposed test procedure. Table 1.5 presents AFUE and Eff_{SS} data according to the existing test procedure, and in addition, presents AFUE values transformed for compliance with the new test procedure.

Most of the AFUE values presented in Tables 1.5 through 1.7 are averages of values provided as survey responses by the MHF manufacturers. For cases in which only one manufacturer submitted a response, the selected value is the single reported value. Exceptions to the use of the questionnaire as a source are the following:

- Fan-assisted combustion with EI (for gas furnaces). The AFUE shown for this option is the average of the values reported in the GAMA Directory (12) for furnaces currently being produced by both MHF manufacturers.
- Two-stage operation. According to the recommendation of one of the MHF manufacturers, the incremental AFUE increase was calculated as 65% of the increase available from full (continuous) furnace modulation. The same incremental value was applied to both gas and oil furnaces.
- Full (continuous) furnace modulation. The estimated value of one MHF manufacturer was averaged with the AFUE increase available in changing from the Carrier 58SXA (single-stage condensing, 91.5 AFUE) model to the 58SXB (modulating condensing, 93.5 AFUE) model. The same incremental value was applied to both gas and oil furnaces.
- Burner box damper (for gas furnaces). The estimates of incremental AFUE provided by the two MHF manufacturers were averaged with an incremental AFUE value (4.0 AFUE points) obtained from tests at the National Institute for Standards and Technology (NIST).

1.4.3 Estimation of Steady-State Efficiencies for Design Options

Steady-state efficiency (Eff_{SS}) is used in this analysis for two purposes: (1) to derive heating season efficiency (Eff_{HS}) for design options involving standing pilot ignition, and (2) to calculate various intermediate values for the modulating furnace design options. The paragraphs below describe the various methods used to obtain values of Eff_{SS} . It should be

noted that the oil furnace calculations required no estimations of Effy_{SS} except for the continuous modulation option, so the paragraphs below mostly refer only to the gas furnace. The values are shown in Table 1.5.

- Baseline furnace and design option 2 (Electric Ignition with Fan-Assisted Combustion⁷): Values of Effy_{SS} were available as test data for the furnaces under production at the time of this analysis and were obtained from the manufacturers.
- Design options 1, 6, and 11: Steady-state efficiency was assumed to be equal to steady-state efficiency for the preceding option.
- Design options 3 and 7: Estimates were made based on extrapolation from the efficiencies of the preceding design options. The rationale used in making extrapolations was based on the following observation: Improvements in efficiency due to increased steady-state efficiency alone (e.g., improvements to heat exchange effectiveness that do not otherwise change the operation characteristics of the furnace) appear to result in AFUE increases that are approximately equal to the steady-state efficiency increases. Thus, with given AFUE increases (as described above), Effy_{SS} increases for these options were chosen as equal to the AFUE increases.
- Gas Furnace design options 4, 5, 8, and 9: Effy_{SS} values were not necessary for the energy calculation procedure (presented in Section 1.4.1). The values shown in Table 1.6 were estimated using the various approximation methods described above.
- Gas Furnace design option 10 and Oil Furnace design option 4 (both Continuous Furnace Modulation): The difference between AFUE and Effy_{SS} was estimated by noting that the difference between AFUE (93.5) and Effy_{SS} (93.7 at maximum fire) for the Carrier 58SXB (modulating) furnace is about 0.2 percentage points. The Carrier furnace is not fully modulating (because the burner operates in a two-stage mode), and the reasoning used here is that a fully modulating furnace would have a slightly higher AFUE in relation to Effy_{SS} . The difference for the fully modulating MHF option was arbitrarily chosen at 0.3 points for the gas furnace and 0.5 for the oil furnace.
- Design option 12: The difference between AFUE and Effy_{SS} was assumed to be the same as the difference between AFUE (81.5) and Effy_{SS} (84.7) for option 2.

⁷The steady-state efficiency value (reported by the MHF manufacturers) for design option 2 is actually less than the baseline steady-state efficiency. This reflects unique characteristics of the (common) combustion configuration used by both manufacturers.

1.4.4 Transformation of AFUE and Effy_{HS} Values from Existing Test Procedure to Proposed Test Procedure Values

Since the *proposed* DOE test procedure assumes jacket heat losses to be zero, the AFUE and data obtained via the *existing* test procedure must be adjusted to eliminate the jacket heat-loss factor. This adjustment can be made by noting that the expression for Effy_{HS} for all design options is of the form:

$$\text{Effy}_{\text{HS}} = 100 - C_j L_j - (\text{other terms...})$$

where the term $C_j L_j$ designates the jacket losses. The value used for the term $C_j L_j$ in calculating MHF efficiency is 1.7⁸. Thus, it is possible to adjust Effy_{HS} values obtained from existing test data by adding 1.7 percentage points (or 0.017 in the decimal form).

Table 1.5 shows the transformation calculations for the gas MHFs. Several points should be noted regarding the values shown:

- The value of "Proposed Effy_{HS}" was not directly available for standing pilot options and has been calculated in Table 1.5 by recasting the AFUE equation to obtain Effy_{HS} as a function of AFUE and Effy_{SS}. For options without standing pilot ignition, the Effy_{HS} is identical to AFUE, and calculations to derive "Existing Effy_{HS}" are not necessary.
- The difference between the "Existing Effy_{HS}" and "Proposed Effy_{HS}" values is 0.017.
- The value for Effy_{SS} does not change from the existing to the proposed test procedure.
- The "Proposed AFUE" values are calculated by using the standard AFUE equation (i.e., AFUE as a function of Effy_{SS} and Effy_{HS}).

A table equivalent to Table 1.5 is not shown for oil MHFs. Oil furnaces are all equipped with electronic ignition, so existing Effy_{HS} values are equal to AFUE values. Proposed Effy_{HS} and AFUE values are calculated by simply adding 0.017 to the existing values.

The AFUE values shown in Tables 1.6 and 1.7 are based on the proposed test procedure. The Table 1.6 (gas furnace) AFUE and Effy_{HS} values are taken from Table 1.5. Table 1.7 (oil furnace) AFUE values are generated by adding 1.7 points to the AFUE values (obtained mostly from manufacturers) based on the existing test procedure.

⁸The value 1.7 is a default value. While lower values can be established by test, the MHF manufacturers accept the default.

Table 1.5 Transformation of AFUE and Effy_{HS} Values from Existing Test Procedure to Proposed Test Procedure Values

Standard Level	Design Option	Design Option Description	Effy _{ss}	<u>Existing Procedure</u>		<u>Proposed Procedure</u>	
				AFUE	Effy _{HS}	Effy _{HS}	AFUE
0	0	Baseline	0.826	75.0	0.775	0.792	76.6
1	1	Improved fan motor effic'cy	0.826	75.0	0.775	0.792	76.6
4	2	Fan-assisted combustion, EI	0.821	81.2	0.812	0.829	82.9
	3	Improved heat exchanger	0.841	83.2	0.832	0.849	84.9
	4	Two-stage operation	0.841	84.5	0.845	0.862	86.2
	5	Infrared Burner	0.844	84.8	0.848	0.865	86.5
2	6	Burner Box Damper	0.826	78.0	0.807	0.824	79.6
3	7	Improved heat exchanger	0.846	80.0	0.828	0.845	81.6
5	8	Condensing Flue Gas	0.923	90.0	0.900	0.917	91.7
	9	Two-stage operation	0.923	91.3	0.913	0.930	93.0
6	10	Continuous furnc modulatr	0.923	92.0	0.920	0.937	93.7
	11	Cabinet Insulation	0.826	75.0	0.775	0.792	76.6
	12	Fan-assisted combustion	0.821	76.0	0.785	0.802	77.6

Table 1.6 Efficiency Calculation Details for Gas MHFs

Option Number	Design Option Description	AFUE	Steady State Eff'cy	Heating Season Eff'cy	PE: Combustn Blower Power (kW)	BE: Circulating AirBlower Power (kW)	Pilot Input (Bth)	"A" Factor	"B" Factor	BOH _{SS}	E _M	BOH _R	BOH _H	Q _{OUT} , M	BOH _M	E _P	E _{AE}	BEBOH	AE
0	Baseline	76.6	0.826	0.792	0.	0.350	525	0.0219	0.0182	985						59246031	478	344.8	72.7
1	Improved fan motor eff'cy	76.6	0.826	0.792	0.	0.200	525	0.0223	0.0185	1001						60110529	278	200.1	74.3
2	Fan-assisted combustion, EI	82.9	0.821	0.829	0.0575	0.200	0	0.0210	0.0000	981						54937567	329	196.2	79.1
3	Improved heat exchanger	84.9	0.841	0.849	0.0575	0.200	0	0.0205	0.0000	958						53673789	321	191.7	81.0
4	Two-stage operation	86.2	0.841	0.862	0.0575	0.200	0	0.0198	0.0000	924	51736388	1728	60.1			51736388	266	184.8	82.7
5	Infrared Burner	86.5	0.844	0.865	0.0575	0.200	0	0.0197	0.0000	921	51564882	1722	59.9			51564882	265	184.2	83.0
6	Burner Box Damper	79.6	0.826	0.824	0.	0.200	525	0.0214	0.0185	961						57910914	267	192.2	77.1
7	Improved heat exchanger	81.6	0.846	0.845	0.	0.200	525	0.0209	0.0186	937						56576802	260	187.4	79.0
8	Condensing Flue Gas	91.7	0.923	0.917	0.0575	0.200	0	0.0190	0.0000	889						49780311	298	177.8	87.4
9	Two-stage operation	93.0	0.923	0.930	0.0575	0.200	0	0.0184	0.0000	859	48109417	1607	55.8			48109417	247	171.8	89.1
10	Continuous furn. modulation	93.7	0.923	0.937	0.0575	0.200	0	0.0183	0.0000	853	47773272	1595		26785	107	47773272	260	180.9	89.5
11	Cabinet Insulation	76.6	0.826	0.792	0.	0.350	525	0.0219	0.0182	985						59246031	478	344.8	72.7
12	Fan-assisted combustion	77.6	0.821	0.803	0.0575	0.350	525	0.0216	0.0182	968						58313737	526	338.9	72.8

Table 1.7 Efficiency Calculation Details for Oil MHFs

Option Number	Design Option Description	AFUE	Steady State Eff'cy	PE Combustn Blower Power (Bth)	BE Circulating Air Blower Power (Bth)	"R" Factor	"A" Factor	BOH _{SS}	E _M	BOH _R	BOH _H	Q _{OUT,M}	BOH _M	E _F (MMBtu/yr)	E _{AE} (kWh/yr)	BEBOH	AE
0	Baseline	82.1		0.282	0.760	1.0	0.0140	938						76534391	1254	713	72.8
1	Improved fan motor eff'cy	82.1		0.282	0.496	1.0	0.0142	955						77898056	926	473	74.7
2	Improved heat exchanger	84.1		0.282	0.496	1.0	0.0139	933						76129778	905	462	76.5
3	Condensing Flue Gas	91.7		0.282	0.496	1.0	0.0128	858						70047737	832	425	83.2
4	Full furnace modulation	93.7	0.942	0.282	0.496	2.3	0.0120	807	65859105	1509		39415	102	65859105	730	425	85.8
5	Two-stage operation	93.0		0.282	0.496	2.3	0.0121	813	66303422	1519	52.8			66303422	692	403	85.6
6	Added Cabinet Insulation	82.1		0.282	0.760	1.0	0.0140	938						76534391	1254	713	72.8

1.4.5 Calculations for Gas-Fired Single-Stage Furnaces with Pilot Ignition

Furnaces in this category include gas furnace design options 0, 1, 6, 7, 11, and 12. They are treated here as a group because the same calculations are used for each of the options, with slight variations for option 12 (Increased Cabinet or Jacket Insulation).

Values of E_F , E_{AE} , y , $BEBCH$, BOH_{SS} , F , A , and B were used or calculated as specified under Paragraph 10.19 of the DOE test procedure.

The value for $Effy_{HS}$ is used in calculating the quantities A and B . Given the values of steady-state efficiency and AFUE for all of the design options, it was possible to calculate $Effy_{HS}$ by recasting the equation for AFUE as found in ASHRAE, Paragraph 11.2.12,

$$AFUE = \frac{5200 (Effy_{SS}) (Effy_{HS})}{5200 (Effy_{SS}) + 2.5 (1.7) (4600) (Effy_{HS}) (Q_P/Q_{IN})}$$

in order to obtain an explicit expression for $Effy_{HS}$ (in terms of AFUE and $Effy_{SS}$). In the above equation, 1.7 has been used for the quantity $(1+\alpha)$, where α is the oversize factor. The quantities Q_P and Q_{IN} are also known and summarized in Tables 1.6 and 1.7.

1.4.6 Calculations for Single-Stage Furnaces with Electronic Ignition

Gas furnaces in this category include design options 2, 3, 4, 5, and 8. Oil furnaces in this category include all options except numbers 4 and 5. The major difference between the analysis of these options and the ones presented above in Section 1.4.4 lies in the computation of heating season efficiency, or $Effy_{HS}$. For furnaces without pilot ignition (i.e., with electronic ignition) the value of $Effy_{HS}$ is identical to AFUE. This result derives from the disappearance of the pilot input energy term ($Q_P = 0$) in the denominator of the above equation. Since AFUE values are already available (as described above in Section 1.4.2), no additional computation is required in order to obtain $Effy_{HS}$.

1.4.7 Calculations for Two-Stage Furnaces

This category includes gas furnace options 4 (non-condensing) and 9 (condensing), and oil furnace option 5. Basic assumptions for these furnaces have been presented above in Section 1.3.5, and the following paragraphs describe the implementation of those assumptions in the test procedure calculations.

Given the assumptions in Section 1.3.5 regarding input ratio and steady-state efficiencies for high- and low-fire modes, the ratio $Q_{OUT,R}/Q_{OUT}$ was approximated as equal to the input energy ratio [i.e., $Q_{OUT,R}/Q_{OUT} = Q_{IN,R}/Q_{IN} \approx 0.5$]. This assumption enabled calculation of the balance point temperature, T_C :

$$T_C = 65 - \left[(60)(1+\alpha) \frac{Q_{OUT,R}}{Q_{OUT}} \right] = 65 - [(60)(1.7)(0.5)] = 14 ^\circ\text{F}$$

With this value, the graph in Figure 24 of ANSI/ASHRAE Standard 103-1988 was used to obtain fractions of the heating load occurring at high and low fire, X_H and X_R , respectively [$X_H = .065$ and $X_R = .935$].

The value of Effy_{HS} , as required in the DOE test procedure (Paragraph 10.19.1) for the calculation of the A and B values, was taken as equal to AFUE (as explained above in Section 1.4.5).

Subsequent calculations to obtain energy usage values conform to the DOE test procedure for two-stage furnaces.

1.4.8 Calculations for Full Modulating Furnaces

Modulating furnaces are gas furnace option 10 and oil furnace option 4. Basic assumptions for these furnaces have been presented above in Section 1.3.6, and the following paragraphs describe the implementation of those assumptions in the test procedure calculations.

According to Paragraph 11.4.8.8 (and 11.5.8.8) of ANSI/ASHRAE 103-1988, the assumption in Section 1.3.6 regarding equality between steady-state efficiencies (i.e., $\text{Effy}_{SS} = \text{Effy}_{SS,R}$) also implies equality between all three steady-state efficiencies of the average modulating, maximum fuel input, and minimum fuel input modes [$\text{Effy}_{SS,M} = \text{Effy}_{SS} = \text{Effy}_{SS,R}$].

Modulating mode average outdoor temperature was established (per Paragraph 11.4.8.5 of ANSI/ASHRAE 103-88) by first calculating balance-point temperature using the same values as in the above equation for the two-stage case [$Q_{OUT,R}/Q_{OUT} = 0.5$, $T_C = 14 ^\circ\text{F}$, $X_H = .065$, and $X_R = .935$]. The value of T_C was then used in Figure 23 of ANSI/ASHRAE 103-1988 in order to obtain average outdoor temperature for the modulating mode, $T_{OA,H}$ [$T_{OA,H} = 11.4 ^\circ\text{F}$], for both oil and gas furnaces.

Given values described in the above paragraphs, the ASHRAE Standard Paragraph 11.4.8.10, specifies the following equation to calculate values of $Q_{OUT,M}$:

$$Q_{OUT,M} = \left[(DHR - Q_{OUT,R}) \left(\frac{T_C - T_{OA,H}}{T_C - 5} \right) \right] + Q_{OUT,R}$$

For gas furnaces, this is evaluated with the DHR and $Q_{OUT,R}$ as given above:

$$Q_{OUT,M} = \left[(29136 - .5[56,000][.923]) \left(\frac{14 - 11.4}{14 - 5} \right) \right] + .5(56,000)(.923) = 26785 \text{ Btu/hr}$$

For oil furnaces, the values of DHR and $Q_{OUT,R}$ are different:

$$Q_{OUT,M} = \left[(41880 - .5[81,600][.9245]) \left(\frac{14 - 11.4}{14 - 5} \right) \right] + .5(81,600)(.9245) = 38921 \text{ Btu/hr}$$

Given the values for $Effy_{SS,M}$ (determined as explained above) and the values of $Q_{OUT,M}$ as shown here, it is possible to calculate $Q_{IN,M}$ and then BOH_M according to Paragraph 10.19.1 of the DOE test procedure.

The value of $Effy_{HS}$, as required in the DOE test procedure (Paragraph 10.19.1) for the calculation of the A and B values, was taken as equal to AFUE (as explained above in Section 1.4.5).

Subsequent calculations to obtain energy-usage values conform to the DOE test procedure for step-modulating furnaces.

1.4.9 Energy-Usage Calculations

The DOE test procedure specifies a national average weather condition for usage in the standardized AFUE and AE calculations. This average weather condition is characterized by the value of 2,080 heating load hours (HLH). However, for annual energy-usage calculations, the (revised) proposed test procedure specifies a weather condition for MHFs characterized by ($HLH_{MHF} =$) 1,880 heating load hours. This value is based on the geographical distribution of recent mobile home sales and reflects the fact that mobile homes are most populous in warmer climates of the U.S. The proposed test procedure specifies (in Paragraph 10.19.7) a procedure for adjusting the (standard weather) annual fossil fuel energy consumption, E_F , and the annual auxiliary electrical energy consumption, E_{AE} , to values based on HLH_{MHF} . These quantities are designated $E_{F,MHF}$ and $E_{AE,MHF}$, respectively. Table 1.8 and 1.9 presents the results of the annual energy-usage calculations.

Table 1.8 Sales Weighted-Average Annual Energy Consumption (Based on HLH = 1880 Hours) for Gas Furnaces

Option Number	Design Option Description	E _{F,MHF} (Btu/yr)	E _{AE,MHF} (kWh/yr)
0	Baseline	54003956	433
1	Improved fan motor eff'cy	54785527	251
2	Fan-assisted combustion, EI	49667623	297
3	Improved heat exchanger	48525074	290
4	Two-stage operation	46773520	240
5	Infrared burner	46618466	239
6	Burner box damper	52796913	241
7	Improved heat exchanger	51590776	235
8	Condensing flue gas	45005082	269
9	Two-stage operation	43494470	223
10	Continuous furn. modulation	43190570	235
11	Cabinet insulation	54003956	433
12	Fan-assisted combustion	53161094	475

Table 1.9 Sales Weighted-Average Annual Energy Consumption (Based on HLH = 1880 Hours) for Oil Furnaces

Option No.	Design Option Description	E _{F,MHF} (Btu/yr)	E _{AE,MHF} (kWh/yr)
0	Baseline	69175315	1133
1	Improved fan motor eff'cy	70407858	837
2	Improved heat exchanger	68809607	818
3	Condensing flue gas	63312377	752
4	Full furnace modulation	59526498	660
5	Two-stage operation	59928093	626
6	Cabinet insulation	69175315	1133

1.5 COST-EFFICIENCY DATA

Tables 1.13 and 1.14 summarize cost, efficiency, and energy-usage values based on the results of energy calculations described in the previous section. Consumer costs presented in these tables are the sum of (1) the consumer's purchase price of the furnace (as already installed in the manufactured home), (2) any incremental furnace installation cost (above the baseline installation cost) incurred by the home manufacturer and/or the field crew installing the home,

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

6 of 6

and (3) any maintenance costs born by the home owner during the furnace lifetime. For purposes of this analysis, maintenance costs are treated by calculating their present value (at the time of home purchase).

A special note should be made regarding the presentation of installed costs in the above tables. As consumer costs, the values include not only maintenance and installation costs, but also the markup multipliers from MHF manufacturer-to-mobile home manufacturer, from mobile home manufacturer-to-retail outlet, and from retail outlet-to-owner. The retail prices included in the total values shown were calculated by a supply and demand model in the Manufacturer Impact Model (LBL-MIM) analysis, described later in this volume (and also in Appendix C, of Volume A of this Technical Support Document. Manufacturing costs submitted by the manufacturers and total markup values (which varied between design options) are not presented here in order to maintain confidentiality of manufacturer cost data. In contrast to the appliances presented in other volumes of this document, the existence of only two MHF manufacturers makes it possible for either manufacturer to determine the responses of the other manufacturer if average costs are presented. The unrevealed markup factors are therefore used in this presentation to obscure the actual manufacturer cost data.

Tables 1.10, 1.11, and 1.12 give the maintenance and installation costs used in calculating the "Incremental Consumer Installed Cost" values in Tables 1.13 and 1.14. The values for gas furnaces in Table 1.10 are taken from the following sources:

- Maintenance costs for standing pilots, intermittent ignition, combustion fans, and burner box dampers are taken directly from Table D.1 in Volume A.
- Estimation of the installation cost differential for condensing furnaces is described in Section 1.3.7. Additional installation costs are not included for different thermostats for two-stage and modulating furnaces.
- Maintenance costs for condensing furnaces include a cost for cleaning sensors and secondary finned-tube heat exchanger coils, as described in Volume A, Appendix F, Section F.5. However, one of the MHF manufacturers presently produces a condensing furnace (not for the manufactured housing market) with a secondary heat exchanger that is not of the finned-tube type. For this analysis, a heat exchanger without finned tubing is assumed to require no cleaning. Therefore, the maintenance costs in Table 1.10 are taken to be one half of the cost presented in Appendix F of Volume A. The rationale for this is based on the possibility that the other MHF manufacturer could produce a condensing furnace with a finned-tube type secondary heat exchanger.
- Maintenance costs for two-stage operation are considered to be exclusively due to control failure. With the lack of data for this case, maintenance costs for two-stage controls are estimated at 40% of the maintenance costs for intermittent ignition (i.e., 40% of \$81).

- Maintenance costs for continuous modulating operation are also considered to be exclusively due to control failure. These costs are estimated at 200% of the costs for two-stage operation (i.e., 200% of \$32).

The maintenance and installation costs for oil furnaces in Table 1.11 were obtained from several sources. The baseline maintenance costs were obtained through a phone interview with the staff of one oil service company located in Connecticut. Results of the interview are presented in Table 1.11.⁹ The resulting present value of all baseline maintenance costs, \$627, appears also in the summary of costs in Table 1.12. Note should be made that payback, life-cycle costs, and net present value costs are not affected by the baseline maintenance costs.

Other costs presented in Table 1.12 are taken from the following sources:

- Incremental maintenance costs for condensing furnaces (i.e., the entry for "Clean Coils and Sensors") are taken to be equal to the corresponding costs for gas furnaces.
- Incremental installation costs for all oil furnace options are taken as equal to the corresponding gas furnace costs.
- Incremental maintenance costs for two-stage furnaces are based on the assumption that two-stage oil furnace operation would be implemented through the use of two sets of burner nozzles. The maintenance costs, then, are the same as the gas furnace costs for two-stage controls (\$32.40), but also include a cost for routine replacement of an additional set of nozzles. According to Table 1.11, the cost for an extra set of nozzles is \$15.90. The incremental labor cost, \$35.50, is taken as 15% of the biennial labor cost reported in Table 1.11. In summary, the two-stage incremental cost is taken as \$32.40 (from gas furnace costs) plus an additional \$51.40.
- Incremental maintenance costs for continuous modulating furnaces are based on the assumption that modulating oil furnaces would be implemented in a step-wise manner, and that multiple-burner nozzles would be used. The maintenance costs include the same costs as the gas furnace for modulating controls (\$65), but also include a cost for routine replacement of additional nozzles. The incremental cost for nozzle replacement is taken as 130% of the incremental cost for nozzle replacement for two-stage oil furnaces (as described in the paragraph above), or 130% of \$51.40.

⁹The Present Value costs presented in the final column of Table 1.11 include costs for not only the first failure of a particular component, but also costs for subsequent failures (during the lifetime of the furnace) as well.

Table 1.10¹⁰ Gas Furnace Maintenance Cost Components and Installation Costs(1990 \$)

Option Number	Design Option Description	MAINTENANCE COST COMPONENTS							INCREMENTAL INSTALLATION COSTS
		Pilot	Combustion Fan	Two Stage Controls	Continuous Modulation Controls	Burner Box Damper	EI	Clean Coils & Sensors	
0	Baseline	30							na
1	0 + Improved fan motor efficiency	30							
2	1 + Fan-assisted combustion, EI		57				81		
3	2 + Improved heat exchanger		57				81		
4	3 + Two-stage operation		57	32			81		
5	4 + Infrared Burner		57	32			81		
6	1 + Burner Box Damper	30				36			
7	6 + Improved heat exchanger	30				36			
8	1 + Condensing Flue Gas		57				81	25	74
9	8 + Two-stage operation		57	32			81	25	74
10	8 + Continuous furnace modulation		57		65		81	25	74
11	0 + Cabinet Insulation	30							
12	0 + Fan-assisted combustion	30	57						

¹⁰Note: Some rows in this and subsequent tables do not appear to add up correctly because the entries have been rounded off.

Table 1.11 Maintenance Cost Breakdown for Baseline Oil Furnace (1990\$)

Description of Maintenance Items		Cost (\$)	Life (yrs)	Present Value (\$)
Major Component Failures	Motor	95	8	97
	Fuel Pump	166	10	93
	Transformer	83	5	143
	Ignitor	57	12	28
	SUBTOTAL			361
Biennial Maintenance	Electrodes	2.6	2	14
	Nozzles	3.0	2	16
	Labor	45	2	237
	SUBTOTAL			266
TOTAL (All maintenance)				627

Table 1.12 Oil Furnace Maintenance Cost Components and Installation Costs (1990 \$)

Option Number	Design Option	MAINTENANCE COST COMPONENTS					INCREMENTAL INSTALLATION COSTS
		Baseline Maint	Clean Coils & Sensors	Two Stage Controls	Continuous Modulation Controls	TOTAL	
0	Baseline	627				627	
1	0 + Improved fan motor eff'cy	627				627	
2	1 + Improved heat exchanger	627				627	
3	1 + Condensing Flue Gas	627	25			651	74
4	3 + Full furnace modulation	627	25		132	783	74
5	3 + Two-stage operation	627	25	84		735	74
6	0 + Cabinet Insulation	627				627	

Table 1.13 Cost-Efficiency Data for Gas Mobile Home Furnaces

Standard Level	Option Number	Design Option Description	Annual Fuel Utilization Efficiency AFUE	Annual Efficiency AE	Incremental Consumer Installed Cost (\$)	Annual Fuel Usage (MMBtu/yr)	Annual Electric Usage (kWh/yr)
0	0	Baseline	76.6	72.7	0	54.00	433
1	1	0 + Improved fan motor efficiency	76.6	74.3	6	54.79	251
4	2	1 + Fan-assisted combustion, Ei	82.9	79.1	261	49.67	297
	3	2 + Improved heat exchanger	84.9	72.7	371	48.56	290
	4	3 + Two-stage operation	86.2	82.7	586	46.77	240
	5	4 + Infrared burner	86.5	83.0	623	46.62	239
2	6	1 + Burner box damper	79.6	77.1	74	52.80	241
3	7	6 + Improved heat exchanger	81.6	79.0	183	51.59	235
5	8	1 + Condensing flue gas	91.7	87.4	555	45.01	269
	9	8 + Two-stage operation	93.0	89.1	763	43.49	223
6	10	8 + Continuous furnace modulation	93.7	89.5	1130	43.19	235
	11	0 + Cabinet insulation	76.6	72.7	17	54.00	433
	12	0 + Fan-assisted combustion	77.6	72.8	129	53.16	475

Table 1.14 Cost-Efficiency Data for Oil Mobile Home Furnaces

Standard Level	Option Number	Design Option Description	AFUE	Annual Efficiency AE	Incremental Consumer Installed Cost (\$)	Annual Fuel Usage (MMBtu/yr)	Annual Electric Usage (kWh/yr)
0	0	Baseline	82.1	72.8	0	69.18	1133
1,2	1	0 + Improved fan motor efficiency	82.1	74.7	20	70.41	837
3,4	2	1 + Improved heat exchanger	84.1	76.5	141	68.81	818
5	3	1 + Condensing Flue Gas	91.7	83.2	540	63.31	752
6	4	3 + Full furnace modulation	93.7	85.8	1245	59.53	660
	5	3 + Two-stage operation	93.0	85.6	1157	59.93	626
	6	0 + Cabinet Insulation	82.1	72.8	24	69.18	1133

1.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGNS

The full modulating condensing furnace is the design option that provides the maximum technologically feasible efficiency for both gas (89.5 AE) and oil (85.8 AE) MHFs. While energy usage and efficiency characteristics (in terms of AE, and annual fuel and electrical energy usages) were already presented above for modulating furnaces, further analysis for this maximum technology design option is presented below in order to describe the ranges of uncertainty in annual fuel and electrical energy usage values.

The @RISK¹¹ spreadsheet software, as described in Appendix A of Volume A of this Technical Support Document, was used to analyze the uncertainty of fuel and electric energy usages. Table 1.15 presents 95% confidence level efficiency intervals obtained through the @RISK program uncertainty calculations.

Table 1.15 Furnace Efficiency Uncertainty Ranges

Furnace Type	AFUE Range	AE Range
Gas	93.5 to 93.8	87.5 to 91.4
Oil	93.5 to 97.5	82.1 to 89.3

¹¹ © Palisades Corp. Newfield, NY, 1988.

CHAPTER 2. BASE CASE FORECASTS: MOBILE HOME FURNACES

Analyzing impacts of federal energy-efficiency standards requires comparing projected U.S. residential energy consumption with and without the standards. The cases without standards are referred to as *base case projections*. These base case projections are compared to projections of conditions that would be likely prevail if standards were enacted (see Chapter 3//). The difference between the two projections is defined as the incremental impact of standards.

Projections are made for a number of demographic, economic, and energy variables, including energy prices, household income, housing stock, housing starts, mix of house types (single-family, multifamily, mobile homes), building shell thermal characteristics, appliance purchases, equipment prices, unit energy consumption, and aggregate residential energy consumption by fuel type.

2.1 DEMOGRAPHIC AND ECONOMIC ASSUMPTIONS

The demographic and economic assumptions are described in Volume A, Chapter 5 of this Technical Support Document.

2.2 AVERAGE EQUIPMENT LIFETIME

A distribution of equipment lifetimes, or the rates at which appliances retire as a function of years since purchase, are determined by analyzing historical shipments reported by the industry trade association. Average lifetimes are 23 years for electric, 19 years for gas, and 20 years for oil mobile home furnaces.

Table 2.1 Average Equipment Lifetime (Years) of Mobile Home Furnaces

	Years	Source
Electric	23.0	LBL
Gas	19.0	LBL
Oil	20.0	LBL

2.2 BASE CASE PROJECTIONS

This section contains projections of unit energy consumption of new appliances, annual appliance installations, annual residential energy consumption, and price of purchased appliances.

2.2.1 New Appliance Unit Energy Consumptions

Annual unit energy consumption (UEC) of new appliances is projected based upon a set of designs available (each design characterized by a purchase price and an energy-efficiency factor or UEC), and a market discount rate (derived from implicit decision-making in recent purchase decisions for the product). The LBL-REM produces projections of annual energy consumption of new appliances after 1980. Table 2.2 shows the trends in efficiency and annual unit energy consumption.

Table 2.2 Base Case Projection of Unit Energy Consumption for New Mobile Home Furnaces

Year	Average Energy Factor		UEC (MMBtu/yr)	
	Gas	Oil	Gas	Oil
1981	0.727	0.728	55.48	73.06
1990	0.748	0.755	53.66	69.39
1996	0.754	0.785	53.24	66.84
2000	0.754	0.796	53.22	65.93
2030	0.772	0.814	51.80	64.49

Source: LBL-REM (1980-2030).

2.2.1.1 Efficiency Distributions

The distributions are presented in Appendix B.

2.2.1.2 Usage

The relative usage expressing hours of operation per year as a relative index with a value of 1.0 in the base year (1980) is shown in Table 2.3. Usage is projected as a function of energy price, equipment efficiency, and shell efficiency.

Table 2.3 Projected Average Usage of Mobile Home Furnaces

Year	Gas	Oil
1981	0.98	1.00
1990	1.03	1.20
1996	1.05	1.22
2000	1.05	1.22
2030	0.90	1.14

Source: LBL-REM.

2.2.2 Annual U.S. Appliance Installations

The market for appliances is seen as having two segments: new construction and existing housing. All new households are considered eligible to purchase each appliance. The pool of potential purchasers among existing households each year is defined as households that retired a unit that year, plus a fraction of households that did not previously own the product.

The initial (1980) fraction of new (and of existing) households expected to purchase each product and fuel type is specified as input to LBL-REM. LBL-REM produces projected fractions, for each year, of new households (and of existing households) that purchase the product. The projection is based on market share elasticities with respect to income, equipment price, and annual operating expense. Market share elasticities are given in Appendix B of this volume.

The projection for the period 1981-1990 is calibrated to reasonable agreement with available data, including domestic shipments (from published trade association data) and surveys of appliance ownership (e.g., from DOE/EIA RECS (13) and the Bureau of the Census).

Tables 2.4 and 2.5 show the significant trends in the installation and saturation of this product.

Table 2.4 Annual Installations of Mobile Home Furnaces in U.S. Households (Thousands)

Year	Electric	Gas	Oil	Other	Total
1981	83	118	20	11	232
1990	63	139	27	10	239
1996	65	157	33	12	267
2000	66	152	33	11	262
2030	79	161	50	13	303

Table 2.5 Percent of Occupied U.S. Housing Units Having Mobile Home Furnaces

Year	Mobile Homes Only				All Households			
	Elec	Gas	Oil	Other	Elec	Gas	Oil	Other
1980	9.3	57.8	17.6	2.8	0.4	2.8	0.9	0.1
1990	19.5	53.5	13.9	3.2	1.0	2.6	0.7	0.1
1996	22.3	53.2	12.7	2.9	1.1	2.6	0.6	0.1
2000	23.7	52.7	12.2	2.9	1.2	2.6	0.6	0.2
2030	20.3	54.4	15.8	2.5	1.0	2.7	0.8	0.1

Source: LBL-REM.

2.2.3 U.S. Residential Energy Consumption

U.S. residential energy consumption for this product is calculated each year as the product of: number of occupied households, fraction of households owning the appliance, average unit energy consumption (engineering estimate), and usage behavior factor.

Table 2.6 shows the U.S. energy consumption, expressed in quadrillion Btu of primary energy, using a conversion factor for electricity of one kWh per 11,500 Btu.

Table 2.6 U.S. Residential Energy Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary Energy)

Year	Electric	Gas	Other	Total
1981	0.03	0.11	0.04	0.18
1990	0.03	0.10	0.03	0.16
1996	0.05	0.10	0.03	0.18
2000	0.05	0.11	0.03	0.19
2030	0.04	0.10	0.04	0.18

2.2.4 Price of Purchased Appliances

Prices of new units increase over time as energy-efficiency improvements are incorporated. Table 2.7 shows projected shipment-weighted average prices.

Table 2.7 Average Price of New Mobile Home Furnaces in U.S. Households (1990 dollars)

Year	Gas	Oil
1981	551	1562
1990	574	1636
1996	594	1822
2000	595	1889
2030	704	1994

Source: LBL-REM.

2.3 SENSITIVITY ANALYSIS OF THE BASE CASE

The sensitivity cases selected are defined as follows:

1. *Lower Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level is decreased by the estimated uncertainty interval.

2. *Higher Equipment Price.* The price of the baseline unit and the incremental price associated with each engineering level is increased by the estimated uncertainty interval.
3. *Lower Energy Price.* Assume lower energy prices. Starting from 1992 to 2030, electricity prices are 3% lower while gas and distillate prices are 5% lower than those in the AEO 1991(14) forecast.
4. *Higher Energy Price.* Assume higher energy prices. Starting from 1992 to 2030, electricity prices are 3% higher while gas and distillate prices are 5% higher than those in the AEO 1991 forecast.
5. *High Equipment Efficiency.* Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.
6. *Market Discount Rates Decline.* Assume that market discount rates used to determine future efficiency choices are declining over time by 2% per year, i.e., efficiency improvements appear in the marketplace sooner.

The results of these six sensitivity cases are presented in the following tables. Tables 2.8a to 2.8.b show how the average price varies. Tables 2.9a to 2.9.b show the differences in unit energy consumption or efficiency. The first line of these tables gives the results of the reference case described in the previous section; the rest of the lines give the corresponding results of the sensitivity cases listed above.

Table 2.8a Average Purchase Price of New Gas-Fired Mobile Home Furnaces (1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	551	574	594	595	704
1	486	498	509	580	1021
2	634	668	697	698	699
3	551	574	594	595	704
4	551	574	594	595	704
5	551	572	993	1694	1694
6	551	574	594	595	1401

Table 2.8b Average Purchase Price of New Oil-Fired Mobile Home Furnaces (1990 Dollars)

Year:	1981	1990	1996	2000	2030
Reference	1562	1636	1822	1889	1994
1	1278	1323	1441	1483	1782
2	1852	1960	2238	2337	2495
3	1562	1636	1822	1889	1994
4	1562	1636	1822	1889	1994
5	1562	1609	2728	2806	2806
6	1562	1636	1822	1889	2331

Table 2.9a Average Unit Consumption of New Gas-Fired Mobile Furnaces (MMBtu/Year)

Year:	1981	1990	1996	2000	2030
Reference	55.5	53.7	53.2	53.2	51.8
1	55.5	53.7	53.2	51.8	44.7
2	55.5	53.7	53.2	53.2	53.2
3	55.5	53.7	53.2	53.2	51.8
4	55.5	53.7	53.2	53.2	51.8
5	55.5	53.7	46.9	43.2	43.2
6	55.5	53.7	53.2	53.2	44.7

Table 2.9b Average Unit Consumption of New Oil-Fired Mobile Furnaces (MMBtu/Year)

Year:	1981	1990	1996	2000	2030
Reference	73.1	69.4	66.8	65.9	64.5
1	73.1	69.4	66.8	65.9	62.6
2	73.1	69.4	66.8	65.9	64.5
3	73.1	69.4	66.8	65.9	64.5
4	73.1	69.4	66.8	65.9	64.5
5	73.1	69.7	60.0	59.5	59.5
6	73.1	69.4	66.8	65.9	62.6

Source: LBL-REM.

CHAPTER 3. PROJECTED NATIONAL IMPACTS OF STANDARDS: MOBILE HOME FURNACES

The LBL Residential Energy Model (LBL-REM) projects a number of economic and energy-use variables that are used to assess the impact of proposed standards on consumers, electric utilities, and appliance manufacturers. This chapter presents projections from the model, which assume various trial standards.

The principal outputs from the LBL-REM for each year are:

- unit equipment price and operating expense by product,
- projected annual shipments of residential appliances,
- energy consumption by end use and fuel, and
- differences in these quantities between a base case and each trial standards case.

These outputs are provided annually (or for selected years) and cumulatively over a period of time, i.e., 1996-2030. Energy savings are given for each year from implementation of standards to the end of the period. Net present value of the standards is evaluated for each regulated product and for the end use(s) comprising the regulated and competing products. The sensitivity of the outputs to the key assumptions and data is analyzed; the results of this analysis are also presented.

Section 3.1 presents the trial standards levels analyzed. Section 3.2 presents the historical and projected energy consumption, including unit energy consumption for new purchases and total national energy consumption. Section 3.3 presents historical and projected annual installations. Section 3.4 presents purchase prices. Section 3.5 presents net present value and Section 3.6 discusses the results of the sensitivity analyses.

An overview of the general REM methodology and demographic assumptions is in Volume A of this Technical Support Document. Product-specific input data are described in Appendix C of this volume.

3.1 STANDARD LEVELS

Table 3.1 shows the correspondence between the trial standards levels, the engineering design levels, and the associated unit energy factor.

Table 3.1 Trial Standards Levels for Mobile Home Furnaces

	Trial Standard Level					
	1	2	3	4	5	6
Engineering design option:						
Gas-fired Mobile Home Furnaces	1	6	7	2	8	10
Oil-fired Mobile Home Furnaces	1	1	2	2	3	4
Minimum energy factor:						
Gas-fired Mobile Home Furnaces	74.3%	77.1%	79.1%	79.1%	87.4%	89.5%
Oil-fired Mobile Home Furnaces	74.7%	74.7%	76.5%	76.5%	83.2%	85.8%

3.2 ENERGY CONSUMPTION

Tables 3.2a and 3.2b show the past and projected average energy use of new mobile home furnaces. The unit energy consumption of an average new gas-fired mobile home furnace is projected to change from 53.7 MMBtu/yr in 1990 to 53.2 MMBtu in 1996 in the absence of amended standards. The unit energy consumption of an average new oil-fired mobile home furnace is projected to change from 69.4 MMBtu/yr in 1990 to 66.8 MMBtu in 1996 in the absence of amended standards.

Table 3.2a Unit Energy Consumption for New Gas-Fired Mobile Home Furnaces (Million Btu/Year)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	55.5						
1990	53.7						
1996	53.2	53.6	52.7	51.6	49.7	45.0	43.2
2000	53.2	53.6	52.7	51.6	49.7	45.0	43.2
2015	53.2	53.6	52.7	51.6	49.7	45.0	43.2
2030	51.8	51.8	51.0	50.5	49.6	45.0	43.2

Table 3.2b Unit Energy Consumption for New Oil-Fired Mobile Home Furnaces (Million Btu/Year)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	73.1						
1990	69.4						
1996	66.8	67.0	67.0	66.8	66.8	63.3	59.5
2000	65.9	66.1	66.1	65.9	65.9	63.3	59.5
2015	64.7	64.9	64.9	64.6	64.6	63.3	59.5
2030	64.5	64.6	64.6	64.4	64.4	63.3	59.5

Source: LBL-REM.

Tables 3.3a through 3.3e present projections of savings in (a) electricity consumption (b) gas consumption, (c) oil consumption, (d) other energy consumption, and (e) total energy consumption of mobile home furnaces. Standards are projected to produce cumulative energy savings ranging from -0.02 Quads for standards level 5 to 0.11 Quads for standards level 6, during the period 1996-2030. At standards level 5, purchases of gas furnaces decrease, and purchases of electric and oil furnaces increase, resulting in a net increase in energy consumption.

Table 3.3a U.S. Electricity Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary) (Includes Electric Heat, Fossil Furnaces, Heat Pumps)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	0.029						
1990	0.034						
1996	0.045	0.045	0.045	0.045	0.045	0.045	0.047
2000	0.050	0.050	0.050	0.051	0.052	0.053	0.057
2015	0.045	0.045	0.045	0.048	0.050	0.058	0.072
2030	0.042	0.042	0.042	0.045	0.047	0.054	0.069
1996-2030	1.61	1.61	1.63	1.69	1.76	1.95	2.34
Cumulative Savings:	0.00	-0.01	-0.08	-0.14	-0.34	-0.73	
Percent of Base:	0.1%	-0.9%	-5.0%	-9.0%	-21.0%	-45.2%	

Table 3.3b U.S. Gas Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	0.111						
1990	0.103						
1996	0.103	0.103	0.103	0.102	0.101	0.100	0.097
2000	0.106	0.106	0.105	0.103	0.102	0.095	0.086
2015	0.107	0.106	0.104	0.098	0.093	0.075	0.046
2030	0.096	0.096	0.094	0.089	0.085	0.066	0.036
1996-2030	3.67	3.66	3.60	3.43	3.30	2.79	2.00
Cumulative Savings:		0.01	0.07	0.24	0.37	0.88	1.67
Percent of Base:		0.3%	1.9%	6.5%	10.1%	24.0%	54.5%

Table 3.3c U.S. Oil Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	0.037						
1990	0.033						
1996	0.029	0.029	0.030	0.030	0.30	0.030	0.031
2000	0.029	0.029	0.029	0.030	0.031	0.032	0.037
2015	0.033	0.033	0.034	0.037	0.040	0.048	0.066
2030	0.039	0.039	0.040	0.043	0.046	0.057	0.081
1996-2030	1.15	1.14	1.16	1.25	1.34	1.57	2.09
Cumulative Savings:		0.02	-0.01	-0.10	-0.19	-0.43	-0.94
Percent of Base:		0.9%	-0.9%	-8.7%	-16.5%	-36.5%	-81.7%

Table 3.3d U.S. Other Energy Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	0.001						
1990	0.001						
1996	0.002	0.002	0.002	0.002	0.002	0.002	0.002
2000	0.002	0.002	0.002	0.002	0.002	0.002	0.002
2015	0.002	0.002	0.002	0.002	0.002	0.002	0.002
2030	0.001	0.001	0.001	0.001	0.001	0.001	0.001
1996-2030	0.05	0.05	0.05	0.06	0.06	0.06	0.07
Cumulative Savings:		0.00	0.00	-0.01	-0.01	-0.01	-0.02
Percent of Base:		0.0%	0.0%	-20.0%	-20.0%	-20.0%	-40.0%

Table 3.3e Total U.S. Energy Consumption for Mobile Home Furnaces (Quadrillion Btu, Primary)

Year	Trial Standard Level						
	Base	1	2	3	4	5	6
1981	0.18						
1990	0.17						
1996	0.18	0.18	0.18	0.18	0.18	0.18	0.18
2000	0.19	0.19	0.19	0.19	0.19	0.18	0.18
2015	0.19	0.19	0.19	0.19	0.19	0.18	0.19
2030	0.18	0.18	0.18	0.18	0.18	0.18	0.19
1996-2030	6.48	6.46	6.44	6.43	6.46	6.37	6.50
Cumulative Savings:		0.02	0.05	0.05	0.03	0.11	-0.02
Percent of Base:		0.3%	0.7%	0.8%	0.4%	1.7%	-0.3%

Source: LBL-REM.

3.3 ANNUAL INSTALLATIONS

As shown in Table 3.4, installations¹² of mobile home furnaces are affected by standards. This result is a function of the change in operating expense, change in equipment price, and market share elasticities. The projection shows a change of between 55% decrease (standard 5) and 0.2% increase (standard 1) from base due to the various standards levels for cumulative shipments of gas mobile home furnaces from 1996 to 2030. For oil-fired mobile home furnaces, shipments remain unchanged (standard 1) or increase up to 130% (standard 5).

¹² If there are no imports or exports, annual installations are equivalent to domestic shipments. Domestic shipments can be calculated as annual installations, less imports, plus exports.

Table 3.4 Cumulative Installations of Mobile Home Furnaces (Millions)

1996-2030	Trial Standard Level						
	Base	1	2	3	4	5	6
Electric	2.39	2.39	2.42	2.53	2.64	3.02	3.77
Gas	5.62	5.63	5.56	5.33	5.08	4.26	2.50
Oil	1.44	1.44	1.47	1.60	1.73	2.20	3.32
Other	0.08	0.08	0.08	0.08	0.09	0.09	0.10
Heat Pumps	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Total	9.86	9.87	9.86	9.87	9.87	9.90	10.02
Change from Base:							
Electric		0.00	0.03	0.14	0.25	0.63	1.38
Gas		0.01	-0.06	-0.29	-0.54	-1.36	-3.12
Oil		0.00	0.03	0.16	0.29	0.76	1.88
Other		0.00	0.00	0.00	0.01	0.01	0.02
Heat Pumps		0.00	0.00	0.00	0.00	0.00	0.00
Total		0.01	-0.00	0.01	0.01	0.04	0.16
Percent Change:							
Electric		0.0%	1.3%	5.9%	10.5%	26.4%	57.7%
Gas		0.2%	-1.1%	-5.2%	-9.6%	-24.2%	-55.5%
Oil		0.0%	2.1%	11.1%	20.1%	52.8%	130.6%
Other		0.0%	0.0%	0.0%	12.5%	12.5%	25.0%
Heat Pumps		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total		0.1%	-0.0%	0.1%	0.1%	0.4%	1.6%

3.4 APPLIANCE PRICES

Projections of the purchase prices for new mobile home furnaces in 1990 dollars are shown in Tables 3.5a and 3.5b. The prices typically increase when standards come into effect.

Table 3.5a Average Purchase Price for New Gas-Fired Mobile Home Furnaces (1990 Dollars Per Unit)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	551						
1990	574						
1996	594	596	627	729	816	1112	1694
2000	595	598	628	729	816	1112	1694
2015	595	598	628	729	816	1112	1694
2030	704	704	734	781	818	1112	1694

Table 3.5b Average Purchase Price for New Oil-Fired Mobile Home Furnaces (1990 Dollars Per Unit)

Year	Base	Trial Standard Level					
		1	2	3	4	5	6
1981	1562						
1990	1636						
1996	1822	1825	1825	1840	1840	2093	2806
2000	1889	1891	1891	1906	1906	2093	2806
2015	1979	1981	1981	1996	1996	2093	2806
2030	1994	1996	1996	2011	2011	2093	2806

3.5 NET PRESENT VALUE (NPV)

The NPV of standards for any product is calculated by first determining the difference in present value of unit life-cycle costs between the base case and standards case each year. That difference is then multiplied by the standards case shipments for the year. The NPV for the period (1996-2030) is the sum over the years of the annual values. A positive NPV of standards results when the new units in the standards case have lower present value of life-cycle cost than do new units in the base case. Table 3.6 shows the NPV to society of the trial standards levels.

3.6 SENSITIVITY ANALYSIS

The base case and standards levels as described above constitute a reference case against which the impacts of standards under different assumptions may be compared. The sensitivity analysis is performed by running the LBL-REM for the base case and *trial standards level 1* for mobile home furnaces. For each sensitivity case, the results for the trial standards level are compared to the corresponding base-case run and the differences are tabulated.

Table 3.6 Net Present Value for Mobile Home Furnaces Purchased from 1996-2030 (Billion 1990\$ Discounted at 7%)¹³

	Trial Standard Level					
	1	2	3	4	5	6
Fuel costs savings:						
Electricity	0.000	-0.000	-0.001	-0.002	-0.004	-0.014
Gas	0.028	0.078	0.134	0.123	0.327	0.194
Oil	0.004	0.005	0.011	0.014	0.086	0.227
TOTAL benefit (energy):	0.032	0.083	0.144	0.135	0.408	0.407
Equipment costs:						
Electric	0.000	0.000	0.000	0.000	0.000	0.000
Gas	0.018	0.255	0.964	1.504	3.021	3.849
Oil	0.002	0.003	0.019	0.021	0.243	1.957
TOTAL cost (equipment):	0.020	0.258	0.983	1.525	3.265	5.806
NET = benefit - cost:						
Electric	0.000	-0.000	-0.001	-0.002	-0.004	-0.014
Gas	0.010	-0.177	-0.830	-1.381	-2.695	-3.655
Oil	0.002	0.002	-0.008	-0.007	-0.158	-1.731
TOTAL across fuels:	0.012	-0.175	-0.839	-1.390	-2.857	-5.400
Ratio: Benefit/cost:	1.57	0.32	0.15	0.09	0.12	0.07

Source: LBL-REM.

The assumptions in the sensitivity cases are described in Section 2.3 and listed in Table 3.7. Tables 3.8a and 3.8b show results for cumulative energy consumption. The sensitivity analysis of product shipments is given in Tables 3.9a and 3.9b. Table 3.10 shows the net present values. The first line of these tables gives the results of the reference case (base case, standards level, and difference). The rest of the lines each give the results corresponding to one of the sensitivity cases, including the base case, standards case, and difference. Note that the changes in the impact of standards as a function of the changed assumptions (difference between the base and standards cases) are the principal results of the sensitivity analysis.

¹³Normalized to standards case shipments

Table 3.7 Sensitivity Analysis Cases

Case	Description
1	Lower Equipment Prices
2	Higher Equipment Prices
3	Lower Energy Price
4	Higher Energy Price
5	High Equipment Efficiency
6	Market Discount Rates Decline

**Table 3.8a Cumulative Energy Consumption of Gas Mobile Home Furnaces
During the Period 1996-2030 (Quadrillion Btu, Primary)**

	Trial Standard		Difference
	Base	Level 1	
Reference	3.67	3.66	0.01
1	3.60	3.60	0.00
2	3.67	3.65	0.02
3	3.76	3.75	0.01
4	3.57	3.56	0.01
5	2.14	2.14	0.00
6	3.55	3.54	0.01

**Table 3.8b Cumulative Energy Consumption of Oil Mobile Home Furnaces
During the Period 1996-2030 (Quadrillion Btu, Primary)**

	Trial Standard		Difference
	Base	Level 1	
Reference	1.15	1.14	0.01
1	1.16	1.16	0.00
2	1.14	1.14	0.00
3	1.14	1.13	0.01
4	1.16	1.15	0.01
5	1.99	1.99	0.00
6	1.21	1.21	0.00

Table 3.9a Cumulative Shipments of Gas Mobile Home Furnaces
During the Period 1996-2030 (Millions)

	Trial Standard		Difference
	Base	Level 1	
Reference	5.62	5.63	-0.01
1	5.54	5.54	0.00
2	5.68	5.67	0.01
3	6.69	5.70	-0.01
4	5.55	5.55	0.00
5	2.64	2.64	0.00
6	5.02	5.02	0.00

Table 3.9b Cumulative Shipments of Oil Mobile Home Furnaces
During the Period 1996-2030 (Millions)

	Trial Standard		Difference
	Base	Level 1	
Reference	1.44	1.44	0.00
1	1.47	1.47	0.00
2	1.39	1.40	-0.01
3	1.41	1.41	0.00
4	1.47	1.46	0.01
5	3.21	3.21	0.00
6	1.77	1.77	0.00

Table 3.10 Total Net Present Value to Consumers for Units Sold During the Period 1996-2030
(Discounted to 1990 at 4% Real)

Case	Net Present Value (Million \$)	
	Trial Standard	Level 1
Reference	29.8	
1	14.9	
2	-83.3	
3	32.8	
4	27.0	
5	0.0	
6	17.8	

Source: LBL-REM.

CHAPTER 4. LIFE-CYCLE COSTS AND PAYBACK PERIODS: MOBILE HOME FURNANCES

The effect of standards on individual consumers includes a change in operating expense (usually decreased) and a change in purchase price (usually increased). The net effect is analyzed by calculating the life-cycle cost, using the engineering data (Chapter 1) for energy consumption and equipment price, and assuming the energy price projected for 1996. Section 4.1 presents the life-cycle costs (LCC) for each design option. The results are displayed as graphs and as tables of values. Sections 4.2 through 4.4 show the impacts of standards on consumers. Section 4.5 presents the effect of different assumptions on the life-cycle cost calculations.

The *difference* due to standards is calculated (Sections 4.2 to 4.4) after a base case forecast is made (see Chapter 2). The base case forecast accounts for market-based shifts in efficiency and usage that are projected to occur independently of standards. Then only those appliance purchasers who are impacted by standards (i.e., those who would have chosen a design eliminated by standards) are included in calculating the impact of standards on consumers. The impact of standards is expressed by three measures:

- Section 4.2: Payback Period (PBP),
- Section 4.3: Change in Life-Cycle Cost (LCC), and
- Section 4.4: Cost of Conserved Energy (CCE).

4.1 LIFE-CYCLE COST FOR DESIGN OPTIONS

The LCC is the sum of the purchase price (PC) and the operating expense (OC) discounted over the lifetime (N) of the appliance.

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

If operating expenses are constant over time, Eq. 1 simplifies to:

$$LCC = PC + PWF \cdot OC, \quad (2)$$

where we have defined the present worth factor:

$$PWF = \sum_{t=1}^N \frac{1}{(1+r)^t} = \frac{1}{r} \left[\frac{1}{(1+r)^N} \right] \quad (3)$$

The LCC is calculated for each class in the year standards are imposed, using a discount rate, r .

4.1.1 LCC Data Inputs

The purchase price is based on the factory costs in the Engineering Analysis (Chapter 1) and includes a factory markup plus distributor and retailer markups, calculated by LBL-MIM. Installation and maintenance costs are also from the Engineering Analysis. Purchase price and installation costs are added to the present value of operating expenses (including maintenance, if applicable), discounted, and summed over the life of the product. Expenses in future years are discounted to the year of purchase, 1996. For the residential sector, the discount rate is 6% real, with sensitivity analysis performed at 2% and 10% real.

The energy price is the projected 1996 average residential energy price times an end-use factor of 0.90 (electricity) or 0.98 (gas) (See discussions in Volume A, Section 5.1.5).

4.1.2 LCC Results

Figures 4.1 and 4.2 show the LCCs by design option. The values used to produce these figures are presented in Tables 4.1 and 4.2.

Figure 4.2 Life-Cycle Cost for an Oil-fired, Low Capacity Mobile Home Furnace (81.6 Mbth input)

Figure 4.2 Life-Cycle Cost for an Oil-fired, Low Capacity Mobile Home Furnace (81.6 Mbth input)

Figure 4.1 Life-Cycle Cost for a Gas-fired, Low Capacity Mobile Home Furnace (56 Mbth input)

Table 4.1 Life-Cycle Costs of Gas-Fired Mobile Home Furnace (56 Mbth input)

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	Energy Factor	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
	0	Baseline	29.58	513.04	542.62	72.7%	54.00	432.52	452.51	6492.12	5591.73	4318.51
1	1	0 + Improved fan motor eff.	29.58	518.78	548.36	74.3%	54.79	251.06	442.95	6372.42	5490.90	4244.36
4	2	1 + Fan-assisted comb., IID	138.18	678.15	816.33	79.1%	49.67	297.14	407.55	6205.63	5363.82	4175.75
	3	2 + Improved heat exchanger	138.18	787.59	925.77	81.0%	48.53	290.30	398.19	6192.20	5368.87	4206.94
	4	3 + Two-stage operation	170.55	973.69	1144.24	82.7%	46.77	240.13	380.34	6185.41	5388.11	4263.88
	5	4 + Infrared burner	170.55	1010.70	1181.25	83.0%	46.62	239.34	379.12	6206.37	5411.49	4290.67
2	6	1 + Burner box damper	65.12	554.30	619.42	77.2%	52.80	241.12	426.80	6238.70	5381.65	4169.24
3	7	6 + Improved heat exchanger	65.12	663.85	728.97	79.1%	51.59	235.08	416.97	6219.21	5381.57	4196.61
5	8	1 + Condensing flue gas	236.75	875.19	1111.94	87.4%	45.01	269.24	369.31	6002.89	5232.77	4145.43
	9	8 + Two-stage operation	269.12	1054.17	1323.29	89.1%	43.49	223.30	353.67	6018.01	5269.55	4213.75
6	10	8 + Continu. furnace modul.	301.48	1392.70	1694.18	89.5%	43.19	235.12	352.38	6381.21	5626.06	4561.69
	11	0 + Cabinet insulation	29.58	529.85	559.43	72.7%	54.00	432.52	452.51	6508.93	5608.54	4335.32
	12	0 + Fan-assisted combustion	86.85	590.38	677.23	72.8%	53.16	475.47	449.74	6603.92	5695.52	4410.74

Notes: Average lifetime for gas-fired mobile home furnaces is 19 years; all costs are in 1990 dollars; electricity rate is 8.61 cent/kWh (1996); gas rate is 7.69 \$/MMBtu (1996, assuming 59% natural gas and 41% LPG); consumer costs include installation costs and maintenance costs (present value at 6% real discount rate).

Table 4.2 Life-Cycle Costs of Oil-Fired Mobile Home Furnace (81.6 Mbth input)

Standard Design Level	Design No.	Design Option	Install & Maint	Retail Price	Equip-ment Price	Energy Factor	Annual Energy Use		Annual Energy Cost	Life-Cycle Costs		
							Gas (MMBtu)	Elec (kWh)		4%	6%	10%
	0	Baseline	626.51	924.72	1551.23	72.8%	69.19	1133.4	608.70	9948.87	8532.99	6554.78
1,2	1	0 + Improved fan motor eff.	626.51	944.76	1571.27	74.7%	70.43	837.0	592.34	9746.53	8365.35	6435.51
3,4	2	1 + Improved heat exchanger	626.51	1065.26	1691.77	76.5%	68.83	818.0	578.88	9684.18	8331.53	6441.46
5	3	1 + Condensing flue gas	725.08	1367.44	2092.52	83.2%	63.33	752.6	532.63	9460.17	8201.73	6442.34
6	4	3 + Full furnace modulation	856.57	1948.91	2805.48	85.8%	59.54	660.0	496.66	9714.84	8502.13	6807.59
	5	3 + Two-stage operation	808.80	1905.23	2714.03	85.6%	59.94	625.9	496.67	9611.54	8410.83	6732.37
	6	0 + Cabinet insulation	626.51	948.82	1575.33	72.8%	69.19	1133.4	608.70	9972.97	8557.09	6578.88

Notes: Average lifetime for oil-fired mobile home furnaces is 20 years;
All costs are in 1990 dollars;
Electricity rate is 8.61 cent/kWh (1996);
Oil rate is 7.387 \$/MMBtu (1996);
Consumer costs include installation costs and maintenance costs (present value at 6% real discount rate).

4.2 PAYBACK PERIODS BY STANDARD LEVEL

The payback period (PBP) measures the amount of time needed to recover the additional consumer investment in increased efficiency through lower operating costs. PBP is found by solving the equation:

$$\Delta PC + \sum_{t=1}^{PAY} \Delta OC_t = 0 \quad (4)$$

for *PAY*. In general, *PAY* is found by interpolating between the two years when the expression in Eq. 4 changes sign. If the operating cost is constant, the equation has the simple solution:

$$PAY = -\frac{\Delta PC}{\Delta OC} \quad (5)$$

Numerically, the PBP is the ratio of the increase in purchase (and installation) price from the base to the standards cases to the decrease in annual operating expenditures (including maintenance). PBPs are expressed in years. A PBP of three years means that the increased purchase price is equal to three times the value of reduced operating expenses achieved in the year of purchase, or that the increased purchase price is recovered in approximately three years because of lower operating expenses. PBPs greater than the life of the product mean that the increased purchase price is not recovered in reduced operating expenses.

4.2.1 PBP Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.2.2 PBP Results

The PBPs by standard level shown in Tables 4.3 through 4.4 are the weighted- averages. They compare that portion of the projected distribution of designs in the base case which are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts.

Table 4.3 shows the calculation of LCC differences, payback, and CCE. The table is composed of several parts. Table 4.3a summarizes the equipment cost, operating cost, LCC, and energy use for each design option. Table 4.3b shows the distribution of units sold in 1996, according to the base case forecast. In the other columns, part of this distribution is expressed as the percent of eliminated units due to standards. That is, if 78% of units sold in the base case correspond to design 0, and standard level 1 (equivalent to design 1) eliminates only design 0, then the fraction of eliminated units due to standard level 1 is 100% for design 0.

Table 4.3c applies the weights in Table 4.3b to the values in Table 4.3a to obtain the weighted-average values shown. Table 4.3d shows the resulting LCC differences, PBPs, and CCE.

4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS

The impact of standards is calculated as the difference in LCC, base case minus standards case. If the LCC difference is greater than zero (positive savings), the standard provides a net decrease in expenses to the consumer. That is, the present value of decreased operating expenses offsets the increased purchase price. Conversely, if the LCC difference is negative, the standard causes a net increase in expenses to the consumer.

4.3.1 Data Inputs for Change in LCC

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding to the minimum compliance with the standard.

4.3.2 Results for Change in LCC

Tables 4.3 through 4.4 show the LCC differences by standard level, one table for each class. The results are the weighted-average of LCC differences comparing that portion of the projected distribution of designs in the base case that are less efficient than the standard level to the design at the standard level. Designs with energy consumption at or below the standard level are not affected by the standard, so these are excluded from the calculation of impacts. These LCCs are calculated at a 6% discount rate; a higher discount rate (e.g., 10%) gives a smaller difference.

Tables 4.3d to 4.4d show lower LCC (positive LCC difference) for standard levels 1 through 5 for both classes and higher LCC for standard level 6.

4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS

The CCE is the increase in purchase price amortized over the lifetime of the appliance at the consumer discount rate divided by the annual energy savings:

$$CCE = -\frac{CRF \cdot \Delta PC}{\Delta E}, \quad (6)$$

where the capital recovery factor $CRF = 1/PWF$ is used to annualize the capital costs. Note that although the CCE can be measured in cents per kWh, it does not depend on current or future energy prices. The consumer will benefit whenever the cost of conserved energy is less than the price of energy for that end use.

4.4.1 CCE Data Inputs

The data inputs are the same as in Section 4.1.1, except that, in addition, a distribution of design options is projected (by LBL-REM) in the base case. Only those designs that are eliminated by the standard level are included in the calculation of impacts. Consumers whose base case choice is eliminated by standards are assumed to purchase the design option corresponding the minimum compliance with the standard.

4.4.2 CCE Results

Tables 4.3 through 4.4 show the cost of conserved energy of the standards levels as compared to the base case. Note that the current (1990) and projected (1996) average residential gas prices are 5.69 and 6.15 dollars per million Btu, respectively.(15) The residential price of distillate oil was \$7.64 per million Btu in 1990 and is projected to be \$7.39 in 1996. (13)

Standard levels with CCEs less than projected costs of energy supply include: for gas standard levels 1, 2, 4, and 5; and for oil, standard levels 1, 2, and 5.

Standard levels with CCEs greater than projected costs of energy supply include: for gas, standards levels 3 and 6; and for oil, standards levels 3 and 4.

Table 4.3a Cost and Energy-Use Summary Gas-Fired, Low-Capacity Mobile Home Furnaces

Design Number	Equipment Price	Operating Cost	LCC	Annual Energy Use
	(1990 \$)	(1990 \$)	(1990 \$)	(MMBtu)
0	542.62	452.51	5591.73	55.48
1	548.36	442.95	5490.90	55.65
6	619.42	426.80	5381.65	53.62
7	728.97	416.97	5381.57	52.39
2	816.33	407.55	5363.82	50.68
8	1111.94	369.31	5232.77	45.93
10	1694.18	352.38	5626.06	43.99

Table 4.3b Distribution of Units Sold Below Standards, Gas-Fired, Low-Capacity Mobile Home Furnaces

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6
0	43.00%	100.00%	100.00%	46.05%	43.00%	43.00%	43.00%
1	0.00%	<Standard>	0.00%	0.00%	0.00%	0.00%	0.00%
6	50.37%		<Standard>	53.95%	50.37%	50.37%	50.37%
7	6.63%			<Standard>	6.63%	6.63%	6.63%
2	0.00%				<Standard>	0.00%	0.00%
8	0.00%					<Standard>	0.00%
10	0.00%						<Standard>

Table 4.3c Weighted-Averages of Units Sold Below Standards, Gas-Fired, Low-Capacity Mobile Home Furnaces

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6
Equip. Price (1990 \$)	542.62	542.62	584.05	593.66	593.66	593.66
Operating Cost (1990 \$)	452.51	452.51	438.64	437.20	437.20	437.20
Life Cycle Cost (1990 \$)	5591.73	5591.73	5478.40	5471.98	5471.98	5471.98
Energy Use (MMBtu/yr)	55.48	55.48	54.48	54.34	54.34	54.34

Table 4.3d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy at 6% Real), Gas-Fired, Low-Capacity Mobile Home Furnaces

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6
LCC difference	100.8	210.1	96.8	108.2	239.2	-154.1
Payback	0.6	3.0	6.7	7.5	7.6	13.0
CCE (\$/MMBtu)	-3.0	3.7	6.2	5.5	5.5	9.5

Table 4.4a Cost and Energy-Use Summary, Oil-Fired, Low-Capacity Mobile Home Furnaces

Design Number	Equipment Price (1990 \$)	Operating Cost (1990 \$)	LCC (1990 \$)	Annual Energy Use (MMBtu)
0	1551.23	608.70	8532.99	73.06
1	1571.27	592.34	8365.35	73.29
2	1691.77	578.88	8331.53	71.62
3	2092.52	532.63	8201.73	65.90
4	2805.48	496.66	8502.13	61.79

Table 4.4b Distribution of Units Sold Below Standards, Oil-Fired, Low-Capacity Mobile Home Furnaces

Design Number	1996 Distribution	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6
0	12.61%	100.00%	100.00%	100.00%	100.00%	20.02%	12.61%
1	0.00%	<Standard>	<Standard>	0.00%	0.00%	0.00%	0.00%
2	50.37%			<Standard>	<Standard>	79.98%	50.36%
3	37.03%					<Standard>	37.03%
4	0.00%						<Standard>

Table 4.4c Weighted-Averages of Units Sold Below Standards, Oil-Fired, Low-Capacity Mobile Home Furnaces

Weighted Average	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6
Equip. Price (1990 \$)	1551.23	1551.23	1551.23	1551.23	1663.63	1822.43
Operating Cost (1990 \$)	608.70	608.70	608.70	608.70	584.85	565.52
Life Cycle Cost (1990 \$)	8532.99	8532.99	8532.99	8532.99	8371.87	8308.87
Energy Use (MMBtu/yr)	73.06	73.06	73.06	73.06	71.91	69.68

Table 4.4d Life-Cycle Cost Differences (\$1990), Payback Periods (Year), and Costs of Conserved Energy (at 6% Real), Oil-Fired, Low Capacity Mobile Home Furnaces

	Trial Standard Level 1	Trial Standard Level 2	Trial Standard Level 3	Trial Standard Level 4	Trial Standard Level 5	Trial Standard Level 6
LCC difference	167.6	167.6	201.5	201.5	170.1	-193.3
Payback	1.2	1.2	4.7	4.7	8.2	14.3
CCE (\$/MMBtu)	-7.6	-7.6	8.5	8.5	6.2	10.9

4.5 LCC SENSITIVITY ANALYSIS

The sensitivity of the national LCC results were tested by varying assumptions about energy prices and equipment prices. These tables should be compared to the first set of tables in Section 4.1.

Low and high energy prices were defined as the minimum and maximum, respectively, of states' energy prices. Projected (1992) state energy prices (16) relative to the national average were applied to the projected 1996 national average price from the *Annual Energy Outlook 1991* to obtain state prices for 1996. (This represents a wider range of prices than analyzed in previous analyses, which used the average across Census regions.)

Low and high equipment prices were defined as one standard deviation below and above, respectively, the equipment prices used elsewhere in this chapter (from the Engineering Analysis). Note that the uncertainty in the baseline price is a percent of the total price, while the uncertainty in the price of other designs is applied to the incremental price of that design.

The following sensitivity cases were analyzed:

- (1) low (state) energy prices,
- (2) high equipment prices,

(3) low (state) energy prices and high equipment prices,

(4) high (state) energy prices,

(5) low equipment prices, and

(6) high (state) energy prices and low equipment prices.

Figure 4.3 and Table 4.5 summarize the results of the sensitivity analysis. They include:

- graph of highest and lowest LCC sensitivity, and reference case; and**
- table of LCCs for all sensitivity cases. The table also shows the number of sensitivity cases for which each design option is the minimum LCC.**

Figure 4.3 Life-Cycle Cost for a Gas-fired, Low Capacity Mobile Home Furnace (56 Mbtu input)

Table 4.5 Sensitivity Summary of Life-Cycle Costs of Gas Mobile Home Furnaces

Standard Level	1	4	2	3	5	6		Sid Level @	Design Option
Design Option	0	1	2	6	7	8	10	min LCC	@ min LCC
Reference	5592	5491	5364	5382	5382	5233	5626	5	8
1	4320	4147	4165	4086	4116	4147	4577	2	6
2	5658	5581	5543	5506	5556	5593	6166	2	6
3	4386	4237	4345	4211	4291	4506	5177	2	6
4	13202	13151	12331	12763	12594	11546	11677	5	8
5	5530	5426	5196	5286	5235	4941	5148	5	8
6	13140	13087	12163	12668	12447	11254	11199	6	10
# of cases as min LCC				3		3	1		

CHAPTER 5. IMPACTS ON THE MANUFACTURERS OF MOBILE HOME FURNACES

5.1 LONG-RUN IMPACTS

The analysis shows that compared to the 1996 base case, the mobile home furnace industry is likely to experience a return on equity (ROE) decrease at all trial standards levels. At standards level 1, there is approximately a 60% chance that ROE will decrease, with an expected decrease of 0.04%. At standards level 2 there is approximately a 63% chance of a decrease in ROE with an expected decrease of 0.08%. At standards level 3 there is approximately a 60% chance of an decrease in ROE with an expected decrease of 0.12%. At standards level 4 there is approximately a 56% chance of decrease in ROE with an expected decrease of 0.08%. At standards level 5 there is approximately a 68% chance of a decrease in ROE with an expected decrease of 1.21%. At standards level 6 there is approximately a 60% chance of a decrease in ROE with an expected decrease of 0.51%. These results are based on Table 5.1. The probabilities of change are computed from the expected change, the standard error of this estimate, and the assumption of a normal distribution.

5.1.1 Qualitative Analysis

According to reports from within the industry, mobile home furnace manufacturing is characterized by economies of scale; this means that for the purposes of price determination there are fixed costs. Depending on the standards level considered, these are estimated to range from about 6% to 10% of total costs. Increases in fixed costs cannot be passed on, which implies that the markup over variable cost must be approximately 6% to 10% (depending on the standards level) if the typical firm is to have a near-average ROE. To the extent that this markup is the same after standards are imposed, and to the extent that standards induce an increase in variable costs, such costs will be more than completely passed on in the form of a price increase which in itself is profitable, but which also tends to reduce profit because of the effect of a price increase on sales. If standards induce an increase in fixed costs, this cost cannot be passed on and will negatively influence profit. Because of the mandated increase in efficiency, operating costs will necessarily decline, which will tend to increase profit by making mobile home furnaces more attractive and thereby increasing demand. Since demand is specified as a function of purchase price and operating cost (i.e., life-cycle cost) under constant life-cycle cost elasticity, as price changes, so does price elasticity, and consequently, markup. (For instance, as price rises, price elasticity rises, and markup falls.) The model calculates that these effects, when combined, are more likely to reduce economic profits than increase them at all standards levels.

5.1.2 Quantitative Analysis

Table 5.1 summarizes all essential outputs from the LBL-MIM simulations using the primary scenario for mobile home furnaces. Six other scenarios are summarized and discussed in the sensitivity section, Section 5.4.

Once the above interpretations are understood, the results of the model concerning the long-run impact of standards on the mobile home furnace manufacturing industry can be read from the output table.

Table 5.1 Output Table: Primary Scenario – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.06	0.07	0.06
% change		0.43%	0.81%	0.32%	0.81%	2.16%	-3.44%
S.E.		1.56%	2.40%	3.92%	10.70%	119.15%	93.52%
Price	\$245.41	\$246.91	\$252.88	\$288.79	\$294.53	\$355.23	\$565.66
% change		0.61%	3.04%	17.68%	20.02%	44.75%	130.50%
S.E.		2.43%	3.37%	7.86%	8.18%	13.95%	41.75%
Revenue (in \$M)	15.78	15.94	16.39	18.63	19.09	23.33	35.12
% change		1.05%	3.88%	18.05%	20.98%	47.88%	122.57%
S.E.		2.63%	4.03%	8.26%	14.94%	155.09%	214.41%
Net Income (in \$M)	0.51	0.51	0.51	0.51	0.51	0.52	0.55
Difference		0.00	0.00	0.00	0.00	0.01	0.04
S.E.		0.02	0.04	0.05	0.15	2.08	1.64
ROE	7.30%	7.25%	7.22%	7.18%	7.22%	6.09%	6.79%
Difference		-0.04%	-0.08%	-0.12%	-0.08%	-1.21%	-0.51%
S.E.		0.16%	0.27%	0.44%	0.58%	1.81%	3.32%

5.2 SHORT-RUN IMPACTS

The business cycle presents the mobile home furnace manufacturing industry with fairly sharp periodic fluctuations in demand, much larger than the fluctuations predicted for any of the standards levels. These normal demand fluctuations present the same types of opportunities for price competition that will accompany fluctuations resulting from a change in standards.

Regressing price on demand and a time trend for the past 18 years shows that a 10% fall in demand typically leads to a 0.3% fall in the price of mobile home furnaces; a 10% demand increase has the reverse effect. This effect is taken into account as described in Volume A, Chapter 3, Section 3.3.4.2 of this Technical Support Document and is used to produce a short-run version of the output table that is displayed in Table 5.2. Note that at each standards level analyzed for the mobile home furnace manufacturing industry, the short-run ROE results are generally lower than the long-run results. For reasons that are explained in the above reference, the short-run change has been overestimated. Thus the values for change in Table 5.2 should be viewed as somewhat too large in absolute value.

Table 5.2 **Output Table: Primary Scenario – Short-Run**

	1996.BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.06	0.07	0.06
% change		0.42%	0.80%	0.31%	0.79%	2.11%	-3.34%
Price	\$245.41	\$247.21	\$253.34	\$289.10	\$295.06	\$356.61	\$563.01
% change		0.74%	3.23%	17.80%	20.24%	45.32%	129.42%
Revenue (in \$M)	15.78	15.96	16.42	18.64	19.12	23.41	34.99
% change		1.16%	4.06%	18.16%	21.18%	48.38%	121.77%
Net Income (in \$M)	0.51	0.51	0.51	0.48	0.51	0.28	0.15
Difference	7.30%	0.00	0.00	-0.03	0.00	-0.23	-0.36
ROE	7.31%	7.22%	7.26%	6.76%	7.30%	3.33%	1.86%
Difference		-0.08%	-0.04%	-0.54%	0.00%	-3.97%	-5.44%
S.E.		3.83%	4.60%	5.38%	6.34%	10.60%	20.73%

5.3 IMPACT AS A FUNCTION OF FIRM SIZE

There are two firms supplying gas-fired mobile home furnaces which constitute the entire industry. Our discussions with the industry indicate that market shares of the two firms are approximately 50% each, hence there is no significant impact on small firms.

5.4 SENSITIVITY ANALYSIS FOR MOBILE HOME FURNACES

The three following subsections discuss different aspects of the sensitivity analysis conducted by LBL-MIM. The first subsection, on sensitivity charts, shows the implications of the uncertainty of each control variable for the prediction of ROE. The next subsection shows six alternative scenarios that are of particular importance and deserve a more detailed analysis than those randomly generated by Monte Carlo runs. The last subsection shows the use of Monte Carlo runs to find combinations of errors that would cause the change in ROE to be considerably more negative than is predicted.

5.4.1 Sensitivity Charts

Table 5.3 illustrates the sensitivity of ROE to changes in control panel inputs. The variables analyzed are industry price elasticity of demand (IPE), discount rate (RD), the equity cost of capital (ECC), economic profit (EP), the fixed part of costs (FCA), the fixed part of one-time costs (FIX), one-time capital costs (CC.N), one-time variable costs (dVC.N), and the shape parameter of the demand curve (ro.N).

Table 5.3 Sensitivity Chart: Primary Scenario (Sensitivity of ROE to 1 S.E. Change in Control Variable)

Control Variables			Possible Standard Levels					
Name	Value	Changed	1	2	3	4	5	6
IPE	-0.080	-0.184	0.05%	0.10%	0.04%	0.10%	0.46%	-0.72%
RD	32.00%	73.57%	-0.00%	0.02%	0.21%	0.25%	0.13%	1.19%
ECC	0.068	0.075	-0.00%	-0.00%	-0.01%	-0.00%	-0.09%	-0.09%
EP	0.006	0.016	-0.01%	-0.02%	-0.02%	-0.02%	-0.19%	-0.11%
FCA	0.063	0.102	-0.02%	-0.04%	-0.02%	-0.04%	-0.09%	0.17%
FIX	0.088	0.153	-0.04%	-0.04%	-0.10%	-0.03%	-0.90%	-0.38%
CC.N	0.335	0.408	-0.01%	-0.01%	-0.03%	-0.01%	-0.18%	-0.16%
dVC.N	18.555	24.886	0.02%	0.03%	0.06%	0.08%	-0.00%	-0.02%
ro.N	0.000	0.300	0.04%	0.07%	0.03%	0.07%	0.14%	-0.27%

As can be seen from the table, five control variables account for nearly all of the uncertainty in the determination of ROE. These are (1) the industry elasticity of demand with respect to price (IPE), (2) the discount rate (RD) from which operating cost elasticity is derived, (3) fixed part of costs (FCA), (4) one-time fixed costs (FIX), and (5) one-time capital costs (CC.N). The reasons that these variables are important are discussed below.

5.4.2 Alternative Scenarios

The sensitivity analysis shows that both price and operating cost elasticities (the former being derived from the discount rate) play crucial roles in determining the model's output. These are both *industry* elasticities as opposed to single-firm elasticities; this means they measure the effect on demand of a change in price by all firms and a change in operating cost of all mobile home furnaces. The estimates of standard errors that are calculated by the Monte Carlo analysis fully acknowledge the uncertainties of these two variables. However, in order to show in detail all of the ramifications of changing one or both of them, six alternative scenarios have been run. The six scenarios include low and high price elasticity scenarios, a constant shipments scenario (i.e., industry price and operating cost elasticity set to zero), high and low discount rate scenarios (i.e., high and low operating cost scenarios), and a low discount rate and high price elasticity scenario. Tables 5.4 through 5.9 show the results of running these six scenarios for the mobile home furnace manufacturing industry.

In these alternative scenarios, note the impact of changes in the discount rate. A high discount rate input value lowers ROE and a lower discount rate value increases ROE. Because markup is determined by price elasticity, it will tend to change as the ratio of price to operating cost changes. Standards will always increase this ratio, which decreases markup. This effect will be the strongest when appliance demand is relatively elastic with respect to operating cost. That is, a more elastic operating cost elasticity will result in a greater decrease in markup under standards, resulting in a greater decrease in profitability.

The other tables show that increasing price elasticity also tends to lower ROE. This effect is probably due to the greater decline in shipments when price elasticity is greater.

The percentages of fixed costs (FCA) and one-time fixed costs (F1X) are important because of their role in the model. They determine the LBL-MIM's estimate of the markup over variable cost, which, in turn, determines the firm's ability to pass on various combinations of fixed and variable costs. For a more detailed explanation, see Volume A, Appendix C.

The one-time capital cost (CC.N) variable is important because of its impact on price and because it is largely a fixed cost. Firms cannot pass on increases in fixed costs in the form of higher prices. Therefore, firm profitability is affected by the level of fixed costs. As noted in Volume A, Appendix C, variable costs are passed on, while fixed costs are not, so fixed costs hurt profitability.

5.4.3 Monte Carlo Analysis

The Monte Carlo approach is described in Volume A, Chapter 3, Section 3.3.4.2, and the standard errors it generates are reported in the output tables. More details of a Monte Carlo run can be seen in Table 5.10. Table 5.10 shows the control panels from two Monte Carlo runs, which were selected because they show a decrease in long-run ROE. Both Monte Carlo runs were done on standards level 2. In both runs, we see how large increases in price

elasticity coupled with increases in the discount rate are the primary factors in reducing ROE despite lower percentages of fixed costs, which are not passed through in prices.

Table 5.4 Output Table: Low Industry Price Elasticity Scenario – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.06	0.06	0.06
% change		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Price	\$245.41	\$246.91	\$252.88	\$288.79	\$294.53	\$355.23	\$565.66
% change		0.61%	3.04%	17.68%	20.02%	44.75%	130.50%
S.E.		2.36%	3.24%	7.79%	8.20%	13.52%	40.38%
Revenue (in \$M)	15.72	15.82	16.20	18.50	18.87	22.76	36.23
% change		0.61%	3.05%	17.68%	20.02%	44.76%	130.49%
S.E.		2.36%	3.24%	7.79%	8.20%	13.52%	40.37%
Net Income (in \$M)	0.51	0.50	0.50	0.50	0.50	0.48	0.61
Difference		-0.01	-0.01	-0.00	-0.00	-0.01	0.10
S.E.		0.00	0.01	0.01	0.01	0.07	0.07
ROE	7.27%	7.18%	7.11%	7.11%	7.11%	5.70%	7.29%
Difference		-0.09%	-0.16%	-0.16%	-0.15%	-1.56%	0.03%
S.E.		0.07%	0.11%	0.20%	0.21%	0.84%	0.81%

Table 5.5 Output Table: High Industry Price Elasticity Scenario – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.07	0.07	0.07	0.07	0.06
% change		1.31%	2.46%	0.95%	2.44%	6.62%	-9.96%
S.E.		0.63%	0.86%	1.73%	2.31%	4.23%	8.95%
Price	\$245.41	\$246.91	\$252.88	\$288.79	\$294.53	\$355.23	\$565.66
% change		0.61%	3.04%	17.68%	20.02%	44.75%	130.50%
S.E.		2.36%	3.20%	6.59%	8.69%	14.89%	43.10%
Revenue (in \$M)	15.89	16.20	16.78	18.88	19.54	24.53	32.98
% change		1.93%	5.58%	18.80%	22.94%	54.33%	107.53%
S.E.		1.75%	2.36%	4.54%	5.94%	9.24%	15.95%
Net Income (in \$M)	0.52	0.53	0.54	0.53	0.54	0.61	0.44
Difference		0.01	0.02	0.02	0.02	0.09	-0.07
S.E.		0.01	0.01	0.02	0.02	0.10	0.15
ROE	7.37%	7.40%	7.43%	7.31%	7.44%	6.86%	5.74%
Difference		0.04%	0.07%	-0.05%	0.07%	-0.51%	-1.63%
S.E.		0.09%	0.15%	0.17%	0.22%	1.06%	1.68%

Table 5.6 Output Table: Constant Shipments Scenario – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.06	0.06	0.06
% change		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
S.E.		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Price	\$245.41	\$246.91	\$252.88	\$288.79	\$294.53	\$355.23	\$565.66
% change		0.61%	3.04%	17.68%	20.02%	44.75%	130.50%
S.E.		2.45%	3.04%	7.05%	8.46%	15.40%	41.92%
Revenue (in \$M)	15.72	15.82	16.20	18.50	18.87	22.76	36.23
% change		0.61%	3.04%	17.68%	20.02%	44.75%	130.50%
S.E.		2.45%	3.04%	7.05%	8.46%	15.40%	41.92%
Net Income (in \$M)	0.51	0.50	0.50	0.50	0.50	0.48	0.61
Difference		-0.01	-0.01	-0.00	-0.01	-0.03	0.10
S.E.		0.01	0.01	0.01	0.01	0.08	0.09
ROE	7.27%	7.18%	7.11%	7.11%	7.11%	5.70%	7.30%
Difference		-0.09%	-0.16%	-0.16%	-0.15%	-1.56%	0.03%
S.E.		0.08%	0.13%	0.18%	0.21%	1.01%	1.01%

Table 5.7 Output Table: Low Discount Rate Scenario – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.06	0.07	0.06
% change		0.43%	0.81%	0.32%	0.81%	2.16%	-3.44%
S.E.		0.21%	0.27%	0.65%	0.75%	1.26%	3.04%
Price	\$245.41	\$246.91	\$252.88	\$288.79	\$294.53	\$355.23	\$565.66
% change		0.61%	3.04%	17.68%	20.02%	44.75%	130.50%
S.E.		2.41%	3.09%	7.46%	8.58%	13.82%	40.16%
Revenue (in \$M)	15.78	15.94	16.39	18.63	19.09	23.33	35.12
% change		1.05%	3.88%	18.05%	20.98%	47.88%	122.57%
S.E.		2.21%	2.83%	6.66%	7.67%	12.15%	30.84%
Net Income (in \$M)	0.51	0.51	0.51	0.51	0.51	0.52	0.55
Difference		0.00	0.00	0.00	0.00	0.01	0.04
S.E.		0.00	0.01	0.01	0.01	0.07	0.06
ROE	7.30%	7.25%	7.22%	7.18%	7.22%	6.09%	6.79%
Difference		-0.04%	-0.08%	-0.12%	-0.08%	-1.21%	-0.51%
S.E.		0.06%	0.12%	0.14%	0.14%	0.85%	0.71%

Table 5.8 Output Table: High Discount Rate Scenario – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.06	0.06	0.06
% change		-0.01%	-0.16%	-1.26%	-1.38%	-2.85%	-7.29%
S.E.		0.20%	0.27%	0.58%	0.64%	0.97%	2.01%
Price	\$246.20	\$247.84	\$254.13	\$291.42	\$297.49	\$360.92	\$578.93
% change		0.67%	3.22%	18.37%	20.83%	46.60%	135.15%
S.E.		2.47%	3.28%	8.06%	8.94%	15.39%	44.59%
Revenue (in \$M)	15.69	15.79	16.17	18.34	18.69	22.34	34.20
% change		0.66%	3.06%	16.88%	19.17%	42.42%	118.00%
S.E.		2.26%	3.00%	7.23%	7.99%	13.44%	36.88%
Net Income (in \$M)	0.53	0.53	0.54	0.59	0.60	0.65	0.98
Difference		0.00	0.01	0.06	0.06	0.12	0.45
S.E.		0.01	0.02	0.07	0.07	0.17	0.64
ROE	7.70%	7.70%	7.80%	8.49%	8.72%	8.02%	12.56%
Difference		0.00%	0.10%	0.79%	1.02%	0.32%	4.87%
S.E.		0.19%	0.28%	0.99%	1.03%	1.97%	8.16%

Table 5.9 Output Table: Low Discount Rate Scenario and High Price Elasticity – Long-Run

	1996 BASE	Lev 1	Lev 2	Lev 3	Lev 4	Lev 5	Lev 6
Shipments (in Mil)	0.06	0.06	0.06	0.06	0.07	0.07	0.07
% change		0.29%	0.61%	0.85%	1.25%	3.11%	2.71%
S.E.		0.04%	0.06%	0.13%	0.15%	0.30%	0.78%
Price	\$245.24	\$246.71	\$252.62	\$288.24	\$293.92	\$354.05	\$562.90
% change		0.60%	3.01%	17.53%	19.85%	44.37%	129.53%
S.E.		2.28%	3.27%	7.63%	8.26%	15.22%	42.17%
Revenue (in \$M)	15.78	15.93	16.36	18.71	19.15	23.50	37.21
% change		0.89%	3.63%	18.53%	21.34%	48.86%	135.75%
S.E.		2.25%	3.23%	7.53%	8.18%	15.23%	41.22%
Net Income (in \$M)	0.50	0.50	0.50	0.50	0.49	0.49	0.55
Difference		0.00	-0.01	-0.01	-0.02	-0.02	0.04
S.E.		0.01	0.01	0.01	0.02	0.08	0.05
ROE	7.21%	7.13%	7.05%	6.92%	6.90%	5.65%	6.39%
Difference		-0.08%	-0.16%	-0.29%	-0.31%	-1.56%	-0.82%
S.E.		0.07%	0.13%	0.20%	0.25%	0.92%	0.56%

Table 5.10 Mobile Home Furnace Monte Carlo Runs: Searching for Low ROE

		Scenario: Primary		Standard Level = 4		
MOBILE HOME FURNACES CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity		-0.080	2.89	100%	-0.885	IPE
Consumer Discount Rate		32.00%	1.70	100%	131.62%	RD
Equity Cost of Capital		0.068	1.79	10%	0.081	ECC
Economic Profit		0.006	1.42	1%	0.020	EP
L-R Fixed Part of Costs & Assets		0.063	0.55	50%	0.082	FCA
L-R Fixed Part of 1-X Cap. Cost		0.078	-0.27	60%	0.067	FIX
One-Time Capital Costs		0.370	0.05	20%	0.374	CC.N
Unit Variable Cost Increase		\$66.20	-0.15	30%	63.356	dVC.N
Elasticity Curve Parameter		0.000	0.82	30%	0.247	ro.N
Short Run Price Response to Demand		0.157	-1.27	76%	0.029	SRPR
		NAECA	NEW	PRVIOUS	NEW	
SUMMARY		BASE	L-RUN	CHANGE	S-RUN	
Shipments		0.06	0.05	-10.69%	0.06	
Price		\$245.71	\$292.56	19.07%	\$291.38	
Revenue (in \$M)		15.08	16.03	6.34%	16.06	
Net Income		0.64	0.50	-0.15	0.45	
ROE		9.60%	8.25%	-1.35%	7.41%	
08-Sep-92		16:57	Trys =		89.00	
		Scenario: Primary		Standard Level = 4		
MOBILE HOME FURNACES CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity		-0.080	0.24	100%	-0.098	IPE
Consumer Discount Rate		32.00%	-0.97	100%	14.23%	RD
Equity Cost of Capital		0.068	0.25	10%	0.070	ECC
Economic Profit		0.006	1.16	1%	0.017	EP
L-R Fixed Part of Costs & Assets		0.063	2.03	50%	0.165	FCA
L-R Fixed Part of 1-X Cap. Cost		0.078	-1.38	60%	0.036	FIX
One-Time Capital Costs		0.370	1.09	20%	0.459	CC.N
Unit Variable Cost Increase		\$66.20	-1.61	30%	41.258	dVC.N
Elasticity Curve Parameter		0.000	-1.91	30%	-0.572	ro.N
Short Run Price Response to Demand		0.157	1.27	76%	0.852	SRPR
		NAECA	NEW	PRVIOUS	NEW	
SUMMARY		BASE	L-RUN	CHANGE	S-RUN	
Shipments		0.07	0.07	6.86%	0.07	
Price		\$244.02	\$264.34	8.33%	\$282.78	
Revenue (in \$M)		15.95	18.47	15.77%	19.60	
Net Income		0.58	0.54	-0.05	1.34	
ROE		8.21%	7.08%	-1.13%	17.69%	
08-Sep-92		17:00	Trys =		421.00	

CHAPTER 6. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES: MOBILE HOME FURNACES

6.1 INTRODUCTION

Appliance efficiency standards have four principal effects on electric utilities: (1) they allow utilities to avoid fuel and other operating costs because less electricity needs to be generated, (2) they may allow utilities to defer construction of new generating capacity, (3) they may allow utilities to defer construction of new or upgraded transmission and distribution (T&D) capacity, and (4) they reduce revenues from electricity sales. The second section of this chapter presents the results of the avoided cost calculations. The third section presents the expected peak load and reliability savings for the analyzed standard levels. The fourth section presents the results of the revenue loss calculation. More details on methodology may be found in Appendix E of Volume A of this Technical Support Document.

6.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS

Figure 6.1 shows avoided energy and reliability costs for electricity savings from mobile home furnaces. These figures show the sum of avoided costs for the base-, high-, and low-energy price cases.¹⁴ The value per million Btu (MMBtu) of avoided reliability costs is zero in all three energy price cases, because capacity savings only have value in summer (see Appendix E of Volume A). The avoided fuel and capital component depends on fuel prices and varies among the three cases. As explained in Appendix E of Volume A, this component implicitly contains the costs avoided when baseload power plants are deferred or canceled (it also contains avoided T&D of capital costs). These avoided costs represent a simple summary of the utility analysis, and they are a measure of the societal benefit of the electricity saved in each year. They are used in the LBL-REM to value electricity savings from the societal perspective.

6.3 PEAK LOAD AND CAPACITY REDUCTIONS

Because peak savings only have value in summer, any shifts in electricity use caused by standards on fuel-fired mobile home furnaces have no peak demand savings or capacity savings.

¹⁴ Fuel price forecasts for the period 1990 to 2000 are taken from the DOE/EIA *Annual Energy Outlook 1991* (DOE/EIA-0383(91)). The forecasts for years after 2000 were linearly extrapolated using the methodology described in Volume A. The high- (low)-energy price case is derived by increasing (decreasing) the reference case AEO fuel price forecasts for gas and coal by 5%.

Figure 6.1 Utility-Avoided Costs for Mobile Home Furnaces

6.4 REVENUE LOSSES

Appliance standards allow utilities to avoid the variable costs of generating electricity, but standards also reduce electricity sales. In a rate case, the utility and the regulators agree on the revenue requirements and rates based on some estimate of future sales. If the effects of appliance efficiency standards are not included in this forecast, actual sales will be less than forecasted sales, which implies that the utility will not be able to recover some of the fixed costs that were included in the original revenue requirements calculation. This effect can be eliminated if electric utilities and regulators, when calculating rates, use the most current information on the impacts of appliance efficiency standards.

Utilities routinely petition regulators for changes in rates. In the course of such a petition, the utility's forecasted sales can be adjusted to account for the appliance efficiency standards and hence eliminate these "lost" revenues. Those revenues lost as a result of time lags in regulation are not a true economic cost, but are a transfer payment from the utility to utility customers. The size of this transfer payment depends on regulatory behavior and on the net change in revenues, which is equal to the difference between sales reductions and avoided costs.

Since the magnitude of these losses is dependent on assumptions about regulatory behavior, and because this behavior is so varied among states, it is difficult to perform this calculation for the nation. An additional complication is that unanticipated sales growth from other sectors may compensate for the revenue shortfall. Two cases are presented here, one that assumes that regulators adjust the rates to reflect the reduced sales in five years, and one that assumes that they never adjust the rates. These cases also assume that there is no unanticipated sales growth. These results are presented both on a year-by-year and a present-value basis.

It is possible that the regulators could adjust the rates in anticipation of the new standards, in which case there would be no revenue impact at all. It is also possible that the regulators would not grant rate relief for several years after the standards go into effect, which is approximated by the five-year-lag case. While it is unlikely that regulators would never adjust the rates to reflect the post-standard sales forecast, this case is included as an absolute upper bound. Figure 6.2 shows annual revenue losses and avoided costs over time for level 1 standards and Table 6.1 shows net revenue losses for all standards levels. Cumulative changes in net revenues for mobile home furnaces range from a loss of \$3 million to a gain of \$1.2 billion.

Figure 6.2 Revenue Reductions and Avoided Costs for Mobile Home Furnaces

Table 6.1 Net Revenue Losses - Mobile Home Furnaces (Million 1990 Dollars)

Year	Net Revenue Losses					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
1996	0	0	-1	-2	-3	-7
1997	0	0	-1	-3	-5	-12
1998	0	0	-2	-3	-7	-16
1999	0	0	-2	-4	-9	-20
2000	0	0	-2	-5	-10	-24
2001	0	0	-3	-5	-12	-27
2002	0	-1	-3	-6	-14	-31
2003	0	0	-3	-7	-15	-34
2004	0	-1	-4	-7	-17	-37
2005	0	-1	-4	-8	-18	-39
2006	0	-1	-5	-8	-19	-42
2007	0	-1	-5	-9	-20	-44
2008	0	-1	-5	-9	-22	-47
2009	0	-1	-5	-10	-22	-49
2010	0	-1	-5	-10	-23	-51
2011	0	-1	-6	-10	-24	-52
2012	0	-1	-6	-11	-24	-52
2013	0	-1	-6	-11	-24	-52
2014	0	-1	-6	-11	-24	-52
2015	0	-1	-6	-10	-23	-50
2016	0	-1	-5	-10	-23	-49
2017	0	-1	-5	-10	-22	-47
2018	0	-1	-5	-9	-21	-45
2019	0	-1	-5	-9	-20	-42
2020	0	-1	-4	-8	-18	-39
2021	0	-1	-4	-7	-17	-36
2022	0	-1	-4	-7	-16	-33
2023	0	-1	-3	-6	-14	-30
2024	0	-1	-3	-5	-13	-27
2025	0	-1	-3	-5	-11	-24
2026	0	0	-2	-4	-10	-21
2027	0	0	-2	-3	-8	-18
2028	0	0	-2	-3	-7	-15
2029	0	0	-1	-2	-6	-12
2030	0	0	-1	-2	-4	-9
Total	3	-22	-130	-238	-548	-1182

The figures show utility revenue losses, assuming no regulatory adjustment. When this adjustment is made, rates will be increased over the base case forecast and utilities will cease to lose revenue. Total residential rates would not change in 2000 and 2005, respectively, if mobile home furnaces are subject to level 3 standards and regulators only change commercial rates to compensate for any loss in revenue.

Table 6.2 shows the present value of net revenue losses at a 5% real utility discount rate for all standard levels and for the two assumptions about regulatory behavior. This discount rate is based on the assumed average utility capital structure and current rates of return.

Table 6.2 Present Value of Revenue Losses - Mobile Home Furnaces (Million 1990 Dollars)

Regulatory Lag	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
None	0	0	0	0	0	0
1996-2001	0	-1	-6	-10	-23	-52
1996-2030	1	-7	-46	-84	-194	-420

For mobile home furnaces, the change in present value of net revenues may range from \$0 to a gain of \$52 million for a five-year lag, and the gain would be as large as \$420 million if the regulators did not make adjustments. The present values over the period 1996 to 2030 also represent the rate decreases needed over this period to compensate for increased revenues, assuming that regulators adjust rates immediately.

6.5 SENSITIVITY ANALYSIS

Table 6.3 shows the present value of net lost revenues for the sensitivity cases. The assumptions for the sensitivity cases are the same as those for previous tables.

Table 6.3 Present Value of Net Lost Revenues (Million 1990 \$) - Mobile Home Furnaces (Sensitivity Cases)

Regulatory Lag	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
None	0	0	0	0	0	0
1996-2001	0	-2	0	0	0	0
1996-2030	1	-6	1	1	0	1

CHAPTER 7. ENVIRONMENTAL EFFECTS

7.1 INTRODUCTION

The environmental effects from a range of new candidate energy-conservation standards for mobile home furnaces are presented here. The results are presented for each potential standard level. Each measure of possible environmental change is an alternative action, and it is compared to what is expected to happen if no new standards for mobile home furnaces were finalized, i.e., the "no action" alternative.

The main environmental concern addressed is emissions from fossil-fueled electricity generation. Although mobile home furnaces consist entirely of fuel-burning space-heating appliances, design options for mobile home furnaces have the effect of impacting the sales of electric space-heating equipment. This ultimately results in either an increase or decrease in electricity use and, therefore, changes in the amount of power plant emissions. The greatest changes in air pollution will generally be for sulfur oxides, listed in equivalent weight of sulfur dioxide, or SO_2 . Reductions of nitrogen oxides and carbon dioxide also occur and are listed by weight of NO_x and CO_2 , respectively. CO_2 emissions from fossil-fuel burning are considered an environmental hazard because they contribute to the "greenhouse effect" by trapping heat energy from the earth that is emitted as infrared radiation. The "greenhouse effect" is expected to gradually raise the mean global temperature. Since mobile home furnaces consist entirely of fuel-burning space-heating equipment, design options will also reduce in-home fuel consumption, resulting in lower emissions from these fuel-burning appliances.

For a detailed description of the methodology that was used in estimating the environmental impacts, refer to the Environmental Assessment in Volume A of this Technical Support Document.

7.2 RESULTS

The following tabular results indicate what changes can be brought about in the amounts of emitted CO_2 , SO_2 , and NO_x by imposing efficiency standards for mobile home furnaces. A table is presented for each of the appliance's trial standard levels. Each table details the changes that occur to each of the three emissions (i.e., CO_2 , SO_2 , and NO_x) through the imposition of an appliance's specific trial standard level. Each table includes the following information for a specific year between 1996 and 2030: the amount of emissions abated from power plant generation, the amount abated from in-home generation, the net change in the emissions, and the percent the net change comprises of total U.S. power plant emissions. Also included are the cumulative changes of each pollutant (between the years 1996 and 2030).

Changes in the amounts of CO₂, SO₂, and NO_x emitted at trial standards levels 1 through 6 are summarized in Tables 7.1 through 7.6.

7.2.1 Sulfur and Nitrogen Oxide Emissions

SO₂ emissions would be increased by a cumulative total of up to 0.27 million tons between 1996 and 2030 in the level 6 scenario. In the year 1996, increases in SO₂ will represent about 0.01% of the SO₂ emissions estimated to come from power plants in that year. In the year 2030, increases in SO₂ emissions will represent about 0.18% of the SO₂ emissions estimated to come from power plants in that year. Although increased in the level 6 scenario, SO₂ emissions would be decreased between 1996 and 2030 in the level 1 scenario. However, because of provisions in the Clean Air Act Amendments (Pub. L. 101-549, November 15, 1990), the possible reductions of SO₂ that are caused by standards can be earned as credits by the utility realizing the reductions. To the extent SO₂ credits are used for future emissions, the net effect on SO₂ emissions from standards would be only a postponement of those SO₂ emissions.

Level 6 design changes to mobile home furnaces would result in an estimated increase in NO_x emissions of 0.87 million tons between 1996 and 2030. NO_x increases would represent 0.005% and 0.04% of the NO_x emissions estimated to come from power plants in the years 1996 and 2030, respectively.

7.2.2 Carbon Dioxide Emissions

The cumulative increase in CO₂ emissions from level 6 design changes is 49 million tons of CO₂. For the year 1996, the estimated CO₂ reduction is 5 thousand tons of CO₂ or about 0.001% of estimated U.S. total CO₂ emissions in 1996. For the year 2030, the estimated CO₂ increase is 2464 thousand tons of CO₂, or about 0.05% of estimated U.S. total CO₂ emissions in 2030.

APPENDIX A. ENGINEERING ANALYSIS NOMENCLATURE

The following nomenclature is extracted from Paragraph 9 of the DOE test procedure (only the AE and t_p definitions) and Section 10 of ANSI/ASHRAE Standard 103-88.

AE	= annual efficiency, %.
AFUE	= annual fuel utilization efficiency, %.
BE	= electrical power to circulating air blower or water pump, kW.
BE _R	= electrical power to circulating air blower or water pump at reduced heat input rate, kW.
BEBOH	= the product of BE and BOH values, as specified in the DOE test procedure, Par. 10.19.1.
BOH _{SS}	= burner operating hours, as defined in the DOE test procedure, Par. 10.19.1.
BOH _R	= burner operating hours at the reduced operating mode, as defined in the DOE test procedure, Par. 10.19.1.
BOH _H	= burner operating hours at the maximum operating mode, as defined in the DOE test procedure, Par. 10.19.1.
BOH _M	= burner operating hours at the modulating operating mode, as defined in the DOE test procedure, Par. 10.19.1.
DHR	= design heating requirement, Btu/h.
Effy _{HS}	= heating seasonal efficiency, %.
Effy _{SS}	= steady state efficiency, %.
Effy _{SS,M}	= average steady-state efficiency for the modulating mode, %.
Effy _{SS,R}	= steady-state efficiency at reduced input, %.
PE	= electrical power to power burner, kW.
PE _R	= electrical power to power burner, kW.
Q _{IN}	= fuel energy maximum nameplate input rate at steady-state operation (including any pilot light input), Btu/h.
Q _{IN,R}	= steady-state reduced fuel input rate, Btu/h.
Q _{OUT}	= heating capacity, rate of useful heat output when operating under steady-state conditions, Btu/h.
Q _{OUT,M}	= average heat output rate for the modulating mode, Btu/h.
Q _{OUT,R}	= heating capacity at reduced fuel input rate, Btu/h.
Q _P	= fuel energy input rate to pilot light, Btu/h.
t_p	= power burner post purge time period, min.
t^+	= delay time between burner shut off and blower or pump shut off, min.
t^-	= delay time between burner start up and blower or pump start up, min.
T _C	= balance point temperature, °F.
T _{OA}	= average outdoor temperature, °F.
T _{OA,H}	= average outdoor temperature at maximum input operating mode, °F.
T _{OA,R}	= average outdoor temperature at reduced input operating mode, °F.

y	= ratio of blower or pump on-time to burner on-time.
y_p	= ratio of induced or forced draft blower on-time to average burner on-time.
X_H	= fraction of heating load at maximum fuel input operating mode.
X_R	= fraction of heating load at reduced fuel input operating mode.
α	= oversize factor.

APPENDIX B. LBL-REM INPUT DATA: CENTRAL SPACE HEATING

The complete input listing is available on electronic medium in ASCII format. The input database includes demographic, economic, and engineering data.

The following is the regular LBL-REM input for central space-heating equipment, including mobile home furnaces.

For standards cases, simply replace the input values for two variables in each class of each product regulated. The two variables are labeled: "first year for standard" and "UEC of standard". For example, for mobile home furnace standards taking effect in 1996, change the lines "first year for standard = 2031" to "first year for standard = 1996" and enter the appropriate maximum UEC values in the lines "UEC of standard" for each class.

CENTRAL HEAT

```
total saturation      = 1.00
elec price multiplier = 0.90
gas price multiplier  = 0.98
ncalc                = 2
ndr1 (1, read drate & curve) = 1
nv1 (# of eun inputs) = 3
nv5 (# of cap inputs) = 3
nv2 (# of peq inputs) = 0
nv4 (# of usage inputs) = 0
ndis (year to forecast eff) = 11
nv3 (# of ti inputs)  = 3
```

----- UEC of stock unit in base year by fuel type i (MMBTU/yr) -----

1	2	3	4	5	
178.84	87.03	89.270	94.02	110.950	** SF **
71.19	35.59	92.780	35.93	40.630	** MF **
99.36	51.56	49.430	53.54	61.260	** MB **

----- Purchase price of a reference unit (\$1990) -----

1	2	3	4	5	
2904.98	2931.57	4251.01	2931.57	1827.75	** SF **
2904.98	2931.57	4251.01	2931.57	1827.75	** MF **
2904.98	2931.57	4251.01	2931.57	1827.75	** MB **

----- Relative UEC and Capacity of a reference unit to a stock unit -----

1	2	3	4	5	
1.0000	0.9660	0.9835	0.9660	1.0000	** re **
1.0000	0.8930	0.8000	0.8930	1.0000	** recap**

```

----- Base Year Saturations - c70 -----
      1      2      3      4      5      6
0.060  0.620  0.185  0.080  0.055  0.0000      ** SF **
0.110  0.320  0.210  0.320  0.040  0.0000      ** MF **
0.090  0.670  0.210  0.005  0.025  0.0000      ** MB **

----- Marginal Saturations for Replacement Units - cn(m=1) -----
      1      2      3      4      5      6
0.040  0.540  0.150  0.090  0.180  0.0000      ** SF **
0.190  0.255  0.265  0.250  0.040  0.0000      ** MF **
0.010  0.775  0.180  0.010  0.025  0.0000      ** MB **

----- Marginal Saturations for New Houses - cn(m=2) -----
      1      2      3      4      5      6
0.150  0.430  0.020  0.045  0.355  0.0000      ** SF **
0.400  0.260  0.030  0.220  0.090  0.0000      ** MF **
0.360  0.500  0.085  0.015  0.040  0.0000      ** MB **

----- Historical Shipments (from 1980 to 30 years back) -----
1 Electric Central Heater (large)
0.358  0.274  0.253  0.407  0.370  0.367  0.265  0.162  0.090  0.090
0.090  0.090  0.090  0.090  0.090  0.090  0.090  0.090  0.090  0.090
0.090  0.090  0.090  0.090  0.090  0.090  0.090  0.090  0.090  0.090
2 Gas Central Heater (large)
1.318  1.094  1.113  1.327  1.805  2.145  1.854  1.571  1.573  1.484
1.214  1.273  1.286  1.220  1.122  1.026  0.827  0.766  0.839  0.762
0.554  0.451  0.417  0.457  0.535  0.285  0.200  0.217  0.192  0.051
3 Oil Central Heater (large)
0.397  0.415  0.341  0.371  0.501  0.553  0.484  0.443  0.439  0.433
0.412  0.426  0.452  0.422  0.324  0.298  0.314  0.380  0.433  0.432
0.462  0.553  0.589  0.521  0.513  0.389  0.194  0.229  0.119  0.082
4 Other Central Heater (large)
0.106  0.088  0.089  0.106  0.145  0.172  0.149  0.126  0.126  0.119
0.097  0.102  0.103  0.098  0.090  0.082  0.078  0.081  0.082  0.066
0.061  0.067  0.061  0.044  0.036  0.033  0.037  0.043  0.023  0.016
5 Heat Pump (large)
0.376  0.201  0.090  0.058  0.085  0.082  0.059  0.051  0.050  0.048
0.047  0.048  0.060  0.067  0.049  0.038  0.032  0.030  0.025  0.017
0.006  0.003  0.002  0.001  0.001  0.000  0.000  0.000  0.000  0.000

----- Retirement Function (from age 1 to 30 years) -----
for i 1 2 4
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0380 .0690 .0930
.1110 .1210 .1240 .1210 .1110 .0930 .0690 .0380 .0120 .0000
for i 3
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000 .0000
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0380 .0700 .0950
.1120 .1230 .1260 .1230 .1120 .0950 .0700 .0360 .0000 .0000
for i 5
.0000 .0000 .0000 .0000 .0000 .0000 .0000 .0330 .1020 .1340

```

.1530	.1560	.1530	.1340	.1020	.0330	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

----- Average Life Times (by fuel type i) -----

1	2	3	4	5
23.0	23.0	23.0	23.0	14.0

----- Operating Cost Elasticities (for 5 fuel types and income) -----

1	2	3	4	5	6	
-1.00	0.20	0.10	0.25	0.00	0.00	** j=1 **
0.25	-0.65	0.55	0.00	0.25	0.00	** j=2 **
0.25	0.20	-0.60	0.15	0.25	0.00	** j=3 **
0.25	0.00	0.15	-0.50	0.25	0.00	** j=4 **
0.00	0.00	0.00	0.00	-1.00	0.00	** j=5 **
0.15	0.25	-0.20	-0.90	0.15	-0.90	** j=6 **

----- Real Interest Rate for calc of Price Elast. (for 5 fuel types) -----

1	2	3	4	5	
0.08	0.11	0.11	0.11	0.00	** j=1 **
0.11	0.08	0.11	0.11	0.11	** j=2 **
0.11	0.11	0.08	0.11	0.11	** j=3 **
0.11	0.11	0.11	0.08	0.11	** j=4 **
0.00	0.00	0.00	0.00	0.08	** j=5 **

----- Usage Elasticities (for 5 fuel types and income) -----

1	2	3	4	5	
-0.30	0.00	0.00	0.00	0.00	** j=1 **
0.00	-0.30	0.00	0.00	0.00	** j=2 **
0.00	0.00	-0.30	0.00	0.00	** j=3 **
0.00	0.00	0.00	-0.30	0.00	** j=4 **
0.00	0.00	0.00	0.00	-0.30	** j=5 **
0.10	0.10	0.10	0.10	0.10	** j=6 **

----- Discount Rates for Replacement Units (m=1) -----

1	2	3	4	5	
0.0000	0.3010	0.3520	0.3120	0.0000	** SF **
0.0000	0.1300	0.4140	0.1260	0.0000	** MF **
0.0000	0.1670	0.2100	0.1750	0.0000	** MB **

----- Discount Rates for New Units (m=2) -----

1	2	3	4	5	
0.0000	0.2540	0.2870	0.2670	0.0000	** SF **
0.0000	0.1060	0.3300	0.1260	0.0000	** MF **
0.0000	0.1250	0.1350	0.1250	0.0000	** MB **

----- Cost-Efficiency Curve Parameters -----

1	2	3	4	5	
0.6133	0.5243	0.8165	0.5243	0.3106	** einf **
2.9350	4.3735	16.6728	4.3735	1.7420	** calfa **

----- Thermal Integrity of New Units -----

1	2	3	4	5	
0.942	0.967	0.969	0.967	0.897	** SF **
0.975	0.991	0.996	0.991	0.933	** MF **

0.922 0.920 0.976 0.920 0.743

** MB **

----- Historical Relative Energy Use (eun) for New Units -----

i	1	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
2	0	0.969	0.951	0.934	0.890	0.881	.8748	.8655	.8428	.8202	.7975
3	0	0.977	0.968	0.958	0.954	0.954	.9422	.9398	.9381	.9364	.9347
4	0	0.969	0.951	0.934	0.890	0.881	.8748	.8655	.8428	.8202	.7975

----- Historical Relative Capacity (cap) for New Units -----

i	1	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
2	0	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120
3	0	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
4	0	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120	1.120

of products in MH Furnace = 2

=====

product type id# = 17
product name = GMHF (Gas-fired Mobile Home Furnace)
end-use id# = 1
fuel type id# = 2
number of classes = 1

----- the 1st class -----

class id# = 72
class name = GMHF (Gas-fired Mobile Home Furnace)
discount rate = 0.31
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 56.6601
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
.727	.727	.727	.727	.727	.727	.727	.727	.727

----- Adjusted volumes (1981-2030) ((54.00+1.4758) * .727 / 365)

0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050
0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050
0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050	0.11050
0.11050	0.11050	0.11050	0.11050	0.11050						

----- Fraction of market share (1981-2030)

L = 3

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price	MMBtu	
542.62	54.00	1.4758
548.36	54.79	0.8566
619.42	52.80	0.8227
728.97	51.59	0.8021
816.33	49.67	1.0138
1111.94	45.01	0.9186
1694.18	43.19	0.8022

----- Shipment Distribution

EF	Units
0.61	42961.
0.65	56946.

product type id# = 18
product name = OMHF (Oil-fired Mobile Home Furnace)
end-use id# = 1
fuel type id# = 3
number of classes = 1

----- the 1st class -----

class id# = 73
class name = OMHF (Oil-fired Mobile Home Furnace)
discount rate = 0.21
first year to forecast UEC = 1989
first year for standard = 2031
UEC of standard = 966.5
conversion (Kwh-MMBTU&usage) = 1.000

----- Historical energy factors

1981	1982	1983	1984	1985	1986	1987	1988	1989
.728	.728	.728	.728	.728	.728	.728	.728	.728

----- Adjusted volumes (1981-2030) ((69.19+3.8670) * .728 / 365)

0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571
0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571
0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571	0.14571
0.14571	0.14571	0.14571	0.14571	0.14571					

----- Fraction of market share (1981-2030)

L = 3

1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.00	1.00	1.00	1.00	1.00					

----- UEC (Kwh) & Purchase Price (\$1990) data

Price MMBtu

1551.23	69.19	3.8670
1571.27	70.43	2.8557
1691.77	68.83	2.7909
2092.52	63.33	2.5679
2805.48	59.54	2.2521

----- Shipment Distribution

EF Units

0.59	2614.
0.67	18120.

APPENDIX C. LBL MANUFACTURER IMPACT MODEL: MOBILE HOME FURNACES

C.1 INTRODUCTION

The Lawrence Berkeley Laboratory Manufacturer Impact Model (LBL-MIM) collects all the calculations necessary to determine the impact of a change in appliance efficiency standards on an industry's profitability and scale of operation into one spreadsheet. Volume A, Appendix C of this Technical Support Document, provides an overview and description of the LBL-MIM. There is a description of the economic theory and a discussion of each of the model's modules. In this appendix, the LBL-MIM input data and model runs for the analysis of mobile home furnaces are described together.

C.1.1 Engineering Cost Data

The source of the engineering data is the Engineering Analysis performed in Chapter 1 of this volume. The data came from manufacturers of these products and/or discussions with industry consultants and other studies. The engineering data used as inputs to the model consist of several components:

1. The incremental unit variable cost incurred by the manufacturer for each of the design options that increases the efficiency of the appliance such as raw materials, direct labor, purchased parts, and increased transportation costs. The incremental variable cost is listed for each design option for each product class.
2. The annual unit energy consumption (UEC) associated with each design option for each product class.
3. Some of the design options also require additional capital investment in the form of retooling, new tooling, or other capital expenditures. These expenses are listed as one figure for each design option requiring capital expenditures; the single figure covers all of the product classes.

The engineering input data are also listed for each standards level being analyzed (a 1990 calibration case, a 1996 base case using the 1990 standards, and standards levels 1, 2, 3, etc., which are the new levels being analyzed). The figures used are exactly the same as those used for the design options, but are calculated for standards levels instead. The engineering data used as inputs to the LBL-MIM are listed on the engineering data page of the model, which follows this section. The actual data are listed there rather than here since there are several tables of data. For a thorough description of the collection and meaning of the engineering data, see the Engineering Analysis.

C.1.2 Industry Market Data

Industry Shipments

These data include annual industry shipments for the 1990 calibration case, the 1996 base case (using the 1990 standards), and the 1996 shipments for each of the standards levels. The 1990 shipments figure is based on estimates from the industry (17).

Elasticities

Price and operating cost elasticities determine the effect on shipments of changes in appliance price and operating cost. For mobile home furnaces, the price elasticity is estimated to be -0.08. The consumer discount rate is estimated to be 32% which gives an operating cost elasticity of -0.42. The source is LBL. Because these elasticities are very important, a sensitivity analysis using different elasticities is done.

Product Class Market Share

Each of the product classes has a share of the mobile home furnace market, and the market share, or unit sales, for each product class is an input to the model. For mobile home furnaces, the market shares for gas-fired and oil-fired furnaces is about 89% and 11%, respectively. The figures are based on estimates from the industry (as noted earlier).

Markups

Manufacturers charge different markups over variable cost for different product classes, resulting in different profit margins for different product classes. For mobile home furnaces, the estimated markups range from 1.38 for a gas-fired model and 1.76 for an oil-fired model. The figures are based on estimates from the industry (18).

Initial Prices

The 1990 baseline manufacturer's selling price is used as a base to which are added incremental costs of reaching the higher efficiency levels. The unit price quoted for each product class refers to the most inexpensive, fewest-frills model produced by the manufacturer. The source of the baseline manufacturer's price for each product class is research by the Manufacturer Analysis team with review by industry consultants.

Energy Price

This figure is the ratio of the price of a 1990 kWh to a 1996 kWh. The source is the LBL-REM. Industry market data appear on the Cost, Sales, and Revenues page of the model.

C.1.3 Financial Input Data

Financial Inputs

The financial inputs for mobile home furnaces are summarized in Tables C.1 to C.4.

Table C.1 Rates of Financial Costs

Variable	Value	Source
After-tax equity cost of capital ¹	6.8%	MIM calc. from public financial data ²
Interest rate on debt ¹	2.5%	MIM calc. from public financial data
Interest lost in cash ¹	1.0%	MIM calc. from public financial data
Rate of depreciation	17.7%	Public financial data
Tax rate	34.0%	Tax law

¹Cost of capital and interest rate are *real* rather than nominal.

²Public financial data include data from Value Line, Standard and Poor's, Moody's, individual company annual reports, and economic reports.

Table C.2 Other Financial Inputs

Variable	Value	Source
Cash	10.0%	Public financial data
Inventory and receivables	30.0%	Public financial data
Net depreciable assets	19.0%	Public financial data
General and administrative expenses	14.0%	Public financial data
Engineering expense	1.2%	Public financial data and industry sources ¹

¹Industry sources include consultants under contract to LBL and discussions with industry representatives.

Table C.3 Fixed, Variable, and Revenue-Related Cost Split

Variable	Value	Source
Fixed part of costs and depr. assets	6.3%	Industry sources
Fixed part of one-time capital costs	5.9%	Industry sources
Economic profit	0.6%	MIM est. from financial data
Debt/equity ratio	25.0%	Public financial data
Markup on typical model	1.38	Industry sources
Ratio of highest to lowest markup	2.00	Industry sources

Table C.4 One-Time Costs

Variable	Value	Source
One-time capital cost's life	8 years	Industry sources
One-time capital cost's tax life	8 years	MIM calculation
Percent additional 1-X capital	50%	MIM estimate
Age of replaced capital	6 years	Public financial data

The expenditure schedule above lists the costs incurred over time for preparations to meet the new standards. A percentage of the total cost is attributed to each year before the standards go into effect since that is when these expenses will occur.

C.2 LBL-MIM INPUTS AND OUTPUTS SHOWING THE PRIMARY SCENARIO

Table C.5 Mobile Home Furnaces Version of LBL-MIM

Control Panel

MOBILE HOME FURNACES CONTROL FACTORS	Scenario: Primary		Standard Level = 6		
	Input Value	Cntrl	Vari- ation	Progrm Value	Name
Price Elasticity	-0.080	0.00	100%	-0.080	IPB
Consumer Discount Rate	32.00%	0.00	100%	32.00%	RD
Equity Cost of Capital	0.068	0.00	10%	0.068	ECC
Economic Profit	0.006	0.00	1%	0.006	EP
L-R Fixed Part of Costs & Assets	0.063	0.00	50%	0.063	FCA
L-R Fixed Part of 1-X Cap. Cost	0.059	0.00	60%	0.059	FIX
One-Time Capital Costs	6.405	0.00	20%	6.405	CC.N
Unit Variable Cost Increase	\$320.87	0.00	30%	320.872	dVC.N
Elasticity Curve Parameter	0.000	0.00	30%	0.000	ro.N
Short Run Price Response to Demand	0.157	0.00	76%	0.157	SRPR
SUMMARY	NABCA	NEW	PRVIOUS		
	BASE	L-RUN	CHANGE	CHANGE	S-RUN
Shipments	0.06	0.06	-3.47%	1.37%	0.06
Price	\$244.58	\$565.66	131.28%	119.65%	\$563.01
Revenue (in \$M)	15.73	35.12	123.26%	122.65%	34.99
Net Income	0.51	0.55	0.05	0.09	0.15
ROE	7.34%	6.79%	-0.56%	-0.17%	1.86%
Trys =			2.00		

Table C.6 Mobile Home Furnaces Version of LBL-MIM

The Monte Carlo Module

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.

	Secnds/iteration =	0.73	time
	Iterations to go =	0.00	nn
MOBILE HOME FURNACES	Sample Size =	398.00	

	%dQ	%dP	%dR	dNI	dROE.N	dROE.S
Value	-3.44%	130.50%	122.57%	4.30%	-0.51%	-5.44%
Means	7.07%	136.83%	151.05%	29.93%	0.42%	-2.20%
Std. Dev	93.52%	41.75%	214.41%	163.81%	3.32%	20.73%
	0.06	1.63	1.79	0.22	0.01	0.13
	-0.01	1.41	1.39	0.09	0.00	-0.03
	-0.07	0.98	0.84	0.11	0.00	-0.04
	-0.15	0.89	0.61	-0.17	-0.03	-0.14
	-0.05	1.08	0.98	0.02	0.00	-0.04
	-0.03	1.10	1.04	-0.02	-0.01	-0.05
	-0.01	2.63	2.59	0.12	0.00	-0.03
	0.28	1.17	1.77	0.57	0.03	0.57
	-0.07	1.54	1.37	0.11	0.01	-0.26
	0.00	1.84	1.84	0.04	0.00	-0.03
	0.05	0.83	0.91	0.14	0.00	0.07
	0.03	1.10	1.16	0.00	-0.01	-0.04
	-0.02	0.91	0.87	0.08	-0.01	-0.04
	-0.03	1.34	1.26	0.03	0.00	-0.04
	-0.05	1.54	1.42	-0.02	-0.01	-0.06
	0.16	0.71	0.98	0.24	0.01	0.07
	0.00	1.56	1.55	0.13	0.00	-0.05
	-0.09	1.16	0.96	0.00	-0.01	-0.23
	0.04	1.65	1.77	0.11	0.00	0.04
	0.00	1.05	1.05	0.13	-0.01	-0.05
	0.01	0.83	0.85	0.07	-0.01	-0.04
	0.02	1.54	1.59	0.11	0.00	-0.02
	0.03	1.71	1.79	0.09	0.00	-0.02
	0.00	1.35	1.34	0.10	0.00	-0.03
	1.71	0.68	3.56	3.27	0.08	1.63
	-0.03	1.11	1.04	0.05	-0.01	-0.05
	-0.11	2.57	2.19	0.10	0.01	-0.12
	-0.11	1.98	1.66	0.06	0.00	-0.29

Table C.7 Mobile Home Furnaces Version of LBL-MIM

The Accounting Module

(All units are millions or millions of \$ unless labeled with \$ or %.)

	1990	BASE '96	NEW '96	CHANGE
Revenue	14.59	15.78	35.12	122.6%
Expenses				
Cost of Goods Sold	10.15	11.28	29.76	163.9%
Selling & G & A	2.88	2.91	2.84	-2.3%
Engineering	0.25	0.25	0.24	-2.3%
Depreciation	0.50	0.50	0.50	NA
1-X Depreciation	0.00	0.04	0.80	NA
Total Expenses	13.78	14.98	34.15	128.0%
Earnings Before Interest & Taxes	0.81	0.80	0.96	20.3%
Interest	0.04	0.02	0.00	-104.5%
Earnings Before Taxes	0.77	0.78	0.96	23.5%
Taxes	0.26	0.27	0.50	83.0%
Net Income	0.51	0.51	0.46	-8.8%
Gross Margin	30.43%	28.53%	15.26%	-46.52%
Return on Sales	3.48%	3.20%	1.31%	-59.0%
Total Assets	8.61	8.74	10.19	16.6%
Return on Assets (w/Intst taxed)	6.20%	5.94%	4.52%	-1.4
Equity	6.89	6.99	8.15	16.6%
Return on Equity	7.38%	7.23%	5.65%	-1.6

ECONOMIC ANALYSIS

	1990	BASE '96	NEW '96	CHANGE
INCOME				
Shipments	0.06	0.06	0.06	-3.4%
Price	\$227.79	\$245.41	\$565.66	130.5%
Revenue	14.59	15.78	35.12	122.6%
Fixed Costs	0.92	0.92	0.92	-9.2%
Variable Costs (w/ Q)	12.90	14.03	0.06	-11.5%
Total Expenses	13.82	14.96	0.98	-10.9%
Cash	1.46	1.46	1.41	-10.8%
Inventories	4.38	4.39	4.24	-3.4%
Depreciable	-898.77	-865.66	-770.05	-11.0%
Total Assets	8.61	8.74	10.19	16.6%

Table C.8 Mobile Home Furnaces Version of LBL-MIM

The Engineering Inputs Module

Increment in Additional UVC by Level and Class													
Baseline	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas	190	4	64.5	40.7	72.6	13.5	15.7	40.7	110	72.6	207	6.3	28.3
Oil	356	8	36.5	132	212	185	9.6						

VCS.E	Additional UVC. (Above Level 0 cost). Lots of Branches												
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	4	69	109	182	195	20	60	114	187	321	6	28
1	0	8	45	140	352	325	10	0	0	0	0	0	0

KWH.PRINT	Electricity Consumption in Kw Hrs /Yr												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas	433	251	297	290	240	239	241	235	269	223	235	433	475
Oil	1133	837	818	753	660	626	1133						

Natural Gas and Oil Consumption in MBTU/Yr													
	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas	54.00	54.79	49.67	48.53	46.77	46.62	52.80	51.59	45.01	43.49	43.19	54.00	53.16
Oil	69.19	70.43	68.83	63.33	59.54	59.94	69.19						

Operating Costs: KwHr and MBTUs converted to \$													
KWS.E	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas	361	351	324	317	302	301	338	331	294	281	280	361	360
Oil	605	590	576	530	494	495	605	0	0	0	0	0	0

Capital cost / unit / 7													
	0	1	2	3	4	5	6	7	8	9	10	11	12
Gas	0	0	0.5	3	1.2	1.5	0.3	3	29	1.2	0	0.5	0.9
Oil	0	0	3	25	0	0	0.5						

CC.E	Additional CC./7 (Above Level 0 cost.): Lots of Branches												
CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0.0	0.5	3.5	4.7	6.2	0.3	0	29.0	30.2	29.0	0.5	0.9
1	0	0.0	3.0	25.0	25.0	25.0	0.5	0	0	0	0	0	0

CCEE.E	0	0	0	3	3	4	0	1	12	12	12	0	0
--------	---	---	---	---	---	---	---	---	----	----	----	---	---

Table C.9 Mobile Home Furnaces Version of LBL-MIM

The Standards Level Module

Levl'n prev	LEV.B	lev.N	Eng:	0 ...	0	"Emax
-1	0	6	REM:	-1 ...	0	"Smax
1	0	1		1 ==> Stndrds	0 ==> Eng.	
SIE	SIE.B	SIE.N	Esc = QUIT			

VCSR	Additional UVC by Level and Class. (Above Base cost.)							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6
Gas	3.44	13.93	15.65	22.40	60.40	68.50	114.40	321.10
Oil	4.09	74.07	75.08	75.08	79.68	79.68	139.50	351.50

KWS.R	Kw Hrs /Yr							
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6
Gas	355	348	343	338	331	324	294	280
Oil	597	563	561	561	559	559	530	494

CC.R								
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6
Gas	0.02	0.15	0.15	0.28	0.00	0.50	29.00	29.00
Oil	0.00	10.77	10.77	10.77	11.15	11.15	25.00	25.00

CCEE.R								
LEVEL -->	-1=1990	0=1996	1	2	3	4	5	6
Cumltv CC	0	0	0	0	0	1	29	29
	0	0.33	0.33	0.36	0.93	0.37	6.41	6.41

	1990	1996	NEW96	1990	1996	NEW96
	VC87	VCB	VCN	KW87	KWB	KWN
Gas	3.44023	13.9274	321.1	354.628	347.756	279.905
Oil	4.0944	74.0715	351.5	597.069	562.799	494.484

	1990	1996	NEW96	Base Case		New Stds
	CPC87	CPCB	CPCN	Weighted	Weighted	Weighted
				Op Cost	d P	d P
Gas	0.02217	0	29	316.33	9.35	283.35
Oil	0	0	25	64.48	7.56	37.52
		Wgt Fuel Cost: F		380.81	16.91	320.87
					dVC.B0	dVC.N0

	---OUTPUT---					
	CC.87	CCB	CCN	CC.B0	CC.N0	dVC.B.CV
	0	0	6.40504	0	6.40504	25.00%

Table C.10 Mobile Home Furnaces Version of LBL-MIM

The Costs, Sales, and Revenue Module

Ratio of highest to lowest markup:	ratio.0	2.00	ratio.cv	0.20
Typical markup over UVC	mid.0	0.38	mid.cv	0.20
Size of firm as % of industry	size.0	0.50		

CALIBRATION CASE (1990)

	Indst	Relatv	----- Firm -----					
	Ship.	Ship.	Ship.	Price	Rev.			Weightd
		Q%	Q.1	P.1/Range	R.1	m.1	UVC.1	"UVC
Gas	0.11	0.89	0.06	208.13	11.89	1.38	150.82	134.53
Oil	0.01	0.11	0.01	390.18	2.70	1.76	221.69	23.94
TOTAL S	0.13	20.00%	0.06	\$228	14.59	1.44	20.00%	158.47
	"TS.0	"Q.CV	Q.0	P.0	R		"P.CV	UVC

BASE CASE (1996)

	Rule-of-	Rule-of-		Op Cost	Weightd		
	Thb d P	Thb Price		Ratio	OpCst-R	Qi.B	Ri.B
Gas	14.44	12.77	12	\$221	0.98	0.87	0.0574
Oil	123.16	3.57	105	\$435	0.94	0.10	0.0069
	0.01	16.33	117	244.6	15.73	-0.02	0.0643
Alpha.B	Sum P (2)	Sum (3)	"P.B	Sum(Ri)	OC%.B0	"Q.B	"R.B
check=R.B							

NEW STANDARDS CASE (1996)

	Rule-of-	Rule-of-		% Chng	Weightd		
	Thb d P	Thb Price		Op Cost	OpCst-R	Qi.N	Ri.N
Gas	475.98	37.88	12546	\$540.6	0.79	0.70	0.0554
Oil	652.82	6.99	2857	\$773.0	0.83	0.09	0.0067
TOTAL	0.00	44.88	15403	565.7	35.12	-0.21	0.0621
Alpha.N	Sum P (2)	Sum (3)	"P.N	Sum(Ri)	OC%.N0	"Q.N	"R.N
check=R.N.							

Table C.11 Mobile Home Furnaces Version of LBL-MIM

The Financial Module

INPUT	NAME	VALUE	NAME	C.V. or Control Factor
RATES of COST				
After Tax Equity Cost of Capital	BCC.0	0.07	BCC.CV	10%
Interest Rate on Debt	I.0	2.50%	LCV	100%
Interest Lost on Cash	ICash.0	0.01	ICASH.CV	100%
Rate of Depreciation	Dep.0	0.18		
Tax Rate	T.0	34.00%	T.CV	20%
ASSETS and COSTS as a PERCENT of REVENUE				
Cash	C.R.0	10%	C.R.CV	100.00%
Inventory & Receivables	IR.R.0	30%	IR.R.CV	27.19%
Depreciable Assets	DA.R.0	19%	DA.R.CV	36.89%
G & A	G&A.0	14%	G&A.CV	40.00%
Engineering	Eng	1.20%		
FIXED AND VARIABLE COST SPLIT				
Fixed Part of All Costs & Depr Assets	FDA.0	6.33%	FCA.CV	50.00%
Fixed Part of 1-X Capital Cost	FIX.0	5.95%	FIX.CV	60.00%
OTHER				
Economic Profit	EP.0	0.58%	EP.CV	1.00%
Debt to Equity ratio	DER.0	25.00%	DER.CV	43.36%
Markup on typical model	"mid	38.00%		
Ratio of highest to lowest markup	"ratio	200.00%		
OUTPUT				
Depreciation	DRR	3.5%		
G&A to Overhead Ratio	G:O	92.1%		
Engineering to Overhead Ratio	E:O	7.9%		
Debt Ratio	DR	20.0%		
Equity Ratio	ER	80.0%		
Pre-Tax Equity Cost of Capital*	PECC	10.3%		
Weighted Average Cost of Capital	WACC	8.7%		
After Tax WACC	ATWACC	5.8%		
Return on Equity	ROE	7.38%	ROE.0	7.38%

All interest rates and costs of capital are "real".

*When Pre-Tax ECC is used, all costs are counted tax-exempt.

Table C.12 Mobile Home Furnaces Version of LBL-MIM

The One-Time Cost Amortization Module

INPUT				
Economic life of existing capital		L	8.00	years
Tax life of existing capital		TL	6.00	years
Age of existing capital		AGE	1.00	years
Percent of 1X capital that is add-on (as opposed to replacement capital)		%NC	50%	
COMPUTATIONS				
DESCRIPTION		NAME	VALUE	
Continuous After-Tax WACC		ATR	5.61%	
Weighted CC Lead-Time Factors	0.00	0.29	0.54	0.26
Cumulative CC Lead-Time Factors		LTC.0	1.092	
$\exp(-ATR \cdot TL)$		EMRT	0.714	
$\exp(-ATR \cdot L)$		EMRL	0.638	
Rate of tax benefit	3.30	BN	0.057	
Remaining tax life		RTL	5.00	years
Tax Benefit Rate: $(1 - \%NC) \cdot BN$		BEN	0.028	
Discount factor: $@\exp(-ATR \cdot (L - (TL - RTL)))$		DIS	0.68	
Loss of tax benefit on portion of existing capital with remaining tax life		LEC1	0.124	
Loss of tax benefit on discounted existing capital expenditure in the future		LEC2	0.097	
LEVELIZED CC			GROSS CC	TAX EFF
Initial Cost			1.000	
Tax Benefit of Straight-Line Depreciation				0.289
Savings from not replacing existing Capital later			-0.338	
Loss of Tax Benefit from existing Capital				-0.221
Present Value of CC:			0.662	0.068
Adjusted for Capital Lead Time			0.723	0.074
Levelized Tax Benefit: 1-X dep. of existing Cap.				0.004
LEVELIZED CC FACTOR		CCLF	0.112	0.016
AVERAGE ASSET FACTOR				
Asset Factor for Any New Cap. or Asset		AFB	0.574	
Average Asset Factor for Add-on Capital		AAF	0.287	
INPUT				
NEW CAP. COST: 1990-96 (\$000)	CC.B0	0.00		
1996 CHANGE	CC.N	6.41		
COEFFICIENTS OF VARIATION	OCLCV	0.20		
OUTPUT				
	BASE CASE 1996		NEW STNDS 1996	
Levelized 1-X CC: Gross	LOC.B	0.00	LOC.N	0.72
Levelized 1-X CC: Tax Effects	LOC.TB	0.00	LOC.TN	0.10
Levelized 1-X CC: Net	LOC.NB	0	LOC.NN	0.61723
Levelized 1-X Assets	LA.B	0.00	LA.N	1.84

Table C.13 Mobile Home Furnaces Version of LBL-MIM

The Long-Run Model Module

1990 CASE		A.F	A.Q	A.R	A
Assets -->		0.012	0.578	0.590	9
Costs except taxes		TC.F	TC.Q	TC.R	TC
and equity -->		0.063	0.884	0.947	14
		EC.F	EC.Q	EC.R	EC
Economic costs -->		0.042	0.615	0.997	15
	Economic Income			EL.R	0.0028
	Markup (mu - 1)			mul	0.0735
	Price Leader's elasticity of demand:				-14.6
BASE 1996		A.BF	A.BQ		A.B
Assets		0.18	131.66		8.64
		TC.BF	TC.BQ		TC.B
Costs except taxes		0.92	218.26		15
		EC.BF	EC.BQ		EC.B
Economic costs		0.62	151.21		15
NEW 1996		A.NF	A.NQ		A.N
Assets		0.18	131.66		10.19
		TC.NF	TC.NQ		TC.N
Costs except taxes		0.92	522.22		33
		EC.NF	EC.NQ		EC.N
Economic costs		0.66	362.37		28
Assets	-----1990-----	---BASE 1996---		---NEW 1996---	
Shipments	"Q 0.06	Q.B	0.06	Q.N	0.06
Price	"P \$227.79	P.B	\$244.58	P.N	\$565.66
Revenue	"R 14.59	R.B	15.73	R.N	35.12
Unit Var. Cost	"UVC \$158.47	UVC.B	\$175.38	UVC.N	\$479.35
V. Cost Goods Sold	VCGS 10.15	VCGS.B	11.28	VCGS.N	29.76
1X tax benefit		X1T.B	0.00	X1T.N	0.10
Pre-tax cost	PTC 13.82	PTC.B	14.96	PTC.N	34.06
Taxes	TAX 0.26	TAX.B	0.26	TAX.N	0.50
Net Income	NI 0.51	NLB	0.51	NLN	0.55
Economic Income	EI 0.04	ELB	0.04	ELN	0.00
Equity	EQ 6.89	EQ.B	6.91	EQ.N	8.15
Retrn on Equity	"ROE 7.38%	ROE.B	7.34%	ROE.N	6.79%
ACCOUNTING PAGE CALCULATIONS					
	-----1990-----	---BASE 1996---		---NEW 1996---	
Interest not 1X	IC 0.04	IC.B	0.02	IC.N	-0.01
Pre-intrst cst	PIC 13.78	PIC.B	14.94	PIC.N	34.16
1X depreciation		X1D.B	0.00	X1D.N	0.80
1X interest		X1LB	0.00	X1LN	0.01
1X equity cost		X1E.B	0.00	X1E.N	0.10

Table C.14 Mobile Home Furnaces Version of LBL-MIM

The Short-Run Model Module

Short-Run "Supply Elasticity of Price":				SRQE.O	0.157
(Q/P)*dP/dQ					
Standard Error of SRQE				SRQE.SD	0.120
Random Value selected for this run:				"SRQE	0.157
R.S	34.99		"P.N	\$565.66	
UVC.S	\$479.35		"Q.N		0.06
VCGS.S	29.79				
TC.S	33.38			ap	bp
TAX.S	0.65	P=s+bQ		476.85	1386.37
PTC.S	34.19		0.88	cq	dq
NI.S	0.15	Q=c+dP		0.08	0.00
A.S	10.19				
EQ.S	8.15		P.S	563.01	
ROE.S	1.86%		Q.S		0.06
Check P				\$562.67	
Check Q					0.0620

Short-Run Assumptions:

The industry installs the long-run optimal level of capital.

The industry produces to meet demand at the low short-run price.

Table C.15 Mobile Home Furnaces Version of LBL-MIM

The Charts Module

CHARTS OF SENSITIVITY AND PROFIT FOR MOBILE HOME FURNACES

Sensitivity of ROE to 1 S.E. change in Control Variable

Scenario = Primary

Control Variables			Possible Standards Levels				
Name	Value	Changed	1	2	3	4	5
IPE	-0.080	-0.184	0.05%	0.10%	0.04%	0.10%	0.46%
RD	32.00%	73.57%	0.00%	0.02%	0.21%	0.25%	0.13%
ECC	0.068	0.075	0.00%	0.00%	-0.01%	0.00%	-0.09%
EP	0.006	0.016	-0.01%	-0.02%	-0.02%	-0.02%	-0.19%
FCA	0.063	0.102	-0.02%	-0.04%	-0.02%	-0.04%	-0.09%
FIX	0.088	0.153	-0.04%	-0.04%	-0.10%	-0.03%	-0.90%
CC.N	0.335	0.408	-0.01%	-0.01%	-0.03%	-0.01%	-0.18%
dVC.N	18.555	24.886	0.02%	0.03%	0.06%	0.08%	0.00%
ro.N	0.000	0.300	0.04%	0.07%	0.03%	0.07%	0.14%
SRPR	0.157	0.594	0.00	0.00	0.00	0.00	0.00

Change in Long-Run ROE from 1996 NAECA Base Case by Engineering and Standards Levels

Scenario = Primary

Level	Engin	Standds
1	-0.04%	-0.04%
2	-0.12%	-0.08%
3	-0.39%	-0.12%
4	-0.41%	-0.08%
5	-0.86%	-1.21%
6	0.29%	-0.51%

REFERENCES

1. U.S. Department of Housing & Urban Development (HUD). 1975. "Manufactured Home Construction and Safety Standards", Part 3280 CFR, Section 3280.709 (Subpart H), *Federal Register*, Washington, DC, December 189, 1975.
2. F. Walter. 1991. *Personal communication*. Manufactured Housing Institute, Arlington, VA, October 15, 1991.
3. Manufactured Housing Institute, 1990. *Manufacturing Report*. Arlington, VA, December, 1990.
4. The Levy Partnership, Inc. 1989. *Technical Support Document: Development of recommendations for Revision to the Manufactured Housing Construction and Safety Standards, Subpart F - Thermal Protection*. Prepared by the Levy Partnership, Inc., New York, NY, for the Manufactured Housing Institute Consensus Committee, Arlington, VA, Table 2.3, p 2.19.
5. US Office of the Federal Register. 1991. *Code of Federal Regulations. Title 10, Energy, Part 430, Subpart B, Appendix N: Uniform Test Method for Measuring the Energy Consumption of Furnaces*. Washington, DC, January, 1991.
6. G.E. Kelly, et al. 1978. *Recommended Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers*. National Bureau of Standards (renamed National Institute of Standards and Technology), NBSIR 78-1543, Washington, DC, October, 1978.
7. National Appliance Energy Conservation Act (NAECA). 1987. Public Law 100-12, Part B - *Energy Conservation Program for Consumer Products Other than Automobiles*. 42 USC 6291, Section 325 (f) 2. Washington, DC.
8. NAECA, 1987. *Op. cit.* Section 325(n) 1A.
9. Gas Appliance Manufacturers Association (GAMA). 1990. *Consumers' Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment*. Prepared by ETL Testing Laboratories Inc., Cortland, NY, for GAMA, Arlington, VA, October, 1990.
10. B. Brown. 1990. *Personal communication*. White-Rodgers Corp., St. Louis, MO, October, 1991.
11. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). 1988. ANSI/ASHRAE Standard 103-1988m *Methods of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers*, ASHRAE, Atlanta, GA, 1988.

12. GAMA. 1990. *Op. cit.*
13. U.S. DOE, Energy Information Administration. 1989. *Household Energy Consumption and Expenditures 1987*. DOE/EIA-0321/1 (87), Washington, DC.
14. U.S. DOE, Energy Information Administration. 1991. *Annual Energy Outlook 1991*. DOE/EIA-0383(91), Washington, DC.
15. *Ibid.*
16. U.S. DOE, Energy Information Administration, 1991. *State Energy Price Projections for the Residential Sector, 1991-1992*. Service Report SR/EMEU/91-04, Washington, DC, November.
17. A. Zimmerman, Vice President, Evcon Industries, Inc., Wichita, KS, and D. Lagrand, Director, Marketing Planning, Nordyne, St. Louis, MO. 1990. *Personal communications*, June 1990.
18. *Private communications* (LBL questionnaire responses), 1990. Evcon Industries, Inc., Wichita, KS, and Nordyne, St. Louis, MO, April 1990

DATE

FILMED

9 / 8 / 94

END