DOE/EE-0064

TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY STANDARDS FOR CONSUMER PRODUCTS:

REFRIGERATORS, REFRIGERATOR-FREEZERS, & FREEZERS

RECEIVED
JUL 28 1995
OSTI

Including:
Draft Environmental Assessment
Regulatory Impact Analysis

July 1995

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

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.

Available to the public from the U.S. Department of Commerce, Technology Administration, National Technical Information Service, Springfield, VA 22161.
(703) 487-4650.

Printed with soy ink on recycled paper

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/EE-0064

TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY STANDARDS FOR CONSUMER PRODUCTS:

REFRIGERATORS, REFRIGERATOR-FREEZERS, & FREEZERS

Including:
Draft Environmental Assessment
Regulatory Impact Analysis

July 1995

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.

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

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

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

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION 1-1
1.1 PURPOSE AND SCOPE 1-1
1.2 STRUCTURE OF THE DOCUMENT 1-1

CHAPTER 2. ANALYTIC APPROACH 2-1
2.1 INTRODUCTION 2-1
2.2 OVERVIEW OF ANALYTIC FRAMEWORK 2-2
2.3 MODELS, DATA, AND ASSUMPTIONS 2-4
2.3.1 Engineering Cost and Performance Models 2-4
2.3.2 LBL Residential Energy Model (LBL-REM) 2-7
2.3.3 LBL Manufacturer Analysis Model (LBL-MAM) 2-14
2.3.3.1 Long-Run Impact Analysis 2-18
2.3.3.2 Short-Run Impacts 2-20
2.3.3.3 Industry Net Present Value Analysis 2-20
2.3.3.4 Sensitivity Analysis 2-21
2.3.4 Appliance Standards Environmental and Utility Model (ASEUM) . 2-26
2.3.5 Life-Cycle Cost Analysis, Payback Period, and Cost of Conserved Energy 2-29
2.3.6 Environmental Analysis 2-29

CHAPTER 3: ENGINEERING ANALYSIS 3-1
3.1 INTRODUCTION 3-1
3.2 PRODUCT CLASSES 3-2
3.3 DESIGN OPTIONS 3-4
3.4 ENERGY USE DATA 3-13
3.4.1 Energy Use Versus Adjusted Volume 3-29
3.5 COST EFFICIENCY DATA 3-41
3.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN 3-41

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 4-21
4.2.1 PBP Data Inputs 4-21
4.2.2 PBP Results 4-21
4.3 CHANGE IN LIFE-CYCLE COSTS DUE TO STANDARDS 4-22
4.3.1 Data Inputs for Change in LCC 4-22
4.3.2 Results for Change in LCC 4-22
4.4 COST OF CONSERVED ENERGY (CCE) DUE TO STANDARDS 4-23
4.4.1 CCE Data Inputs 4-23

4.4.2 CCE Results 4-23
4.5 LCC SENSITIVITY ANALYSIS 4-36

CHAPTER 5. NATIONAL ENERGY AND ECONOMIC IMPACTS 5-1
5.1 ECONOMIC AND DEMOGRAPHIC DATA 5-1
5.1.1 Occupied Households 5-1
5.1.2 Housing Starts 5-2
5.1.3 Disposable Personal Income 5-2
5.1.4 Residential Energy Prices 5-3
5.1.5 Average Equipment Lifetime 5-4
5.2 BASE CASE FORECAST 5-5
5.2.1 New Appliance Unit Energy Consumptions 5-5
5.2.1.1 Efficiency Distributions 5-6
5.2.1.2 Usage 5-6
5.2.2 Annual U.S. Appliance Installations 5-6
5.2.3 U.S. Residential Energy Consumptions 5-7
5.2.4 Price of Purchased Appliances 5-7
5.3 STANDARDS FORECASTS 5-8
5.3.1 Standard Levels 5-9
5.3.2 Energy Consumption 5-10
5.3.3 Annual Installations 5-12
5.3.4 Appliance Prices 5-12
5.3.5 Net Present Values (NPV) 5-13
5.4 SENSITIVITY ANALYSIS 5-15
5.4.1 Sensitivity Analysis of the Base Case 5-15

6. IMPACTS OF STANDARDS ON MANUFACTURERS 6-1
6.1 INDUSTRY PROFILE 6-1
6.1.1 Demand 6-1
6.1.2 Supply 6-4
6.1.3 Prices 6-10
6.2 IMPACTS ON THE MANUFACTURERS OF REFRIGERATORS AND FREEZERS 6-12
6.2.1 Long-Run Impacts 6-12
6.2.2 Short-Run Impacts 6-18
6.2.3 Impact as a Function of Firm Size 6-18
6.2.4 Sensitivity Analysis for Refrigerators and Freezers 6-20

CHAPTER 7. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES 7-1
7.1 INTRODUCTION 7-1
7.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS 7-1
7.3 PEAK LOAD AND CAPACITY REDUCTIONS 7-1
7.4 REVENUE LOSSES 7-5
7.5 SENSITIVITY ANALYSIS 7-9

APPENDIX A. ENGINEERING ANALYSIS ERA COMPUTER SIMULATION PROGRAM AND MANUFACTURE COST DATA A-1
A.1 INTRODUCTION A-1
A.2 CABINET LOADS MODEL (CAB.EXE) A-1
A.2.1 Wall Heat Loads A-2
A.2.2 Gasket Model A-3
A.2.3 Anti-Sweat Heat. A-4
A.3 REFRIGERATION CYCLE ANALYSIS AND ENERGY USE (ERACYC.EXE) A-4
A.3.1 Cycle Model Solution Procedure A-5
A.3.2 Map-Based Compressor Model A-5
A.3.3 Matching Evaporator Capacities and Cabinet Loads A-7
A.3.3.1 Single Evaporator Cycle A-7
A.4 ENERGY CONSUMPTION MODEL A-8
A.5 COST DATA FOR REFRIGERATORS AND FREEZERS A-9

APPENDIX B. FORECASTING MODELS B-1
B.1 LBL RESIDENTIAL ENERGY MODEL B-1
B.1.1 Overview B-1
B.1.2 Housing B-2
B.1.2.1 Number of Households B-2
B.1.2.2 Housing Starts B-2
B.1.3 Building Shell Thermal Integrity B-2
B.1.4 Equipment Efficiency B-3
B.1.5 Market shares B-3
B.1.6 Usage Behavior B-4
B.1.7 Equipment Turnover B-4
B.1.8 Outputs B-5
B.1.9 Changes since Previous Technical Support Document B-6
B.2 LBL-REM INPUT DATA: REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS B-6

APPENDIX C. LBL MANUFACTURER ANALYSIS MODEL C-1
APPENDIX C.1 OVERVIEW OF LBL MANUFACTURER ANALYSIS MODEL . C-1
C.1.1 Purpose C-1
C.1.2 The Economic Approach C-1

C.1.3 Measures of Impact C-2
C.1.4 Methodology C-2
C.2 STRUCTURE OF THE LBL-MAM C-4
C.2.1 Economic Theory and Assumptions C-4
C.2.2 Structural Assumptions C-13
C.2.3 Description of Modules C-14
C.2.3.1 Control Panel C-16
C.2.3.2 The Monte Carlo Module C-17
C.2.3.3 The Accounting Module C-17
C.2.3.4 The Engineering Inputs Module C-18
C.2.3.5 The Standards Levels Module C-19
C.2.3.6 The Costs, Sales, and Revenue Module C-20
C.2.3.7 The Financial Module C-22
C.2.3.8 The One-Time Cost Amortization Module C-23
C.2.3.9 The Long-Run Model Module C-26
C.2.3.10 The Short-Run Model Module C-29
C.2.3.11 Sensitivity Charts Module C-30
C.2.3.12 Engineering-to-Standards Conversion Module C-30
C.2.3.13 Industry Net Present Value Module C-30
C.2.4 Model Inputs C-30
C.2.4.1 Input Generating Assumptions C-30
C.2.4.2 Control Factors in the Control Panel C-31
C.2.4.3 Engineering Data C-33
C.2.4.4 Costs, Sales, and Revenues C-33
C.2.4.5 Financial Inputs C-34
C.2.5 Model Outputs C-36
C.2.5.1 Control Panel Outputs C-36
C.2.5.2 Accounting Summary Outputs C-37
C.2.5.3 Economic Analysis Outputs C-38
C.2.5.4 Monte Carlo Outputs C-38
C.2.5.5 Retail Prices C-38
C.2.6 Development and Integration of the Industry Npv Module C-39
C.2.6.1 The Integration and Cost Iteration Process C-39
C.3 INPUT DATA AND DATA DEVELOPMENT FOR REFRIGERATORS AND FREEZERS C-47
C.3.1 Engineering Cost Data C-47
C.3.2 Industry Market Data C-48
C.3.3 Financial Input Data C-49
C.3.4 LBL-MAM Inputs and Outputs Showing the Primary Scenario C-51

APPENDIX D. ELECTRIC UTILITY IMPACT MODELING D-1
D.1 INTRODUCTION D-1
D.2 AVOIDED COST BACKGROUND AND CONVENTIONS D-1

D.3 ENERGY COST SAVINGS D-2
D.4 CAPACITY SAVINGS D-5
D.4.1 Value of Capacity Savings D-5
D.4.2 Amount of Capacity Savings D-7
D.4.3 Avoided Transmission and Distribution Capital Costs D-9

APPENDIX E. SI UNIT CONVERSIONS E-1

ENVIRONMENTAL ASSESSMENT EA-1
1. INTRODUCTION AND NEED FOR PROPOSED ACTION EA-1
2. METHODS OF ESTIMATING ENVIRONMENTAL IMPACTS EA-2
2.1 Baseline Emissions EA-2
2.2 Sulfur and Nitrogen Oxide Emissions EA-4
2.3 Carbon Dioxide Emissions EA-6
3. RESULTS EA-7
3.1 Sulfur and Nitrogen Oxide Emissions EA-7
3.2 Carbon Dioxide Emissions EA-8
3.3 Sensitivity Cases EA-13

REGULATORY IMPACT ANALYSIS R-1
1. INTRODUCTION R-1
2. DESCRIPTION AND ANALYSIS OF MAJOR ALTERNATIVES R-3
2.1 Comparative Analysis of the Alternatives R-3
2.2 No-Action Alternative R-6
2.2.1 Energy Prices R-7
2.2.2 Increasing Consumer Information R-9
2.2.3 Existing Mandatory Standards R-9
2.2.4 Quantitative Description R-10
2.3 Tax Credits to Consumers R-10
2.3.1 Discussion R-10
2.3.2 Quantitative Description R-11
2.4 Tax Credits to Manufacturers R-11
2.4.1 Discussion R-11
2.4.2 Quantitative Description R-12
2.5 Rebates to Consumers R-12
2.5.1 Discussion R-12
2.5.2 Quantitative Description R-13
2.6 Prescriptive Standards R-14
2.6.1 Discussion R-14
2.6.2 Quantitative Description R-14
2.7 Voluntary Energy Efficiency Targets R-14
2.7.1 Discussion R-14
2.7.2 Quantitative Description R-15

2.8 Enhanced Consumer Education and Labeling Programs R-15
2.8.1 Discussion R-15
2.8.2 Quantitative Description R-16
2.9 Performance Standards R-17
2.9.1 Discussion R-17
2.9.2 Quantitative Description R-17
3. COSTS AND BENEFITS OF ALTERNATIVE STANDARDS LEVELS R-17
3.1 Choice of Standards Levels to Analyze R-18
3.2 Impacts on Consumers R-19
3.3 Impacts on Manufacturers R-21
3.4 Impacts on Electric Utilities R-23
3.5 National Impacts R-25
3.5.1 Energy Savings R-25
3.5.2 Net Present Value of Standards R-26
3.5.3 Environmental Impacts R-27
4. ECONOMIC IMPACTS OF THE PROPOSED AND ALTERNATIVE STANDARDS R-28
4.1 Introduction R-28
4.2 Methodology R-29
4.3 Effects of Proposed Standards on Consumers R-29
4.4 Effects of Proposed Standards on Manufacturers R-30
4.5 Effects of Proposed Standards on GNP and Employment R-31
4.5.1 Overview R-31
4.5.2 Crowding Out R-32
4.5.3 The Multiplier R-32
4.5.4 The Rational Expectations View R-32
4.5.5 Efficiency R-33
4.5.6 Demand Effects and the Retail Sector R-33
4.5.7 Demand Effects and the Manufacturer Sector R-33
4.5.8 Demand Effects and the Energy Industry R-33
4.5.9 Summary and Conclusions R-34
4.5.10 Trade R-34
4.6 The Impact of Alternative Regulations R-34
4.6.1 Tax Credits R-34
4.6.2 Consumer Rebates R-35
4.6.3 Prescriptive Standards R-35
4.6.4 Voluntary Efficiency Targets R-35
4.6.5 Enhanced Labeling and Consumer Education R-36

LIST OF TABLES

Table 2.1 Sensitivity of ROE to 1 S.E. Change in Control Variable 2-22
Table 2.2 Emissions Factors for Power Generation 2-30

Table 3.1 Product Classes 3-3
Table 3.2 Design Options for Refrigerators and Freezers 3-4
Table 3.3 Baseline Refrigerator-Freezer, Freezer, and Compact Characteristics 3-15
Table 3.4 Estimated 1998 Compressor COPs (using HFC 134a) 3-16
Table 3.5 Energy Use of a Top Mount Auto Defrost Refrigerator-Freezer 3-20
Table 3.6 Energy Use of a Top Mount Auto Defrost Refrigerator-Freezer With Through-The-Door Features 3-21
Table 3.7 Energy Use of a Side-by-Side Auto Defrost Refrigerator-Freezer 3-22
Table 3.8 Energy Use of a Side-by-Side Auto Defrost Refrigerator-Freezer With Through-The-Door Features 3-23
Table 3.9 Energy Use of a Bottom Mount Auto Defrost Refrigerator-Freezer 3-25
Table 3.10 Energy Use of an Upright Auto Defrost Freezer 3-26
Table 3.11 Energy Use of an Upright Manual Defrost Freezer 3-27
Table 3.12 Energy Use of a Chest Manual Defrost Freezer 3-28
Table 3.13 Energy Use of a Compact Manual Defrost Refrigerator-Freezer 3-29
Table 3.14 Regression Coefficients for Top Mount A-D Refrigerator-Freezers 3-32
Table 3.15 Top Mount Auto Defrost Refrigerator-Freezer Slopes and Intercepts for Individual Design Levels 3-33
Table 3.16 Top Mount Auto Defrost Refrigerator-Freezer with Through-the-Door Features Slopes and Intercepts for Individual Design Levels 3-34
Table 3.17 Side-by-Side Auto Defrost Refrigerator-Freezer Slopes and Intercepts for Individual Design Levels 3-35
Table 3.18 Side-by-Side Auto Defrost Refrigerator-Freezer with Through-the-Door Features Slopes and Intercepts for Individual Design Levels 3-36
Table 3.19 Bottom Mount Auto Defrost Refrigerator-Freezer Slopes and Intercepts for Individual Design Levels 3-37
Table 3.20 Upright Auto Defrost Freezer Slopes and Intercepts for Individual Design Levels 3-38
Table 3.21 Upright Manual Defrost Freezer Slopes and Intercepts for Individual Design Levels 3-39
Table 3.22 Chest Manual Defrost Freezer Slopes and Intercepts for Individual Design Levels 3-40
Table 3.23. Compact Manual Defrost Refrigerator-Freezer Slopes and Intercepts for Individual Design Levels 3-41

Table 4.1 Life Cycle Costs for Top Mount Auto Defrost Refrigerator-Freezer 4-3

Table 4.2 Life Cycle Costs for Top Mount Auto Defrost Refrigerator-Freezer With Through-The-Door Features 4-5
Table 4.3 Life-Cycle Costs for Side by Side Auto Defrost Refrigerator-Freezer 4-7
Table 4.4 Life-Cycle Costs for side by Side Auto Defrost Refrigerator-Freezer with Through-The-Door Features 4-9
Table 4.5 Life-Cycle Costs for Bottom Mount Auto Defrost Refrigerator-Freezer 4-11
Table 4.6 Life-Cycle Costs for Upright auto Defrost Freezer 4-13
Table 4.7 Life-Cycle Costs for Upright Manual Defrost Freezer 4-15
Table 4.8 Life-Cycle Costs for Chest Manual Defrost Freezer 4-17
Table 4.9 Life-Cycle Costs for Compact Manual Defrost Refrigerator-Freezer 4-19
Table 4-10 Cost (1992$) and Energy-Use Summary of Top Mount Auto-Defrost Refrigerator, no TTD 4-24
Table 4.11 Weighted-Average of Units Sold below Standards, Top Mount Auto-Defrost Refrigerator, no TTD 4-25
Table 4.12 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Top Mount Auto-Defrost Refrigerator, no TTD 4-25
Table 4.13 Cost (1992$) and Energy-Use Summary of Top Mount Auto-Defrost Refrigerator with TTD 4-26
Table 4.14 Weighted Average of Units Sold below Standards, Top-Mount Auto Defrost Refrigerator with TTD 4-26
Table 4.15 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Top Mount Auto Defrost Refrigerator with TTD 4-27
Table 4.16 Cost (1992$) and Energy-Use Summary of Bottom Mount Auto Refrigerator 4-27
Table 4.17 Weighted Average of Units Sold below Standards, Bottom Mount Auto Refrigerator 4-28
Table 4.18 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Bottom Mount Auto Refrigerator 4-28
Table 4.19 Cost (1992$) and Energy Use Summary of Side-by-Side Refrigerator, no TTD 4-29
Table 4.20 Weighted Average of Units Sold Below Standards, Side-by-Side Refrigerator, no TTD 4-29
Table 4.21 Life-Cycle Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Side-by-Side Refrigerator, No TTD 4-30
Table 4.22 Cost (1992$) and Energy Use Summary of Side-by-Side Refrigerator with TTD 4-30
Table 4.23 Weighted-Average of Units Sold below Standards, Side-by-Side Refrigerator with TTD 4-31
Table 4.24 Life-Cycle Cost Difference (1992$), Payback Periods (Year),

and Costs of Conserved Energy at 6% Real),
Side-by-Side Refrigerator with TTD 4-31
Table 4.25 Cost (1992$) and Energy-Use Summary of Compact Refrigerator 4-31
Table 4.26 Weighted Average of Units Sold below Standards,
Compact Refrigerator 4-32
Table 4.27 Life-Cycle Cost Difference (1992$), Payback Periods (Year)
and Costs of Conserved Energy (At 6% Real), Compact Refrigerators 4-32
Table 4.28 Cost (1992$) and Energy-Use Summary of Manual
Defrost Upright Freezer 4-32
Table 4.29 Weighted-Average of Units Sold below Standards, Manual
Defrost Upright Freezer 4-33
Table 4.30 Life-Cycle Cost Difference (1992$), Payback Periods (Year),
and Costs of Conserved Energy(at 6% Real),
Manual Defrost Upright Freezer 4-33
Table 4.31 Cost (1992$) and Energy-Use Summary of Auto
Defrost Upright Freezer 4-34
Table 4.32 Weighted-Average of Units Sold below Standards, Auto
Defrost Upright Freezer 4-34
Table 4.33 Life-Cycle Cost Difference (1992$), Payback Periods (Year),
and Costs of Conserved Energy (At 6% Real),
Auto Defrost Upright Freezer 4-35
Table 4.34 Cost (1992$) and Energy Use Summary of
Manual Defrost Chest Freezer 4-35
Table 4.35 Weighted-Average of Units Sold below Standards,
Manual Defrost Chest Freezers 4-36
Table 4.36 Life-Cycle Cost Difference (1992$), Payback Periods (Year),
and Costs of Conserved Energy (At 6% Real),
Manual Defrost Chest Freezer 4-36
Table 4.37 Sensitivity Summary of Life-Cycle Costs of Top Mount Auto
Defrost Refrigerator-Freezer (1992$ at 6% Real) 4-38
Table 4.38 Sensitivity Summary of Life-Cycle Costs of Side-By-Side Auto
Refrigerator-Freezer with TTD (1992$ at 6% Real) 4-39
Table 4.39 Sensitivity Summary of Life-Cycle Costs of Manual Defrost
Compact Refrigerator (1992$ at 6% Real) 4-40
Table 4.40 Sensitivity Summary of Life-Cycle Costs of Manual Defrost
Upright Freezer (1992$ at 6% Real) 4-41
Table 4.41 Sensitivity Summary of Life-Cycle Costs of Manual Defrost
Chest Freezer (1992$ at 6% real) 4-42

Table 5.1 Occupied Households Projections (millions) 5-1
Table 5.2 Housing Starts Projections (thousands) 5-2
Table 5.3 Disposable Personal Income (1990 Dollars) 5-3
Table 5.4 Average Residential Energy Prices

1990 $/EJ ($/MMBtu) of Primary Energy 5-4
Table 5.5 Average Equipment Lifetime (Years) of Refrigerators and Freezers 5-5
Table 5.6 Base Case Projection of Unit Energy Consumption (kWh/a) for New Refrigerators and Freezers 5-5
Table 5.7 Annual Installations of New Refrigerators and Freezers in U.S. Households (Millions) 5-6
Table 5.8 Percent of Occupied U.S. Housing Units Having Refrigerators and Freezers 5-7
Table 5.9 U.S. Residential Energy Consumption for Refrigerators and Freezers (EJ, Quads in parenthesis, Primary Energy) 5-7
Table 5.10 Average Price of New Refrigerators and Freezers in U.S. Households (1990$) 5-8
Table 5.11 Trial Standards Levels for Refrigerators 5-9
Table 5.12 Trial Standards Levels for Freezers 5-10
Table 5.13 Unit Energy Consumption for New Refrigerators (kWh/a) 5-10
Table 5.14 Unit Energy Consumption for New Freezers (kWh/a) 5-11
Table 5.15 U.S. Energy Consumption for Refrigerators, EJ (Quads) Primary 5-11
Table 5.16 U.S. Energy Consumption for Freezers, EJ (Quads) Primary 5-11
Table 5.17 Cumulative Installations of Refrigerators and Freezers (Millions) 5-12
Table 5.18 Average Purchase Price for New Refrigerators (1990 Dollars per Unit) 5-12
Table 5.19 Average Purchase Price for New Freezers (1990 Dollars per Unit) 5-13
Table 5.20.a Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 10% Real) 5-14
Table 5.20.b Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 7% Real) 5-15
Table 5.20.c Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 4% Real) 5-16
Table 5.21 Average Purchase Price of New Refrigerators (1990 Dollars) 5-17
Table 5.22 Average Purchase Price of New Freezers (1990 Dollars) 5-17
Table 5.23 Average Unit Energy Consumption of New Refrigerators (kWh/a) 5-18
Table 5.24 Average Unit Energy Consumption of New Freezers (kWh/a) 5-18
Table 5.25 Cumulative Energy Consumption of Refrigerators During the Period 1998-2030, EJ (Quads) Primary 5-19
Table 5.26 Cumulative Energy Consumption of Freezers During the Period 1998-2030, EJ (Quads), Primary 5-19
Table 5.27 Cumulative Shipments of Refrigerators and Freezers During the Period 1998-2030 (Millions) 5-19
Table 5.28 Total Net Present Value to Consumers for Refrigerators and Freezers Sold during the Period 1998-2030 (Discounted to 1990 at 7% Real) 5-20

Table 6.1 Market Saturations 6-5
Table 6.2 Percent of Market Controlled by the Largest Producers of the Two Products 6-5
Table 6.3 Major Mergers and Acquisitions 6-8
Table 6.4 Refrigerator: Primary Scenario - Long-Run 6-14
Table 6.5 Freezer: Primary Scenario - Long-Run 6-15
Table 6.6 Refrigerators: Industry Net Present Values 6-16
Table 6.7 Freezers: Industry Net Present Values 6-17
Table 6.8 Refrigerator: Primary Scenario - Short-Run 6-19
Table 6.9 Freezer: Primary Scenario - Short-Run 6-20
Table 6.10 Refrigerators: High IPE Scenario 6-23
Table 6.11 Refrigerators: Low IPE Scenario 6-24
Table 6.12 Refrigerators: High Discount Rate Scenario 6-25
Table 6.13 Refrigerators; Low Discount Rate Scenario 6-26
Table 6.14 Freezers: Low IPE Scenario 6-27
Table 6.15 Freezers: High IPE Scenario 6-28
Table 6.16 Freezers: High Discount Rate Scenario 6-29
Table 6.17 Freezers: Low Discount Rate Scenario 6-30
Table 6.18 Refrigerators: Sensitivity of ROE to a 1 S.E. Change in Control Variables 6-31
Table 6.19 Freezers: Sensitivity of ROE to a 1 S.E. Change in Control Variables 6-31
Table 6.20 Refrigerator Monte Carlo Runs 6-33
Table 6.21 Refrigerator Monte Carlo Runs 6-34
Table 6.22 Freezer Monte Carlo Runs 6-35
Table 6.23 Freezer Monte Carlo Runs 6-36

Table 7.1 Peak Demand Reductions (GW) - Refrigerators, Refrigerator-Freezers, and Freezers 7-3
Table 7.2 Capacity Savings (GW) - Refrigerators, Refrigerator-Freezers, and Freezers 7-4
Table 7.3 Net Revenue Losses - Refrigerators, Refrigerator-Freezers, Freezers (million 1990$) 7-8
Table 7.4 Present Value of Revenue Losses - Refrigerators, Refrigerator-Freezers, and Freezers (million 1990$) 7-9
Table 7.5 Peak Demand Reduction (GW) 7-9
Table 7.6 Capacity Reduction (GW) 7-10
Table 7.7 Present Value of Net Lost Revenues 7-10

Table A-1 Summary of Refrigerant State Point Locations A-5
Table A.2 Manufacturing Cost Breakdown Top Mount Auto Defrost Refrigerator-Freezer ($) A-10
Table A.3 Manufacturing Cost Breakdown Top Mount Auto Defrost

Refrigerator-Freezer with Through-The-Door Features ($) A-11
Table A.4 Manufacturing Cost Breakdown Side-by-Side Auto Defrost Refrigerator-Freezer without Through-The-Door Features ($) A-12
Table A.5 Manufacturing Cost Breakdown Side by Side Auto Defrost Refrigerator-Freezer with Through-The-Door Features ($) A-13
Table A.6 Manufacturing Cost Breakdown Bottom Mount Auto Defrost Refrigerator-Freezer A-14
Table A.7 Manufacturing Cost Breakdown Upright Auto Defrost Freezer A-15
Table A.8 Manufacturing Cost Breakdown Upright Manual Defrost Freezer A-16
Table A.9 Manufacturing Cost Breakdown Chest Manual Defrost Freezer A-17
Table A.10 Manufacturing Cost Breakdown Compact Manual Defrost Refrigerator-Freezer A-18
Table A.11 Manufacturing Cost Breakdown Compact Auto Defrost Refrigerator-Freezer A-18
Table A.12 Manufacturing Cost Breakdown Compact Chest Manual Defrost Freezer . . A-19
Table A.13 Manufacturing Cost Breakdown Compact Upright Auto Defrost Freezer . . . A-19

Table B.1 Parameters of Thermal Integrity/Cost Curves by House Type B-3
Table B.2 Percent Share of each Class of Refrigerators and Freezers B-4
Table B.3 Survival Function of Refrigerators and Freezers B-5

Table C.1 Accounting Module C-18
Table C.2 Equations Used in the Costs, Sales, and Revenue Module C-21
Table C-3 Financial Module C-22
Table C.4 One-Time Cost Amortization Module C-24
Table C.5 Rates of Financial Costs C-49
Table C.6 Other Financial Data C-50
Table C-7 Fixed, Variables, and Revenue-Related Cost split C-50
Table C-8 One-Time Costs C-50
Table C-9 Refrigerators C-51
Table C.10 Refrigerators C-52
Table C.11 Refrigerators C-53
Table C.12 Refrigerators C-54
Table C.13 Refrigerators C-63
Table C.14 Refrigerators C-65
Table C.15 Refrigerators C-66
Table C.16 Refrigerators C-67
Table C.17 Refrigerators C-69
Table C.18 Refrigerators C-71
Table C.19 Refrigerators C-72
Table C.20 Refrigerators C-73
Table C.21 Freezers C-75
Table C.22 Freezers C-76

Table C.23 Freezers C-77
Table C.24 Freezers C-79
Table C.25 Freezers C-82
Table C.26 Freezers C-83
Table C.27 Freezers C-84
Table C.28 Freezers C-86
Table C.29 Freezers C-88
Table C.30 Freezers C-89
Table C.31 Freezers C-90
Table C.32 Freezers C-91
Table C.33 Freezers C-92

Table D.1 Utility Marginal OGFs and Year of Capacity Need by NERC Region D-4
Table D.2 Sums of Baseload Energy Savings Fractions for NERC Regions That Need Capacity D-9

Table 1.a U.S. CO_2, SO_2, and NO_x Power Plant Emissions - Metric Units EA-4
Table 1.b U.S. CO_2, SO_2, and NO_x Power Plant Emissions - American Units EA-4
Table 2.a Electricity Generation, Emissions Data, and Emission Rates for SO_2 and NO_x at Fossil Fuel-Burning Power Plants - Metric Units EA-5
Table 2.b Electricity Generation, Emissions Data, and Emission Rates for SO_2 and NO_x at Fossil Fuel-Burning Power Plants - American Units EA-5
Table 3.a Electricity Generation Data, Emissions Data, and Emission Rates for CO_2 at Fossil Fuel-Burning Power Plants - Metric Units EA-6
Table 3.b Electricity Generation Data, Emissions Data, and Emission Rates for CO_2 at Fossil Fuel-Burning Power Plants - American Units EA-7
Table 4. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level One SO_2, NO_x, CO_2 . . . . . EA-9
Table 5. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level Two SO_2, NO_x, CO_2 . . . . . EA-10
Table 6. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level Three SO_2, NO_x, CO_2 . . . . . EA-11
Table 7. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level Four SO_2, NO_x, CO_2 . . . . . EA-12
Table 8.a Sensitivity Results on Cumulative Emissions - Metric Units EA-13
Table 8.b Sensitivity Results on Cumulative Emissions - American Units EA-14

Table R.1 Escalation Rates for Residential Electricity Prices and Household Income R-4
Table R.2 Market Discount Rates for Efficiency Choice (Percent) R-4
Table R.3 Market Share Elasticities R-5
Table R.4 Consumer Price vs Energy Consumption R-5
Table R.5 Expected Impacts of Program Alternatives R-8

Table R.6 Trial Standards Levels for Refrigerators R-19
Table R.7 Average Purchase Price for New Refrigerators (1990 Dollars per Unit) R-20
Table R.8 Average Purchase Price for New Freezers (1990 Dollars per Unit) R-20
Table R.9 Life-Cycle Cost Differences at 6% Discount Rate (1992 Dollars) R-21
Table R.10 Refrigerator: Primary Scenario - Long-Run R-22
Table R.11 Freezer: Primary Scenario - Long-Run R-23
Table R.12 Impacts of Different RIA Cases on U.S. Electric Utilities R-25
Table R.13 U.S. Energy Consumption for Refrigerators, EJ (Quads) Primary R-26
Table R.14 U.S. Energy Consumption for Freezers, EJ (Quads) Primary R-26
Table R.15 Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 . . . . . R-27
Table R.16 Change in Profitability Due to Proposed Standards: Refrigerator-Freezers . R-30
Table R.17 Change in Profitability Due to Proposed Standards: Freezers R-31

LIST OF FIGURES

Figure 2.1 Analytic framework for the appliance standard analysis 2-3
Figure 2.2 Activities in the LBL residential energy model 2-9
Figure 2.3 Conceptual approach to the manufacturer impact model 2-15
Figure 2.4 How standards cause a change in ROE and NPV 2-16

Figure 3.1 Production Process for Refrigerators and Freezers 3-2
Figure 3.2 Annual Energy Use vs Adjusted Volume for Top Mount Auto Defrost Refrigerator-Freezer 3-31

Figure 4.1 Life-cycle cost for design options of top mount auto defrost refrigerator-freezer 4-4
Figure 4.2 Life-cycle cost for design options of top mount auto defrost refrigerator-freezer with through-the-door feature 4-6
Figure 4.3 Life-cycle cost for design options of side-by-side auto defrost refrigerator-freezer 4-8
Figure 4.4 Life-cycle cost for design option of side-by-side auto defrost refrigerator-freezers with through-the-door features 4-10
Figure 4.5 Life-cycle cost for design option of bottom mount auto defrost refrigerator-freezers 4-12
Figure 4.6 Life-cycle cost for design options for upright auto defrost freezer 4-14
Figure 4.7 Life-Cycle Cost for Design Options of Upright Manual Defrost Freezer 4-16
Figure 4.8 Life-Cycle Cost for Design Options of Chest Manual Defrost Freezer 4-18
Figure 4.9 Life-cycle cost for design options of compact manual defrost refrigerator-freezer 4-20
Figure 4.10 Sensitivity analysis of life-cycle costs of top mount auto defrost refrigerator freezer 4-38
Figure 4.11 Sensitivity analysis for life-cycle costs of side-by-side refrigerator freezer with TTD 4-39
Figure 4.12 Sensitivity analysis of life-cycle costs of manual defrost compact refrigerator 4-40
Figure 4.13 Sensitivity analysis of life-cycle costs of manual defrost upright freezer . . . 4-41
Figure 4.14 Sensitivity analysis of life-cycle costs of manual defrost chest freezer 4-42

Figure 6.1 Refrigerator and freezer shipments compared to housing starts 6-3
Figure 6.2 Refrigerator share of market 6-6
Figure 6.3 Freezer share of market 6-7
Figure 6.4 PHI and CPI indices 6-11

Figure 7.1 Total utility avoided costs: refrigerators 7-2
Figure 7.2 Revenue reductions and avoided costs for refrigerators 7-6

Figure A.1. Schematic Diagram of a single evaporator system A-6

Figure C.1 Profit maximization and fixed costs C-3
Figure C.2 LBL-MAM modules and primary routes of data flow C-14
Figure C.3 LBL-MAM and GRIM integration overview C-41
Figure C.4 Cost comparison factors and their relationships C-42

Figure D.1 Simplified load-duration curve D-3

CHAPTER 1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The Energy Policy and Conservation Act (P.L. 94-163), as amended by the National Appliance Energy Conservation Act of 1987 (P.L. 100-12) and by the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357), and by the Energy Policy Act of 1992 (P.L. 102-486), provides energy conservation standards for 12 of the 13 types of consumer products[1] covered by the Act, and authorizes the Secretary of Energy to prescribe amended or new energy standards for each type (or class) of covered product.

The assessment of the proposed standards for refrigerators, refrigerator-freezers, and freezers presented in this document is designed to evaluate their economic impacts according to the criteria in the Act. It includes an engineering analysis of the cost and performance of design options to improve the efficiency of the products; forecasts of the number and average efficiency of products sold, the amount of energy the products will consume, and their prices and operating expenses; a determination of change in investment, revenues, and costs to manufacturers of the products; a calculation of the costs and benefits to consumers, electric utilities, and the nation as a whole; and an assessment of the environmental impacts of the proposed standards.

This Technical Support Document (TSD) contains units compliant with Le Systéme International d'Unités (SI or metric system) and traditional American units. Many SI units, such as watts (W), are familiar in the contexts the reader will find them; others are not. Appendix E contains a few conversion factors that may assist in the interpretation of unfamiliar metric units.

The use of SI units in this TSD represents the first step towards the intended complete metrication of the appliance standards supporting analysis. This change is being made in compliance with Section 5164 of the Trade and Competitiveness Act of 1988, Executive Order 12770 of 1991, and DOE Order 5900.2. LBL intends to fully adopt SI units in future TSDs, but for a short transitional period both SI and American units are presented, as far as is practical.

1.2 STRUCTURE OF THE DOCUMENT

This TSD consists of seven chapters, five appendices, an Environmental Assessment, and a Regulatory Impact Analysis.

Chapter 1 Introduction: outlines the structure of the document.

---

[1] The 13 products covered in the legislation are: (1) refrigerators, refrigerator-freezers, and freezers; (2) room air conditioners; (3) central air conditioners and central air-conditioning heat pumps; (4) water heaters; (5) furnaces; (6) dishwashers; (7) clothes washers; (8) clothes dryers; (9) direct heating equipment; (10) kitchen ranges and ovens; (11) pool heaters; (12) television sets; and (13) fluorescent lamp ballasts.

Chapter 2 Analytic Approach: summarizes the methodology used in the analysis; discusses the components of the analysis and their interrelationships; describes the models used, their data requirements, and their outputs; and identifies the primary assumptions of the analysis. This chapter also provides an overview of the methodology employed to examine the sensitivity of the results to changes in the key assumptions, parameters, and exogenous forecasts used in the analysis.

Chapter 3 Engineering Analysis: contains detailed energy use and cost information.

Chapter 4 Life-Cycle Costs and Payback Periods: describes the effects of standards on individual purchasers and users of the appliances. It compares the life-cycle cost of appliances and other measures of consumer impact with and without the proposed standards.

Chapter 5 National Energy and Economic Impacts: describes national forecast of energy consumption, efficiency of new units, units installed in households, and annual appliance sales in the absence (or presence) of new regulations. Discusses the choice of standards levels to be analyzed and the projected impacts of each standard level. The chapter summarizes the energy savings; the sales, average efficiencies, purchase costs, and operating costs of new and replacement appliances; the net present benefit of the standards; and the results of the sensitivity analyses.

Chapter 6 Impacts of Standards on Manufacturers: discusses appliance saturations, market shares, and industry structure. Describes the analysis methodology, short- and long-run impacts, and sensitivity analysis.

Chapter 7 Impact of Standards on Electric Utilities: describes the effects of standards on the electric utility industry, focusing on marginal costs of electricity, generating capacity growth, changes in regional capacity and energy demand, and changes in utility revenues and costs.

Environmental Assessment: describes standards-induced changes in emissions of oxides of carbon, sulfur, and nitrogen from combustion of fossil fuels for electricity generation and in homes.

Regulatory Impact Analysis: describes economic impacts of the standards and their major alternatives.

Appendices A through D contain more detailed information on the models and databases used in the economic analysis.

Appendix A Engineering Analysis of ERA Computer Simulation Program: Energy Use and Cost Data: provides a breakdown of the costs for each design option.

Appendix B Overview of Forecasting Model: structure of the LBL Residential Energy Model (LBL-REM). The principal components of the model are discussed and the component interrelationships are explained. Gives a detailed description of the data used to calculate consumer impacts. The input data stream for the base case runs is shown and changes to the input data for the standards cases are indicated.

Appendix C Manufacturer Analysis Model: Overview of manufacturer analysis model (LBL-MAM): outlines how an industry profile of the affected manufacturing firms is constructed; describes how the effects on appliance manufacturers of imposing standards by product are quantified; defines the results of the analysis in terms of changes in gross margin, return on sales, return on equity, return on assets, total assets, and labor requirements; and presents the method for conducting a sensitivity analysis of the results. Provides a detailed description of the model to estimate financial impacts of the imposition of standards on the manufacturers of covered products. The appendix shows the structure of the model, the data sources used, and detailed outputs of base case, standards case, and sensitivity analysis runs.

Appendix D Electric Utility Impact Modeling: Quantifies impacts on the electric utility industry's need for new generation capacity and calculates the net impact of standards on utility revenues.

Appendix E Metric Conversion.

There are two documents that follow these appendices: these are the Environmental Assessment and the Regulatory Impact Analysis.

CHAPTER 2. ANALYTIC APPROACH

2.1 INTRODUCTION

The economic impacts of new or amended energy efficiency standards depend largely on the relationship between the cost of a consumer product and its energy efficiency. The cost-efficiency relationships are determined for each product class based on engineering analyses. DOE has segregated product types into classes to which different energy efficiency standards might apply. Within each class, the energy-conserving designs are ordered by cost-effectiveness; then combinations of energy-saving design options are used to generate the relationships that are inputs to the other analyses of the impacts of setting standards at various efficiency levels. The product type analyzed in this document consists of refrigerators, refrigerator-freezers, and freezers.

Identification of product classes, baseline units, design options, and maximum technologically feasible efficiencies is based on information gathered from the trade associations, manufacturers, discussions with researchers, a literature survey, and comments on the Advance Notice of Proposed Rulemaking (ANOPR). Energy use data have been obtained from AHAM (Association of Home Appliance Manufacturers), published literature, manufacturers, and simulation models. Sources of factory cost data include manufacturers, suppliers, and the ANOPR comments. The cost estimates are combined with the efficiency estimates to generate the cost-efficiency relationships.

The relationships between manufacturer costs and efficiency that are presented in this chapter are used throughout the other parts of the analysis. The manufacturer analysis uses manufacturer costs to produce retail prices. Retail prices, installation costs, and maintenance costs in conjunction with the corresponding efficiencies are used in the forecasting models to forecast sales and efficiencies and to calculate life-cycle costs and payback periods.

This chapter briefly describes how the economic analysis of standards was performed. Section 2.2 presents an overview of the analytic methodology and discusses the major components of the analysis: the Engineering Analysis, the Consumer Analysis (national and individual), the Manufacturer and Industrial Analyses, and the Utility Analysis. This section discusses the interrelationships among the components that ensure consistency throughout the analysis.

Section 2.3 describes the computerized models used in the analysis. The models predict consumer, manufacturer, and utility responses to future changes in the economy, including the imposition of minimum efficiency standards. Quantitative estimates of the impacts of standards are calculated from the outputs of the models. The models utilized in the analysis are:

- Engineering Cost and Performance Models;
- Consumer Impact Models;
- Manufacturer Analysis Models;
- Appliance Standards Environmental and Utility Model.

Section 2.4 discusses the sensitivity analysis performed on the economic impacts and focuses on the methods used to determine the parameters that have the largest effects and to determine their range of variation.

2.2 OVERVIEW OF ANALYTIC FRAMEWORK

The impact of appliance efficiency standards is determined by comparing projections of a wide range of economic variables under the existing legislation with the projections under the proposed standards. These projections are first made for a base case (existing legislation) using the analytic models described below. Chapter 5 describes the data and assumptions used to calculate the baseline forecasts. The calculations are then repeated imposing the proposed standards as discussed in Chapter 5. The differences between the projections of the energy consumption and economic variables in the base and standards cases provide quantitative estimates of the impacts of the standards. To evaluate the significance of the differences, a sensitivity analysis is performed on the key parameters and assumptions.

The economic impact analysis is performed in seven major areas:

- An *Engineering Analysis*, which establishes technical feasibility and product attributes including costs of design options to improve appliance efficiency;

- A *Consumer Analysis* at two levels: impacts on individuals and national aggregate impacts. The *individual impacts* are analyzed by Life-Cycle Cost (LCC), Payback Periods (PBP), and Cost of Conserved Energy (CCE), which evaluate the savings in operating expenses relative to increases in purchase price. The *national aggregate impacts* include LBL Residential Energy Model (LBL-REM) forecasts of appliance sales, efficiencies, energy use, and consumer expenditures;

- A *Manufacturer Analysis*, which provides an estimate of manufacturers' response to the proposed standards.

Their response is quantified by changes in several measures of financial performance for a firm;

- An *Industry Impact Analysis*, which shows financial and competitive impacts on the appliance industry;

- A *Utility Analysis* that measures the impacts of the altered energy-consumption patterns on electric utilities;

- An *Environmental Effects Analysis*, which estimates changes in emissions of carbon dioxide, sulfur oxides, and nitrogen oxides because of reduced energy consumption in the home and at the power plant; and

- A *Regulatory Impact Analysis*, which collects the results of all the analyses into the net benefits and costs from a national perspective.

A simplified diagram of the analysis is shown in Figure 2.1. If appliances having the maximum efficiency improvement that is technologically feasible show no significant energy savings in the Engineering Analysis, then the legislation requires that no modified standard be prescribed for that product type. If the appliance efficiency can be increased to produce significant energy savings, then a detailed energy savings, economic, and impact analysis is done. The analysis is performed for a base case plus several trial levels of standards.

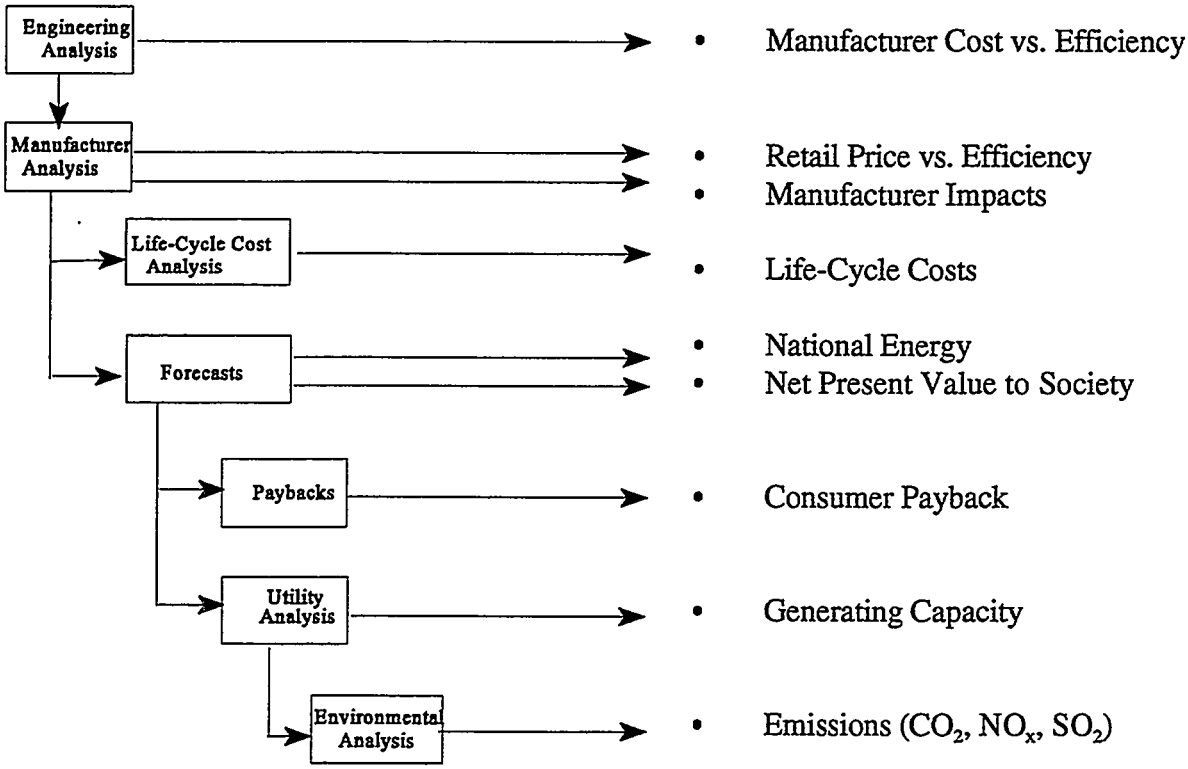

Figure 2.1 Analytic framework for the appliance standards analysis.

Figure 2.1 illustrates the interaction among the Engineering, Consumer, and Manufacturer Analyses. The Engineering Analysis establishes appliance designs and related attributes such as efficiency and costs. Based on these costs, the Manufacturer Analysis predicts retail prices for use in the Consumer Analysis (the Life-Cycle Cost Analysis and Forecasts). Based on the relationship between the prices and operating costs of design options, the Consumer Analysis forecasts national sales and efficiencies of new and replacement appliances. Some of these data (e.g., distribution of sales by efficiency, elasticities, and market discount rates), are used as inputs to the Manufacturer Analysis to determine financial impacts on typical firms within the industry. The Consumer Analysis also forecasts energy savings and consumer expenditures for the purchase and operation of the appliances. The Life-Cycle Cost Analysis calculates the economic impact for the average individual consumer, including payback period and cost of conserved energy. The Utility Analysis calculates changes in sales, revenues, and avoided costs of electric utilities from the energy savings.

Three time frames are considered in the analysis. First, the Engineering Analysis examines the technical feasibility of improving the efficiency of appliances before the standards come into effect in 1998. Second, the Manufacturer Analysis is performed for a typical year after the imposition of standards. Third, the analysis of consumer and utility impacts extends over a time frame consistent with the life of the products and includes the time required to approach market saturation.

2.3 MODELS, DATA, AND ASSUMPTIONS

2.3.1 Engineering Cost and Performance Models

The Engineering Analysis provides information on efficiencies, manufacturing costs, and other appliance characteristics for use in other components of the analysis. Appliance features that provide utility to the consumer are incorporated into the analysis through the creation of appliance classes. Classes are a subset of appliance types. For example, refrigerators-freezers is an appliance type, but a chest freezer is an appliance class. The Engineering Analysis develops cost and efficiency data for a set of design options within each appliance class. These data are the output of the engineering performance and cost models discussed later in this section. The Engineering Analysis is performed in seven steps: (1) select appliance classes; (2) select baseline units; (3) select design options within each class; (4) determine maximum technically feasible designs; (5) calculate the efficiency improvement provided by each design option; (6) develop cost estimates; (7) generate cost-efficiency relationships.

Appliance Classes

The first step in the Engineering Analysis is the segregation of product types into separate classes to which different energy-efficiency standards apply. DOE differentiates classes by the type of energy used (oil, natural gas, or electricity), and capacity or performance-related features that provide utility to the consumer and affect efficiency. For specific appliances, classes are defined using

data collected in discussions with appliance manufacturers, trade associations, other interested parties, and from comments received on the ANOPR. Those classes for which no DOE test procedure has been specified are omitted. The appliance classes covered by the analysis are listed in Chapter 3.

Baseline Units

A baseline unit is the starting point for analyzing design options for improving energy efficiency. To select a baseline unit, the Engineering Analysis uses information gathered from trade organizations, manufacturers, consultants with expertise in specific product types, and from public comments on the ANOPR. For each product class, the baseline unit generally represents a model with the maximum allowable energy use specified by the National Appliance Energy Conservation Act (NAECA) as amended. Other than efficiency, features are representative of the class as a whole.

Design Options

The Engineering Analysis identifies individual or combinations of design options with a potential for improving energy efficiency. Design options that are commercially available at the present time or that are present in prototypes are considered. They are selected after discussions with experts and an extensive literature review. The efficiency improvement and manufacturer cost of design options added to the baseline unit are calculated.

Maximum Technologically Feasible Designs

For each product class, a maximum technologically feasible design option or combination of design options is identified. This option, or combination of options, results in the highest energy efficiency for each product class. The maximum technologically feasible efficiency level is one that can be reached by the addition of design options, both commercially feasible and in prototypes, to the baseline units. This design must be possible to assemble, but not necessarily to manufacture in large numbers. Economic criteria are applied to all design options in other parts of the analysis.

Efficiency Calculation

For each of the product classes, the efficiency levels corresponding to various design options are determined from manufacturer data and from engineering calculations.

Cost Estimates

The manufacturer cost data are obtained through a lengthy process that includes meetings with manufacturers, submission of formal requests to manufacturers for costing data, discussions with compressor and fan motor manufacturers, and review of the data received. Estimates of manufacturer cost are also received in response to the ANOPR. Appendix A contains detailed incremental cost data disaggregated into labor, purchased parts, materials, shipping/packaging, and tooling.

Cost-Efficiency Relationships

The results of the Engineering Analysis are summarized in the cost-efficiency relationships showing the efficiency and manufacturer cost of the design options for each appliance class. Manufacturer and dealer markups derived in the Manufacturing Analysis are applied to the factory costs to arrive at the purchase price of the appliance. The price-efficiency relationships are a fundamental input to the Consumer Analysis.

Assumptions in the Analysis

Justifications for the most important assumptions of the Engineering Analysis are listed below.

Assumption	*Justification*
• Industry production processes can be characterized in terms of medium and large manufacturing facilities.	Manufacturing costs for small manufacturers are highly varied because of dependence on purchased parts and sensitivity to labor and distribution costs. An effort was made to obtain these data, but they were not made available by small firms. Because of this difficulty and the fact that they represent a small fraction of total shipments for most of the product classes, analysis concentrated on the medium and large manufacturers.
• Baseline units can be selected to represent typical product offerings within a class.	The baseline unit is the starting point to which design options are added to create higher efficiency units. The selection of baseline units is based on studies of products on the market in 1993 and consultations with manufacturers.
• Unit energy consumption is based on DOE usage estimates, unless otherwise noted.	As part of the Consumer Product Efficiency Standards program, DOE was required to establish test procedures to determine average consumer utilization and energy usage for the covered products. Test procedures for each product type have been promulgated and were employed to determine unit energy consumption throughout the Engineering Analysis.

Data Sources

Shipment data are based on information from industry sources and published data from industry trade associations. Costs of purchased materials and parts are based on quotations from product manufacturers and suppliers of these items. Data on engineering and labor costs are taken from on-site visits to manufacturing plants and from manufacturer information. Data characterizing baseline units for each class are based on information from industry sources and published data.

Outputs from the Engineering Analysis

For each combination of design options considered in the analysis, the models and data provide:

- energy efficiency (expressed as the DOE energy factor[1] and/or unit energy consumption);
- increased material, labor, and investment costs by product class for medium and large manufacturers;
- annual energy consumption per unit (based on DOE test procedures);
- the relationship between cost and energy use by product class; and
- other information on product characteristics such as appliance lifetimes, installation costs, and maintenance costs.

Validation of the Results

Experimental data on efficiencies are available for some of the design options studied. For the others, engineering calculations based on physical principles are performed.

2.3.2 LBL Residential Energy Model (LBL-REM)

Purpose

The LBL-REM models the appliance purchase choices made in households, as well as these households' subsequent usage behavior and energy consumption. See Appendix B for details about the model.

Engineering, economic, and demographic data are used in LBL-REM. The engineering data for appliances are described in Section 2.3.1. Additional data include age distribution of existing appliance stock and retirement functions. Economic data include projected energy prices and household income and models of energy investment, appliance purchase, and usage behavior

[1] The energy factor is a measure of energy efficiency derived from the DOE test procedure for each product type.

(including fuel and technology choice for each end use). Demographic data include number of households by type, projected housing starts and demolitions, and appliance holdings.

Historical Development

Early energy-demand modeling focused on engineering estimates or on the relationship between energy consumption and economic growth. In the 1970s, Oak Ridge National Laboratory (ORNL) developed the first model to integrate these two important aspects of energy demand, the Engineering-Economic Model of Residential Energy Use [1].

The ORNL Model was brought to LBL in 1979 and adapted to the analysis of federal appliance efficiency standards. Further extensive changes were made at LBL from 1979 to the present, resulting in the LBL-REM [2]. Many of these changes have already been documented [3]. More recent changes for this rulemaking are described in Appendix B.

Structure of the Model

The LBL-REM segments annual energy consumption into house types, end uses, and fuel types. The house types include single-family, multifamily, and mobile homes. Calculations are performed separately for existing and new housing construction each year during the forecast period, 1980-2030.[2] The end uses are space-heating (including room and central), air-conditioning, water heating, refrigeration, freezing, cooking, dish-washing, clothes-washing, clothes-drying, televisions, lighting, and miscellaneous. Up to four fuels are considered, as appropriate to each end use: electricity, natural gas (utility gas), heating oil, and liquid petroleum gas (LPG). The national version of the model, which treats the country as a single region, is used in the analysis. For this analysis, national electricity consumption by refrigerators and freezers is modeled.

The model projects five types of activities: technology/fuel choice, building shell thermal integrity choice, appliance efficiency choice, usage behavior, and turnover of buildings and appliances. The interrelationship of the five types of activities is shown in Figure 2.2.

A housing stock submodel prepares data about the housing stock projection for the main model. The initial number of occupied households, by type, is taken from the 1980 Census of Population and Housing. Historical housing starts are from Census data; projected housing starts and stocks are from *Annual Energy Outlook 1994*. The housing submodel interpolates historical housing stocks (1981-91) and extrapolates housing stocks and starts after 2010. The method is fully described in Appendix B.

---

[2] The model forecasts beginning in 1980. Historical data from 1980-1992 are used to check the validity of the forecast.

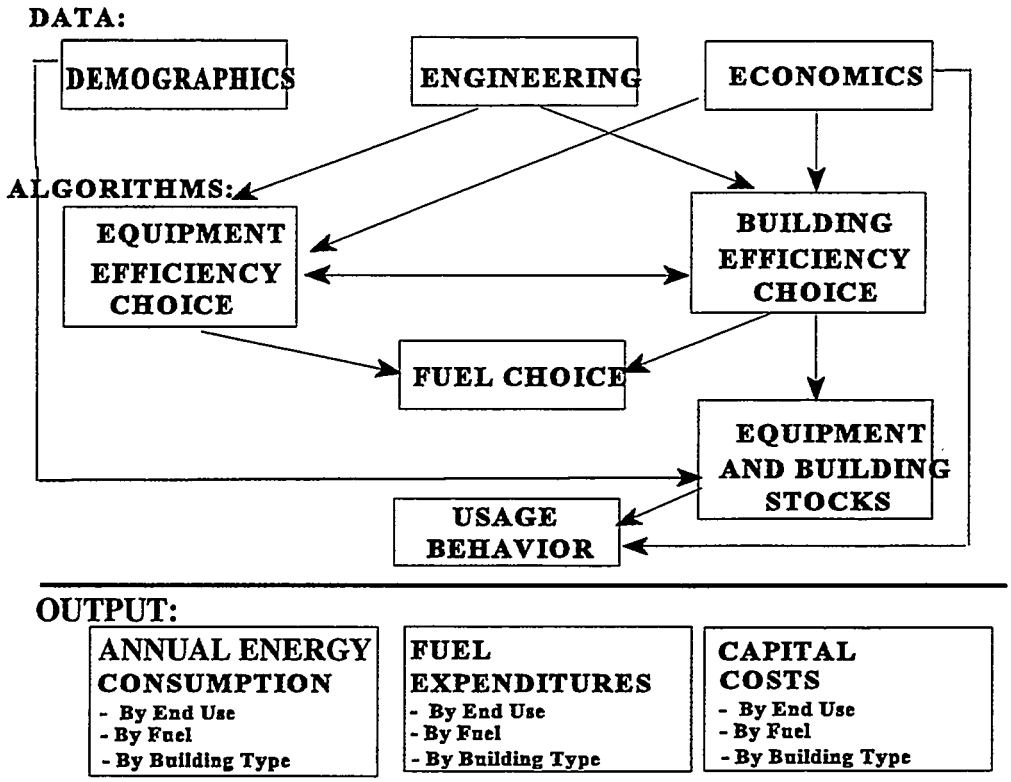

Figure 2.2 Activities in the LBL Residential Energy Model

Efficiency Choice Algorithm

Historical efficiency data for refrigerators and freezers are available for selected years through 1992. After 1992, efficiency improvements are projected as a function of designs available (technological change) and of electricity prices. If energy prices increase, the life-cycle cost of more efficient designs will increase more slowly than that of less efficient designs, making the more efficient designs more attractive. When the life-cycle cost of a more efficient design falls below the life-cycle cost of the current average design, then the more efficient design is projected to be purchased. Conversely, if energy prices decline, the model projects no further efficiency change.

Thermal Integrity

The projection of investment in thermal integrity measures in new houses is based on a life-cycle

cost calculation analogous to that done for equipment efficiencies.[3] Engineering estimates of the incremental costs of thermal integrity measures are used together with current fuel prices and a market discount rate for each house type and heating fuel type. Secondary impacts of appliance efficiency changes on energy consumed to heat or cool houses are not estimated in the current analysis.

Modeling Efficiency Standards

The LBL-REM projects the average efficiency of new products, purchased each year, taking account of existing federal regulations. A distribution of unit energy consumptions (UEC) is constructed around the projected average unit energy consumption for each class, based on relative efficiency distributions previously observed in the marketplace. New federal standards would eliminate at least part of the distribution. A new distribution is constructed in which all units below the standards are increased in efficiency to meet the standards. The new shipment-weighted average efficiency then characterizes the efficiency of new units in that year. The same process is applied to all years after implementation of the standards. The model is then run again, for the standards case, with the adjusted average efficiencies, to calculate any changes in market shares, usage behavior, or investment in building shell thermal improvements that may occur as a result of standards, and to calculate the net energy savings.

Turnover of Appliance Stocks

The initial age distribution of appliances in stock is characterized from industry data about historical annual shipments and national surveys of appliance holdings. The fraction of each product that retires each year is based on the number of years since purchase for each age cohort.[4] Each age cohort is associated with an average efficiency; when older appliances retire, they are recognized as less efficient.

The number of potential purchasers of an appliance in new homes is equal to the number of new homes constructed each year. The number of potential purchasers in existing houses is equal to the number of retiring appliances, plus a small fraction of those households that did not previously own the product.

Calculation of Market Shares

Potential buyers may make no purchase or may buy any competing technology within an end use. For each product, the decision to purchase or not is modeled, and the fraction of the total that choose each class, e.g., top-freezer or side-by-side refrigerator is specified exogenously. Long-term

---

[3] The equipment efficiency and thermal integrity decisions are not solved simultaneously, but recursively. The previous year's thermal integrity is assumed in projecting this year's equipment efficiency; then this year's equipment efficiency is used to calculate this year's thermal integrity.

[4] For example, a cohort consists of all 8-year-old refrigerators. Up to 30 cohorts, one for each year of purchase, are tracked.

market share elasticities have been assumed with respect to equipment price, operating expense, and income. Standards are expected to lower operating expenses and increase equipment prices. The percentage changes in these quantities are used, together with the elasticities, to determine changes in market share resulting from standards. Higher equipment prices will decrease market shares, while lower operating expense will increase market shares. The net result depends on the standard level selected and associated equipment price and operating expense.

Usage Behavior

For some products, changing the operating expense results in changes in usage behavior. These changes are modeled with usage elasticities in operating expense and income. For refrigerators and freezers, these elasticities are assumed to be zero.

Energy Consumption Calculations

The energy consumption per appliance for each end use and fuel by house type and vintage (existing or new) is the UEC. The corresponding energy consumption for all households is the consumption per appliance times the number of households of that type and vintage, times the fraction of households that owns that appliance.

Aggregate energy consumption is obtained from summations over intermediate results. For example, national electricity consumption for residential refrigerators in a particular year is the sum, over house types, classes, and vintages, of the electricity consumption of all refrigerators. National residential electricity consumption in that year is the sum of electricity consumption over all end uses.

Assumptions in the Analysis

The Consumer Analysis assumes that decisions on the purchase and use of appliances depend on operating expenses, household income, and appliance prices. Manufacturers are projected to respond to the demand for more efficient products by incorporating technologically feasible and cost-effective design options in new units. Forecasts of population growth, housing starts, personal income, and energy prices from published sources are utilized. Justifications for the most important assumptions in the Consumer Analysis are listed below.

Assumption	*Justification*
Occupied households will increase from 93 million in 1990 to 130 million in 2030.	The *Annual Energy Outlook 1994* projects annual growth of 1.0%, 0.5%, and 0.2% for single family, multifamily, and mobile homes, respectively, from 1992 to 2010.
Housing starts are projected to be near constant for single family and mobile homes, but to increase from the current low levels for multifamily.	The *Annual Energy Outlook 1994* projects annual housing starts of 1.04 to 1.08 million for single family, from 1992-2010, of 0.17 to 0.46 million for multifamily, and 0.19 to 0.22 million for mobile homes.
Real disposable personal income is projected to grow from $3.5 billion in 1990 to $7.1 billion in 2030 (in 1990 dollars). This corresponds to disposable income per household growing from $43,100 in 1990 to $63,100 in 2030.	The *Annual Energy Outlook 1994* projects growth in real disposable personal income for the nation as 1.7% per year from 1990 to 2010.
Residential electricity prices are projected to increase from 8.11 cents/kWh in 1992 to 9.75 cents/kWh in 2010.	The *Annual Energy Outlook 1994* projects annual growth of 1.0% for residential electricity prices from 1992 to 2010.
Appliance purchase decisions are based on operating expenses, as well as on equipment price.	Research on equipment sales for competing alternatives and on historical efficiency choices indicates that operating expenses are significant variables.
Manufacturers are projected to respond to consumer demand for energy efficiency. Engineering designs that are technologically feasible and attractive to purchasers are assumed to be available.	Industry is competitive and historically has responded to changes in consumer demand.
The lifetimes of appliances are projected to remain the same as empirically observed in the past, independent of energy efficiency.	Retirement functions are based on reconciliation of historical appliance stocks and shipments. To date, efficiency improvements have occurred without any apparent effect on reliability.

Data Sources

The LBL-REM takes the range of possible energy efficiencies of new equipment from the Engineering Analysis. The purchase price of these products is derived from the factory cost supplied by the Engineering Analysis and adjusted for manufacturer and dealer markups in the Manufacturer Analysis. Historical housing stocks and starts are from U.S. Department of Commerce, Bureau of the Census. Shipments of refrigerators and freezers are from the Association of Home Appliance Manufacturers. Projected energy prices, household incomes, and housing stocks and starts are from U.S. Department of Energy, *Annual Energy Outlook 1994*.

Model Outputs

The principal outputs from the LBL-REM for each year are:

- National energy consumption by end use and fuel;
- Per-unit equipment price and operating expense by product;
- Total residential energy consumption by fuel;
- Projected annual shipments of residential appliances; and
- Differences in these quantities between a base case and each standards case.

These outputs are provided annually (or for selected years) and cumulatively for the period 1996-2030. Energy savings from implementation of standards are provided annually to the end of the period. Net present value (NPV) of standards is evaluated for each regulated product.

Cost-Benefit Analysis

The costs and benefits of the proposed standards from a national perspective are quantified by calculating a net present value. The NPV is the sum of discounted savings in operating expenses minus the sum of discounted increases in equipment prices.

DOE has determined that 7% real is the appropriate discount rate for calculating societal NPV.

Different assumptions about technology choice are invoked when calculating energy savings of standards on the one hand, and when calculating the net present benefit of standards on the other. Energy savings are the net of any adjustments households make in changing their technology or fuel choice or from using appliances differently. For example, if, after standards, a regulated product captures larger market shares (without displacing consumption of another fuel), then the net energy savings will be diminished. The energy savings are calculated as the net result of standards, accounting for such secondary effects as shifts in market share.

NPV excludes these secondary effects. Base case purchase behavior, without market share changes, is assumed in calculating the NPV, because any market share shift reflects the consumer's judgment that change is worth more than the direct energy savings associated with keeping market share constant. NPV is calculated from per unit changes in equipment and operating costs, multiplied by standards case shipments. If the NPV was calculated without normalizing to shipments, the results would be erroneous: if standards caused decreased purchase of a product, this would appear as an economic benefit, namely less money spent on purchasing and use of the appliance,[5] and if standards caused an increase in purchases, this would be counted incorrectly as a cost, when it actually reflects consumers' preference for the post-standards product.

2.3.3 LBL Manufacturer Analysis Model (LBL-MAM)

Conceptual Approach

The Manufacturer Impact Analysis estimates both the short- and long-run impacts of new or amended standards on profitability (return on equity) and many other variables for each industry under consideration. All computations used in this analysis are carried out by the Manufacturer Analysis Model (LBL-MAM). The LBL-MAM is a spreadsheet composed of thirteen modules. It consists of the earlier LBL-Manufacturer Impact Model (LBL-MIM) along with version 1.2 of the Government Regulatory Impact Model (GRIM) developed by the Arthur D. Little Consulting company under contract to AHAM, GAMA, and ARI. Figure 2.3 lists these and displays their interactions. In addition to computing estimated values for the above-mentioned descriptive variables, the LBL-MAM also computes standard errors for each by explicitly evaluating the standard errors in the estimates of input variables and then using Monte Carlo simulations.

Measures of Impact

Three types of long-run impacts are analyzed: (1) profitability, (2) growth, and (3) competitiveness. To do this, the following six measures of impact are tracked for the industry: (1) shipments, (2) price, (3) revenue, (4) net income, (5) return on equity (ROE), and (6) industry net present value (NPV).

ROE is the primary measure of profitability, although gross margin, return on assets, and return on sales are also reported. Changes in assets and revenue are the measures of growth (positive or negative). Because all the industries analyzed are in an historical process of consolidation, any decrease in ROE will tend to hasten this process; thus, ROE also provides an indication of the impact of standards on competitiveness. Industry NPV is theoretically identical to ROE but has been included to provide additional insight into the impact of standards.

---

[5] Without normalization, the greatest economic benefit would be obtained by standards that resulted in no future purchases of the product. Then, no money would be spent on purchasing the product, or on operating expenses, and the value of the savings would equal the amount of money that would have been spent without the standards. Clearly, this would be a misrepresentation of the NPV of standards.

A short-run calculation is also made. If the long-run calculation indicates a decrease in sales, the predicted price is reduced by an amount determined by the industry's observed behavior during historical downturns in sales. The adjusted price is used to calculate the other measures of impact.

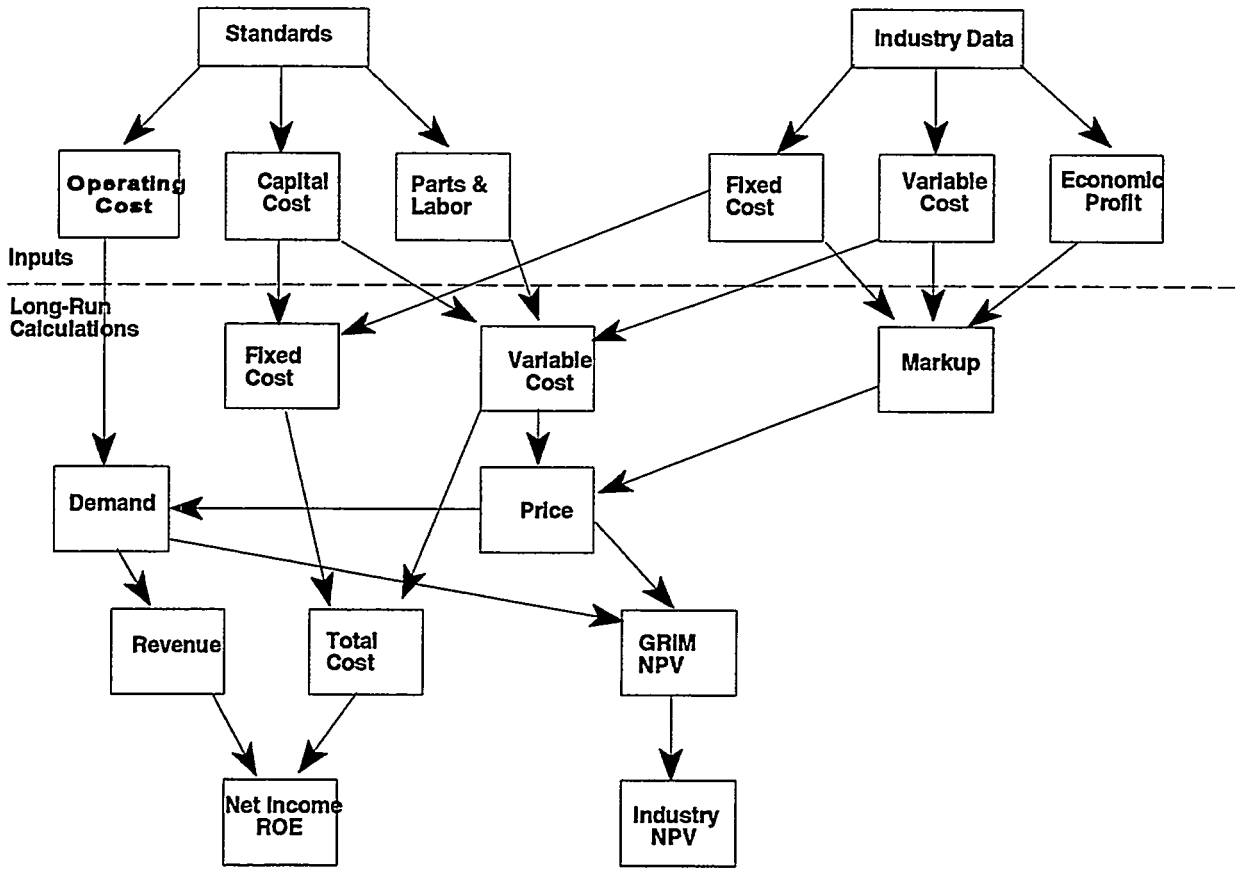

Figure 2.3 Conceptual approach to the Manufacturer Analysis Model

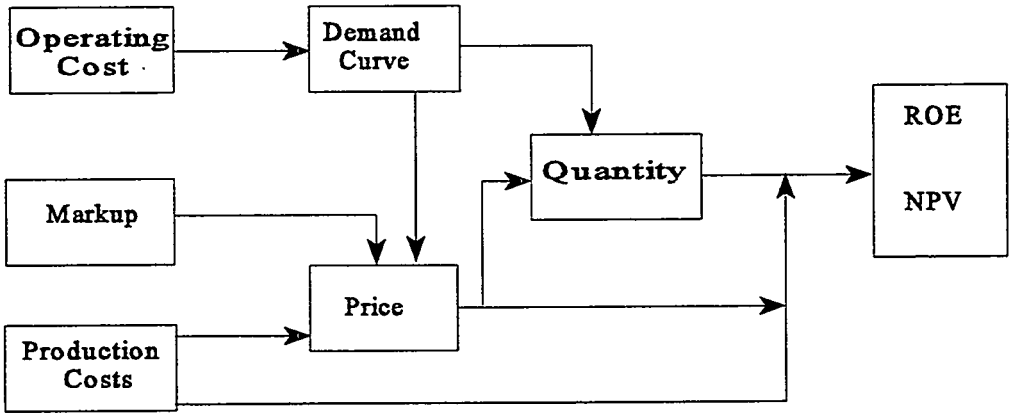

Figure 2.4 How standards cause a change in ROE and NPV.

Description of the LBL-MAM

Although LBL-MAM examines many aspects of an industry, its most important role is to compute the effect on profits and industry net present value of a cost increase caused by standards. To accomplish this, the model first estimates how much of the cost increase is passed on in the form of higher prices. (An accompanying effect is the decrease in operating expense due to standards, which makes the product more desirable to the consumer and, thus, increases demand for the product.) Then, it estimates how this price increase and the accompanying reduction of operating expense influence demand. Finally, given the new price and level of demand, it computes a new level of profit. These calculations use estimated long-run costs. The LBL-MAM makes an additional calculation to correct for any short-run difficulties the industry may have in achieving its long-run markup and also estimates the impact of possible standards levels on industry net present value.

It is important to note from the start that the model does not assume perfect competition, nor does it assume that the level of profit will remain unchanged. The results of the model depend entirely on the input values.

The basic behavior of the model can be understood only in light of the following standard economic consideration. In the long run, an increase in *fixed costs will not be passed on* via a price increase except when it is sufficient to cause some firms to leave the industry.[6] This result is derived from the assumption that firms act individually to maximize profits and from the definition of fixed

[6]When firms leave the industry, the latter becomes less competitive and the remaining firms can increase their markup over variable costs, thus, indirectly covering their increased fixed costs.

costs as those that are not proportional to output. The mathematical derivation is given in Appendix C of this volume.

A second influence on profits is the change in purchases resulting from both the change in price and the change in operating expense. These tend to offset each other because price increases lower quantity demanded, and increased efficiency increases demand (by lowering operating expense). The LBL-MAM takes these effects into account through the use of two demand elasticities which play an important role in determining the outcome and are therefore examined more closely in the sensitivity analysis.

Assumptions in the Analysis

This section begins with a series of short discussions of different aspects of the modeling procedure that require careful interpretation (such as "long-run variable cost") or simplifying assumptions. This is followed by a list of more detailed assumptions.

The long-run costs. The LBL-MAM requires input of long-run costs. A firm is in long-run equilibrium when it has optimal productive capacity. Thus, during a recession (when firms experience excess capacity), firms are not in long-run equilibrium, and the theory of price as a markup over long-run costs may not apply. Long-run fixed costs are those that remain unchanged when a firm moves from one long-run equilibrium to another; they do not include capital costs that are proportional to output. The latter are considered long-run variable (marginal) costs and are marked up and passed on. To the extent that costs are not strictly proportional to output, but decrease on average with quantity produced, there are fixed costs. Also, a cost that does not depend on the scale of production, i.e., an engineering cost, is a long-run fixed cost.

Use of "typical" firm. The analysis estimates the impact of the standards by using "typical" firms. A typical firm is a hypothetical firm that is described by industry-average values. Each one is modeled as if it produced only products of the industry being analyzed. This procedure is justified by the observation that real firms generally are organized into autonomous divisions, each of which produces a different type of appliance and one of which generally corresponds to the industry being modeled. Also, these divisions are generally run on a profit-and-loss basis similar to a firm. It is not feasible to analyze inter-divisional interactions within real firms.

Aggregation. Generally, it has been impossible to obtain data on cross-elasticities of the various product lines within an industry. Therefore, data for the various products are aggregated before the markup is computed and applied. However, once the aggregate calculations have been made, individual prices are computed for the various classes of products.

How standards are implemented in the model. A change in standards affects the model in three distinct ways. In general, stricter standards will require additional investment, will raise production costs, and will affect revenue through both price and demand.

The most obvious investment induced by standards is the purchase of new plants and equipment. This cost is first evaluated from engineering data, and then amortized by taking into account the life of the investment, the date at which it is made, tax laws, and the appropriate cost of funds. An additional, and sometimes larger, investment takes place as the old inventory is replaced with more expensive new units. The model assumes that the ratio of inventory to revenue remains unchanged; in this way both changes in quantity sold and unit value are taken into account. A third form of investment tracked by the LBL-MAM is the change in the demand for cash that accompanies a change in revenues.

Financial inputs. Several simplifying assumptions are used in the process of generating inputs for the LBL-MAM. First, all firms within a particular industry segment (e.g., large manufacturers of water heaters) are assumed to have the same cost structure. Second, it is assumed that financial data collected for the parent company are representative of the specific product division being studied. These data come from publicly available sources such as Value Line, Standard and Poor's, Moody's, and company reports.

Impact Analysis: An Overview

The next section provides a general discussion of the methods of the impact analysis together with some cautions about interpreting the results.

The significance of long-run impacts and how they are analyzed are discussed below. These impacts are most important simply because they will either persist or be so severe as to cause a restructuring of the industry. The meaning and analysis of short-run impacts are also discussed. Additionally, the various types of sensitivity analysis performed on the model's results are discussed. This analysis is crucial for understanding the accuracy and reliability of the model's predictions, and includes the use of alternative scenarios, sensitivity checks on individual inputs, and Monte Carlo simulations involving the random selection of all control inputs.

2.3.3.1 Long-Run Impact Analysis

Implementation

The heart of the model is the long-run impact analysis. It assumes that enough time has passed for any changes in demand to have been accommodated by changes in the industry's productive capacity. Thus, in the long-run, capacity, or capital stock, is variable. Because capital is sometimes thought to be the only fixed cost, it might seem that fixed costs would be zero in the long run. This is not the case. For the purpose of price determination, whenever there are returns to scale, there are, effectively, fixed costs. This means that if the cost of meeting standards is less than proportional to plant capacity, there are fixed costs. Design costs would typically fall into this category. See Appendix C.2.1 of this volume for a more detailed discussion of the long run.

The fraction of increased costs of production (due to more stringent standards) that

manufacturers are able to pass on is determined by the nature of the cost, i.e., whether it is fixed or variable, the price elasticity of demand, and the consumer discount rate as seen by the price-setting firm. Once the price increase has been determined, it and the operating expense decrease (obtained from engineering data) are used with the price elasticity of demand and the discount rate to determine the change in sales. These mechanisms are presented in Figure 2.4, which displays the most basic economic forces analyzed by the LBL-MAM.

As shown in Figure 2.4, the two cost changes do not translate directly into price changes. Instead, the reduction in operating costs makes the appliance more desirable, thereby shifting the demand curve out (e.g., an increase in production costs changes the marginal cost curve). Together, these determine price and the number of units shipped (quantity). Price and quantity, together with production costs, determine net income (profit), and these, together with changes in capital stock (not shown), determine ROE.

The LBL-MAM simulates standards as follows. For each product, a set of engineering designs is specified. For each design, the engineering analysis provides a per-unit cost, a one-time capital cost, and an energy usage. The two costs effectively determine the production costs used in Figure 2.4 and the energy usage determines the operating expense. The LBL-MAM calculates a weighted average of the two costs and the energy usage for the relevant engineering designs. The weights used correspond to the relative numbers of shipments for each engineering design as determined by LBL-REM.

Another and more subtle point is that markup is determined by price elasticity, and because life-cycle-cost elasticity is constant, price elasticity changes with a change in either price or operating expense. This change in markup can have an important impact on ROE.

The markup discussed here is a markup over economic variable costs, which is a broader category than the typical business definition of variable costs. The manufacturer markup listed in the model and this volume is used only to calculate the baseline model price (calculated by multiplying the baseline manufacturer cost by the manufacturer markup). This is called the calibration case in LBL-MAM. The manufacturer markup listed is not used in calculating the manufacturer prices for the base case or the standard levels. In these cases, the manufacturer price is calculated from the economic markup[7] which, as described above, is dependent on elasticities, discount rates, and price and operating expense changes. Thus, prices at different standards levels do not exactly reflect the manufacturer cost times the manufacturer markup.

Typical results of an analysis of a standard at a particular level might be the following: wholesale price increases 10%, sales decline 2%, revenue increases 8%, net income increases 12%, and ROE increases 0.5%. Associated with each of these numbers is a standard error. The errors might be as follows: 4% on price, 1% on sales, 4% on revenue, 10% on net income, and 1.5% on ROE. To interpret the prediction for ROE, one could then conclude (by checking a table of the normal

[7]For a thorough description of how markups are derived and used in LBL-MAM, see Appendix C.2.1.

distribution) that there is about a 69% chance that ROE will increase, and a 31% chance that it will decrease. One could also conclude that the chance of profits declining by more than 2% is only 2.3%.

2.3.3.2 Short-Run Impacts

In the shortest run, capacity is fixed; however, the short run of interest is, at the shortest, approximately three years. During this time, some change in capacity may occur, and demand, apart from the change induced by standards, will change. Demand for each appliance is projected to grow by approximately 2% during the three years, so, to that extent, it will alleviate any tendency toward excess capacity resulting from standards.

In order to simplify the analysis and to take a cautious approach, the analysis has ignored the ability of the industry to actively or passively adjust its capacity relative to demand. The estimated short-run effect is what would happen if the industry converted, as a result of standards, all of its present capacity, and if the demand curve did not shift except as an indirect consequence of standards.

The short-run analysis is based on the analogy between a change in demand caused by standards and one caused by the business cycle. The business cycle periodically presents the industry with a fairly sharp decrease in demand that is much greater than the decrease predicted for any of the standards levels. This demand shortfall seems to present all of the opportunities for price competition that would accompany a shortfall resulting from a change in standards. Data for the last few business cycles (18 years) have been analyzed to determine the ratio between the decline in demand (industry-wide) and the induced decline in price.

If, for example, the long-run prediction is for a decline in demand of 2%, then, using the above figure, the short-run price could be predicted to be 0.06% (0.03 × 2%) lower than the long-run price. Actually, this is just a first approximation, and the model does better, as follows: the short-run price response factor (SRPR) of 0.03 means that the short-run price will be 0.06% lower than predicted with the long-run price formula if the actual decline in demand is 2%. This is different from the long-run prediction of a 2% decline, because the short-run price fall will keep the long-run demand fall from fully materializing. Thus, in the short run, the actual fall in demand will be less than the long-run prediction of 2%, and the actual fall in price will be greater than the long-run prediction, but not by a full 0.06%. Short-run demand and price must be determined simultaneously, which occurs in the short-run module of LBL-MAM.

Short-run prices, profit levels, and other variables will gradually, over a period of several years, approach their long-run values. How long this will take depends on the industry, on the fact that the implementation of standards is announced three or four years in advance, and on how fast (and if) the demand for the product is growing.

2.3.3.3 Industry Net Present Value Analysis

In this analysis, the LBL-MAM was modified to include an analysis of the impacts of standards

on industry net present value. Beginning in late 1990, a number of trade associations[8] contracted with the Arthur D. Little consulting firm to develop a model they named the Government Regulatory Impact Model (GRIM). Given exogenously-supplied price, shipments, and cost inputs, the GRIM provides an analysis of standards on industry net present value (NPV). Theoretically, NPV provides an alternate measure of impact that is identical to industry ROE that has been historically used by the LBL-MAM.

In response to the industry's concerns, the LBL-MAM has been modified to include all the programming code from the latest version of the GRIM that is available.[9] The GRIM has been integrated as a separate module within the LBL-MAM and generates the industry net present value analysis given price, shipments, and cost inputs from LBL-MAM. For a detailed explanation of the GRIM module and its integration with the LBL-MAM, please refer to Appendix C.

2.3.3.4 Sensitivity Analysis

Both because of the nature of the information required and the desire of sources to protect proprietary information, many of the data used by the model represent uncertain estimates. Therefore, the effect of these uncertainties on the accuracy of the model's predictions is analyzed. Two types of questions need to be answered. First, how does a particular input variable contribute to the uncertainty of the outputs? Second, how uncertain is the estimate of a particular output variable?

Sensitivity charts

The model's sensitivity to inputs is measured by the impact of a change of one standard error (S.E.) in the input variable. This analysis is presented only for the impact of input variables on ROE; this standardizes and simplifies the process. The results are displayed in a sensitivity chart (Table 2.1), an example of which is given and explained below.

---

[8]They were the Association of Home Appliance Manufacturers, Gas Appliance Manufacturers Association, and Air-conditioning and Refrigeration Institute.

[9]GRIM Version 1.2 dated 1 March 1993 which we received from AHAM in March 1993.

Table 2.1 Sensitivity of ROE to 1 S.E. change in control variables

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%
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%

Table 2.1 lists the sensitivities of ROE to the control panel inputs defined below:

1. IPE is the industry price elasticity.
2. RD is the consumer discount rate.
3. ECC is the firm's real equity cost of capital.
4. EP is the firm's economic profit.
5. FCA is the percentage of a firm's costs that are fixed before standards.
6. F1X is the percentage of one-time costs (i.e., costs that are induced by standards) that are fixed.
7. CC.N is the estimate of one-time capital costs induced by standards.
8. dVC.N is the increase in variable costs necessary to reach a standards level.

Note that for CC.N and dVC.N the change of one standard error from the mean is applicable for standards level 2 only. These two variables are dollar values rather than percentages, and thus their value and the change in one standard error are different at each standards level.

To construct the table, each control variable is first set to its normal value. Next, one at a time, each is increased in absolute value by one standard error and the change in profit is recorded. Then the variable is returned to its normal value and the next variable is tested. The matrix in the table lists the percentage point change in ROE as a result of the change of one standard error in the variable's value. The change in ROE is listed for each control panel variable and at each standard level being analyzed.

Since each variable has its own standard error, the sensitivity reported in the table measures both how sensitive the model is to a change in the variable, and how uncertain the variable's value is. Note that the change in profit is simply the difference between long-run ROE and base case ROE. Note also that, as expected, increasing the absolute values of some variables increases ROE and, for other variables, decreases ROE.

The comparison of the various inputs' contributions to the uncertainty in ROE focuses attention on the parts of the model that should be examined most closely to determine their accuracy and on the parts where improvement in the certainty of input variables would have the greatest payoff. Because of the differences in the sensitivities among input variables, it will generally be found that one to three of the inputs will dominate the model's uncertainty, in the sense that perfecting all the rest of the inputs would make only a negligible difference to the model's accuracy.

Alternative Scenarios

For each appliance class and hypothetical standards level, hundreds of different scenarios are run for the Monte Carlo analysis described in a following section. However, a few scenarios that involve different demand elasticities are singled out for special attention.

If the reader wishes to estimate some other scenario not reported here, he or she can often simply use the sensitivity charts. To do this, first look up how sensitive ROE is to a one standard deviation change in the control variables that are changed by the proposed scenario. Then estimate by how many standard deviations the desired scenario variables differ from the primary scenario control variables and calculate a proportional change in ROE. Lastly, add the changes in ROE resulting from the different variables. This method should be reasonably accurate for changes in the control variables that are likely to be of interest.

Uncertainty of Outputs (Monte Carlo Analysis)

Output uncertainty is most directly addressed by the Monte Carlo analysis. This analysis assigns an uncertainty to each of the nine control-panel input variables and then chooses a value for each based on this uncertainty. The model is then solved using these randomly chosen variables. All of the important outputs are tabulated on the Monte Carlo page of the model. These outputs are changes from the base case of price, shipments, revenue, net income, long-run ROE, and short-run ROE. Next, new values of the input variables are drawn from the same distribution. The model is run again and the new outputs recorded. This cycle can be repeated as many as 400 times (or more). After a sufficient number of runs, the mean and standard deviations of each output variable are computed.

The standard deviations of the Monte Carlo output variables are the best estimate of the true uncertainty of the model's predictions. However, this does not mean they are absolutely reliable because they are based on estimates of the uncertainty of the inputs, and these are often not based on something as objective as the standard error of a regression coefficient. In short, if the uncertainty

in the inputs is misperceived, the estimate of uncertainty in the outputs cannot be relied upon. Nonetheless, the standard errors generated by the Monte Carlo procedure are useful for the interpretation of the LBL-MAM outputs.

Assumptions in the Analysis

Assumption	*Justification*
• Firms maximize revenues minus economic costs (R-EC), where EC includes the cost of equity and all taxes.	This follows from the assumptions of standard economic theory, in which firms are rational profit maximizers.
• The life-cycle-cost elasticity of demand experienced by a single firm is constant. This means that price elasticity will tend to decrease with operating cost. Note also that since price elasticity is finite, firms have market power.	There is no reason to assume that life-cycle-cost elasticity either increases or decreases with cost; thus, constancy is the base assumption.
• Costs are assumed to have two components: one fixed, and one proportional to quantity.	A linear cost function approximates any smooth curve over a small region; since quantity changes very little with standards, the linear approximation should be adequate.
• Assets are assumed to be a linear function of sales.	Same as previous justification.
• The debt-to-equity ratio remains constant while the firm finances any investment necessary to meet standards.	Firms attempt to maintain a relatively constant overall debt-to-equity ratio, which they believe is optimal. Although specific new expenditures (such as those induced by standards) may be financed primarily by debt or by equity, in the long run, the debt-to-equity ratio will be restored to its desired value.
• The additional costs of parts, materials, and labor are assumed to be long-run marginal costs.	These costs are proportional to production except for cases in which there are discounts for large quantity purchases. Industry sources state that at the scales of production under consideration, these discounts are very nearly exhausted.

Assumption	*Justification*
• A percentage (that varies from industry to industry) of capital costs are long-run fixed costs.	Although industry informants have stated that one-time capital costs will be proportional to the production capacity of the plant in question, it seems inevitable that there will be some associated engineering costs that are not. These will be long-run fixed costs.
• Any fall in demand caused by standards (because of a price increase) will affect prices in the industry by the same amount as a normal fall in demand experienced during the business cycle.	To the extent that a normal demand shortfall reduces the firm's short-run marginal cost, the demand decrease caused by standards will be indistinguishable. The crucial assumption here is that the business cycle does not influence the consumers' elasticity of demand. There is no evidence one way or the other on this.

Outputs of the LBL-MAM

The LBL-MAM tracks six essential output variables, with emphasis on ROE. The other five variables are industry NPV, price, sales, revenue, and net income. Base case and short- and long-run values of these variables are reported on the control panel. In addition, LBL-MAM constructs an output table that shows the long-run values of the variables at each of the standard levels under consideration. LBL-MAM also produces a simplified income statement. As part of its algorithm, it calculates the markup from manufacturers' costs to consumer purchase price. The purchase price is used in the calculation of price-efficiency curves, the life-cycle-cost curves, and the calculation of payback periods, and throughout the LBL-REM.

All of these values are estimates that necessarily reflect some uncertainty. Estimates of these uncertainties and identification of their sources comprise another set of model outputs. Under each estimate of one of the five main output variables, the output table displays that variable's change from its base level and the standard error of the estimate of that change. The LBL-MAM also computes the effect on ROE of a one-standard-deviation change in each of the control variables. This is reported for each standard level in a sensitivity chart, designed to help discover the source of uncertainty in the output variables.

Data Sources

The LBL-MAM uses data that characterize both a particular industry and typical firms within that industry. Estimates of data are based on information from five general sources: (1) the Engineering Analysis, (2) the Consumer Analysis, (3) industry consultants, (4) public financial data, and (5) industry profiles. A detailed discussion of model inputs appears in Appendix C.

2.3.4 Appliance Standards Environmental and Utility Model (ASEUM)

The two analyses used in the prior appliance standards rulemakings, the Utility Impact Model and the Environmental Analysis have been integrated in one new model, the Appliance Standards Environmental and Utility Model (ASEUM). By calculating utility avoided costs and lost revenues, ASEUM provides marginal electricity costs to be used in evaluating the societal benefits of standards. ASEUM also quantifies impacts on the electric utility industry's need for new generating capacity. Appendix D of this volume contains more information on the model and data used to perform these calculations.

ASEUM adopts the standard industry convention that the financial value of electricity savings to an electric utility can be broken down into fuel cost and capacity cost savings. The sum of the two is usually called avoided cost. The fuel cost element measures variable production costs avoided by reduced electrical demands, valued at marginal input energy costs. The capacity cost measures the value of reduced loads during system peak periods; that is, the reduced requirement to have capacity available to meet peak demand. This saving is often valued at the cost of a combustion turbine, which is usually considered the lowest cost capacity available. This convention is explained in Appendix D. ASEUM calculates the avoided costs per kWh of energy saved. These values are used to calculate societal benefits from reduced electricity consumption.

ASEUM calculates avoided energy costs based on a disaggregation of the generation fuel mix to the ten National Electric Reliability Council (NERC) regions and a simplified load duration curve for each region. Refrigerators, refrigerator-freezers, and freezers are a classic baseload temperature-insensitive demand and are treated as such in this analysis. No attempt is made to segment the demand by region, but rather the electricity demand loss is assumed proportional. The fraction of the electricity that would have to be generated at the margin from oil and gas is calculated from total regional oil and gas generation and a simplified load duration curve. Projected utility natural gas and coal prices, weighted by the oil and gas marginal fraction and the non-oil and gas marginal fraction, respectively, are used to calculate utility marginal energy costs during the forecast period.

The avoided-capacity cost calculation in the model is based on a conservation load factor (CLF) for the energy savings attributable to the standard, as well as the cost of a combustion turbine. A conservation load factor is defined as the average load savings of a conservation measure (in kW) divided by its peak-load savings. The peak savings are averaged over an on-peak period from 8:00 to 20:00. This wide on-peak period yields a conservative estimate for peak-load savings that accounts for coincidence with system peak demand.

The CLF, calculated using annual average appliance load curves from Southern California Edison Company data, is used to characterize the peak demand savings of a conservation measure. It is used to convert the capacity value of the standards into a per kWh value described above. The analysis assumes that the load shapes of appliances do not change as these appliances are made more efficient.

The NERC forecasts of capacity requirements for each region are used to account for regional variations in reserve margin. If NERC predicts an adequate reserve margin in a region for a given future year, no reliability value is given to the peak load savings in the region.

The net revenue loss is equal to the difference between the revenue reductions and avoided costs. Revenue reduction is calculated by multiplying the change in electricity consumption by the average national residential rate. Avoided costs are calculated from the change in electricity consumption multiplied by the per-unit, avoided costs.

The inputs needed for the utility impact calculations include electricity savings, conservation load factors, utility fuel prices, average electricity prices, appliance saturations, efficiencies, hours-of-use, and electricity generation by fuel type and capacity need by NERC region. The outputs of the analysis are the fuel savings, the reduction in the need for new generating capacity, the net change in revenues, and the avoided energy and capacity costs for an appliance per EJ of source energy. These marginal costs are used to calculate societal costs and benefits of standards.

Assumptions in the Analysis

Justifications for the most important assumptions in ASEUM are listed below. These assumptions include the shape of the regional load-duration curves, conservation factors that remain constant through the analysis, the regional distribution of energy savings, utility marginal costs, and the substance of NERC forecasts.

Assumption	*Justification*
• The analysis calculates the period during which oil and gas or coal are the marginal fuels for electricity generation based on a simplified load duration curve (LDC) for each NERC region. It therefore assumes that this LDC accurately reflects the distribution of fuels on the margin.	There is little information by NERC region on which fuels are marginal. Since NERC supplies the total amount of fuel burned for generation, a method is needed to convert total generation into an estimate of marginal generation, and using an LDC is the usual way to derive such an estimate. Because most peak generating technologies, such as gas turbines, use light fuels, these fuels will be used by utilities to meet peak loads; hence, oil and gas are assumed to be at the top of the load duration curve. The other fuel assumed to appear on the margin is coal, since nuclear, hydro, and purchases from independent generators are usually base-loaded.
• Oil and gas fractions (OGFs) for each NERC region remain constant throughout the analysis period.	Constant OGFs are assumed to simplify computation. The OGFs are calculated using the simplified LDCs described above and by averaging NERC forecasts of the total amount of oil and gas generation for the years 1990 to 1995. There are no forecasts for the amount of oil and gas generation after 1995. Because these calculations are highly uncertain, and because no other forecasts are available, the analysis assumes constant OGFs.
• Energy savings accrue in each region in proportion to the region's consumption of heating, cooling, and baseload energy in 1980.	This approach is an approximation made necessary by insufficient information and for computational convenience. Information is available on average saturations and appliance efficiencies, by state, that can be aggregated to NERC regions.

Assumption	*Justification*
• Utility marginal energy costs are calculated using the sum of utility natural gas and coal prices weighted by the oil and gas fraction and the non-oil and gas fraction, respectively. This approach assumes that all marginal generation has the same heat rate.	Different generating units have different heat rates, but the extent of this variation for utility generating systems in different NERC regions has not been calculated. A 34% energy conversion efficiency is typical for current generating units.
• The NERC forecasts of changes in adjusted reserve margin are accurate.	The NERC forecasts are widely accepted. They are the only forecasts of adjusted reserve margin at the regional level.

2.3.5 Life-Cycle Cost Analysis, Payback Period, and Cost of Conserved Energy

One measure of the effect of proposed standards on consumers is the change in operating expenses as compared to the change in purchase prices. These changes are quantified by the difference in life-cycle costs (LCC) between the base and standards cases for the appliance classes analyzed. The LCC is the sum of the purchase price and the operating expense discounted over the lifetime of the appliance. It is calculated at the average efficiency for each class in the year standards are imposed using real consumer discount rates of 2%, 6%, and 15%. The purchase price is based on the factory costs in the Engineering Analysis and includes a factory markup plus a distributor and retailer markup. Maintenance and installation costs are included, when appropriate. The operating expense is calculated using the unit energy consumption data in the LBL-REM. Energy prices and appliance usage are taken from the results of the LBL-REM.

The life-cycle cost analysis also examines the payback periods and the cost of conserved energy associated with the standards. The payback period measures the amount of time it takes to recover additional investment in increased efficiency through lower operating costs. Numerically, it is the ratio of the increase in purchase price between the base and standards cases to the decrease in annual operating expenditures. Both the numerator and denominator of this expression are evaluated at the average efficiency in the year standards come into effect and at energy prices in that year. The cost of conserved energy is the increase in purchase price amortized over the lifetime of the appliance, divided by the annual energy savings.

Details of these calculations may be found in Chapter 4.

2.3.6 Environmental Analysis

As mentioned in Section 2.3.4 above, the ASEUM model now conducts both the electric utility and environmental analyses. Further details of the environmental calculations and results can be

found in the Environmental Assessment, which is included in this volume. The environmental calculations are quite straightforward. Reductions in energy use estimated by LBL-REM are multiplied by emissions factors to estimate net emissions reductions. In the case of refrigerators, refrigerator-freezers, and freezers, the net energy impacts are almost entirely seen in the form of slower growth of electricity consumption and generation, and that is the focus here.

The main environmental effects of electricity generation and distribution on air and water quality result from emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2). With the proposed standards lessening the need for electricity generation, in general, power plant emissions would be reduced. However, the case of SO_2 is complicated by the emissions cap provision of the 1991 Clean Air Act Amendments. In the case of this pollutant, the reduction in pollution reported should be interpreted as reduced demand for emissions. Physical emissions will most likely not change, although the price of emission allowances should be lower than the case absent the standards.

The numerous other, but more minor, effects of power generation, such as water pollution, land-use effects, etc., are not covered in the appliance standards analysis. The net effect of an appliance standard on such environmental problems are just too small to be measurable.

The multipliers used in this report are derived from a report that accompanied the 1991 NES [4]. Estimation of multipliers over future periods is not as straightforward as it may seem. Our reasonable expectation is of improved emission controls over time and the effectiveness of these improvements must be forecast. In addition, future restrictions on emissions of greenhouse gases could have a major impact on CO_2 emissions. Table 2.2 shows some sample emission factors. As is clear, the forecast emission factor for SO_2 falls dramatically as the provisions of the Clean Air Act become effective. The factor for NO_x falls, but less dramatically, while the CO_2 emissions, which have no currently known feasible abatement strategy fall modestly.

Table 2.2 Emissions Factors for Power Generation

Year	SO_2 g/kWh	NO_x g/kWh	CO_2 g/kWh
2000	3.142	2.339	874.9
2010	2.314	2.011	886.9
2020	1.487	1.487	879.9
2030	0.863	1.061	863.8

Clearly, the approach used in this analysis assumes that the generation avoided will be similar in its environmental effects to average generation. That is, no effort is made to conduct a marginal rather than average analysis, even though the fraction of time that a certain fuel is a marginal fuel will not be the same as its share of overall generation. For residential refrigeration, this is a reasonable assumption. Generation will be reduced at all times of the year and coal and gas will both be marginal for some of the time.

REFERENCES

1. Eric Hirst and Janet Carney. *The ORNL engineering-economic model of residential energy use*, Oak Ridge National Laboratory, Oak Ridge, TN. ORNL/CON-24.

2. James E. McMahon. 1987. The LBL Residential Energy Model: An Improved Policy Analysis Tool, *Energy Systems and Policy*, Vol. 10, No. 1, pp. 41-71.

3. U.S. Department of Energy. 1989. *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces*, DOE/CE-0277, November.

4. U.S. Department of Energy, Energy Information Administration, *Effects of the Clean Air Act Amendments on Reducing SO_2/NO_x Emissions*. 1991. Energy Information Administration, SR/NES/90-01.

CHAPTER 3: ENGINEERING ANALYSIS

3.1 INTRODUCTION

Refrigerators, refrigerator-freezers, and freezers are major household appliances designed for the refrigerated storage of food products. A refrigerator consists of a refrigerated cabinet at 0°C (32°F) or above. A refrigerator may include a compartment for freezing and storage of food at temperatures below 0°C (32°F) but does not provide a separate low temperature compartment designed for freezing and storage of food at temperatures below -13.3°C (8°F). A refrigerator-freezer is a cabinet which consists of one or more compartments with at least one of the compartments designed for the refrigerated storage of food at temperatures above 0°C (32°F) and with at least one of the compartments designed for the freezing and storing food at temperatures below -13.3°C (8°F). A freezer consists of a cabinet for the storage and freezing of foods at -17.8°C (0°F) or below.

In order to evaluate the costs associated with an efficiency improvement, the current manufacturing process must be understood. Figure 3.1 provides a schematic of the production process for refrigerator-freezers and freezers. The general process does not differ dramatically among the large and small manufacturers. Essentially all the major subassemblies are produced in separate processes, and then the product is assembled on an assembly line.

The major components of refrigerator-freezers are the metal cabinets, plastic liners, insulation, compressor, condenser, evaporator, controls, interior shelves, and all the interconnection components such as tubing, wires, fasteners, and frames. The cabinets are typically produced in one section of the factory. Metal presses and shearing machines are used to produce the cabinet components. The sheet metal for the cabinet is bent into shape and the sides, bottom, and top and the frame are welded together. This process can be completely automated in the largest plants, or may be fairly labor- intensive in smaller operations. The doors are also produced in this section of the plant. The cabinet is cleaned and painted in the paint section of the plant; the whole painting operation is usually automated.

Most refrigerator inner liners are now plastic. The plastic inner liners and the other plastic components are produced in another section of the plant. First the plastic is extruded into plastic sheets and then vacuum-formed into the inner liners. The plastic liners are placed inside the metal cabinets and foam insulation is injected into the space between the liner and the cabinet. Foaming of the doors follows a similar process.

The various components of the refrigerator are added to the foamed cabinet and liner on an assembly line. The compressor, condenser, evaporator, fans, and controls are added. Various subassemblies of components may be produced in other parts of the plant for input on the assembly line. Many of the components added on the assembly line may be purchased parts such as the compressor, valves, fans, controls, and heat exchangers. Some manufacturers produce most of these parts either at the plant site or at other manufacturing operations within the same company.

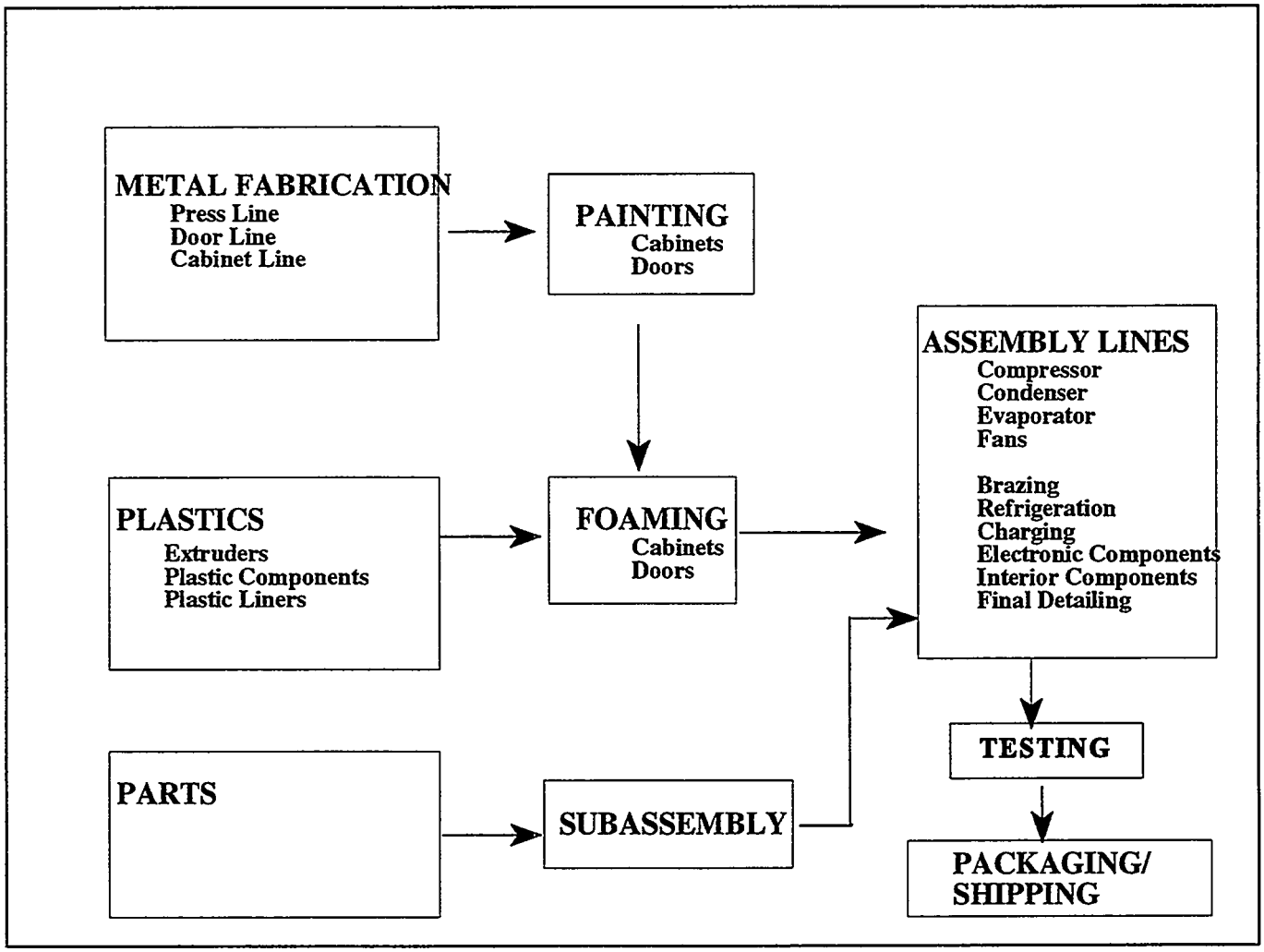

Figure 3.1 Production process for refrigerators and freezers

Once the refrigeration components are added to the cabinet, they are connected and all connections are brazed. Then the system is evacuated and the refrigerant charge added. The final steps on the assembly line are the addition of shelves, interior detailing, and doors. Testing completes the production process. The finished product is packaged and prepared for shipping.

3.2 PRODUCT CLASSES

The product classes analyzed are listed in Table 3.1. Separate product classes were established for compacts ($\leq$220 L or 7.75 ft^3).

Table 3.1 Product Classes

Volume greater than 220 L

Refrigerators and Refrigerator-Freezers

1. Manual Defrost
2. Partial Automatic Defrost
3. Automatic Defrost Top Mount
4. Automatic Defrost Side-by-Side
5. Automatic Defrost Top Mount with Through-the-Door Service Features
6. Automatic Defrost Side-by-Side with Through-the-Door Service Features
7. Automatic Defrost Bottom Mount

Freezers

8. Manual Defrost Upright
9. Automatic Defrost Upright
10. Manual Defrost Chest

Volume less than or equal to 220 L (compacts)

Refrigerators and Refrigerator-Freezers

11. Manual Defrost Single Door
12. Partial Automatic Defrost
13. Automatic Defrost Top Mount
14. Automatic Defrost Side-by-Side
15. Automatic Defrost Bottom Mount

Freezers

16. Manual Defrost Upright
17. Auto Defrost Upright
18. Manual Defrost Chest

Small units such as those that fit under the counter have fewer opportunities to save energy. Space limitations precludes increasing the wall thickness. Improvement in the compressor performance is also limited due to the smaller compressor size and the constant losses associated with a compressor and its motor. These units typically rely on natural convection heat transfer in the evaporator and the condenser and therefore cannot employ better fan motors as an energy-saving option. Due to these facts, refrigerators, refrigerator-freezers, and freezers less than 220 L (7.75 ft^3) have to be analyzed separately.

3.3 DESIGN OPTIONS

Table 3.2 lists the design options considered in this study. The design options are changes that can be incorporated into the design of a refrigerator-freezer or freezer to improve its efficiency. Some of the design options listed are found in existing products; others are being developed. The following discussion describes the status of each design option.

Table 3.2 Design Options for Refrigerators and Freezers

Increased Cabinet Insulation Thickness	Improved Fan Motors for Evaporator and Condenser
Increased Door Insulation Thickness	Improved Fans for Evaporator and Condenser
Improved Resistivity of Insulation	Variable-Speed Fan
Vacuum Panel Insulation	Two-Stage Two-Evaporator System
Gas-Filled Panels	Other Refrigerant Cycles
Improved Gaskets	Improved Heat Exchange in Evaporator
Double Door Gaskets	Improved Heat Exchange in Condenser
Reduced Heat Load for Through-the-Door Feature	Alternative Refrigerants
Reduced Energy for Electric Anti-Sweat Heaters	Improved Expansion Valve
Condenser Hot Gas for Anti-Sweat Heaters	Fluid Control Valve
Reduced Energy for Automatic Defrost	Location of Compressor, Condenser, and Evaporator Fan Motor
Condenser Hot Gas for Automatic Defrost	Use of Natural Convection Currents
Adaptive Defrost	Electrohydrodynamic Enhancement of Heat Exchangers
Improved Compressor Efficiency	Voltage controller
Two-Compressor System	
Variable-Speed Compressor	

Increased Insulation Thickness for Walls and Doors

Seventy-five to 90% of the energy required by a refrigeration unit may be attributed to the thermal performance of the insulated shell. Hence, by improving the performance of the shell, significant savings are possible. One way of improving the overall thermal resistance of the shell is to increase its thickness. Most manufacturers now use approximately 3.81 cm (1.5 inch) to 7.0 cm (2.75 inch) of insulation in the doors of their products and 3.81 cm (1.5 inch) to 7.62 cm (3 inch) in

the walls. Freezers and freezer sections tend to be near the higher end while refrigerators are near the lower end.

Adding 1.27 cm to 2.54 cm (0.5 to 1 inch), more insulation increases the overall efficiency of the product. Improvements relative to the previous design level range from a few percent to over 10%, depending on the specific improvement. The technology to implement this change is readily available and the efficiency improvements are significant. However, manufacturers indicated that this is not one of the first efficiency improvements they would apply. Significant investments would be required in foaming systems, tooling, and molding to accommodate thicker insulation. Increased packaging and shipping costs must also be considered. Greater insulation thickness means the interior volume of the appliance must be decreased, the exterior dimensions must be increased, or some combination of both. Since kitchen dimensions and designed spaces for refrigerator-freezers are limited, there are restrictions on increasing the exterior size of the product. Reducing interior volume is considered undesirable because this is a major product feature for consumers.

Two scenarios were analyzed for door and cabinet insulation thickness increases; they are an increase of 1.27 cm (0.5 inch) and an increase of 2.54 cm (1 inch), respectively. The market served by each product class will be impacted by insulation increases. The magnitude of the impact depends upon the dimensions of the baseline model. For example, for top-mount refrigerator-freezers, for a total increase of 2.54 cm (1 inch) in both width and height, the reduction in served market ranges from 5.8% to 10.7% for the three baseline 514 L (18 ft^3) units evaluated. These three models have widths ranging from 78 cm to 84 cm (30.8 to 33 inches). For a 600 L (21 ft^3) top-mount and a 629 L (22 ft^3) side-by-side, undergoing a total increase of 2.54 cm (1 inch) in width and height, the reductions in served market are 12.7% and 10.7%, respectively. Manufacturers will decide, for each model they produce, whether to increase width or use other available design options to increase efficiency. For freezers, data are not available for served market as a function of freezer dimensions. However, space constraints are not as significant for freezers as for refrigerator-freezers. For compact refrigerators and freezers, which are often used in undercounter configurations, space constraint considerations have led to a decision not to employ insulation increases for the sides or door.

Improved Resistivity of Insulation

Foam is almost universally used in the side walls of refrigerators and freezers. In the present analysis, the use of foam in side walls is considered the baseline case. Foam is also used in most cases for the doors. Only one company was found to be using fiberglass insulation in doors. The fiberglass insulation can be replaced by foam to improve the resistance to heat flow into the cabinet. Technologies such as microcell formation in the foam further improve the resistivity of the foam. However, most manufacturers already use such methods and further improvement is not likely in the near future.

Vacuum Panel Insulation (VPI)

Evacuated insulation panels reduce heat transfer because the amount of air that can transfer heat in the panel is reduced. VPIs offer very low conductances and have been applied in small numbers; some major U.S. manufacturers have tested the panels in refrigerators and freezers. Evacuated panels are filled with low-conductivity powders that prevent collapse. Silica-filled panels with conductivity value of 6 to 8 mW/m·K have been developed by Degussa.

Evacuated panels can be foamed in place between the cabinet liner and wrapper to decrease the heat leakage and energy required to maintain the cabinet at low temperature. However, there are, at present, some unresolved technical questions about these panels, such as long-term vacuum integrity and how to mass produce and test panels and add them to the refrigerators. The time required for U.S. manufacturers to implement this option on a large scale is unknown. Vacuum panels are currently being used by some of the European manufacturers.

There are other strategies for developing low thermal conductivity panels. For example, the Solar Energy Research Institute (SERI) is performing research on hard vacuum insulation panels. They expect to be able to produce 0.254 cm (0.1 inch) panels with thermal conductivity of 0.96 mW/m·K (150 hr-ft^2-°F/Btu-in). In this concept, a very low pressure will be established between steel or glass plates. Experimental confirmation has not yet taken place. Aerogels may also be used in insulation panels for refrigerators and freezers. Silica aerogel is an excellent thermal insulator. Since it is also transparent to solar radiation, it has been considered for use in windows. The thermal conductivity can be reduced by replacing the pore gas with one of lower conductivity or by evacuating the aerogel to pressures below 0.1 atmosphere. Measurements show that a 1.27 cm (0.5 inch) evacuated aerogel panel should have a k-value of 6.5 mW/m·K (22 hr-ft^2-°F/Btu-in) [1].

Gas-Filled Panels

Another method for improving the thermal characteristics of the shell is to use gas-filled panels. Work done at the Lawrence Berkeley Laboratory shows that conductivities of 18 mW/m·K (8 hr-ft^2-F/Btu-in) for Argon-filled and 9.6 mW/m·K (15 hr-ft^2-F/Btu-in) for Krypton-filled panels are achievable [2]. However, a major problem in using gas-filled panels is the lack of structural integrity of the resulting product. In order to overcome this problem, a different cabinet design would be required.

Improved Gaskets

A significant portion of the heat gain to refrigerators and freezers occurs around the edges of the doors and through the gaskets on the door edges. If the insulating value of the gasket is improved and heat leakage through the gasket is reduced, the efficiency of the refrigerator can be increased.

A recent EPA report describes theoretical modeling and experimental research on gasket heat loads [3]. The report concludes that replacing about half of either the metal door flange or cabinet flange with plastic can reduce the heat flow through the gasket region by 25%.

Double Door Gasket

An additional inner door seal gasket can be added to the gasket design to further reduce heat leakage and infiltration into the refrigerator and freezer.

Double door gaskets have not been used by many manufacturers because of performance problems and cost. Ice has a tendency to form between the gaskets, greatly reducing their effectiveness. In addition, the gaskets tend to be visually unattractive and they make it more difficult to meet the minimum door opening force required by the Child Safety Act. Manufacturers instead have focused their efforts on producing thermally improved single gaskets with higher insulating values and better sealing characteristics.

Reduced Heat Load of Through-the-Door Feature

Through-the-door (TTD) features like ice makers displace insulation in the door. These features also make it very difficult to apply foam in the doors. With this design option, however, foam insulation, as well as improved design methods can be used to reduce the heat load of TTD features.

Reduced Energy for Electric Anti-Sweat Heaters

Anti-sweat heaters are needed near the outer shell of refrigerators and freezers to reduce moisture buildup. These heaters contribute to the energy consumption due to their direct electricity usage as well as the fact that part of the heat from these heaters enters the refrigerated space and adds to the overall heat load. Some of the units use unnecessarily high wattage heaters and energy use can be decreased by reducing the heater wattage. It was found that some of the manufacturers do not use electric heaters for anti-sweat anymore, instead either the hot vapor or the liquid line from the condenser is looped around the shell to provide anti-sweat heat.

Condenser Hot Gas for Anti-Sweat Heat

The direct electricity consumption of the anti-sweat heaters can be eliminated by using a hot gas condenser loop which uses the hot refrigerant to eliminate moisture buildup on the outer shell of the unit. After reviewing the data received from the manufacturers, the conclusion was reached that this option has already been exercised by most of the manufacturers of refrigerator-freezers and, therefore, it should be dropped from the analysis. Compacts and freezers, in general, do not use anti-sweat heat.

Reduction in Energy for Automatic Defrost

At present almost all the manufacturers use electric heaters to defrost the excessive ice buildup on the evaporator located in the freezer section of a refrigerator-freezer. The defrost system increases the energy usage of a system in two ways: the electric heater directly effects the electricity use and the heat of defrost increases the heat load inside the refrigerator which, to be rejected, requires compressor work. In some cases, the defrost heat supplied is more than required and energy savings are possible by reducing the defrost heat by either using smaller heaters, reducing the heater on-time, reducing the frequency of defrost, or a combination of these. Another approach is to use adaptive defrost (see below).

Upon review of available data, it has been found that most manufacturers have already significantly reduced the electric heat for auto defrost in order to comply with the 1993 DOE Standards and, hence, there is little opportunity to save further energy by exercising this option. The only exception is for the side-by-side refrigerator-freezer without TTD features, where the baseline model had a higher defrost energy use than other models; for this product class, this option has been included in the analysis.

Adaptive Defrost

One way to reduce the energy used for defrost would be to better control the time and amount of defrost heat by using adaptive defrost. Adaptive defrost systems makes use of "smart" controls to adjust the time between defrost cycles so that the minimum amount of energy is used. Refrigerators and freezers now usually use a timer that initiates defrost after a certain constant time span, usually around 10 to 12 hours of compressor on-time. However, the frost build-up on an evaporator can vary significantly depending on the refrigerator-freezer or freezer type, its usage, and the ambient conditions. By limiting the number of defrost cycles, energy use can be reduced. As an example, for the baseline top mount refrigerator-freezer the difference in simulated energy use with and without defrost is approximately 9%. It is believed that approximately 3-4% energy can be saved with adaptive defrost. There are refrigerators available today with adaptive defrost control, but these units are top-of the-line models with other electronic convenience features.

Condenser Hot Gas for Automatic Defrost

Another method of reducing the energy required for defrost would be to do away with the electric heaters by substituting condenser hot gas in its place. Data were not found to positively prove the condenser hot gas method to be more cost-effective than adaptive defrost which is a well-developed and accepted technology and, therefore, the former was dropped in favor of the latter.

High-Efficiency Compressor Substitution

Data have been obtained on efficiency and costs of HFC-134a compressors from three compressor manufacturers, from AHAM and its members, and other sources (e.g., company literature

from Sunpower, Inc). Compressor efficiencies have improved significantly during the last ten years and advances continue to be made. Since the compressor is the major energy-consuming component in a refrigerator, advances in compressor efficiency have a significant effect on overall refrigerator efficiency.

Most models today have compressor COPs ranging between 0.73 (2.50 EER) for small 57 L (2 ft^3) all-refrigerator to 1.58 (5.40 EER) for the larger 629 L (22 ft^3) refrigerator-freezer. Many manufacturers purchase the compressors for refrigerators and freezers from compressor manufacturers although some manufacturers produce their own compressors. As more efficient compressors become available, refrigerator manufacturers can incorporate them into their products.

Conversion to a high-efficiency compressor is fairly straightforward for manufacturers to implement as long as the compressors are available or can be produced at a reasonable cost. Information (see Table 3.4, in Section 3.4) collected in this analysis, suggests that a 1.64 COP (5.6 EER) compressor for refrigerators will be available within the next few years.

Two-Compressor System

Refrigerator-freezers can operate more efficiently with separate refrigeration systems for the refrigerator and freezer compartments. A higher evaporator temperature in the fresh-food compartment results in a higher efficiency. Another advantage of a two-compressor system is a reduced demand for defrosting. Less moisture condenses on the cold surfaces of the fresh-food section when cold air from the freezer section does not have to be circulated through the fresh-food compartment. Additionally, with this configuration, defrosting in the fresh-food section can be accomplished by leaving the compressor turned off until the evaporator reaches a temperature above freezing. This does not require electricity, nor does it add to the heat load. Some European manufacturers and one small U.S. firm are now building two-compressor systems for high-priced refrigerator-freezers.

The major disadvantage with this system is cost, since two refrigeration systems are required. Using two systems also tends to double design and maintenance requirements. In addition, smaller compressors tend to be less efficient than larger ones. The larger volume of the refrigeration system would either increase product external dimensions or decrease usable refrigerator volume. Experimental energy use and manufacturer cost data are needed to properly evaluate this design option. A test procedure to rate refrigerator-freezers with dual-compressor systems has been published. [4].

Variable-Speed Compressor

Present compressor motors operate at one speed. A variable-speed compressor motor would allow for a better match between heat removal loads and compressor power demand. The heat removal rate and compressor energy consumption rate could be made an implicit function of such factors as food loadings, ambient temperature, and door openings. During most of each 24-hour

period, the compressor would operate at low speed with a high percentage of on-time. This would reduce on- and off-cycling and lower energy consumption. Fan energy consumption would however increase, therefore reducing some of the overall benefits. Data are not presently available to evaluate the potential energy savings from this design.

Several manufacturers are presently performing research on refrigerator-freezer prototypes containing variable-speed compressors. Theoretical estimates of energy savings for this design option range from 10%-20%. The present DOE test procedure uses a closed door procedure at a high ambient temperature to estimate refrigerator and freezer energy consumption. This test procedure would have to be modified to estimate the full benefits of a variable-speed compressor. Experimental data are lacking to properly evaluate this design option.

Fan and Fan Motor Improvement

Fans are used to increase evaporator and condenser heat transfer in units that have bottom-mount condensers. If the efficiency of the fans, in particular the fan motors, is increased, the energy use of the refrigerator-freezer can be reduced. Typical evaporator and condenser fan motors presently require 10 to 16 W of power. Power can be reduced with improved magnets and capacitor-run motors. Dry film capacitor motors could provide additional efficiency improvements in the near future.

Refrigerator manufacturers purchase fans and motors from outside vendors. Therefore, conversion to more efficient fan motors can be easily accomplished when more efficient units are available. By replacing both the condenser and evaporator fan motors with motors requiring only 4.5 W of power, significant efficiency improvement for the refrigerator could be achieved. The costs for the new motors are higher than for current models.

Variable-Speed Fan

Present fan motors operate at one speed. A variable-speed fan motor would allow for a better match between heat removal loads and evaporator capacity. The heat removal rate and fan speed could be made an implicit function of such factors as food loadings, ambient temperature, and door openings. Experimental data is lacking to properly evaluate this design option.

Two-Stage Two-Evaporator System

A two-stage, two-evaporator system has two evaporators, one in the fresh-food section and one in the freezer section. The fresh-food cabinet evaporator acts as a condenser when freezer operation is called for. A lower temperature difference between the evaporator and condenser for both freezer and fresh-food cabinet operation should result in higher COPs. As in the case of two-compressor systems as discussed above, small compresors are not available, service incidence rate increases, product cost increases, additional space is required for the second compressor, and increased sound levels are of concern. This technology is in the early stage of development and

further analysis has not been conducted due to lack of energy and cost data.

Other Refrigerant Cycles

Various alternative refrigeration cycles have been suggested to replace the Rankine cycle for refrigeration. The Lorenz cycle uses a non-azeotropic refrigerant mixture that evaporates over a temperature glide of about 22°C (40°F). The cold end of the glide is used to cool the freezer compartment, the warm end to cool the fresh-food compartment. This option creates problems of load distribution between fresh-food and freezer compartment, sizing of evaporators and expansion valves, and temperature control in the fresh-food and freezer sections. The Stirling cycle has been used by Sunpower Inc. in their photovoltaic powered, super-insulated, very small refrigerators. There are no energy and cost data available for larger-sized units using either of these refrigerant cycles.

Improved Evaporator and Condenser Heat Exchange

The evaporator and condenser are key components of the refrigeration system. Heat exchanger performance can be enhanced by increasing face area, adding more tube rows, increasing the thermal mass, or by integrating the heat exchanger with the outer shell of the unit. These measures are limited by the geometry of the refrigerator-freezer. There is a tradeoff between increasing the volume occupied by the heat exchanger and reducing the interior volume of the refrigerator.

Alternative Refrigerants

Currently, the only universally accepted substitute for R12 is R134a. It is unlikely that refrigerants not yet identified would become commercially available for use before the 1998 standard goes into effect. Even if a substitute with performance better than R134a was identified, time would be needed to conduct tests to determine toxicity, chemical compatibility, reliability, and safety before the product could be used.

Mixed refrigerants may improve performance through enhanced capacity modulation and higher efficiencies at different operating conditions. This design option is still highly developmental. So far, experimental tests have been unable to match the predicted performance from computer models. No practical improvements in efficiency have been demonstrated.

Improved Expansion Valve

Traditionally, capillary tubes have been used to control refrigerant flow and keep the system balanced. Automatic, adjustable expansion valves may provide improved performance. The technology for this design option is available; however a modification in system design is required. No data demonstrating that improved expansion values will save energy in refrigerators could be found.

Fluid Control Valve

A fluid control valve, or liquid line valve, can be used to reduce off-cycle refrigerant movement. When a compressor is turned off during normal cycling, the pressures within the refrigeration system tend to equalize by transference of refrigerant from the high pressure side to the low pressure side of the system. The refrigerant transfers heat from the condenser to the evaporator. Reducing refrigerant migration will increase the off-cycle duration and reduce compressor run-time and energy use.

Refrigeration systems with rotary compressors have higher energy loss due to off-cycle refrigerant migration than systems with reciprocating compressors which are used by most U.S. manufacturers. Experiments at Oak Ridge National Laboratory show no savings in energy when a fluid control valve is used with a reciprocating compressor [5]. Furthermore, when fluid control valves are used, the compressor must start against an unequal pressure.

Location of Compressor, Condenser, and Evaporator Fan Motor

If the compressor and condenser are located on the top of the refrigerator-freezer, they can operate more efficiently because heat is more readily convected away from the system and the condenser fan can be eliminated. Traditionally, the compressor and condenser are located at the bottom rather than the top of the refrigerator-freezer so the user can have easy access to the food compartments. Locating the condenser and compressor at the top of the unit would require modification of traditional practice and consumer preference. It would also require product redesign, which according to manufacturers would be expensive. Locating the evaporator fan motor outside the cabinet would reduce internal loads from the heat loss of the motor. However, it is difficult to prevent air leakage where the motor shaft penetrates the cabinet wall. Experimental data is lacking to properly evaluate this design option.

Use of Natural Convection Currents

Using natural convection instead of fans eliminates electricity use for the fans and reduces the load on the refrigeration system from heat dissipated by the evaporator fan motor. Most larger freezers and compact refrigerators and freezers already rely on natural convection for the heat transfer. However, most popular automatic defrost refrigerator-freezers use both an evaporator fan and a condenser fan. Manual defrost units do not require either fan and thus use less energy (note that a condenser fan may improve performance for larger systems, however). With the reduction in the fan motor power, the potential for savings with this option have decreased substantially. Experimental data are lacking to properly evaluate this design option.

Electrohydrodynamic Enhancement of Heat Exchangers

This technology employs high voltage fields to improve the heat exchange characteristics of the evaporator and condenser. However, safety issues involved in using such high voltages in

domestic appliances have not been resolved as yet. No prototypes are available to test and evaluate this technology for domestic refrigerators and freezers.

Voltage Control Device

Based upon data supplied to the DOE [6], it is believed that this option does not offer any potential for energy savings for new refrigerators and freezers.

3.4 ENERGY USE DATA

Data used in this analysis represents actual refrigerators and freezers presently being manufactured by nine major manufacturers. This data was obtained from the refrigerator-freezer manufacturers and was used to establish the energy consumption and the characteristics of the baseline models. The only exception is the bottom mount auto defrost refrigerator-freezer. For this case, data for only one 566 L (20 ft^3) unit was received and it was found to be almost 25% more efficient than required by the 1993 Standard. In order to bring the energy use closer to the 1993 Standard, the wall thickness was decreased by 1.27 cm (0.5 inch). In all, data for approximately 50 units of refrigerators, refrigerator-freezers, and freezers were obtained and used as input to the ERA program [9]. Out of these 50 units, approximately 90% showed the simulated energy consumption to be within 20% of the DOE Test energy use and about 70% were within 10% of the DOE Test energy use. For each class, the baseline models chosen were those which were 1) close to the 1993 Standard, and 2) whose simulated energy use was close to their actual energy use. Following are the steps used in arriving at the baseline energy consumption in this analysis. It should be kept in mind that the actual models use CFCs at the present time which would be phased out by the time the standard goes into effect. This required two changes: 1) CFC11 be replaced by HFC141b as the foam-blowing agent (no change in conductivity assumed[1]); and 2) CFC12 be replaced by R134a (compressor maps for compressors using R134a used in place of the R12 compressor maps).

(i) Run the simulation on ERA with the data provided by the manufacturer (with the CFCs present) and determine the simulated energy consumption.
(ii) Compare the simulated energy use to the DOE Test energy use and determine the calibration factor (Test Energy/ ERA Energy).
(iii) Make changes for the CFC phaseout (R12 compressor map replaced by R134a map of same COP and similar capacity) and find the simulated energy use.
(iv) Determine the baseline energy consumption as non-CFC energy times the calibration factor[2].

---

[1] Except for the case of side-by-side refrigerator-freezer and chest freezer where the conductivity was changed from 15.9 mW/m·K to 17.5 mW/m·K and 18.2 mW/m·K, respectively.

[2] The energy use is further multiplied by 0.7 for chest freezers and 0.85 for upright freezers as specified in the DOE test procedure for freezers.

Table 3.3 summarizes some of the important data for the baseline refrigerator-freezers and freezers. In addition to the data shown in Table 3.3, detailed geometric and refrigeration system information is needed to perform energy use simulations.

Simulations are carried out using the ERA model. This steady-state energy model calculates heat leakage into a cabinet and then determines the energy needed by the refrigeration system to maintain interior temperatures as specified in the DOE test procedure. Internal loads from heaters and evaporator fans are added to the external heat gain. Total energy used to run the compressor, fans, anti-sweat heaters, and defrost heaters is calculated. Detailed information on the cabinet dimensions, insulation levels, compressor performance, heat exchanger effectiveness, and auxiliary electrical equipment is needed to run the simulation model. Appendix A contains a more detailed description of the ERA model.

The component energy use for a typical 515 L (18.2 ft^3) top-mount auto-defrost refrigerator-freezer has been estimated. The adjusted volume is 606 L (21.4 ft^3).For the baseline case, about 80% of the total energy is used by the compressor. The rest of the energy use is divided among fans, anti-sweat heaters, and defrost heaters. About 15% of the compressor energy use is for removal of internal heat generated by the evaporator fan motor, defrost heater, and anti-sweat heaters. These results indicate that the greatest energy conservation opportunity lies with reductions in compressor energy use. This can be accomplished by using more efficient compressors or by reducing heat gain into the cabinet. However, auxiliary electric equipment accounts for about 30% of the total energy use; thus, there are also significant opportunities for conserving energy by using more efficient fans and reducing heater use.

Table 3.3 Baseline Refrigerator-Freezer, Freezer, and Compact Characteristics

Product Class	Adjusted Volume L (ft^3)	Insulation (cm)				Compressor COP (EER)	Evaporator Fan (W)	Condenser Fan (W)
		Fresh-Food		Freezer				
		Side*	Door	Side*	Door			
Refrig-Freezers								
Top Mount Auto Defrost	606.0 (21.4)	4.32	3.81	5.46	3.81	1.37 (4.68)	9.1	12.0
Top Mount Auto Defrost with Through the Door Feature	726.8 (25.7)	3.99	3.81	5.08	3.81	1.58 (5.40)	9.1	12.0
Side-by-Side Auto Defrost	737.8 (26.1)	5.21	5.08	5.38	5.08	1.48 (5.13)	10.0	10.0
Side-by-Side Auto Defrost with Through the Door Feature	740.9 (26.2)	5.13	3.81	5.84	3.81	1.52 (5.18)	8.0	11.6
Bottom Mount Auto Defrost	686.0 (24.2)	4.04	4.29	6.27	5.08	1.51 (5.15)	10.5	10.0
Freezers								
Upright Auto Defrost	716.3 (25.3)	-	-	4.90	7.01	1.54 (5.24)	9.0	-
Upright Manual Defrost	685.4 (24.2)	-	-	6.35	3.81	1.29 (4.40)	-	-
Chest Manual Defrost	723.1 (25.5)	-	-	6.41	5.48	1.22 (4.15)	-	-
Compacts								
Manual Defrost Refrigerator-Freezer	46.2 (1.6)	2.67	2.59	-**	-**	0.80 (2.73)	-	-
Auto Defrost Refrigerator-Freezer	104.7 (3.7)	3.81	3.81	-**	-**	0.91 (3.10)	-	12.0
Compact Freezers								
Chest Manual Defrost	254.1 (9.0)	-	-	6.38	4.60	1.14 (3.88)	-	-
Upright Manual Defrost	258.0 (9.1)	-	-	4.19	5.49	1.07 (3.65)	-	-

* Average thickness of all the sides except the door.

** Contains an ice box whose walls do not act as insulators.

Compressor data were obtained directly from four major compressor manufacturers. Table 3.4 shows the maximum COP for compressors likely to be available to the refrigerator manufacturers before the standard goes into effect (1998). All the compressor data used for the simulations are either maps of actual compressors or extrapolations from such maps. The extrapolation consisted of multiplying the power requirements in the compressor map by a constant factor to make the compressor COP equal to that of the baseline or the highest achievable (as the case may be). For example, for the case of the 622 L (22 ft^3) side-by-side refrigerator-freezer without through-the-door features, the baseline compressor had a COP of 1.50 (5.13 EER) at the nominal conditions whereas the R134a compressor of similar capacity had a COP of 1.54 (5.27 EER). In order to reconcile the difference in the performance of the two compressors at the nominal condition, the power requirement of the R134a compressor was multiplied by the factor 1.54/1.50 for each combination of the evaporator and condenser temperatures. The fan motor power demand is chosen to be 4.50 W for the more efficient

evaporator and condenser fan motors. The evacuated panel thermal conductance value is 5.76 mW/m·K (25 hr-ft^2-°F/Btu-in) and it is assumed that 50% of the total surface area is covered by 2.54 cm (1 inch) thick panels.

Table 3.4 Estimated 1998 Compressor COPs (using HFC 134a)

Product Class Served	Capacity Range		Maximum by 1998	
	(W)	(Btu/h)	COP	EER
The Five Standard Refrigerator-Freezers	220 to 278	750 to 950	1.64	5.60
	176 to 205	600 to 700	1.60	5.45
Auto Defrost Upright Freezers	250 to 278	850 to 950	1.64	5.60
Manual Defrost Upright Freezers	161 to 176	550 to 600	1.51	5.15
Manual Defrost Chest Freezers	147 to 161	500 to 550	1.45	4.95
Compacts	117	400	1.38	4.70
	103	350	1.26	4.30
	59	200	1.04	3.55
	41	140	0.76	2.6

The heat leak into the cabinet can be reduced by either increasing the insulation thickness or improving the resistivity of the insulation (vacuum insulation panels). Two possible levels of insulation increase have been considered, 2.54 cm (1 inch) increase and a 1.27 cm (1/2 inch) increase. Since a manufacturer would either increase insulation thickness or use vacuum panels, the two options are mutually exclusive. This results in three branches in the analysis for each product class; first where the insulation is increased by 2.54 cm (1 inch), second where the insulation increase is limited to 1.27 cm (1/2 inch), and the third where 50% of the surface area is covered by 2.54 cm (1 inch) thick insulation panels. These options were not considered feasible for compacts or units with volume of 220 L (7.75 ft^3.) or less. Most of the compacts are "under the counter" units. This requires that the exterior dimensions do not exceed 61 cm (24 inch) depth and 86.4 cm height (34 inch). Since most units already have the maximum allowable depth and height, any increase in insulation thickness would result in reduced consumer utility. If insulation is added on the outside, the units will not fit in the space provided for them, and if insulation is added on the inside, the refrigerated volume will decrease. For compacts, the chest freezer is an exception because it does not belong to the "under the counter" category and hence insulation increase on the outside does not decrease consumer utility. VPI was not considered for compacts.

Specific assumptions concerning cost and efficiency for each design option analyzed follow.

The design options are ordered by their cost-effectiveness (the first option being the most cost-effective and the last one being the least cost-effective). The results of the simulation analyses for the nine product classes for which data were available are shown in Tables 3.5 to 3.13. For each design level, compressor run-time, heat leakage rate into the cabinet, compressor power demand at the operating point, fan motor power for evaporator and condenser fans, and annual energy use are shown. The DOE test procedure is run both with and without the anti-sweat heaters in operation and the annual energy use is calculated from the average of the two daily energy use values. To take this into account, the simulations are performed with only half the anti-sweat heater power.

Increased Insulation Thickness for Walls and Doors

The insulation in walls and doors were increased by both 1.27 cm (0.5 inch) and 2.54 cm (1 inch). The cost estimates for these changes were obtained from the manufacturers of refrigerators and freezers and the energy savings were obtained from the ERA program.

Improved Resistivity of Insulation

For the cases where fiberglass was used as the insulation, it was replaced by foam of k-value 18.87 mW/m·K (7.71 hr-ft^2-°F/Btu-in) The cost estimate for this change was obtained from a previous Technical Support Document [7]. The energy savings were obtained from the ERA program.

Evacuated Insulation Panels

Evacuated insulation panels of 2.54 cm thickness and k-value of 5.76 mW/m·K (25 hr-ft^2-°F/Btu-in) are assumed to cover 50% of the wall and door surface area. Using this assumption, the equivalent resistivity of the walls and doors was calculated and used in the ERA program to determine the energy savings. The cost was derived from Waldron [8]. This cost includes the savings that result from using 2.54 cm thinner foam.

Improved Gaskets

The gasket heat leaks in the ERA program were reduced. The cost and efficiency improvements for this design option were based on estimates by refrigerator and freezer manufacturers.

Reduce Heat Load of Through-the-Door Feature

The ancillary heat leak in the ERA program was reduced. The cost and efficiency improvements for this design option were based on estimates by refrigerator and freezer manufacturers.

Condenser Hot Gas for Anti-Sweat Heat

The heat from the electric heaters was replaced by heat from the hot condenser gas. The same amount of heat was generated but the electricity use was eliminated. The costs for this design option were based on estimates by refrigerator and freezer manufacturers.

Adaptive Defrost

The defrost heater wattage was reduced in the ERA program. The cost and efficiency improvements for this design option were based on estimates by refrigerator and freezer manufacturers.

High-Efficiency Compressor Substitution

Table 3.4 shows the maximum COP compressors likely to be available to the refrigerator manufacturers before the standard goes into effect. All the compressor data used for the simulations are either maps of actual compressors or extrapolations from such maps. Costs were obtained by averaging the data received from compressor manufacturers.

Fan and Fan Motor Improvement

Based on input from three motor manufacturers, the fan motor power demand was chosen to be 4.50 W for the more efficient evaporator and condenser fan motors. The cost ($6.50 for evaporator fan motor and $4.50 for condenser fan motor) of switching to better motors was also obtained from the motor manufacturers. The cost and efficiency improvements for the more efficient fan design were based on estimates by refrigerator and freezer manufacturers.

Improved Evaporator and Condenser Heat Exchange

The cost and efficiency improvements for this design option were based on estimates by refrigerator and freezer manufacturers.

Manual/Partial Defrost - Free Standing Products (Taller than 91.4 cm)

A detailed ERA analysis of these product classes was not possible as no data were available. For large manual defrost refrigerators, an approximate analysis was performed by removing the defrost heater from the top mount refrigerator-freezer (adjusted volume 606.0 L (21.4 ft^3)) and performing an ERA simulation analysis. This modification resulted in a decrease of the energy use of the unit by approximately 9% at all design option levels. There may be other differences between auto and manual defrost refrigerators, such as the presence of other equipment such as fan motors and anti-sweat heaters. These potential differences were not accounted for in these simulations.

Partial auto-defrost refrigerator-freezers taller than 91.4 cm (36 inches) were not analyzed. Such products employ two evaporators; the one in the fresh-food section is defrosted automatically. In some partial auto-defrost units, an electric heater is used around the drain pipe to keep water from freezing up. Analysis of a smaller (85.7 L [~3 ft^3]) partial auto-defrost refrigerator-freezer showed that a two-evaporator refrigeration system uses about 5.2% less energy than a typical single evaporator system. Energy consumption of a partial auto-defrost unit, relative to a top-mount unit, depends upon the particular configuration to achieve defrosting and its impact on energy use. If the defrost energy were equal in magnitude to the savings (~5%) from a two-evaporator system, then partial auto-defrost refrigerator-freezers could use approximately the same amount of energy as a similar sized manual defrost refrigerator.

Table 3.5 Energy Use of a Top Mount Auto Defrost Refrigerator-Freezer

Design Opt. Level	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	259.53	43	86.32	145.15	9.10	12.00	700.86
1		0 + 5.45 EER Compressor	270.59	43	86.30	125.36	9.10	12.00	620.13
2		1 + Reduce Condenser Motor Power	275.09	43	86.30	125.36	9.10	4.50	594.45
3		2 + Add 1/2" Insulation to Doors	278.71	42	83.32	123.45	9.10	4.50	572.43
4		3+ Reduce Evaporator Motor Power	285.21	41	81.23	123.45	4.50	4.50	543.07
5		4 + Improve Evaporator Fan Efficiency	286.02	40	81.18	124.73	4.50	4.50	539.40
6		5 + Add 1/2" Insulation to Walls	297.37	37	74.06	123.79	4.50	4.50	495.37
7	1	6 + Reduce Gasket Heat Leak	300.34	36	72.23	123.82	4.50	4.50	484.36
8		7 + Add 1" Insulation to Doors	303.45	35	70.40	123.85	4.50	4.50	473.35
9		8 + Add 1" Insulation to Walls	312.35	33	65.79	123.92	4.50	4.50	444.00
10		9+ Increase Condenser Area	315.61	32	65.74	125.27	4.50	4.50	436.66
11		10 + Adaptive Defrost	322.76	32	64.91	123.99	4.50	4.50	425.65
12		11 + Increase Evaporator Area	325.86	31	64.80	125.38	4.50	4.50	421.98
13	2	7 + Increase Evaporator Area	303.45	35	72.08	126.22	4.50	4.50	477.02
14		13 + Increase Condenser Area	306.71	34	72.02	127.55	4.50	4.50	469.69
15	3	14 + Adaptive Defrost	313.86	34	71.14	125.15	4.50	4.50	458.68
16		2+ Reduce Evaporator Motor Power	281.59	42	84.15	124.43	4.50	4.50	561.42
17		16 + Improve Evaporator Fan Efficiency	282.40	42	84.09	123.66	4.50	4.50	557.75
18		17 + Reduce Gasket Heat Leak	285.37	41	82.30	123.68	4.50	4.50	546.74
19		18 + Increase Evaporator Area	288.47	40	82.13	124.76	4.50	4.50	539.40
20		19 + Increase Condenser Area	291.73	39	82.06	125.90	4.50	4.50	532.07
21		20 + Vacuum Panels on Walls & Doors	338.48	32	66.05	124.02	4.50	4.50	432.99
22	4	21 + Adaptive Defrost	345.63	31	65.25	126.70	4.50	4.50	421.98

Assumptions:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 515.06 L (18.2 ft^3) refrigerator. A correction factor of 1.005 was applied to the ERA values in order to account for the difference beween the simulated and the actual baseline usage.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 700.86 kWh, the ERA baseline cost is $259.53.

(3) Baseline: Compressor EER = 4.68; Evaporator fan motor power = 9.10 W; Condenser fan motor power = 12.00 W. Insulation thicknesses: freezer & fresh-food doors 3.81 cm (1.50"); freezer sides (avg of, top, side and back) 5.46 cm (2.15"); fresh-foods sides (avg of bottom, sides and back) 4.32 cm (1.70"). Foam resistivity is 0.58 $m^2 \cdot °C/W \cdot cm$ in the doors, sides, top and bottom. Evaporator and condenser areas: 2.22 m and 0.64 m, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation," prepared for US EPA Global Change division, EPA Project No. X818749-01-0, October 1992.

Table 3.6 Energy Use of a Top Mount Auto Defrost Refrigerator-Freezer With Through-The-Door Features

Design Opt. Number	Std. Level Number	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	492.93	47	102.01	137.42	9.10	12.00	795.37
1		0 + Reduce Condenser Motor Power	497.43	47	102.01	137.42	9.10	4.50	759.58
2		1+ Reduce Evaporator Motor Power	503.93	45	99.70	139.87	4.50	4.50	723.79
3		2 + 5.60 EER Compressor	510.68	45	99.69	135.37	4.50	4.50	703.91
4		3 + Reduce Load for TTD Features	521.81	43	95.25	134.96	4.50	4.50	672.09
5		4 + Adaptive Defrost	531.10	43	94.33	133.19	4.50	4.50	656.18
6		5 + Add 1" Insulation to Doors	560.32	40	88.91	135.82	4.50	4.50	620.39
7		6 + Reduce Gasket Heat Leak	570.08	40	87.66	133.77	4.50	4.50	612.44
8		7 + Add 1" Insulation to Walls	721.03	33	73.17	135.11	4.50	4.50	520.97
9		8 + Improve Evaporator Fan Efficiency	724.70	33	73.13	135.12	4.50	4.50	516.99
10		9 + Increase Condenser Area	750.46	33	73.07	132.69	4.50	4.50	509.04
11		10 + Increase Evaporator Area	809.90	32	73.01	135.57	4.50	4.50	505.06
12		5 + Reduce Gasket Heat Leak	540.86	42	93.07	134.42	4.50	4.50	648.23
13		12 + Add 1/2" Insulation to Doors	566.75	41	89.74	133.51	4.50	4.50	628.34
14	1	13 + Improve Evaporator Fan Efficiency	570.42	40	89.70	136.02	4.50	4.50	624.37
15	2	14 + Add 1/2" Insulation to Walls	688.28	37	80.83	132.68	4.50	4.50	568.69
16		15 + Increase Condenser Area	714.04	36	80.77	133.00	4.50	4.50	556.76
17	3	16 + Increase Evaporator Area	773.47	35	80.70	136.81	4.50	4.50	552.78
18		4 + VPI to Walls and Doors	571.03	35	76.94	134.40	4.50	4.50	548.81
19		18 + Adaptive Defrost	580.32	35	76.19	132.06	4.50	4.50	536.88
20		19 + Reduce Gasket Heat Leak	590.08	34	74.94	134.74	4.50	4.50	528.92
21		20 + Increase Condenser Area	615.84	34	74.88	131.18	4.50	4.50	520.97
22	4	21 + Increase Evaporator Area	675.27	33	74.81	135.17	4.50	4.50	516.99

Assumptions:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 610.7 L (21.58 ft^3) refrigerator. A correction factor of 1.09 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 795.37 kWh, the ERA baseline cost is $492.93.

(3) Baseline: Compressor EER = 5.40; Evaporator fan motor power = 9.10 W; Condenser fan motor power = 12.00 W. Insulation thicknesses freezer & fresh-food doors 3.81 cm (1.50"); freezer sides (avg of, top, sides and back) 5.08 cm (2.00"); fresh-food sides (avg of bottom, sides and back) 3.99 cm (1.57"). Foan resistivity is 0.58 $m^2 \cdot °C/W \cdot cm$ in the doors, sides, top and bottom. Evaporator and condenser area 2.51 m^2 and 0.70 m^2, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes material, labor, installation, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators. Cost Estimates for Manufacturing and Installation," prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.

Table 3.7 Energy Use of a Side-by-Side Auto Defrost Refrigerator-Freezer

Design Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	397%	47	115.07	170.96	10.00	10.00	761.19
1		0 + 5.60 EER Compressor	407%	47	114.00	156.88	10.00	10.00	699.75
2		1+ Reduce Evaporator Motor Power	413%	45	111.10	156.81	4.50	10.00	662.20
3	1	2 + Reduce Condenser Motor Power	418%	45	111.10	156.81	4.50	4.50	641.72
4		3 + Adaptive Defrost	423%	43	109.75	154.96	4.50	4.50	624.66
5		4 + Add 1" Insulation to Walls	463%	43	90.31	156.32	4.50	4.50	518.84
6		5 + Enhanced Evaporator HT Surface	465%		90.14	155.24	4.50	4.50	512.01
7		6 + Add 1" Insulation to Doors	476%	40	85.51	155.24	4.50	4.50	488.12
8		7 + Reduce Gasket Heat Leak	484%	40	83.42	156.40	4.50	4.50	474.47
9		8 + Increase Condenser Area	489%	33	83.28	155.01	4.50	4.50	467.64
				33					
10		4 + Add 1/2" Insulation to Walls	448%	33	97.86	155.46	4.50	4.50	559.80
11		10 + Enhanced Evaporator HT Surface	451%	32	97.67	158.63	4.50	4.50	552.98
12		11 + Add 1/2" Insulation to Doors	457%		94.97	158.63	4.50	4.50	539.32
13	2	12 + Improved Evaporator Fan Efficiency	458%	42	94.90	158.63	4.50	4.50	535.91
14		13 + Increase Condenser Area	463%	41	94.75	155.47	4.50	4.50	529.08
15	3	14 + Reduce Gasket Heat Leak	471%	40	92.66	156.51	4.50	4.50	518.84
				37					
16		4 + Increase Condenser Area	428%	36	109.58	155.88	4.50	4.50	614.42
17		16 + Enhanced Evaporator HT Surface	431%	35	109.38	157.81	4.50	4.50	607.59
18		17 + Vacuum Panel Insulation in W & D	482%		91.52	155.33	4.50	4.50	515.43
19		18 + Improved Evaporator Fan Efficiency	483%	35	91.46	159.94	4.50	4.50	512.01
20	4	19 + Reduce Gasket Heat Leak	491%	35%	89.36	156.44	4.50	4.50	501.70

Assumptions:

(1) Energy consumption for the baseline and for each design option were obtained from an ERA simulation of an actual 620 L (21.91 ft^3) refrigerator. A correction factor of 0.935 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 761.19 kWh, the ERA baseline cost is $396.95.

(3) Baseline: Compressor EER = 5.13; Evaporator fan motor power = 10.0 W; Condenser fan motor power = 10.0 W. Insulation thicknesses: freezer & fresh-food doors 5.08 cm (2.00"); freezer sides (avg of top, side, bottom and back) 5.38 cm (2.12"); fresh-food sides (avg of top, side, bottom and back) 5.21 cm (2.05"). Foam resistivity is 0.573 $m^2 \cdot °C/W \cdot cm$ in the doors, sides, top and bottom. Evaporator and condenser UA products: 34.3 W/°C and 30.3 W/°C, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foan insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foan Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation," prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.

Table 3.8 Energy Use of a Side-by-Side Auto Defrost Refrigerator-Freezer With Through-The-Door Features

Design. Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	597.41	43	97.41	150.06	8.00	11.60	799.93
1		0 + Add 1/2" Insulation to Doors	601.73	41	93.56	151.40	8.00	11.60	768.41
2		1 + 5.60 EER Compressor	608.48	41	93.56	139.80	8.00	11.60	725.06
3		2 + Reduce Condenser Motor Power	612.98	41	93.56	139.80	8.00	4.50	697.48
4		3 + Increase Evaporator Area	615.18	40	93.20	140.29	8.00	4.50	685.66
5	1	4 + Increase Condenser Area	618.05	39	93.06	140.84	8.00	4.50	669.89
6		5 + Add 1" Insulation to Doors	621.02	38	90.64	139.42	8.00	4.50	654.13
7		6 + Reduce TTD Features Load	623.99	37	88.10	139.90	8.00	4.50	638.37
8		7 + Reduce Evaporator Motor Power	630.49	36	86.70	141.54	4.50	4.50	618.67
9		8 + Improve Evaporator Fan Efficiency	631.55	36	86.63	141.27	4.50	4.50	614.73
10		9 + Add 1" Insulation to Walls	659.47	31	73.30	139.59	4.50	4.50	531.97
11		10 + Reduce Gasket Heat Leak	666.95	29	70.35	142.24	4.50	4.50	516.21
12		11 + Adaptive Defrost	671.43	29	69.84	142.24	4.50	4.50	508.33
13		5 + Reduce TTD Features Load	621.02	38	90.52	139.42	4.50	4.50	654.13
14		13 + Reduce Evaporator Motor Power	627.52	37	89.08	141.00	4.50	4.50	634.43
15		14 + Improve Evaporator Fan Efficiency	628.58	37	89.01	141.85	4.50	4.50	630.49
16	2	15 + Add 1/2" Insulation to Walls	646.14	34	81.11	140.35	4.50	4.50	583.20
17		16 + Adaptive Defrost	650.61	34	80.52	139.17	4.50	4.50	571.38
18	3	17 + Reduce Gasket Heat Leak	658.10	32	77.61	142.81	4.50	4.50	555.62
19		0 + Increase Evaporator Area	599.61	41	97.05	153.43	4.50	4.50	784.17
20		19 + 5.60 EER Compressor	606.36	41	97.04	142.82	4.50	4.50	736.88
21		20 + Reduce Condenser Motor Power	610.86	41	97.04	142.82	4.50	4.50	709.30
22		21 + Increase Condenser Area	613.72	40	93.89	142.40	4.50	4.50	693.54
23		22 + Reduce TTD Features Load	616.70	40	94.36	138.51	4.50	4.50	681.71
24		23 + Improve Evaporator Fan Efficiency	617.75	39	94.26	141.88	4.50	4.50	677.77
25		24 + Reduce Evaporator Motor Power	624.25	38	92.78	143.47	4.50	4.50	654.13
26		25 + Adaptive Defrost	628.73	38	92.11	142.40	4.50	4.50	642.31
27		26 + VPI on Doors and Walls	680.05	31	73.98	139.59	4.50	4.50	531.97
28	4	27 + Reduce Gasket Heat Leak	687.54	30	71.09	138.85	4.50	4.50	516.21

Assumptions (for Table 3.8):

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 613.0 L (21.66 ft^3) refrigerator. A correction factor of 1.08 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 799.93 kWh, the ERA baseline cost is $597.41.

(3) Baseline: Compressor EER = 5.18; Evaporator fan motor power = 8.0 W; Condenser fan motor power = 11.6 W. Insulation thicknesses: freezer & fresh-food doors 3.81 cm (1.50") ; freezer sides (avg of, top, side, bottom and back) 5.84 cm (2.30"); fresh-food sides (avg of top, side, bottom and back) 5.13cm (2.02"). Foam resistivity is 0.53 $m^2 \cdot °C/W \cdot cm$ in the doors, sides, top and bottom. Evaporator and condenser areas : 1.55 m^2 and 0.84 m^2, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation", prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.

Table 3.9 Energy Use of a Bottom Mount Auto Defrost Refrigerator-Freezer

Design. Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. EnergyO Use (kWh/a)
0		BASELINE	405.21	39	90.40	142.75	10.50	10.00	714.81
1		0 + Reduce Evaporator Motor Power	411.71	38	87.82	142.23	4.50	10.00	669.62
2		1 + 5.60 EER Compressor	418.46	38	87.82	129.99	4.50	10.00	624.43
3		2 + Reduce Condenser Motor Power	422.96	38	87.82	129.99	4.50	4.50	603.89
4		3 + Add 1" Insulation to Walls	447.68	32	74.42	131.57	4.50	4.50	521.73
5		4 + Add 1/2" Insulation to Doors	453.10	31	71.26	130.59	4.50	4.50	501.19
6		5 + Reduce Gasket Heat Leak	457.26	30	69.35	130.89	4.50	4.50	488.86
7		6 + Add 1" Insulation to Doors	462.04	29	67.31	131.22	4.50	4.50	472.43
8		7 + Adaptive Defrost	469.43	29	66.43	129.82	4.50	4.50	460.11
9		8 + Increase Evaporator Area	474.34	28	66.26	133.06	4.50	4.50	451.89
10		9 + Increase Condenser Area	483.86	28	66.20	130.25	4.50	4.50	443.67
11	1	3 + Add 1/2" Insulation to Doors	428.38	36	84.74	132.72	4.50	4.50	587.46
12		11 + Add 1/2" Insulation to Walls	445.78	33	76.46	132.03	4.50	4.50	534.05
13		12 + Reduce Gasket Heat Leak	449.94	32	74.60	132.34	4.50	4.50	521.73
14	2	13 + Improve Evaporator Fan Efficiency	451.71	32	74.53	131.59	4.50	4.50	517.62
15		14 + Increase Evaporator Area	456.62	31	74.31	133.27	4.50	4.50	509.40
16		15 + Adaptive Defrost	464.01	30	73.39	136.36	4.50	4.50	497.08
17	3	16 + Increase Condenser Area	473.53	30	73.31	133.74	4.50	4.50	484.75
18		3 + Reduce Gasket Heat Leak	427.12	37	86.00	131.32	4.50	4.50	591.56
19		18 + VPI Insulation to Walls and Doors	469.48	29	68.03	132.64	4.50	4.50	476.54
20		19 + Increase Evaporator Area	474.39	28	67.83	135.97	4.50	4.50	468.32
21		20 + Adaptive Defrost	481.77	28	66.98	131.63	4.50	4.50	456.00
22		21 + Improve Evaporator Fan Efficiency	483.55	28	66.31	133.10	4.50	4.50	451.89
23	4	22 + Increase Condenser Area	493%	27	66.85	135.09	4.50	4.50	443.67

Assumption:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 577.6 L (20.41 ft^3) refrigerator. A correction factor of 1.126 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 714.81 kWh, the ERA baseline cost is $405.22

(3) Baseline: Compressor EER = 5.15; Evaporator fan motor power = 10.50 W; Condenser fan motor power = 10.0 W. Insulation thicknesses: freezer & fresh-food doors 5.08 cm (2") and 4.29 cm (1.69"), respectively; freezer sides (avg of sides, bottom and back) 6.27 cm (2.47"); fresh- food sides (avg of top, sides and back) 4.04 cm (1.59"). Foam resistivity is 0.53 $m^2 \cdot °C/W \cdot cm$ in the doors, and 0.55 $m^2 \cdot °C/W \cdot cm$ in sides, top and bottom. Evaporator and condenser areas : 3.56 m^2 and 7.94 m^2, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation", prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.

Table 3.10 Energy Use of an Upright Auto Defrost Freezer

Design Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	268.43	72.3	100.60	125.93	9.00	0.00	759.24
1		0+ Reduce Evaporator Fan Motor Power	274.93	69.7	97.04	125.63	4.50	0.00	711.14
2		1 + 5.60 EER Compressor	281.68	69.7	97.04	118.48	4.50	0.00	674.62
3		2+ Evaporator Enhanced HT Surface	284.29	68.5	96.88	119.42	4.50	0.00	667.96
4		3 + Add 1" Insulation to Walls	320.13	59.1	83.58	119.38	4.50	0.00	580.15
5		4 + Reduce Gasket Heat Leak	322.06	58.6	82.85	119.34	4.50	0.00	575.23
6		5+ Add 1" Insulation to Door	330.99	56.4	79.70	119.32	4.50	0.00	554.36
7		6 +Condenser Hot Gas for Anti-Sweat Heater	351.51	56.4	79.70	119.25	4.50	0.00	526.25
8		7 +Adaptive Defrost	359.78	55.8	78.86	119.27	4.50	0.00	515.53
9		8 + Increase Condenser Area	367.00	55.2	78.79	118.26	4.50	0.00	506.55
10	1	3 + Reduce Gasket Heat Leak	286.23	68.0	96.17	119.39	4.50	0.00	663.32
11	2	10+ Add 1/2" Insulation to Walls	314.30	62.3	88.12	119.40	4.50	0.00	610.00
12		11 + Add 1/2" Insulation to Door	321.82	61.1	86.32	119.25	4.50	0.00	598.12
13		12 + Increase Condenser Area	329.04	60.4	86.23	118.40	4.50	0.00	587.98
14		13 +Condenser Hot Gas for Anti-Sweat Heater	349.56	60.4	86.23	120.35	4.50	0.00	559.87
15	3	14 +Adaptive Defrost	357.83	59.7	85.33	118.45	4.50	0.00	548.57
16		2 + Vacuum Panel Insulation to Walls & Door	315.45	55.3	77.12	139.12	4.50	0.00	541.03
17		16 + Reduce Gasket Heat Leak	317.39	54.8	76.31	118.51	4.50	0.00	536.40
18		17 + Evaporator Enhanced HT Surface	320.00	53.9	76.18	119.35	4.50	0.00	531.18
19		18 + Condenser Hot Gas for Anti-Sweat Heater	340.51	53.9	76.18	119.27	4.50	0.00	503.07
20		19 +Adaptive Defrost	348.79	53.3	75.38	119.30	4.50	0.00	492.64
21	4	20 + Increase Condenser Area	356.01	52.7	75.31	118.39	4.50	0.00	483.94

Assumptions:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 414.0 L (14.63 ft^3) upright freezer. A correction factor of 0.934 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage. A correction factor of 0.85 was also applied as specified in the test procedure for upright freezers.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 759.24 kWh, the ERA baseline cost is $268.43.

(3) Baseline: Compressor EER = 5.24; Evaporator fan motor power = 9.0W; Insulation thicknesses: freezer door 7.01 cm (2.76"); freezer sides (avg of sides, bottom, top and back) 4.90 cm (1.93"); Foam resistivity is 0.53 $m^2 \cdot °C/W \cdot cm$ in the doors, sides, top and bottom. Evaporator and condenser areas : 1.05 m^2 and 1.22 m^2, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation", prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.

Table 3.11 Energy Use of an Upright Manual Defrost Freezer

Design Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	182.57	64.6	93.05	108.81	0.00	0.00	482.94
1	1	0 + Foam Insulation to Door	184.39	56.7	81.74	108.92	0.00	0.00	424.31
2		1 + 5.15 EER Compressor	189.64	56.5	81.39	93.06	0.00	0.00	361.15
3		2 + Enhanced Condenser HT Surface	190.44	55.7	81.03	92.48	0.00	0.00	353.78
4		3+ Reduce Gasket Heat Leak	192.77	54.0	78.60	85.62	0.00	0.00	343.30
5		4 + Add 1" Insulation to Door	198.78	50.1	72.86	92.45	0.00	0.00	318.09
6		5 + Add 1" Insulation to Walls	219.00	43.1	62.41	92.97	0.00	0.00	275.04
7		6 + Increase Evaporator Area	223.05	42.4	62.38	94.12	0.00	0.00	273.90
8	2	4 + Add 1/2" Insulation to Door	196.93	51.6	75.08	92.56	0.00	0.00	328.00
9		8 + Add 1/2" Insulation to Walls	210.54	47.5	68.91	92.79	0.00	0.00	302.51
10	3	9 + Increase Evaporator Area	214.60	46.7	68.88	93.97	0.00	0.00	301.38
11		4 + Vacuum Panel Insulation in Walls & Door	223.42	43.8	63.41	92.74	0.00	0.00	279.00
12	4	11 + Increase Evaporator Area	227.48	43.0	63.37	94.09	0.00	0.00	277.87

Assumptions:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 396.2 L (14 ft^3) upright freezer. A correction factor of 0.913 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage. A correction factor of 0.85 was also applied as specified in the test procedure for upright freezers.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 482.94 kWh, the ERA baseline cost is $182.57.

(3) Baseline: Compressor EER = 4.40. Insulation thicknesses: freezer door 3.81cm (1.50") ; freezer sides (avg of sides, bottom, top and back) 6.35 cm (2.50"); Foam resistivity is 0.521 $m^2 \cdot °C/W \cdot cm$ in the sides, top and bottom; and 0.286 $m^2 \cdot °C/W \cdot cm$ in the door. Evaporator and condenser Areas: 2.15 m^2 and 2.15 m^2, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation", prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.

Table 3.12 Energy Use of a Chest Manual Defrost Freezer

Design Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	170.42	85.7	74.35	100.91	0.00	0.00	471.72
1		0 + Add 1/2" Insulation to Walls	179.83	72.6	65.49	99.18	0.00	0.00	392.91
2		1 + Add 1" Insulation to Walls	186.35	64.6	59.65	98.15	0.00	0.00	345.76
3		2 + 4.56 EER Compressor	191.87	64.5	59.65	89.39	0.00	0.00	314.55
4		3 + 4.95 EER Compressor	197.12	64.4	59.65	116.46	0.00	0.00	289.18
5		4 + Add 1" Insulation to Door	201.62	62.1	57.46	82.26	0.00	0.00	278.63
6		5 + Reduce Gasket Heat Leak	203.39	61.2	56.64	82.26	0.00	0.00	274.59
7		6 + Increase Evaporator Area	205.51	60.5	56.72	82.74	0.00	0.00	273.02
8		7 + Enhanced condenser HT Surface	220.89	59.5	56.72	82.07	0.00	0.00	266.28
9		1 + 4.56 EER Compressor	185.35	72.5	65.49	90.33	0.00	0.00	357.21
10		9 + 4.95 EER Compressor	190.60	72.4	65.49	83.20	0.00	0.00	328.47
11	2	10 + Reduce Gasket Heat Leak	192.37	71.5	64.68	83.21	0.00	0.00	324.43
12		11 + Add 1/2" Insulation to Door	195.67	70.2	63.42	83.11	0.00	0.00	318.14
13		12 + Increase Evaporator Area	197.78	69.2	63.54	83.66	0.00	0.00	315.67
14	3	13 + Enhanced Condenser HT Surface	213.17	68.1	63.54	82.79	0.00	0.00	307.59
15		0 + 4.56 EER Compressor	175.94	85.6	74.35	91.76	0.00	0.00	428.61
16	1	0 + 4.95 EER Compressor	181.19	85.5	74.35	84.54	0.00	0.00	394.03
17		16 + Vacuum Panel Insulation on Walls & Door	212.01	65.7	59.49	83.16	0.00	0.00	297.94
18		17 + Reduce Gasket Heat Leak	213.79	64.9	58.70	83.04	0.00	0.00	293.90
19		18 + Increase Evaporator Area	215.90	64	58.82	83.51	0.00	0.00	291.43
20	4	19 + Enhanced Condenser HT Surface	231.29	63	58.82	82.69	0.00	0.00	284.02

Assumptions:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 418.0 L (14.77 ft^3) chest freezer. A correction factor of 0.88 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage. A correction factor of 0.7 was also applied as specified in the test procedure for chest freezers.

(2) Manufacturer cost of the baseline unit was interpolated from the AHAM manufacturer cost vs kWh curve for this product class. Using a linear interpolation between the two closest points on the AHAM curve to the ERA baseline consumption of 471.72 kWh, the ERA baseline cost is $170.42.

(3) Baseline: Compressor EER = 4.15. Insulation thicknesses: freezer door 6.41 cm (2.52") ; freezer sides (avg of sides and bottom) 5.48 cm (2.15"); Foam resistivity is 0.55 $m^2 \cdot °C/W \cdot cm$ in the door, sides, and bottom. Evaporator and condenser areas : 1.56 m^2 and 1.08 m^2, respectively.

(4) Vacuum panel option assumes that 50% of total wall and door surface area is covered by 2.54 cm (1") thick vacuum panels. The delta cost (compared to foam insulation) assumes a variable cost of $3.24/$dm^3$ ($1.20 per board foot), which includes materials, installation, labor, and shipping. A depreciated investment cost of $10/unit was also assumed. Both costs are derived from Waldron, J.M., "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation", prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992 .

Table 3.13 Energy Use of a Compact Manual Defrost Refrigerator-Freezer

Design Opt. #	Std. Level #	Option	Mfg. Cost (1992$)	Duty Cycle (%)	Cab. Heat Load (W)	Comp. Power (W)	Evap. Fan Power (W)	Cond. Fan Power (W)	Ann. Energy Use (kWh/a)
0		BASELINE	75.62	67	23.25	57.55	0.00	0.00	277.20
1	1	0 + Enhanced Condenser HT Surface	76.92	66	23.23	54.63	0.00	0.00	271.09
2	2	1 + Enhanced Evaporator HT Surface	77.53	63	23.15	53.51	0.00	0.00	264.99
3	3	2 + Reduce Gasket Heat Leak	78.53	62	22.69	52.46	0.00	0.00	259.85

Assumptions:

(1) Energy consumptions for the baseline and for each design option were obtained from an ERA simulation of an actual 42.46 L (1.5 ft^3) manual-defrost refrigerator. A correction factor of 0.88 was applied to the ERA values in order to account for the difference between the simulated and the actual baseline usage.

(2) Manufacturer cost of the baseline unit was obtained by dividing the manufacturer suggested retail price by the the markup factor.

(3) Evaporator area is 0.15 m^2 and condenser area is 0.22 m^2.

3.4.1 Energy Use Versus Adjusted Volume

The energy consumption of refrigerator-freezers and freezers depends, among other factors, on the volume of the fresh-food and freezer compartments. The relationship between energy consumption and adjusted volume is investigated by modeling products of different capacity but otherwise identical characteristics. For refrigerator-freezers, the adjusted volume (in the DOE test procedure), AV, is defined as the fresh-food volume plus 1.63 times the freezer volume:

$$AV = V_{fresh\text{-}food} + 1.63 \cdot V_{freezer}$$

For freezers, the adjusted volume is defined to be equal to 1.73 times the freezer volume.

The relationship between adjusted volume and energy use was studied for the case of the top mount automatic defrost refrigerator-freezer only. After having chosen one particular model as the baseline and ordering the options by their cost-effectiveness, the same options were applied to eight other top mount automatic defrost refrigerator-freezers with adjusted volumes ranging from 488 L (17.25 ft^3) to 789 L (27.88 ft^3) in the same order. This analysis was done using earlier life-cycle cost analysis. This earlier analysis assumed a 1.46 COP (4.98 EER) compressor for the baseline and also assumed a maximum of 1.70 COP (5.8 EER) to be achievable. This results in a slightly different ordering of options and a difference in the energy use associated with each level as compared to the previously described analysis for top mount refrigerator-freezers. A regression equation resulting from fitting energy use to adjusted volume was obtained for each level of design change, as shown in Figure 3.2. Table 3-14 shows the coefficients for the linear regression lines for each design level. For example, the regression equation for level 3 is the following:

$$\text{Energy Use} = 314.2 + 11.2 \cdot \text{AV}$$

where AV is in ft^3.

The constant is an indicator of direct energy use for fan motors and heaters and compressor energy use to remove the internally generated heat from fan motors and heaters. The slope is the rate of change in energy use with a change in adjusted volume. Lower slopes are associated with a lower rate of cabinet heat gain.

An example shows how to use Table 3.14. Level 5 (E = 274.5 + 10.6 AV) results in a 28.1% energy savings relative to the 1993 standard energy use (at an adjusted volume of 606 L [21.4 ft^3]). Level 6 (E = 284.4 + 8.46 AV) results in 33.26% energy savings. The Energy Savings column in Table 3.14 shows the percent energy savings from the baseline for a top mount refrigerator freezer with adjusted volume of 606.0 L [21.4 ft^3] for each level of regression line. The 1993 standard energy use for this unit is 697.6 kWh/a.

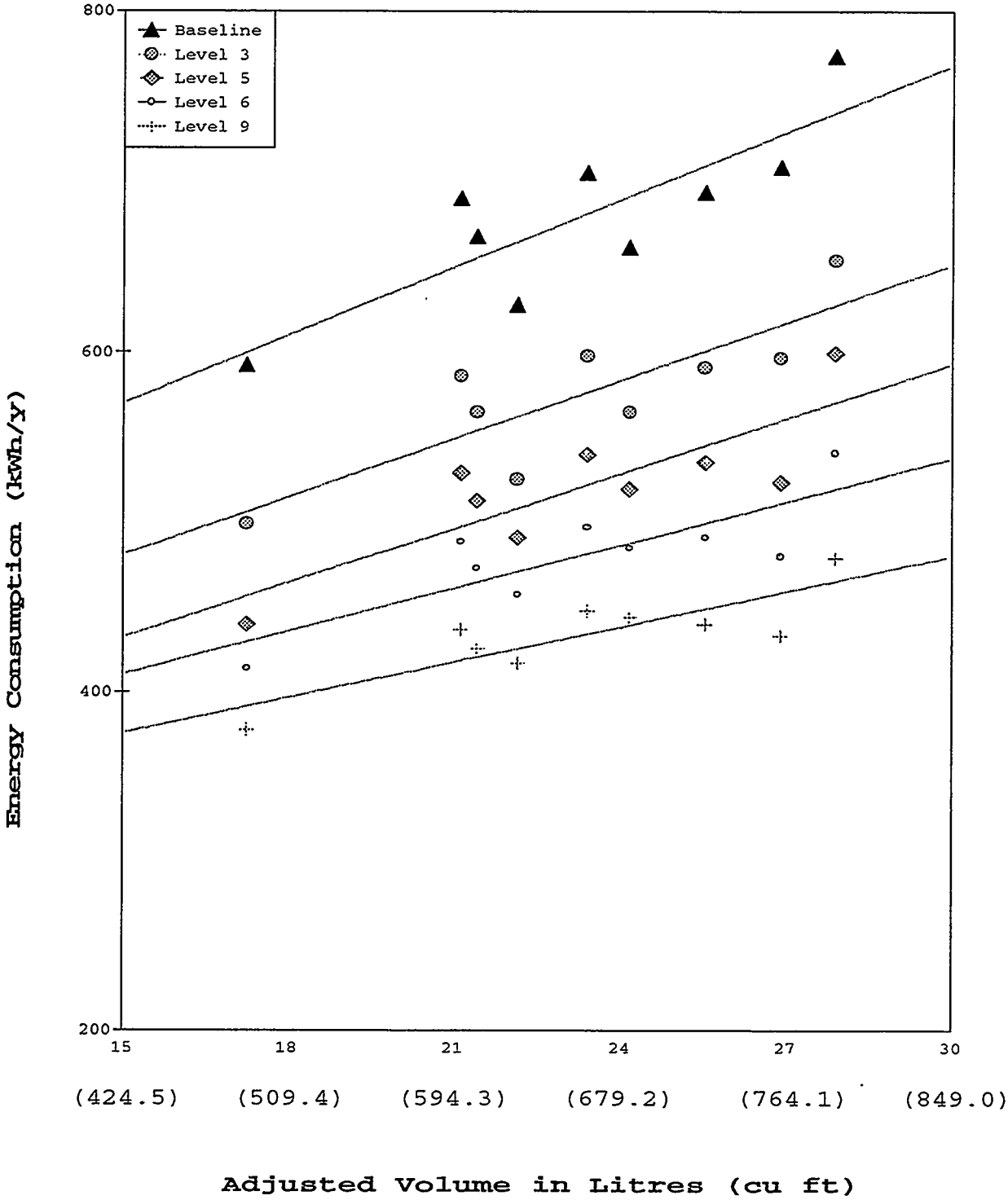

Figure 3.2 Annual energy use vs adjusted volume for top mount auto defrost refrigerator-freezer

Table 3.14 Regression Coefficients for Top Mount A-D Refrigerator-Freezers

Design Opt. #	Design Option	% Energy Savings*	Intercept	Slope		R^2
			kWh/a	kWh/a·L	*(kWh/a·ft³)*	
0	Baseline	—	374.23	0.46	*(13.10)*	0.70
1	0 + 1.59 COP Compressor	11.80	349.50	0.44	*(12.40)*	0.70
2	0 + 1.7 COP Compressor	16.50	327.90	0.42	*(11.90)*	0.69
3	2 + Reduce Condenser Motor Power	20.60	314.20	0.40	*(11.20)*	0.69
4	3 + Reduce Evaporator Motor Power	26.11	277.80	0.39	*(11.10)*	0.63
5	4 + Add 1.27 cm Insulation to Doors	23.10	274.50	0.37	*(10.60)*	0.69
6	5 + Add 1.27 cm Insulation to Walls	33.30	284.40	0.30	*(8.46)*	0.67
7	6 + Reduce Gasket Heat Leak	34.70	269.60	0.31	*(8.68)*	0.67
8	7 + Add 2.54 cm Insulation to Doors	36.20	268.20	0.29	*(8.27)*	0.69
9	8 + Add 2.54 cm Insulation to Walls	39.70	272.04	0.25	*(6.95)*	0.70
10	9 + Increase Evaporator Area	40.70	261.37	0.25	*(7.10)*	0.71
11	10 + Increase Condenser Area	41.40	252.51	0.26	*(7.30)*	0.72
12	11 + Adaptive Defrost	43.30	246.21	0.25	*(6.97)*	0.69

* Relative to 1993 standard energy use at an adjusted volume of 606 L *(21.41 ft³)* .

After completing this analysis for the 606 L top mount refrigerator-freezer, the result was compared with the slope and intercept, for the same type and capacity refrigerator-freezer, provided by the Joint Comments of AHAM and others [8] at an energy use level of 30.35% below the 1993 Standard. The slope for this level of energy savings was found to be close to that obtained by the above regression analysis. It is assumed that the slopes for all product classes will fall close to those provided by Joint Comments. Using this assumption, the following tables provide the slopes for the energy equation for all design option levels of all product classes analyzed, based on the Joint Comments' provided slopes. The method used for obtaining these slopes and intercepts is as follows:

1) find the level with energy consumption closest to that for which the Joint Comments has supplied an energy equation,
2) keeping the slope the same as that of the Joint Comments, change the intercept to make the energy use equal to that of the design level chosen in step 1, and
3) multiply the resulting slope and intercept by a constant at each level so that the energy use equals that of the particular design level.

For manual defrost compact refrigerator-freezers, the slopes and intercepts were obtained by

using the energy consumptions used in the LBL-REM analysis, as they are closer to actual consumption than those obtained by the ERA analysis.

Table 3.15 Top Mount Auto Defrost Refrigerator-Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	*(kWh/a·ft³)*	Intercept kWh/a
0	0.50	*(14.18)*	397.21
1	0.44	*(12.55)*	351.46
2	0.42	*(12.03)*	336.90
3	0.41	*(11.58)*	324.42
4	0.39	*(10.99)*	307.78
5	0.39	*(10.91)*	305.70
6	0.35	*(10.02)*	280.75
7	0.35	*(9.80)*	274.51
8	0.34	*(9.58)*	268.27
9	0.32	*(8.98)*	251.64
10	0.31	*(8.83)*	247.48
11	0.30	*(8.61)*	241.24
12	0.30	*(8.54)*	239.16
13	0.34	*(9.65)*	270.35
14	0.34	*(9.50)*	266.20
15	0.33	*(9.28)*	259.96
16	0.40	*(11.36)*	318.18
17	0.40	*(11.28)*	316.10
18	0.39	*(11.06)*	309.86
19	0.39	*(10.91)*	305.70
20	0.38	*(10.77)*	301.55
21	0.31	*(8.76)*	245.40
22	0.30	*(8.54)*	239.16

Table 3.16 Top Mount Auto Defrost Refrigerator-Freezer with Through-the-Door Features: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	*(kWh/a·ft³)*	Intercept kWh/a
0	0.46	*(12.99)*	461.67
1	0.44	*(12.41)*	440.89
2	0.42	*(11.82)*	420.12
3	0.41	*(11.50)*	408.58
4	0.39	*(10.98)*	390.11
5	0.38	*(10.72)*	380.87
6	0.36	*(10.14)*	360.10
7	0.35	*(10.01)*	355.49
8	0.30	*(8.51)*	302.39
9	0.30	*(8.45)*	300.08
10	0.29	*(8.32)*	295.47
11	0.29	*(8.25)*	293.16
12	0.37	*(10.59)*	376.26
13	0.36	*(10.26)*	364.71
14	0.36	*(10.20)*	362.41
15	*0.33*	*(9.29)*	330.09
16	0.32	*(9.10)*	323.17
17	0.32	*(9.03)*	320.86
18	0.32	*(8.97)*	318.55
19	0.31	*(8.77)*	311.63
20	0.31	*(8.64)*	307.01
21	0.30	*(8.51)*	302.39
22	0.30	*(8.45)*	300.08

Table 3.17 Side-by-Side Auto Defrost Refrigerator-Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	*(kWh/a·ft³)*	Intercept kWh/a
0	0.21	*(5.82)*	609.35
1	0.19	*(5.35)*	560.17
2	0.18	*(5.07)*	530.11
3	0.17	*(4.91)*	513.71
4	0.17	*(4.78)*	500.06
5	0.14	*(3.97)*	415.34
6	0.14	*(3.92)*	409.88
7	0.13	*(3.73)*	390.75
8	0.13	*(3.63)*	379.83
9	0.13	*(3.58)*	374.36
10	0.15	*(4.28)*	448.13
11	0.15	*(4.23)*	442.67
12	0.15	*(4.13)*	431.74
13	0.14	*(4.10)*	429.01
14	0.14	*(4.05)*	423.54
15	0.14	*(3.97)*	415.34
16	0.17	*(4.70)*	491.86
17	0.16	*(4.65)*	486.39
18	0.14	*(3.94)*	412.61
19	0.14	*(3.92)*	409.88
20	0.14	*(3.84)*	401.68

Table 3.18 Side-by-Side Auto Defrost Refrigerator-Freezer with Through-the-Door Features: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	Slope *(kWh/a·ft³)*	Intercept kWh/a
0	0.43	*(12.06)*	484.18
1	0.41	*(11.59)*	465.10
2	0.39	*(10.93)*	438.86
3	0.37	*(10.52)*	422.17
4	0.37	*(10.34)*	415.02
5	0.36	*(10.10)*	405.47
6	0.35	*(9.86)*	395.93
7	0.34	*(9.62)*	386.39
8	0.33	*(9.33)*	374.47
9	0.33	*(9.27)*	372.08
10	0.28	*(8.02)*	321.99
11	0.28	*(7.78)*	312.45
12	0.27	*(7.66)*	307.68
13	0.35	*(9.86)*	395.93
14	0.34	*(9.57)*	384.01
15	0.34	*(9.51)*	381.62
16	0.31	*(8.79)*	353.00
17	0.30	*(8.61)*	345.84
18	0.30	*(8.38)*	336.30
19	0.42	*(11.82)*	474.64
20	0.39	*(11.11)*	446.02
21	0.38	*(10.69)*	429.32
22	0.37	*(10.46)*	419.78
23	0.36	*(10.28)*	412.62
24	0.36	*(10.22)*	410.24
25	0.35	*(9.86)*	395.93
26	0.34	*(9.68)*	388.78
27	0.28	*(8.02)*	321.99
28	0.28	*(7.78)*	312.45

Table 3.19 Bottom Mount Auto Defrost Refrigerator-Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	Slope *(kWh/a·ft³)*	Intercept kW.h/a
0	0.20	*(5.60)*	579.13
1	0.19	*(5.24)*	542.52
2	0.17	*(4.89)*	505.91
3	0.17	*(4.73)*	489.27
4	0.14	*(4.09)*	422.70
5	0.14	*(3.92)*	406.06
6	0.14	*(3.83)*	396.07
7	0.13	*(3.70)*	382.76
8	0.13	*(3.60)*	372.78
9	0.13	*(3.54)*	366.12
10	0.12	*(3.47)*	359.46
11	0.16	*(4.60)*	475.95
12	0.15	*(4.18)*	432.68
13	0.14	*(4.09)*	422.70
14	0.14	*(4.05)*	419.37
15	0.14	*(3.99)*	412.71
16	0.14	*(3.89)*	402.73
17	0.13	*(3.80)*	392.74
18	0.16	*(4.63)*	479.28
19	0.13	*(3.73)*	386.09
20	0.13	*(3.67)*	379.43
21	0.13	*(3.57)*	369.45
22	0.13	*(3.54)*	366.12
23	0.12	*(3.47)*	359.46

Table 3.20 Upright Auto Defrost Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	Slope *(kWh/a·ft³)*	Intercept kWh/a
0	0.50	*(14.23)*	399.13
1	0.47	*(13.33)*	373.84
2	0.45	*(12.64)*	354.65
3	0.44	*(12.52)*	351.14
4	0.38	*(10.87)*	304.98
5	0.38	*(10.78)*	302.40
6	0.37	*(10.39)*	291.42
7	0.35	*(9.86)*	276.65
8	0.34	*(9.66)*	271.01
9	0.34	*(9.49)*	266.29
10	0.44	*(12.43)*	348.70
11	0.40	*(11.43)*	320.67
12	0.40	*(11.21)*	314.43
13	0.39	*(11.02)*	309.10
14	0.37	*(10.49)*	294.32
15	0.36	*(10.28)*	288.38
16	0.36	*(10.14)*	284.42
17	0.36	*(10.05)*	281.98
18	0.35	*(9.95)*	279.24
19	0.33	(9.43)	264.46
20	0.33	*(9.23)*	258.98
21	0.32	*(9.07)*	254.41

Table 3.21 Upright Manual Defrost Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	Slope *(kWh/a·ft³)*	Intercept kWh/a
0	0.30	*(8.59)*	274.82
1	0.27	*(7.55)*	241.46
2	0.23	*(6.43)*	205.51
3	0.22	*(6.30)*	201.32
4	0.22	*(6.11)*	195.36
5	0.20	*(5.66)*	181.01
6	0.17	*(4.89)*	156.51
7	0.17	*(4.87)*	155.86
8	0.21	*(5.84)*	186.65
9	0.19	*(5.38)*	172.14
10	0.19	*(5.36)*	171.50
11	0.18	*(4.96)*	158.77
12	0.17	*(4.94)*	158.12

Table 3.22 Chest Manual Defrost Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	Slope *(kWh/a·ft³)*	Intercept kWh/a
0	0.42	*(11.83)*	169.50
1	0.35	*(9.85)*	141.18
2	0.31	*(8.67)*	124.24
3	0.28	*(7.89)*	113.02
4	0.26	*(7.25)*	103.91
5	0.25	*(5.00)*	100.12
6	0.24	*(6.89)*	98.67
7	0.24	*(6.85)*	98.10
8	0.24	*(6.68)*	95.68
9	0.32	*(8.96)*	128.35
10	0.29	*(8.24)*	118.03
11	0.29	*(8.13)*	116.57
12	0.28	*(7.98)*	114.31
13	0.28	*(7.92)*	113.43
14	0.27	*(7.71)*	110.52
15	0.38	*(10.75)*	154.01
16	0.35	*(9.88)*	141.58
17	0.26	*(7.47)*	107.06
18	0.26	*(7.37)*	105.60
19	0.26	*(7.31)*	104.72
20	0.25	*(7.12)*	102.05

Table 3.23. Compact Manual Defrost Refrigerator-Freezer: Slopes and Intercepts for Individual Design Levels

Level	Slope kWh/a·L	*(kWh/a·ft³)*	Intercept kWh/a
0	0.49	*(13.80)*	292.47
1	0.48	*(13.50)*	286.03
2	0.47	*(13.20)*	279.59
3	0.46	*(12.94)*	274.17

3.5 COST EFFICIENCY DATA

Manufacturer cost and energy efficiency data are presented in Tables 3.5 to 3.13 for all the product classes that were analyzed. The manufacturer cost is the cost to the manufacturer of producing products with the design options shown, and does not include any markups to wholesalers or retailers. The energy use data are annual unit energy consumption in kWh. All costs, except those for fan motors, compressors, and VPI, were obtained from refrigerator manufacturers. The data were collected from several refrigerator-freezer manufacturers and averaged in order to protect the confidentiality of data received from individual manufacturers. Independent estimates of the cost of purchased parts were obtained from compressor and fan motor manufacturers. Estimates for vacuum panel insulation were derived from Waldron [9].

Appendix A contains disaggregated costs for nine product classes. Total costs are divided between variable and fixed costs. The variable cost is further subdivided into material, labor, burden, and shipment. The fixed part of the cost is divided into tooling, building and equipment, and research and development. Variable costs for compacts were not subdivided into their components; instead these categories were combined under the heading "variable costs".

3.6 MAXIMUM TECHNOLOGICALLY FEASIBLE DESIGN

For three (both side-by-sides and top-mount with TTD features) of the five product classes for refrigerator-freezers, the energy consumption at the maximum technologically feasible efficiency level can be obtained by increasing the insulation by 2.54 cm. For example, for the side-by-side refrigerator-freezer, the minimum energy use is 467.6 kWh/a which can be obtained by using a 1.64 COP (5.60 EER) compressor, 4.5 W condenser and evaporator fan motors, adaptive defrost, adding 2.54 cm insulation to the walls and the doors, improving the heat transfer of the condenser and evaporator by 15% and 10% respectively, and reducing the gasket heat leak by 6.6%. The other two classes happen to consume the same energy at the maximum technologically feasible efficiency level whether the insulation is increased by 2.54 cm or vacuum panels are employed for insulation. For one of the three freezer classes, the energy consumption at the maximum technologically feasible

efficiency level can be obtained by employing vacuum panels while in two cases a 2.54 cm increase in insulation results in the lowest energy use. For the manual defrost refrigerator-freezer, the maximum technologically feasible efficiency level occurs at design option 3 and incorporates reduced gasket heat leak and enhanced condenser and evaporator heat transfer surfaces.

REFERENCES

1. A.J. Hunt, C.A. Jantzen and W. Cao, *Aerogel - A High Performance Insulating Material at 0.1 Bar*, Insulation Materials: Testing and Applications, Vol. 2 ASTM STP 1116, R.S. Graves and D.C. Wysocki, Eds., American Society for Testing and Materials, Philadelphia, PA, 1991.
2. B.T. Griffith, D. Arasteh, and S. Selkowitz, *Gas-Filled Panel High-Performance Thermal Insulation*, Insulation Materials: Testing and Applications, Vol. 2 ASTM STP 1116, R.S. Graves and D.C. Wysocki, Eds., American Society for Testing and Materials, Philadelphia, PA, 1991.
3. *Finite Element Analysis of Heat Transfer Through the Gasket Region of Refrigerators/ Freezers*, EPA/430/R-92/009, October 1992.
4. Federal Register, Vol. 53, No. 186, September 26, 1988.
5. J.R. Sand, Oak Ridge National Laboratory, personal communication dated March 16, 1994.
6. F.L. Izagulrre, *Admiral Refrigerator Test Report for the Admiral Company*, International Technical Services, Inc., August 25, 1993.
7. U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets*, November 1988, page 3-46.
8. Joint Comments of The Association of Home Appliance Manufacturers, The Natural Resources Defense Council, The American Council for An Energy Efficient Economy, the New York State Energy Office, the California Energy Commission, Pacific Gas and Electric, and Southern California Edison, relating to Energy Conservation Standarrds for Refrigferator/Freezers, Docket No. EE-RM-93-801, November 15, 1994.
9. J.M. Waldron, *Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation*, prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992.
10. R. Merriam, A. Verone, and H. Feng, *EPA Refrigerator Analysis (ERA) Program: User's Manual Version 1.0*, Arthur D. Little Inc., March 1993, Cambridge, MA.

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 3) for energy consumption and equipment price and assuming the energy price projected for 1998. 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 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 5). 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.

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

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

$$LCC = PC + PWF \cdot OC, \tag{2}$$

where we have defined the present worth factor:

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

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 3) and includes a factory markup plus distributor and retailer markups, calculated by LBL-MAM. 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, 1998. For the residential sector, the discount rate is 6% real, with sensitivity analysis performed at 2% and 15% real. The energy price is the projected 1998 average residential electricity price.

4.1.2 LCC Results

Figures 4.1 to 4.9 show the LCCs by design option. The values used to produce these figures are presented in Tables 4.1 through 4.9. For the case of the compact manual defrost refrigerator-freezer, the energy use used to calculate the LCC is different from that presented in Chapter 3. The energy use listed in Chapter 3 is obtained by multiplying the energy predicted by the ERA model by the ratio of the test energy consumption and the ERA prediction with the original R-12 compressor map. However, for the case of manual defrost refrigerator-freezer, it was found that the ERA predictions with an R-134a compressor map were more accurate and hence those numbers are being used to calculate the LCC. For the sake of consistency in methodology, the energy use in Chapter 3 is left unchanged.

Table 4.1 Life-Cycle Costs for Top Mount Auto Defrost Refrigerator-Freezer (Adjusted Volume = 606.0 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$554.67	700.86	$61.68	$1521.65	$1242.85	$936.95
1	0 + 5.45 EER Compressor	$572.89	620.13	$54.57	$1428.49	$1181.81	$911.14
2	1 + Reduce Condenser Motor Power	$580.39	594.45	$52.31	$1400.55	$1164.08	$904.63
3	2 + Add 1/2" Insulation to Doors	$586.46	572.43	$50.37	$1376.24	$1148.54	$898.69
4	3+ Reduce Evaporator Motor Power	$597.37	543.07	$47.79	$1346.65	$1130.62	$893.59
5	4 + Improve Evaporator Fan Efficiency	$598.69	539.40	$47.47	$1342.91	$1128.34	$892.90
6	5 + Add 1/2" Insulation to Walls	$618.88	495.37	$43.59	$1302.35	$1105.29	$889.08
7	6 + Reduce Gasket Heat Leak	$623.89	484.36	$42.62	$1292.17	$1099.49	$888.08
8	7 + Add 1" Insulation to Doors	$629.24	473.35	$41.66	$1282.33	$1094.03	$887.43
9	8 + Add 1" Insulation to Walls	$645.43	444.00	$39.07	$1258.02	$1081.40	$887.61
10	9+ Increase Condenser Area	$651.50	436.66	$38.43	$1253.96	$1080.26	$889.67
11	10 + Adaptive Defrost	$663.67	425.65	$37.46	$1250.94	$1081.62	$895.84
12	11 + Increase Evaporator Area	$668.81	421.98	$37.13	$1251.02	$1083.16	$898.98
13	7 + Increase Evaporator Area	$628.99	477.02	$41.98	$1287.14	$1097.39	$889.18
14	13 + Increase Condenser Area	$635.06	469.69	$41.33	$1283.09	$1096.25	$891.25
15	14 + Adaptive Defrost	$647.23	458.68	$40.36	$1280.07	$1097.61	$897.41
16	2+ Reduce Evaporator Motor Power	$591.26	561.42	$49.41	$1365.85	$1142.53	$897.48
17	16 + Improve Evaporator Fan Efficiency	$592.58	557.75	$49.08	$1362.11	$1140.24	$896.80
18	17 + Reduce Gasket Heat Leak	$597.59	546.74	$48.11	$1351.93	$1134.44	$895.81
19	18 + Increase Evaporator Area	$602.68	539.40	$47.47	$1346.90	$1132.33	$896.89
20	19 + Increase Condenser Area	$608.75	532.07	$46.82	$1342.84	$1131.19	$898.96
21	20 + Vacuum Panels on Walls & Doors	$688.52	432.99	$38.10	$1285.92	$1113.68	$924.69
22	21 + Adaptive Defrost	$700.69	421.98	$37.13	$1282.90	$1115.04	$930.86

Average lifetime = 19 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

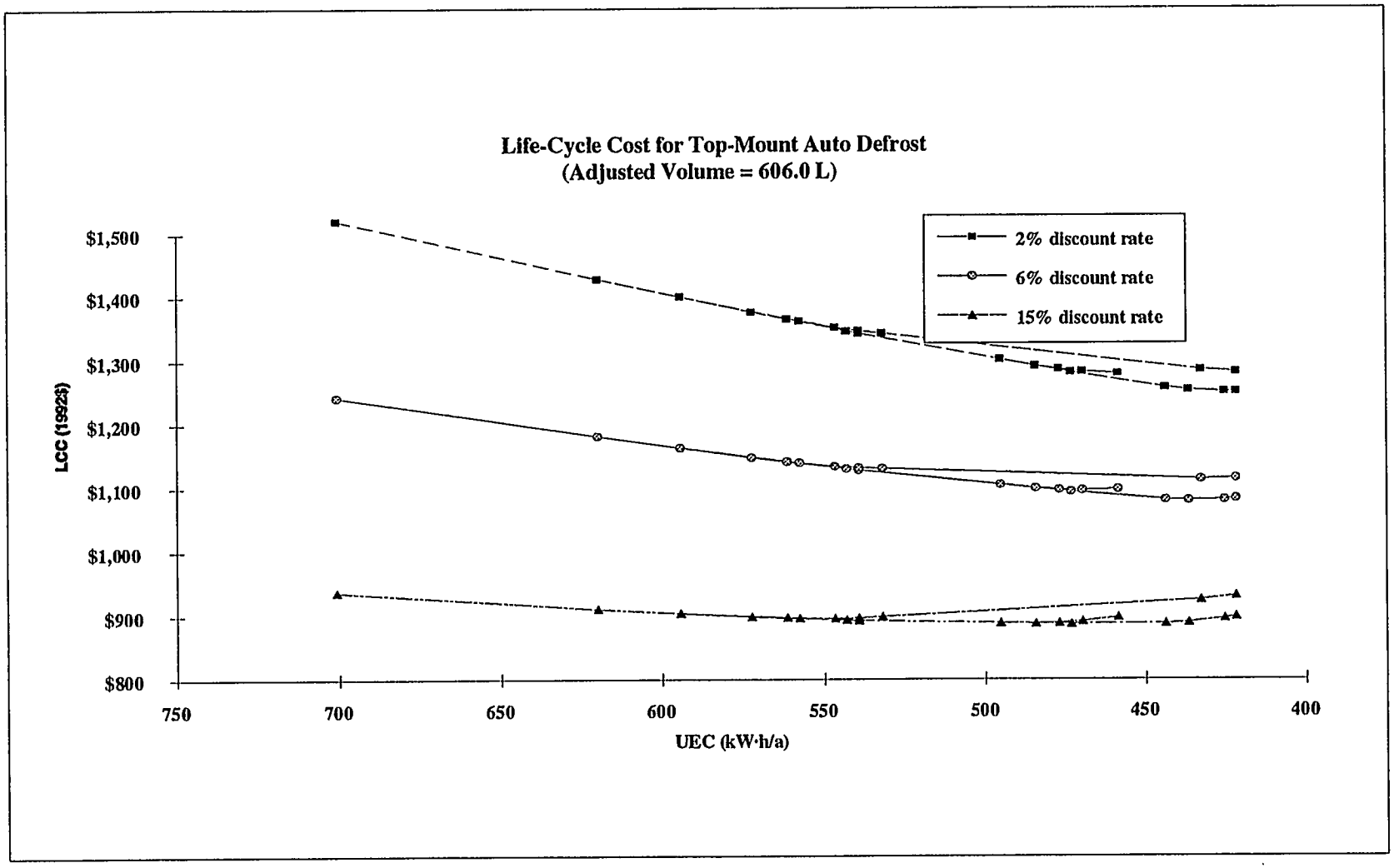

Figure 4.1 Life-cycle cost for design options of top mount auto defrost refrigerator-freezer

Table 4.2 Life-Cycle Costs for Top Mount Auto Defrost Refrigerator-Freezer With Through-The-Door Features (Adjusted Volume = 726.8 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$1047.28	795.37	$69.99	$2144.66	$1828.27	$1481.11
1	0 + Reduce Condenser Motor Power	$1054.28	759.58	$66.84	$2102.28	$1800.12	$1468.59
2	1+ Reduce Evaporator Motor Power	$1064.55	723.79	$63.69	$2063.17	$1775.25	$1459.34
3	2 + 5.60 EER Compressor	$1075.37	703.91	$61.94	$2046.55	$1766.54	$1459.31
4	3 + Reduce Load for TTD Features	$1095.56	672.09	$59.14	$2022.85	$1755.50	$1462.15
5	4 + Adaptive Defrost	$1108.98	656.18	$57.74	$2014.32	$1753.30	$1466.89
6	5 + Add 1" Insulation to Doors	$1158.89	620.39	$54.59	$2014.85	$1768.06	$1497.28
7	6 + Reduce Gasket Heat Leak	$1175.50	612.44	$53.89	$2020.48	$1776.86	$1509.55
8	7 + Add 1" Insulation to Walls	$1489.02	520.97	$45.85	$2207.80	$2000.57	$1773.18
9	8 + Improve Evaporator Fan Efficiency	$1492.75	516.99	$45.50	$2206.05	$2000.39	$1774.74
10	9 + Increase Condenser Area	$1556.95	509.04	$44.80	$2259.27	$2056.78	$1834.60
11	10 + Increase Evaporator Area	$1647.25	505.06	$44.45	$2344.09	$2143.18	$1922.73
12	5 + Reduce Gasket Heat Leak	$1125.59	648.23	$57.04	$2019.95	$1762.10	$1479.16
13	12 + Add 1/2" Insulation to Doors	$1170.26	628.34	$55.29	$2037.19	$1787.24	$1512.99
14	13 + Improve Evaporator Fan Efficiency	$1173.99	624.37	$54.94	$2035.43	$1787.07	$1514.55
15	14 + Add 1/2" Insulation to Walls	$1398.91	568.69	$50.04	$2183.54	$1957.32	$1709.10
16	15 + Increase Condenser Area	$1463.07	556.76	$48.99	$2231.24	$2009.76	$1766.75
17	16 + Increase Evaporator Area	$1553.36	552.78	$48.65	$2316.04	$2096.15	$1854.87
18	4 + VPI to Walls and Doors	$1174.66	548.81	$48.30	$1931.85	$1713.54	$1474.00
19	18 + Adaptive Defrost	$1188.12	536.88	$47.25	$1928.85	$1715.29	$1480.96
20	19 + Reduce Gasket Heat Leak	$1204.73	528.92	$46.55	$1934.49	$1724.09	$1493.23
21	20 + Increase Condenser Area	$1268.93	520.97	$45.85	$1987.71	$1780.48	$1553.09
22	21 + Increase Evaporator Area	$1359.22	516.99	$45.50	$2072.52	$1866.86	$1641.21

Average lifetime = 19 year
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

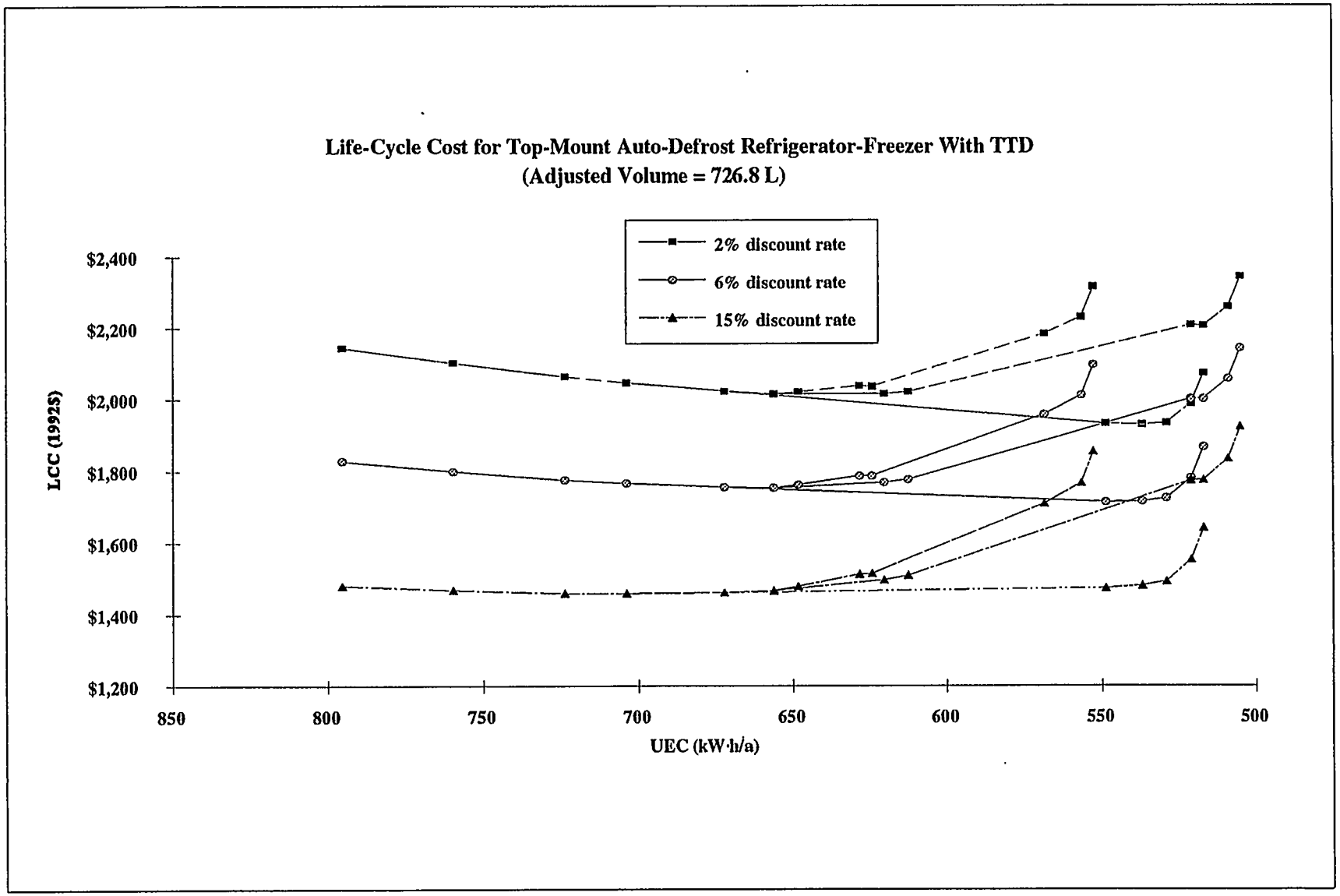

Figure 4.2 Life-cycle cost for design options of top mount auto defrost refrigerator-freezer with through-the-door feature

Table 4.3 Life-Cycle Costs for Side-by-Side Auto Defrost Refrigerator-Freezer (Adjusted Volume = 737.8 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$1055.08	761.19	$66.99	$2105.30	$1802.51	$1470.27
1	0 + 5.60 EER Compressor	$1074.35	699.75	$61.58	$2039.80	$1761.45	$1456.03
2	1+ Reduce Evaporator Motor Power	$1087.44	662.20	$58.27	$2001.09	$1737.67	$1448.64
3	2 + Reduce Condenser Motor Power	$1096.56	641.72	$56.47	$1981.95	$1726.68	$1446.58
4	3 + Adaptive Defrost	$1107.94	624.66	$54.97	$1969.78	$1721.30	$1448.66
5	4 + Add 1" Insulation to Walls	$1202.74	518.84	$45.66	$1918.59	$1712.20	$1485.74
6	5 + Enhanced Evaporator HT Surface	$1206.07	512.01	$45.06	$1912.50	$1708.82	$1485.35
7	6 + Add 1" Insulation to Doors	$1228.45	488.12	$42.95	$1901.91	$1707.74	$1494.69
8	7 + Reduce Gasket Heat Leak	$1241.93	474.47	$41.75	$1896.55	$1707.82	$1500.72
9	8 + Increase Condenser Area	$1251.37	467.64	$41.15	$1896.57	$1710.55	$1506.44
10	4 + Add 1/2" Insulation to Walls	$1162.41	559.80	$49.26	$1934.77	$1712.09	$1467.75
11	10 + Enhanced Evaporator HT Surface	$1165.75	552.98	$48.66	$1928.69	$1708.72	$1467.37
12	11 + Add 1/2" Insulation to Doors	$1179.64	539.32	$47.46	$1923.74	$1709.21	$1473.81
13	12 + Improve Evaporator Fan Efficiency	$1181.76	535.91	$47.16	$1921.15	$1707.98	$1474.07
14	13 + Increase Condenser Area	$1191.21	529.08	$46.56	$1921.19	$1710.72	$1479.79
15	14 + Reduce Gasket Heat Leak	$1204.72	518.84	$45.66	$1920.57	$1714.18	$1487.72
16	4 + Increase Condenser Area	$1117.34	614.42	$54.07	$1965.05	$1720.64	$1452.47
17	16 + Enhanced Evaporator HT Surface	$1120.68	607.59	$53.47	$1958.97	$1717.28	$1452.09
18	17 + Vacuum Panel Insulation in W & D	$1227.02	515.43	$45.36	$1938.16	$1733.13	$1508.16
19	18 + Improved Evaporator Fan Efficiency	$1229.14	512.01	$45.06	$1935.57	$1731.89	$1508.42
20	19 + Reduce Gasket Heat Leak	$1242.66	501.77	$44.16	$1934.96	$1735.36	$1516.35

Average lifetime = 19 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

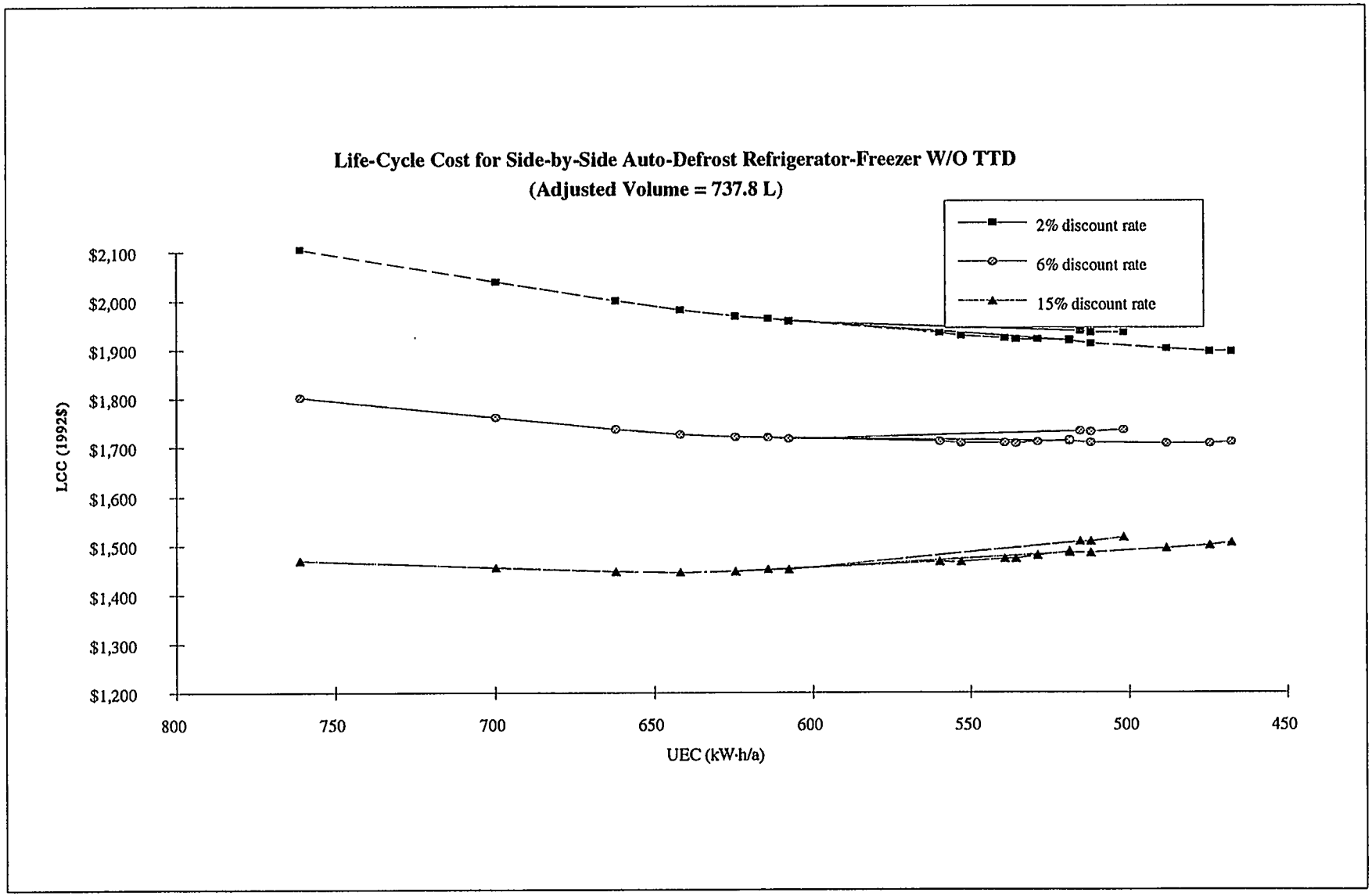

Figure 4.3 Life-cycle cost for design options of side-by-side auto defrost refrigerator-freezer

Table 4.4 Life-Cycle Costs for Side-by-Side Auto Defrost Refrigerator-Freezer with Through-The-Door Features (Adjusted Volume = 740.9 L)

Level	Option	Retail Price (1992$)	Annua Energ (kWh	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$1161.51	799.9	$70.39	$2265.18	$1946.97	$1597.83
1	0 + Add 1/2" Insulation to Doors	$1167.53	768.4	$67.62	$2227.70	$1922.04	$1586.65
2	1 + 5.60 EER Compressor	$1177.56	725.0	$63.81	$2177.93	$1889.51	$1573.04
3	2 + Reduce Condenser Motor	$1184.25	697.4	$61.38	$2146.56	$1869.11	$1564.68
4	3 + Increase Evaporator Area	$1187.02	685.6	$60.34	$2133.02	$1860.27	$1561.01
5	4 + Increase Condenser Area	$1191.30	669.8	$58.95	$2115.55	$1849.08	$1556.69
6	5 + Add 1" Insulation to Doors	$1196.30	654.1	$57.56	$2098.81	$1838.60	$1553.09
7	6 + Reduce TTD Features Load	$1199.88	638.3	$56.18	$2080.64	$1826.70	$1548.07
8	7 + Reduce Evaporator Motor	$1209.73	618.6	$54.44	$2063.31	$1817.21	$1547.18
9	8 + Improve Evaporator Fan	$1211.17	614.7	$54.10	$2059.31	$1814.78	$1546.47
10	9 + Add 1" Insulation to Walls	$1262.26	531.9	$46.81	$1996.23	$1784.61	$1552.42
11	10 + Reduce Gasket Heat Leak	$1271.83	516.2	$45.43	$1984.05	$1778.71	$1553.39
12	11 + Adaptive Defrost	$1278.57	508.3	$44.73	$1979.92	$1777.71	$1555.84
13	5 + Reduce TTD Features Load	$1194.88	654.1	$57.56	$2097.39	$1837.18	$1551.67
14	13 + Reduce Evaporator Motor	$1204.73	634.4	$55.83	$2080.05	$1827.68	$1550.78
15	14 + Improve Evaporator Fan	$1206.17	630.4	$55.48	$2076.06	$1825.25	$1550.07
16	15 + Add 1/2" Insulation to Walls	$1236.84	583.2	$51.32	$2041.49	$1809.49	$1554.94
17	16 + Adaptive Defrost	$1243.55	571.3	$50.28	$2031.88	$1804.60	$1555.21
18	17 + Reduce Gasket Heat Leak	$1253.12	555.6	$48.89	$2019.71	$1798.69	$1556.18
19	0 + Increase Evaporator Area	$1164.24	784.1	$69.01	$2246.16	$1934.23	$1591.96
20	19 + 5.60 EER Compressor	$1174.23	736.8	$64.85	$2190.91	$1897.79	$1576.16
21	20 + Reduce Condenser Motor	$1180.93	709.3	$62.42	$2159.55	$1877.40	$1567.81
22	21 + Increase Condenser Area	$1185.21	693.5	$61.03	$2142.09	$1866.20	$1563.50
23	22 + Reduce TTD Features Load	$1188.83	681.7	$59.99	$2129.39	$1858.22	$1560.67
24	23 + Improve Evaporator Fan	$1190.27	677.7	$59.64	$2125.40	$1855.79	$1559.96
25	24 + Reduce Evaporator Motor	$1200.08	654.1	$57.56	$2102.59	$1842.38	$1556.87
26	25 + Adaptive Defrost	$1206.78	642.3	$56.52	$2092.98	$1837.47	$1557.12
27	26 + VPI on Doors and Walls	$1284.93	531.9	$46.81	$2018.90	$1807.28	$1575.09
28	27 + Reduce Gasket Heat Leak	$1294.50	516.2	$45.43	$2006.72	$1801.38	$1576.06

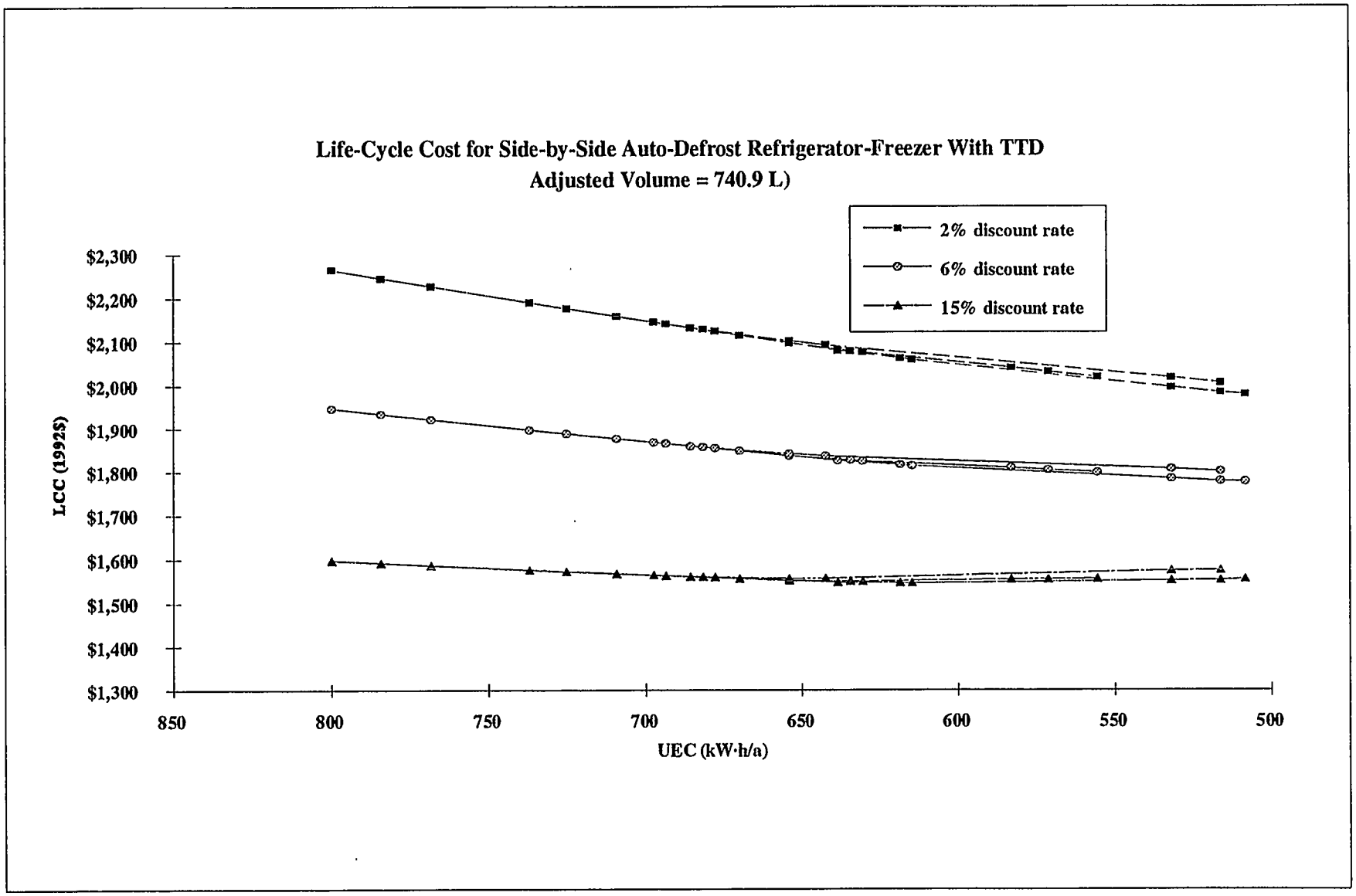

Figure 4.4 Life-cycle cost for design option of side-by-side auto defrost refrigerator-freezers with through-the-door features

Table 4.5 Life-Cycle Costs for Bottom Mount Auto Defrost Refrigerator-Freezer (Adjusted Volume = 686.0 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$908.95	714.81	$62.90	$1895.17	$1610.83	$1298.84
1	0 + Reduce Evaporator Motor Power	$919.42	669.62	$58.93	$1843.30	$1576.93	$1284.66
2	1 + 5.60 EER Compressor	$930.31	624.43	$54.95	$1791.84	$1543.45	$1270.90
3	2 + Reduce Condenser Motor Power	$937.68	603.89	$53.14	$1770.87	$1530.65	$1267.07
4	3 + Add 1" Insulation to Walls	$993.28	521.73	$45.91	$1713.11	$1505.57	$1277.85
5	4 + Add 1/2" Insulation to Doors	$1008.14	501.19	$44.10	$1699.63	$1500.26	$1281.51
6	5 + Reduce Gasket Heat Leak	$1018.66	488.86	$43.02	$1693.15	$1498.68	$1285.31
7	6 + Add 1" Insulation to Doors	$1021.93	472.43	$41.57	$1673.74	$1485.82	$1279.61
8	7 + Adaptive Defrost	$1040.41	460.11	$40.49	$1675.22	$1492.19	$1291.37
9	8 + Increase Evaporator Area	$1055.46	451.89	$39.77	$1678.93	$1499.18	$1301.94
10	9 + Increase Condenser Area	$1074.22	443.67	$39.04	$1686.36	$1509.87	$1316.22
11	3 + Add 1/2" Insulation to Doors	$952.58	587.46	$51.70	$1763.10	$1529.41	$1273.00
12	11 + Add 1/2" Insulation to Walls	$997.33	534.05	$47.00	$1734.16	$1521.72	$1288.63
13	12 + Reduce Gasket Heat Leak	$1007.85	521.73	$45.91	$1727.68	$1520.14	$1292.42
14	13 + Improve Evaporator Fan Efficiency	$1013.85	517.62	$45.55	$1728.01	$1522.11	$1296.18
15	14 + Increase Evaporator Area	$1028.91	509.40	$44.83	$1731.74	$1529.10	$1306.76
16	15 + Adaptive Defrost	$1047.39	497.08	$43.74	$1733.21	$1535.48	$1318.52
17	16 + Increase Condenser Area	$1066.10	484.75	$42.66	$1734.92	$1542.09	$1330.51
18	3 + Reduce Gasket Heat Leak	$948.19	591.56	$52.06	$1764.37	$1529.06	$1270.86
19	18 + VPI Insulation to Walls and Doors	$1018.37	476.54	$41.94	$1675.85	$1486.29	$1278.30
20	19 + Increase Evaporator Area	$1033.43	468.32	$41.21	$1679.58	$1493.28	$1288.87
21	20 + Adaptive Defrost	$1051.91	456.00	$40.13	$1681.05	$1499.66	$1300.63
22	21 + Improve Evaporator Fan Efficiency	$1057.91	451.89	$39.77	$1681.38	$1501.63	$1304.39
23	22 + Increase Condenser Area	$1076.66	443.67	$39.04	$1688.80	$1512.31	$1318.66

Average lifetime = 19 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

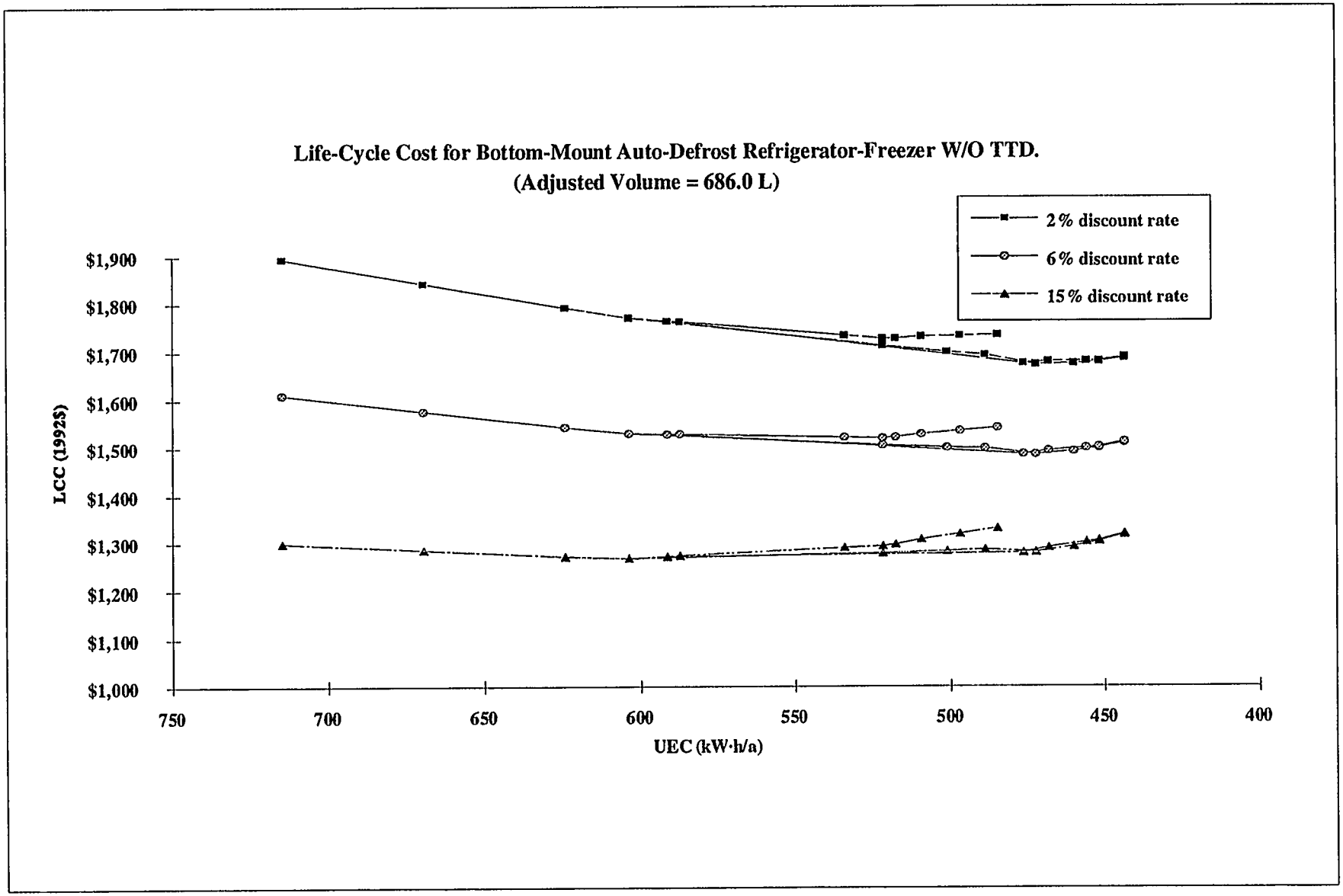

Figure 4.5 Life-cycle cost for design option of bottom mount auto defrost refergerator-freezers

Table 4.6 Life-Cycle Costs for Upright Auto Defrost Freezer (Adjusted volume = 716.3 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$451.11	759.24	$66.81	$1,498.64	$1,196.62	$865.23
1	0+ Reduce Evaporator Fan Motor Power	$462.88	711.14	$62.58	$1,444.04	$1,161.16	$850.77
2	1 + 5.60 EER Compressor	$475.19	674.62	$59.37	$1,405.97	$1,137.61	$843.16
3	2+ Evaporator Enhanced HT Surface	$479.23	667.96	$58.78	$1,400.82	$1,135.11	$843.56
4	3 + Add 1" Insulation to Walls	$545.50	580.15	$51.05	$1,345.94	$1,115.16	$861.94
5	4 + Reduce Gasket Heat Leak	$548.88	575.23	$50.62	$1,342.52	$1,113.70	$862.63
6	5+ Add 1" Insulation to Door	$566.26	554.36	$48.78	$1,331.12	$1,110.60	$868.63
7	6 +Condenser Hot Gas for Anti-Sweat Heat	$595.80	526.25	$46.31	$1,321.87	$1,112.53	$882.84
8	7 +Adaptive Defrost	$610.22	515.53	$45.37	$1,321.50	$1,116.43	$891.41
9	8 + Increase Condenser Area	$622.38	506.55	$44.58	$1,321.27	$1,119.77	$898.67
10	3 + Reduce Gasket Heat Leak	$482.61	663.32	$58.37	$1,397.80	$1,133.94	$844.42
11	10 + Add 1/2" Insulation to Walls	$534.23	610.00	$53.68	$1,375.85	$1,133.20	$866.95
12	11 + Add 1/2" Insulation to Door	$549.14	598.12	$52.63	$1,374.37	$1,136.44	$875.38
13	12 + Increase Condenser Area	$561.29	587.98	$51.74	$1,372.52	$1,138.63	$882.00
14	13 +Condenser Hot Gas for Anti-Sweat	$590.83	559.87	$49.27	$1,363.28	$1,140.57	$896.21
15	14 +Adaptive Defrost	$605.25	548.57	$48.27	$1,362.11	$1,143.89	$904.46
16	2 + Vacuum Panel Insulation to Walls & Door	$537.10	541.03	$47.61	$1,283.56	$1,068.35	$832.20
17	16 + Reduce Gasket Heat Leak	$540.48	536.40	$47.20	$1,280.55	$1,067.17	$833.05
18	17 + Evaporator Enhanced HT Surface	$544.53	531.18	$46.74	$1,277.40	$1,066.10	$834.26
19	18 + Condenser Hot Gas for Anti-Sweat Heat	$574.07	503.07	$44.27	$1,268.16	$1,068.04	$848.47
20	19 +Adaptive Defrost	$588.49	492.64	$43.35	$1,268.18	$1,072.22	$857.20
21	20+ Increase Condenser Area	$600.65	483.94	$42.59	$1,268.35	$1,075.84	$864.61

Average lifetime = 19 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

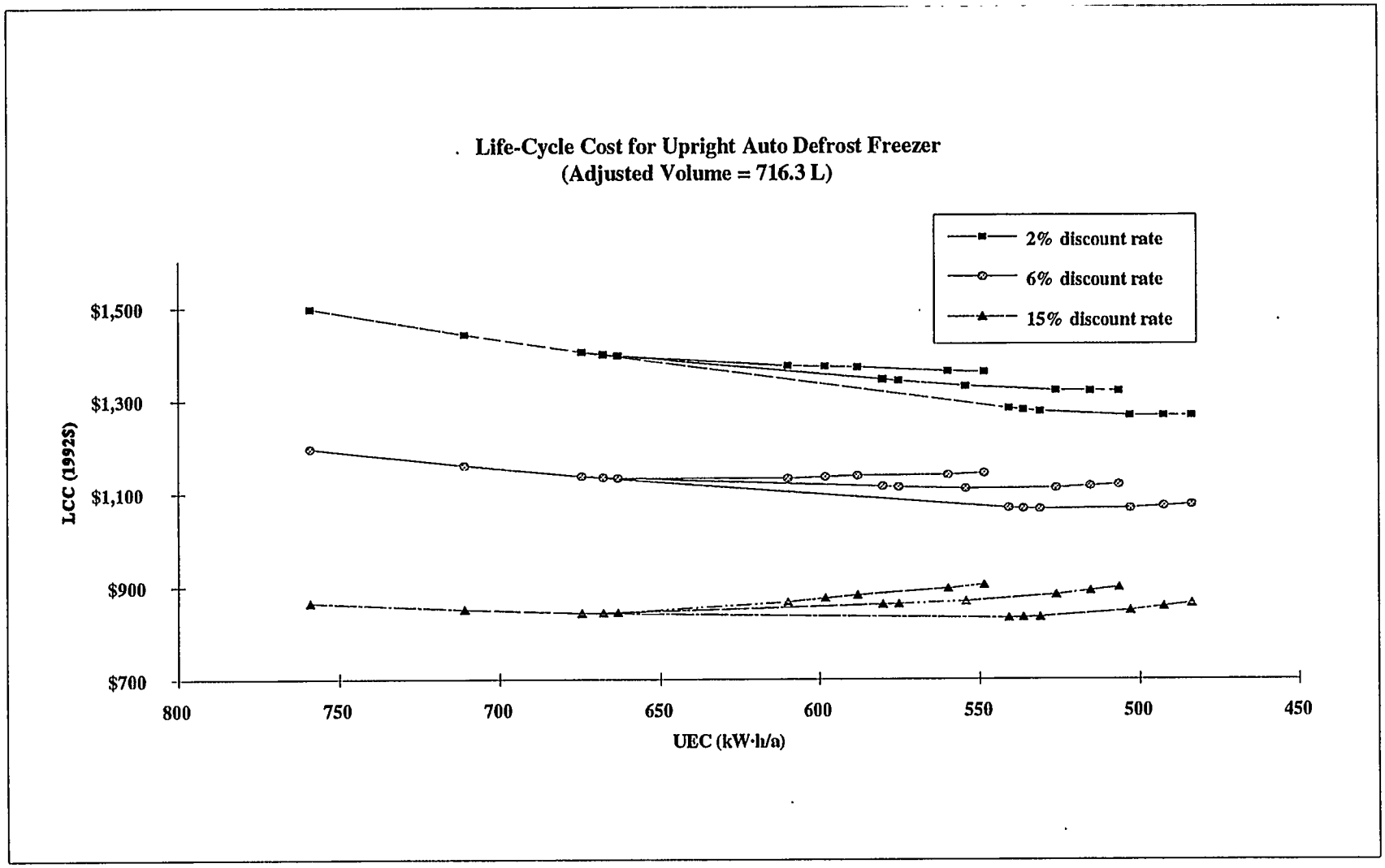

Figure 4.6 Life-cycle cost for design options for upright auto defrost freezer

Table 4.7 Life-Cycle Costs for Upright Manual Defrost Freezer
(Adjusted Volume = 685.4 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$379.63	482.94	$42.50	$1045.95	$853.84	$643.05
1	0 + Foam Insulation to Door	$382.40	424.31	$37.34	$967.82	$799.04	$613.84
2	1 + 5.15 EER Compressor	$391.50	361.15	$31.78	$889.77	$746.11	$588.48
3	2 + Enhanced Condenser HT Surface	$392.91	353.78	$31.13	$881.02	$740.29	$585.88
4	3+ Reduce Gasket Heat Leak	$397.07	343.30	$30.21	$870.72	$734.16	$584.32
5	4 + Add 1" Insulation to Door	$408.57	318.09	$27.99	$847.44	$720.91	$582.07
6	5 + Add 1" Insulation to Walls	$446.54	275.04	$24.20	$826.01	$716.60	$596.56
7	6 + Increase Evaporator Area	$453.87	273.90	$24.10	$831.78	$722.82	$603.27
8	4 + Add 1/2" Insulation to Door	$405.29	328.00	$28.86	$857.84	$727.36	$584.20
9	8 + Add 1/2" Insulation to Walls	$431.33	302.51	$26.62	$848.71	$728.37	$596.33
10	9 + Increase Evaporator Area	$438.66	301.38	$26.52	$854.47	$734.59	$603.05
11	4 + Vacuum Panel Insulation in Walls & Door	$453.40	279.00	$24.55	$838.34	$727.36	$605.58
12	11 + Increase Evaporator Area	$460.72	277.87	$24.45	$844.10	$733.56	$612.28

Average lifetime = 19 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

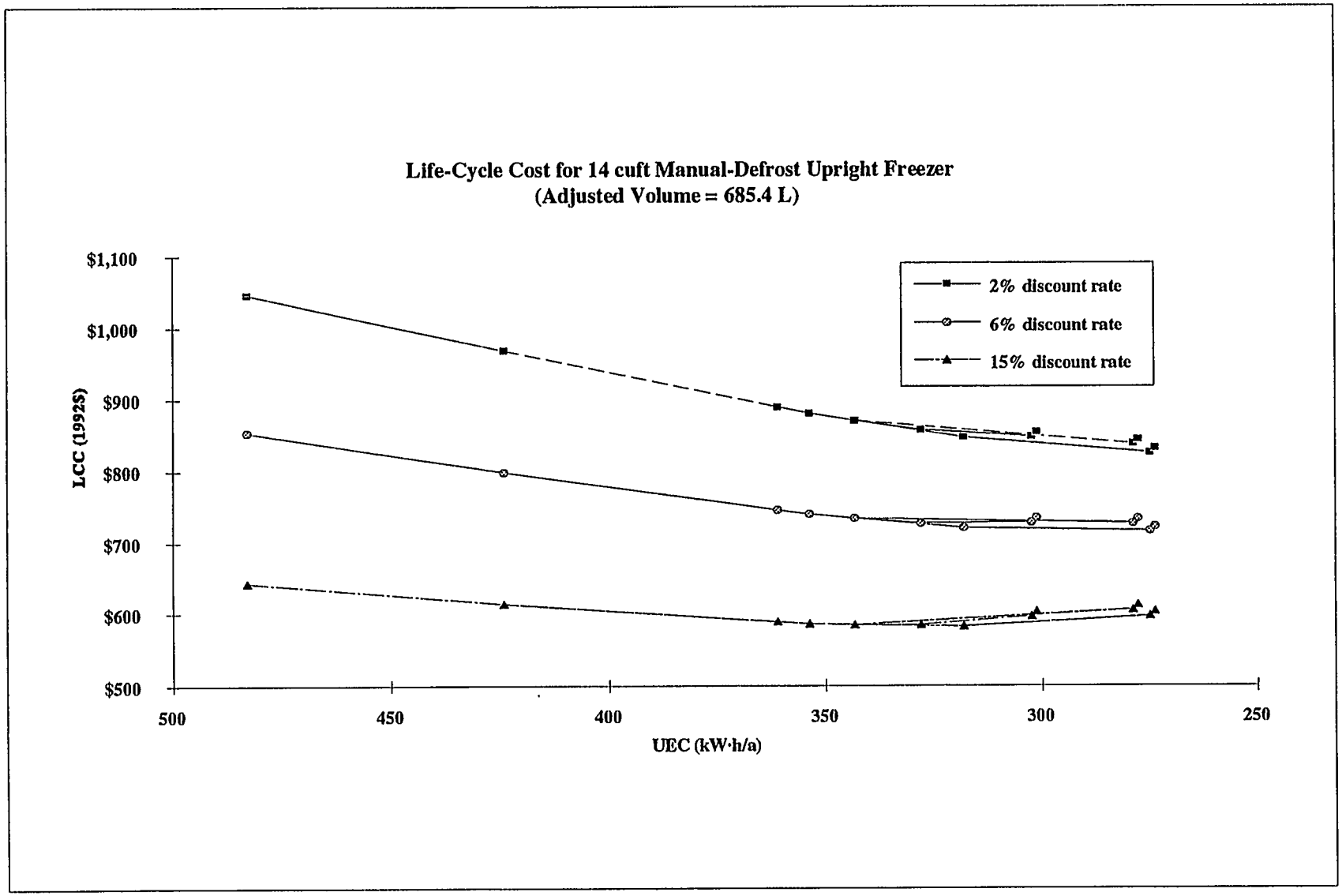

Figure 4.7 Life-cycle cost for design options of upright manual defrost freezer

Table 4.8 Life-Cycle Costs for Chest Manual Defrost Freezer (Adjusted Volume = 723.1 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$356.57	471.72	$41.51	$1007.40	$819.75	$613.86
1	0 + Add 1/2" Insulation to Walls	$373.15	392.91	$34.58	$915.25	$758.95	$587.46
2	1 + Add 1" Insulation to Walls	$385.41	345.76	$30.43	$862.46	$724.92	$574.00
3	2 + 4.56 EER Compressor	$395.34	314.55	$27.68	$829.33	$704.20	$566.91
4	3 + 4.95 EER Compressor	$404.83	289.18	$25.45	$803.81	$688.78	$562.56
5	4 + Add 1" Insulation to Door	$413.41	278.63	$24.52	$797.83	$687.00	$565.39
6	5 + Reduce Gasket Heat Leak	$416.61	274.59	$24.16	$795.46	$686.23	$566.38
7	6 + Increase Evaporator Area	$420.39	273.02	$24.03	$797.07	$688.47	$569.30
8	7 + Enhanced condenser HT Surface	$448.90	266.28	$23.43	$816.29	$710.36	$594.14
9	1 + 4.56 EER Compressor	$383.04	357.21	$31.43	$875.88	$733.79	$577.88
10	9 + 4.95 EER Compressor	$392.49	328.47	$28.91	$845.68	$715.02	$571.65
11	10 + Reduce Gasket Heat Leak	$395.69	324.43	$28.55	$843.31	$714.25	$572.65
12	11 + Add 1/2" Insulation to Door	$402.12	318.14	$28.00	$841.06	$714.51	$575.65
13	12 + Increase Evaporator Area	$405.89	315.67	$27.78	$841.43	$715.85	$578.07
14	13 + Enhanced Condenser HT Surface	$434.39	307.59	$27.07	$858.78	$736.42	$602.16
15	0 + 4.56 EER Compressor	$366.38	428.61	$37.72	$957.73	$787.24	$600.16
16	15 + 4.95 EER Compressor	$375.77	394.03	$34.67	$919.42	$762.67	$590.69
17	16 + Vacuum Panel Insulation on Walls & Door	$432.05	297.94	$26.22	$843.12	$724.60	$594.56
18	17 + Reduce Gasket Heat Leak	$435.25	293.90	$25.86	$840.74	$723.83	$595.55
19	18 + Increase Evaporator Area	$439.02	291.43	$25.65	$841.10	$725.18	$597.98
20	19 + Enhanced Condenser HT Surface	$467.53	284.02	$24.99	$859.39	$746.41	$622.45

Average lifetime = 19 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

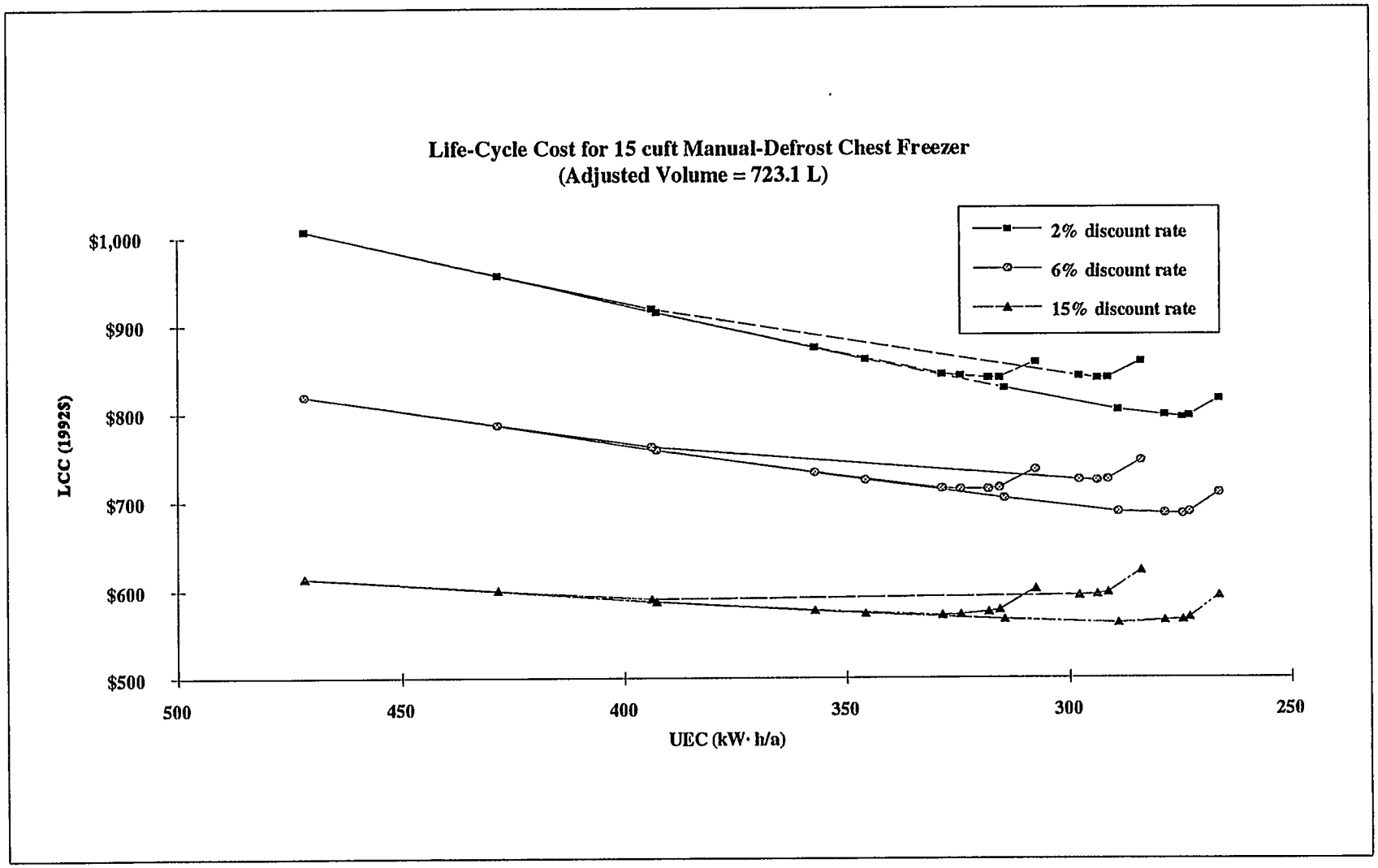

Figure 4.8 Life-cycle cost for design options of chest manual defrost freezer

Table 4.9 Life-Cycle Costs for Compact Manual Defrost Refrigerator-Freezer (Adjusted Volume = 46.19 L)

Level	Option	Retail Price (1992$)	Annual Energy Use (kWh)	Annual Energy Cost (1992$)	Life-Cycle Costs (1992$) 2%	6%	15%
0	BASELINE	$156.20	315.00	$27.72	$434.09	$379.04	$302.91
1	0 + Enhanced Condenser HT Surface	$156.58	308.06	$27.11	$428.35	$374.51	$300.06
2	1 + Enhanced Evaporator HT Surface	$157.28	301.13	$26.50	$422.93	$370.31	$297.53
3	2 + Reduce Gasket Heat Leak	$158.64	295.29	$25.99	$419.14	$367.53	$296.17

Average lifetime = 11.3 years
All costs are in 1992 dollars
Electricity rate is $0.088/kWh
There are no installation and maintenance costs

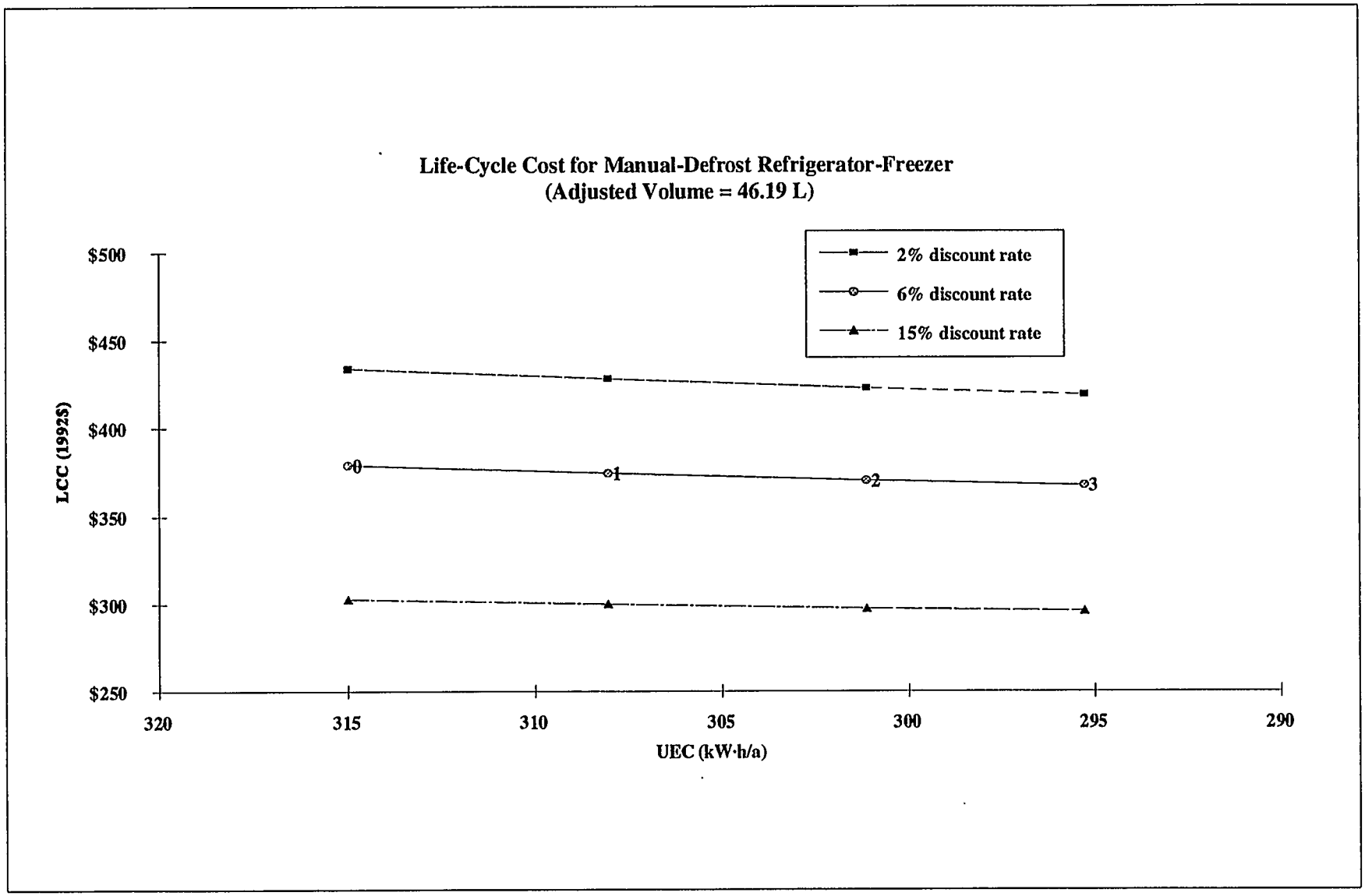

Figure 4.9 Life-cycle cost for design options of compact manual defrost refrigerator-freezer

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:

$$\Delta PC + \sum_{t-1}^{PAY} \Delta OC_t = 0 \tag{4}$$

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:

$$PAY = -\frac{\Delta PC}{\Delta OC} \tag{5}$$

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 the minimum compliance with the standard.

4.2.2 PBP Results

The PBP by standards level shown in Tables 4.12 through 4.36 are calculated by comparing the 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.

For each class of product, three tables are shown to illustrate the calculation process; e.g. Tables 4.10 to 4.12 are for Top Mount Auto-Defrost Refrigerator without TTD. Table 4.10 summarizes the equipment cost, operating cost, LCC and energy use for each design option. Based on the base case forecast, the percentages of total units sold for that product class in 1998 that have energy uses equal to the design options are also shown. Using of the distribution by design option from the base case where no standard is imposed, the weighted-average values of equipment cost, operating cost, LCC and energy use of units sold below each standard level are calculated and are shown in Table 4.11. If the base case distribution falls completely below standard level 1, then the values in Table 4.11 will be the same for all standard levels. Table 4.12 shows the resulting LCC differences, PBPs, and CCE for each standard level.

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 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 4.12 through 4.36 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., 15%) gives a smaller difference.

Tables 4.12 to 4.36 show lower LCC (positive LCC difference) for all standards levels for refrigerators, refrigerator-freezers, and freezers.

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:

$$CCE = -\frac{CRF \cdot \Delta PC}{\Delta E} \tag{6}$$

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 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.

4.4.2 CCE Results

Tables 4.12 through 4.36 show the cost of conserved energy at the site of the standard levels as compared to the base case. Note that the current (1995) and projected (1998) average residential electricity prices are 8.39 and 8.46 cents per kWh respectively (9). These are equivalent to 24.58 and 24.78 dollars per million Btu, respectively, where one kWh is taken as 3,412 Btu site energy.

Standard levels with CCEs less than projected costs of energy supply include:

All classes: Standard level 1

Top Mount Auto-Defrost, no TTD: Standard levels 2 through 4

Bottom Mount Auto-Defrost: Standard levels 2 through 4

Side-by-Side, no TTD: Standard levels 2 through 4

Side-by-Side, with TTD: Standard levels 2 through 4

Compacts: Standard levels 2 through 4

Manual defrost upright freezer: Standard levels 2 through 4

Auto defrost upright freezer: Standard levels 2 through 4

Manual defrost chest freezer: Standard levels 2 through 4

Standard levels with CCEs greater than projected costs of energy supply include:

Top mount auto defrost with TTD: Standard levels 2 through 4

Table 4.10 Cost (1992$) and Energy-Use Summary of Top Mount Auto-Defrost Refrigerator, no TTD

Standard Level	Design Number	Equipment Price ($)	Annual kWh	Operating Cost ($)	LCC @ 6% (1992$)	1998 Distribution
	0	554.67	700.86	61.68	1242.85	77.7%
	1	572.89	620.13	54.57	1181.81	13.8%
	2	580.39	594.45	52.31	1164.08	6.1%
	3	586.46	572.43	50.37	1148.54	2.4%
	4	597.37	543.07	47.79	1130.62	0.0%
	5	598.69	539.40	47.47	1128.34	0.0%
	6	618.88	495.37	43.59	1105.29	0.0%
1	7	623.89	484.36	42.62	1099.49	0.0%
2	13	628.99	477.02	41.98	1097.39	0.0%
	14	635.06	469.69	41.33	1096.25	0.0%
3	15	647.23	458.68	40.36	1097.61	0.0%
4	22	700.69	421.98	37.13	1115.04	0.00%

Table 4.11 Weighted-Average of Units Sold Below Standards, Top Mount Auto-Defrost Refrigerator, no TTD

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	559.52	559.52	559.52	559.52
Operating Cost (1992$)	59.86	59.86	59.86	59.86
Life-Cycle Cost (1992$)	1227.36	1227.36	1227.36	1227.36
Energy Use (kWh/a	680.15	680.15	680.15	680.15

Table 4.12 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Top Mount Auto-Defrost Refrigerator, no TTD

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	127.87	129.97	129.75	112.32
Payback	3.7	3.9	4.5	6.2
CCE (cent/kWh)	2.9	3.1	3.5	4.9

Table 4.13 Cost (1992$) and Energy-Use Summary of Top Mount Auto-Defrost Refrigerator with TTD

Standard Level	Design Number	Equipment Price ($)	Annual kWh	Operating Cost ($)	LCC @ 6% (1992$)	1998 Distribution
	0	1047.28	795.37	69.99	1828.27	47.3%
	1	1054.28	759.58	66.84	1800.12	52.7%
	2	1064.55	723.79	63.69	1775.25	0%
	3	1075.37	703.91	61.94	1766.54	0%
	4	1095.56	672.09	59.14	1755.50	0%
	5	1108.98	656.18	57.74	1753.30	0%
	12	1125.59	648.23	57.04	1762.10	0%
	13	1170.26	628.34	55.29	1787.24	0%
1	14	1173.99	624.37	54.94	1787.07	0%
2	15	1398.91	568.69	50.04	1957.32	0%
	16	1463.07	556.76	48.99	2009.76	0%
3	17	1553.36	552.78	48.65	2096.15	0%
4	22	1359.22	516.99	45.50	1866.86	0%

Table 4.14 Weighted Average of Units Sold Below Standards, Top-Mount Auto Defrost Refrigerator with TTD

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	1050.97	1050.97	1050.97	1050.97
Operating Cost (1992$)	68.33	68.33	68.33	68.33
Life-Cycle Cost (1992$)	1813.43	1813.43	1813.43	1813.43
Energy Use (kWh/a)	776.51	776.51	776.51	776.51

Table 4.15 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Top Mount Auto Defrost Refrigerator with TTD

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	26.36	-143.89	-282.72	-53.43
Payback	9.2	19.0	25.5	13.5
CCE (cent/kWh)	7.2	15.0	20.1	10.6

Table 4.16 Cost (1992$) and Energy-Use Summary of Bottom Mount Auto Refrigerator

Standard Level	Design Number	Equipment Price ($)	Annual kWh	Operating Cost ($)	LCC @ 6% (1992$)	1998 Distribution
	0	908.95	714.81	62.90	1610.83	57.9%
	1	919.42	669.62	58.93	1576.93	42.1%
	2	930.31	624.43	54.95	1543.45	0%
	3	937.68	603.89	53.14	1530.65	0%
1	11	952.58	587.46	51.70	1529.41	0%
	12	997.33	534.05	47.00	1521.72	0%
	13	1007.85	521.73	45.91	1520.14	0%
2	14	1013.85	517.62	45.55	1522.11	0%
	15	1028.91	509.40	44.83	1529.10	0%
	16	1047.39	497.08	43.74	1535.48	0%
3	17	1066.10	484.75	42.66	1542.09	0%
4	23	1076.66	443.67	39.04	1512.31	0%

Table 4.17 Weighted Average of Units Sold Below Standards, Bottom Mount Auto Refrigerator

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	913.36	913.36	913.36	913.36
Operating Cost (1992$)	61.23	61.23	61.23	61.23
Life-Cycle Cost (1992$)	1596.56	1596.56	1596.56	1596.56
Energy Use (kWh/a)	695.79	695.79	695.79	695.79

Table 4.18 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Bottom Mount Auto Refrigerator

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	67.15	74.45	54.47	84.25
Payback	4.1	6.4	8.2	7.4
CCE (cent/kWh)	3.2	5.1	6.5	5.8

Table 4.19 Cost (1992$) and Energy Use Summary of Side-by-Side Refrigerator, no TTD

Standard Level	Design Number	Equipment Price ($)	Annual kWh	Operating Cost ($)	LCC @ 6% (1992$)	1998 Distribution
	0	1055.08	761.19	66.99	1802.51	79.0%
	1	1074.35	699.75	61.58	1761.45	18.5%
	2	1087.44	662.20	58.27	1737.67	2.5%
1	3	1096.56	641.72	56.47	1726.68	0%
	4	1107.94	624.66	54.97	1721.30	0%
	10	1162.41	559.80	49.26	1712.09	0%
	11	1165.75	552.98	48.66	1708.72	0%
	12	1179.64	539.32	47.46	1709.21	0%
2	13	1181.76	535.91	47.16	1707.98	0%
	14	1191.21	529.08	46.56	1710.72	0%
3	15	1204.72	518.84	45.66	1714.18	0%
4	20	1242.66	501.77	44.16	1735.36	0%

Table 4.20 Weighted Average of Units Sold Below Standards, Side-by-Side Refrigerator, no TTD

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	1059.45	1059.45	1059.45	1059.45
Operating Cost (1992$)	65.77	65.77	65.77	65 .77
Life-Cycle Cost (1992$)	1793.29	1793.29	1793.29	1793.29
Energy Use (kWh/a)	747.35	747.35	747.35	747.35

Table 4.21 Life-Cycle Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 65 Real), Side-by-Side Refrigerator, No TTD

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	66.61	85.31	79.11	57.93
Payback	4.0	6.6	7.2	8.5
CCE (cent/kWh)	3.1	5.2	5.7	6.7

Table 4.22 Cost (1992$) and Energy Use Summary of Side-by-Side Refrigerator with TTD

Standard Level	Design Number	Equipment Price ($)	Annual kWh	Operating Cost ($)	LCC @ 6% (1992$)	1998 Distribution
	0	1161.51	799.93	70.39	1946.97	57.2%
	1	1167.53	768.41	67.62	1922.04	18.7%
	2	1177.56	725.06	63.81	1889.51	12.9%
	3	1184.25	697.48	61.38	1869.11	4.9%
	4	1187.02	685.66	60.34	1860.27	0.5%
1	5	1191.30	669.89	58.95	1849.08	1.1%
	13	1194.88	654.13	57.56	1837.18	4.2%
	14	1204.73	634.43	55.83	1827.68	0.6%
	15	1206.17	630.49	55.48	1825.25	0%
2	16	1236.84	583.20	51.32	1809.49	0%
	17	1243.55	571.38	50.28	1804.60	0%
3	18	1253.12	555.62	48.89	1798.69	0%
4	28	1294.50	516.21	45.43	1801.38	0%

Table 4.23 Weighted-Average of Units Sold Below Standards, Side-by-Side Refrigerator with TTD

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	1166.22	1167.93	1167.93	1167.93
Operating Cost (1992$)	68.42	67.78	67.78	67.78
Life-Cycle Cost (1992$)	1929.64	1924.27	1924.27	1924.27
Energy Use (kWh/a)	777.48	770.27	770.27	770.27

Table 4.24 Life-Cycle Cost Difference (1992$), Payack Periods (Year), and Costs of Conserved Energy at 6% Real), Side-by-Side Refrigerator with TTD

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	80.56	114.78	125.58	122.89
Payback	2.6	4.2	4.5	5.7
CCE (cent/kWh)	2.1	3.3	3.6	4.5

Table 4.25 Cost (1992$) and Energy-Use Summary of Compact Refrigerator

Standard Level	Design Number	Equipment Price $	Annual kWh	Operating Cost $	LCC @ 6% (1992$)	1998 Distribution
	0	156.20	315.00	27.72	379.04	97.0%
	1	156.58	308.06	27.11	374.51	3.0%
1, 2	2	157.28	301.13	26.50	370.31	0%
3, 4	3	158.64	295.29	25.99	367.53	0%

Table 4.26 Weighted Average of Units Sold Below Standards, Compact Refrigerator

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	156.21	156.21	156.21	156.21
Operating Cost (1992$)	27.70	27.70	27.70	27.70
Life-Cycle Cost (1992$)	378.90	378.90	378.90	378.90
Energy Use (kWh/a)	314.79	314.79	314.79	314.79

Table 4.27 Life-Cycle Cost Difference (1992$), Payback Periods (Year) and Costs of Conserved Energy (At 6% Real), Compact Refrigerators

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	8.59	8.59	11.37	11.37
Payback	0.9	0.9	1.4	1.4
CCE (cent/kWh)	1.01	1.0	1.5	1.5

Table 4.28 Cost (1992$) and Energy-Use Summary of Manual Defrost Upright Freezer

Standard Level	Design Number	Equipment Price $	Annual kWh	Operating Cost $	LCC @ 6% (1992$)	1998 Distribution
	0	379.63	482.94	42.50	853.84	81.0%
1	1	382.40	424.31	37.34	799.04	19.0%
	2	391.50	361.15	31.78	746.11	0%
	3	392.91	353.78	31.13	740.29	0%
	4	397.07	343.30	30.21	734.16	0%
2	8	405.29	328.00	28.86	727.36	0%
	9	431.33	302.51	26.62	728.37	0%
3	10	438.66	301.38	26.52	734.59	0%
4	12	460.72	277.87	24.45	733.56	0%

Table 4.29 Weighted-Average of Units Sold Below Standards, Manual Defrost Upright Freezer

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	379.63	380.16	380.16	380.16
Operating Cost (1992$)	42.50	41.52	41.52	41.52
Life-Cycle Cost (1992$)	853.84	843.43	843.43	843.43
Energy Use (kWh/a)	482.94	471.80	471.80	471.80

Table 4.30 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy(at 6% Real), Manual Defrost Upright Freezer

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	54.80	116.07	108.84	109.87
Payback	0.5	2.0	3.9	4.7
CCE (cent/kWh)	0.4	1.6	3.1	3.7

Table 4.31 Cost (1992$) and Energy-Use Summary of Auto Defrost Upright Freezer

Standard Level	Design Number	Equipment Price $	Annual kWh	Operating Cost $	LCC @ 6% (1992$)	1998 Distribution
	0	451.11	759.24	66.81	1196.62	70.5%
	1	462.88	711.14	62.58	1161.16	29.5%
	2	475.19	674.62	59.37	1137.61	0%
	3	479.23	667.96	58.78	1135.11	0%
1	10	482.61	663.32	58.37	1133.94	0%
2	11	534.23	610.00	53.68	1133.20	0%
	12	549.14	598.12	52.63	1136.44	0%
	13	561.29	587.98	51.74	1138.63	0%
	14	590.83	559.87	49.27	1140.57	0%
3	15	605.25	548.57	48.27	1143.89	0%
4	21	600.65	483.94	42.59	1075.84	0%

Table 4.32 Weighted-Average of Units Sold Below Standards, Auto Defrost Upright Freezer

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	454.58	454.58	454.58	454.58
Operating Cost (1992$)	65.56	65.56	65.56	65.56
Life-Cycle Cost (1992$)	1186.16	1186.16	1186.16	1186.16
Energy Use (kWh/a)	745.05	745.05	745.05	745.05

Table 4.33 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Auto Defrost Upright Freezer

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	52.22	52.97	42.27	110.32
Payback	3.9	6.7	8.7	6.4
CCE (cent/kWh)	3.1	5.3	6.9	5.0

Table 4.34 Cost (1992$) and Energy Use Summary of Manual Defrost Chest Freezer

Standard Level	Design Number	Equipment Price ($)	Annual kWh	Operating Cost ($)	LCC @ 6% (1992$)	1998 Distribution
	0	356.57	471.71	41.51	819.75	96.2%
1	16	375.77	394.03	34.67	762.67	3.8%
	1	373.15	392.91	34.58	758.95	0%
	9	383.04	357.21	31.43	733.79	0%
	10	392.49	328.47	28.91	715.02	0%
2	11	395.69	324.43	28.55	714.25	0%
	12	402.12	318.14	28.00	714.51	0%
	13	405.89	315.67	27.78	715.85	0%
3	14	434.39	307.59	27.07	736.42	0%
4	20	467.53	284.02	24.99	746.41	0%

Table 4.35 Weighted-Average of Units Sold Below Standards, Manual Defrost Chest Freezers

Weighted Average	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
Equip. Price (1992$)	356.57	357.30	357.30	357.30
Operating Cost (1992$)	41.51	41.25	41.25	41.25
Life-Cycle Cost (1992$)	819.75	817.58	817.58	817.58
Energy Use (kWh/a)	471.71	468.76	468.76	468.76

Table 4.36 Life-Cycle Cost Difference (1992$), Payback Periods (Year), and Costs of Conserved Energy (At 6% Real), Manual Defrost Chest Freezer

	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
LCC difference	57.08	103.33	81.16	71.17
Payback	2.8	3.0	5.4	6.8
CCE (cent/kWh)	2.2	2.4	4.3	5.3

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 [1] 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 Chapter 3, 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 4.10-4-14 and Tables 4.37-41 summarize the results of the sensitivity analysis. They include:

- a 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.

Table 4.37 Sensitivity Summary of Life-Cycle Costs of Top Mount Auto Defrost Refrigerator-Freezer (1992$ at 6% Real). (Shaded Numbers Correspond to Life-Cycle Cost Minimum for Each of the Sensitivity Cases.)

Design Option	Standard Level	Reference	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0		1242.85	932.41	1567.90	1187.38	1298.32	987.88	1512.43
1		1181.81	907.12	1469.41	1122.70	1240.92	966.23	1410.30
2		1164.08	900.78	1439.78	1103.47	1224.69	961.39	1379.17
3		1148.54	894.98	1414.02	1086.82	1210.26	956.70	1352.30
4		1130.62	890.07	1382.49	1066.72	1194.52	953.97	1318.59
5		1128.34	889.41	1378.51	1063.45	1193.23	954.30	1313.62
6		1105.29	885.87	1335.04	1037.60	1172.98	953.56	1267.35
7	1	1099.49	884.95	1324.13	1030.22	1168.76	954.22	1254.86
13	2	1097.39	886.09	1318.62	1025.12	1169.66	958.36	1246.35
14		1096.25	888.21	1314.08	1021.73	1170.77	962.73	1239.56
15	3	1097.61	894.44	1310.34	1021.39	1173.83	970.66	1234.12
22	4	1115.04	928.13	1310.75	1002.86	1227.22	1040.31	1198.57

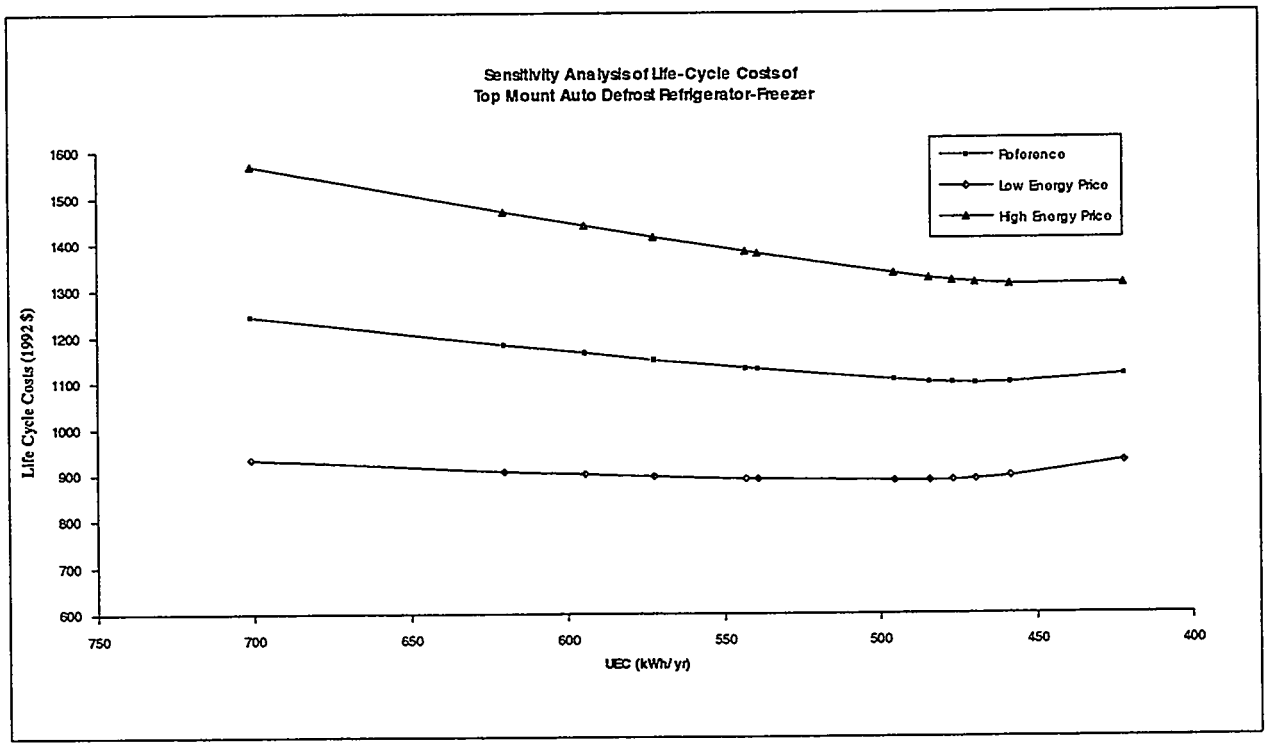

Figure 4-10 Sensitivity analysis of life-cycle costs of top mount auto defrost refrigerator-freezer.

Table 4.38 Sensitivity Summary of Life-Cycle Costs of Side-By-Side Auto Refrigerator-Freezer with TTD (1992$ at 6% Real). (Shaded Numbers Correspond to Life-Cycle Cost Minimum for Each of the Sensitivity Cases.)

Design Option	Standard Level	Reference	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0		1946.97	1592.65	2317.97	1830.82	2063.12	1708.80	2201.82
1		1922.04	1581.68	2278.41	1805.03	2039.05	1698.69	2161.40
2		1889.51	1568.35	2225.78	1770.50	2008.52	1687.36	2106.77
3		1869.11	1560.17	2192.59	1748.76	1989.46	1680.52	2072.24
4		1860.27	1556.57	2178.27	1738.07	1982.47	1678.77	2056.07
5	1	1849.08	1552.35	2159.76	1725.03	1973.13	1676.40	2035.71
13		1837.18	1547.44	2140.56	1712.30	1962.06	1672.32	2015.68
14		1827.68	1546.67	2121.92	1700.83	1954.53	1673.52	1995.07
15		1825.25	1545.98	2117.66	1697.32	1953.18	1673.91	1989.73
16	2	1809.49	1551.17	2079.97	1677.48	1941.50	1683.18	1947.96
17		1804.60	1551.51	2069.59	1671.83	1937.37	1684.28	1936.82
18	3	1798.69	1552.58	2056.37	1662.91	1934.47	1688.36	1920.59
28	4	1801.38	1572.72	2040.79	1643.46	1959.30	1730.64	1882.87

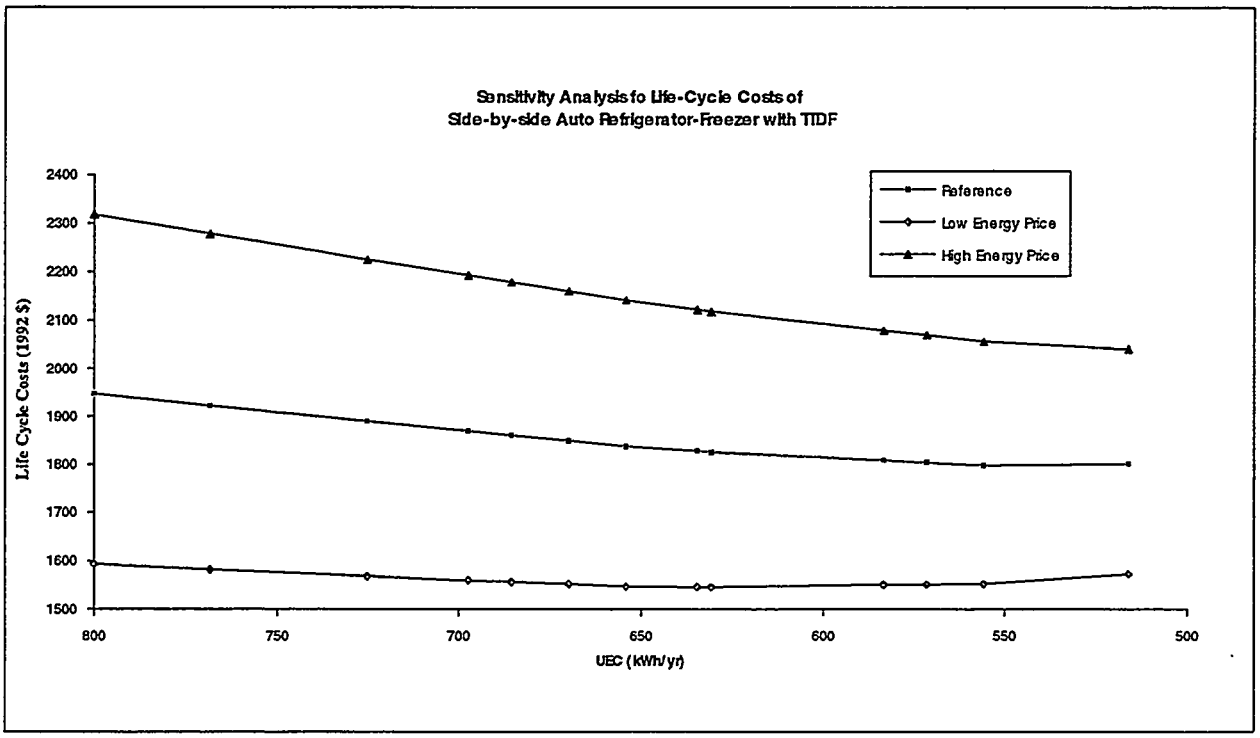

Figure 4-11 Sensitivity analysis for life-cycle costs of side-by-side refrigerator freezer with TTD.

Table 4.39 Sensitivity Summary of Life-Cycle Costs of Manual Defrost Compact Refrigerator (1992$ at 6% Real) (Shaded Numbers Correspond to Life-Cycle Cost Minimum for Each of the Sensitivity Cases.)

Design Option	Standard Level	Reference	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0		379.04	278.52	484.30	363.42	394.66	294.14	468.68
1		374.51	276.20	477.45	358.83	390.19	291.88	461.77
2	1, 2	370.31	274.21	470.93	354.51	386.11	290.01	455.13
3	3, 4	367.54	273.30	466.21	351.46	383.62	289.38	450.13

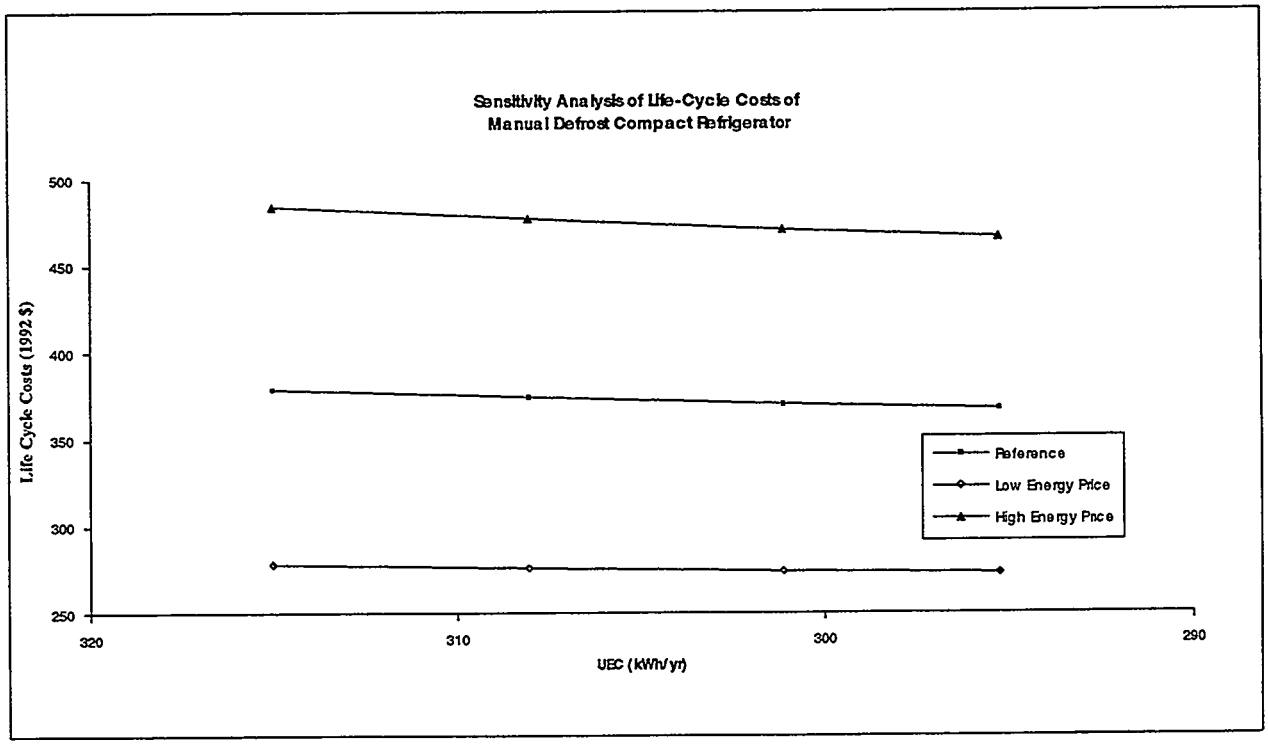

Figure 4-12 Sensitivity analysis of life-cycle costs of manual defrost compact refrigerator.

Table 4.40 Sensitivity Summary of Life-Cycle Costs of Manual Defrost Upright Freezer (1992$ at 6% Real). (Shaded Numbers Correspond to Life-Cycle Cost Minimum for Each of the Sensitivity Cases.)

Design Option	Standard Level	Reference	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0		853.84	639.92	1077.82	815.879	891.799	677.88	1039.86
1	1	799.04	611.09	995.82	760.376	837.696	649.75	957.16
2		746.11	586.15	913.61	705.634	786.594	626.63	873.13
3		740.29	583.59	904.37	699.192	781.392	624.69	863.27
4		734.16	582.1	893.379	691.752	776.572	624.51	850.97
8	2	727.36	582.07	879.486	683.463	771.263	625.97	835.59
9		728.37	594.38	868.671	680.851	775.891	641.90	821.15
10	3	734.59	601.09	874.363	682.759	786.419	652.92	$822.53
12	4	733.56	610.48	862.44	658.68	808.44	$685.36	$787.56

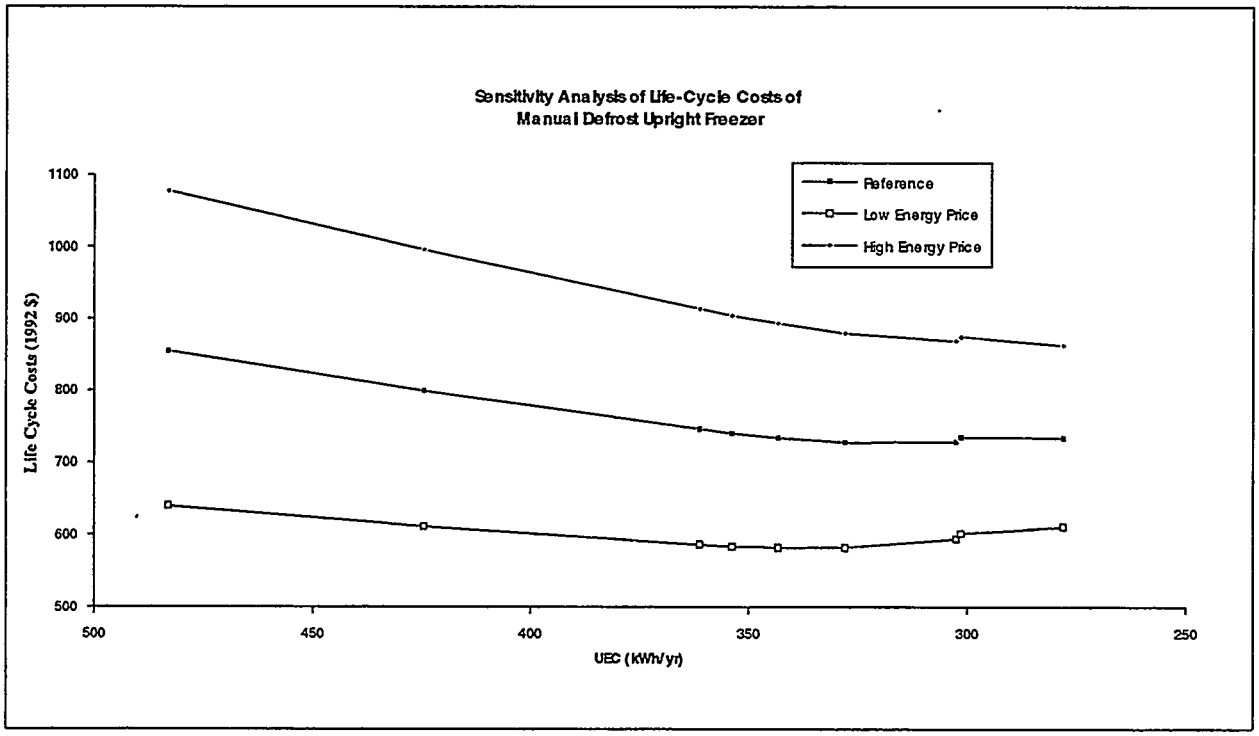

Figure 4-13 Sensitivity analysis of life-cycle costs of manual defrost upright freezer.

Table 4.41 Sensitivity Summary of Life-Cycle Costs of Manual Defrost Chest Freezer (1992$ at 6% real). (Shaded Numbers Correspond to Life-Cycle Cost Minimum for Each of the Sensitivity Cases.)

Design Option	Standard Level	Reference	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
0		819.75	610.81	1038.53	784.09	855.41	646.47	1002.87
16	1	762.67	588.14	945.42	723.17	802.17	627.64	905.92
1		758.95	584.92	941.18	720.99	796.91	622.88	903.22
9		733.79	575.57	899.46	693.85	773.73	615.51	859.52
10		715.02	569.53	867.36	673.19	756.85	611.36	825.53
11	2	714.25	570.55	864.72	681.42	757.08	613.38	821.89
12		714.51	573.59	862.06	670.51	758.51	613.38	821.89
13		715.85	576.03	862.26	669.63	762.07	622.25	816.04
14	3	736.42	600.17	879.07	677.54	795.3	659.05	820.19
20	4	746.41	620.61	878.13	662.89	829.93	704.13	794.61

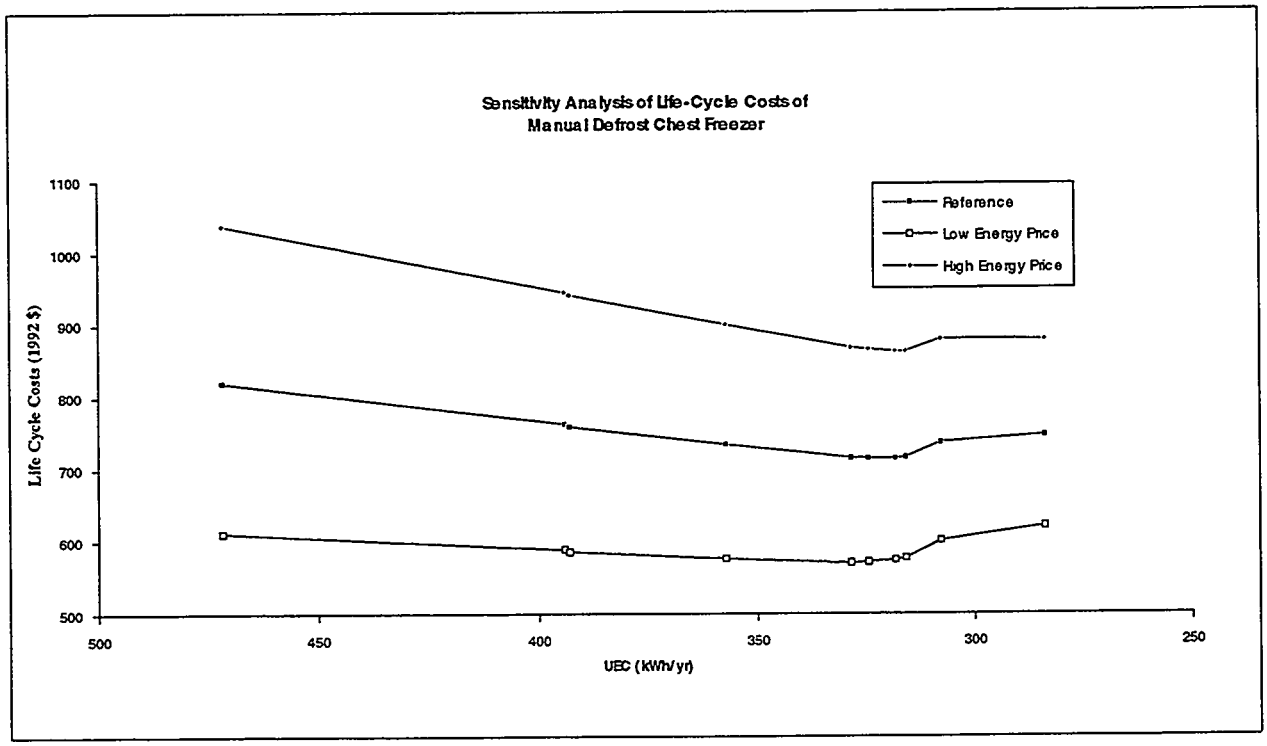

Figure 4-14 Sensitivity analysis of life-cycle costs of manual defrost chest freezer.

REFERENCES

1. U.S. DOE, Energy Information Administration, 1991. *State Energy Price Projections for the Residential Sector,* 1991-1992. Service Report SR/EMEU/91-04, November, Washington, DC.

CHAPTER 5. NATIONAL ENERGY AND ECONOMIC IMPACTS

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. The difference between the two projections is 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.

5.1 ECONOMIC AND DEMOGRAPHIC DATA

The LBL-REM (described in Appendix B) is used to derive projections of residential energy demand. These projections are dependent on assumptions about future years, including occupied households, number of annual housing starts, disposable personal income, and energy prices. These data are described in Tables 5.1 through 5.4. (Economic data specific to each product, such as equipment price, initial market shares, elasticities for market shares, efficiency choices, and usage behaviors are described here and in Appendix B.)

5.1.1 Occupied Households

The number and type of occupied households for the base year (1980) are from the 0.1% Public Use MicroSample (PUMS) of the 1980 Decennial Census. The occupied households projection from 1992 to 2010 is obtained from DOE/EIA's *Annual Energy Outlook 1994*. The stock of households is interpolated in years 1981 to 1991.

Table 5.1 Occupied Households Projections (millions)

	Occupied Households	Single-family	Multi-family	Mobile Homes
1980	80.4	53.8	22.7	3.9
1985	86.1	58.2	23.3	4.6
1990	92.8	63.7	24.0	5.1
1995	97.6	67.9	24.4	5.2
2000	101.7	71.6	24.7	5.3
2005	105.9	75.1	25.4	5.4
2010	110.5	78.7	26.4	5.4
2030	130.2	96.0	28.6	5.6

Sources: U.S. Department of Commerce, Bureau of Census [1].
DOE/EIA *Annual Energy Outlook 1994* [2].

5.1.2 Housing Starts

Figures for past (1980-1989) housing starts by state come from the Bureau of Census' *Housing Starts*. Projections (1990-2010) come from DOE/EIA's *Annual Energy Outlook 1994*. Housing starts in later years (2011-2030) are extrapolated using the projected annual growth rates from 1990 to 2010.

Table 5.2 Housing Starts Projections (thousands)

	Total	Single-family	Multi-family	Mobile Homes
Past				
1980	1514	852	440	222
1985	2025	1072	670	284
Projected				
1990	1390	900	300	190
1995	1487	1044	230	214
2000	1650	1050	380	220
2005	1690	1080	390	220
2010	1710	1040	460	210
2030	2111	1196	684	232

Sources: Bureau of Census, *Housing Starts*[3].
DOE/EIA *Annual Energy Outlook 1994*.
LBL extrapolation.

5.1.3 Disposable Personal Income

Disposable personal income (1980-1986) is from the *Survey of Current Business* [4], converted to 1990 dollars using the Consumer Price Index-Urban. For 1987-2010, the projection from the *Annual Energy Outlook 1994* is used, similarly converted to 1990 dollars. For 2011-2030, the projection is extended, assuming a linear increase in disposable personal income, with the annual increase being the average of the increases from 1990 to 2010.

Table 5.3 Disposable Personal Income (1990$)

	Total (Billions)	Per Occupied Household (Thousands)
Past		
1980	2890	35.9
1985	3435	39.4
Projected		
1990	3517	43.1
1995	3816	45.0
2000	4202	47.6
2005	4563	49.6
2010	4970	51.8
2030	7101	63.1

Sources: (1980-1986) *Survey of Current Business*
(1987-2010) DOE/EIA *Annual Energy Outlook 1994.*
(2011-2030) LBL extrapolation.

5.1.4 Residential Energy Prices

Past energy prices (1980-1988) are from the DOE *Monthly Energy Review* [5]. Energy prices for 1989 and 1990 as well as projected energy prices (1991-2010) are from *Annual Energy Outlook 1994*. Extrapolation of energy prices (2011-2030) assumes average annual increases of 1.0% per year for electricity, 2.1% per year for natural gas, 1.6% per year for distillate, and 2.1% per year for LPG.

Electricity prices are further adjusted to reflect differences in effective price by specific end uses. To capture regional differences in residential rates and appliance holdings, as well as effects of rate structure, a multiplier of 1.06 is used to obtain the effective prices of electricity for refrigerator and freezer use. (For example, if electric heat is common in areas with lower residential rates, then the effective rate for electric space heating is lower than the average residential rate. Also, if the block structure offers declining rates for increased consumption, then end uses associated with higher consumption, including space heating, will have lower effective rates.). The multiplier is derived from the 1990 *Residential Energy Consumption Survey* [6].

Table 5.4 Average Residential Energy Prices of Primary Energy (1990$)

	Electricity	
	$/Giga-Joule	*$/MMBtu*
Past		
1980	6.31	*(6.65)*
1985	7.81	*(8.23)*
1990	6.55	*(6.90)*
1991	6.38	*(6.73)*
1992	6.23	*(6.56)*
1993	6.28	*(6.62)*
Projected		
1994	6.33	*(6.67)*
1995	6.38	*(6.73)*
1996	6.44	*(6.79)*
1997	6.49	*(6.84)*
1998	6.54	*(6.90)*
1999	6.60	*(6.96)*
2000	6.65	*(7.02)*
2005	6.99	*(7.37)*
2010	7.49	*(7.90)*
2030	9.14	*(9.64)*

Sources: (1980-1988) DOE *Monthly Energy Review*.
(1989-2010) DOE/EIA *Annual Energy Outlook 1994*.
(2011-2030) extrapolated by LBL.

5.1.5 Average Equipment Lifetime

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.

Table 5.5 Average Equipment Lifetime of Refrigerators and Freezers

	Years
Standard Refrigerator-Freezer	19.0
Compact Refrigerator	11.3
Standard Freezer	19.0

Source: LBL-REM.

5.2 BASE CASE FORECAST

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

5.2.1 New Appliance Unit Energy Consumptions

Annual unit energy consumption (UEC) of new appliances is projected, each year after 1993, based upon a set of designs (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). Table 5.6 shows the trends in efficiency and annual UEC.

Table 5.6 Base Case Projection of Unit Energy Consumption (kWh/a) for New Refrigerators and Freezers

Year	Refrigerator	Freezer
1990	857	595
1993	681	510
1998	647	491
2010	647	474
2030	646	474

Source: LBL-REM.

5.2.1.1 Efficiency Distributions

For each class of refrigerator and freezer, the range of efficiencies currently available is determined from AHAM directories. 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 standard level.

5.2.1.2 Usage

Usage is assumed constant over time.

5.2.2 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 more than one.

The initial (1980) fraction of new (and 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 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.

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).

Table 5.7 Annual Installations of New Refrigerators and Freezers in U.S. Households (Millions)

Year	Refrigerators	Freezers
1990	7.23	1.76
1993	7.03	1.92
1998	7.23	1.80
2000	7.43	1.78
2015	8.68	2.09
2030	10.09	2.35

Table 5.8 Percent of Occupied U.S. Housing Units Having Refrigerators and Freezers

Year	Refrigerator (%)	Freezer (%)
1990	118	35
1993	119	34
1998	121	32
2000	122	32
2015	125	31
2030	128	32

5.2.3 U.S. Residential Energy Consumption

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

Table 5.9 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 5.9 U.S. Residential Energy Consumption for Refrigerators and Freezers, EJ (Quads), Primary Energy

Year	Refrigerator		Freezer	
1990	1.54	*(1.46)*	0.414	*(0.392)*
1993	1.48	*(1.40)*	0.357	*(0.338)*
1998	1.35	*(1.28)*	0.265	*(0.251)*
2000	1.31	*(1.24)*	0.245	*(0.232)*
2015	1.17	*(1.10)*	0.211	*(0.200)*
2030	1.34	*(1.27)*	0.236	*(0.224)*

5.2.4 Price of Purchased Appliances

Prices of new units generally increase slightly over time as energy-efficiency improvements are incorporated. However, improvements in productivity and shifts in retail sales toward larger retailers have held prices down. Table 5.10 shows projected shipment-weighted average prices.

Table 5.10 Average Price of New Refrigerators and Freezers in U.S. Households (1990$)

Year	Refrigerator	Freezer
1990	626.8	353.4
1993	619.1	377.5
1998	623.3	378.5
2000	623.3	378.5
2015	624.2	379.7
2030	624.9	379.7

5.3 STANDARDS FORECASTS

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, 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., 1998-2030. 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 5.3.1 presents the trial standards levels analyzed. Section 5.3.2 presents the historical and projected energy consumption, including unit energy consumption for new purchases and total national energy consumption. Section 5.3.3 presents historical and projected annual installations. Section 5.3.4 presents purchase prices. Section 5.3.5 presents net present value and Section 5.4 discusses the results of the sensitivity analyses.

An overview of the general LBL-REM methodology and demographic assumptions and product-specific input data are presented in Appendix B.

5.3.1 Standard Levels

Table 5.11 shows the correspondence between the trial standards levels, the engineering design levels, and the associated unit energy consumption.

Table 5.11 Trial Standards Levels for Refrigerators

	Trial Standard Level			
	1	2	3	4
Engineering design option:				
Top-Mount Auto no TTDF*	7	13	15	22
Top-Mount Auto with TTDF	14	15	17	22
Bottom Mount Auto	11	14	17	23
Side-by-side Auto no TTDF	3	13	15	22
Side-by-side Auto with TTDF	5	16	18	28
Compact Manual	2	2	3	3
Annual energy consumption (kWh)				
Top-Mount Auto no TTDF	484	477	459	422
Top-Mount Auto with TTDF	624	569	553	517
Bottom Mount Auto	588	518	485	444
Side-by-side Auto no TTDF	641	536	519	502
Side-by-side Auto with TTDF	670	583	556	516
Compact Manual	301	301	295	295

* TTDF: through-the-door features

Table 5.12 Trial Standards Levels for Freezers

	Trial Standard Level			
	1	2	3	4
Engineering design option:				
Manual Defrost Upright	1	8	10	12
Auto Defrost Upright	10	11	15	21
Manual Defrost Chest	16	11	14	20
Annual energy consumption (kWh)				
Manual Defrost Upright	424	328	301	278
Auto Defrost Upright	663	610	549	484
Manual Defrost Chest	394	324	308	284

5.3.2 Energy Consumption

Table 5.13 and Table 5.14 show the projected average energy use of new refrigerators and freezers.

Table 5.13 Unit Energy Consumption for New Refrigerators (kWh/a)

		Trial Standard Level			
Year	Base	1	2	3	4
1990	857				
1993	681				
1998	647	496	472	454	424
2000	647	496	472	454	424
2015	647	496	472	454	424
2030	646	496	472	454	424

Source: LBL-REM.

Table 5.14 Unit Energy Consumption for New Freezers (kWh/a)

Year	Base	Trial Standard Level 1	2	3	4
1990	595				
1993	510				
1998	491	440	362	336	307
2000	491	440	362	336	307
2015	474	436	362	336	307
2030	474	436	362	336	307

Source: LBL-REM.

Tables 5.15 to 5.16 present projections of total energy savings for refrigerators and freezers. Standards (for refrigerators) are projected to produce cumulative energy savings ranging from 6.7 Quads for standard level 1 to 10 Quads for standard level 4, during the period 1998-2030. For freezers, standard level 1 is projected to save 0.45 Quads, and standard level 4 is projected to save 2.0 Quads, cumulative from 1998 to 2030.

Table 5.15 U.S. Energy Consumption for Refrigerators, EJ (Quads) Primary

Year	Base Case	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
1990	1.54 *(1.46)*				
1993	1.48 *(1.40)*				
1998	1.35 *(1.28)*	1.34 *(1.27)*	1.34 *(1.267)*	1.34 *(1.27)*	1.33 *(1.26)*
2000	1.31 *(1.24)*	1.26 *(1.20)*	1.26 *(1.191)*	1.25 *(1.19)*	1.24 *(1.18)*
2015	1.17 *(1.11)*	0.91 *(0.86)*	0.87 *(0.821)*	0.84 *(0.79)*	0.78 *(0.74)*
2030	1.34 *(1.27)*	1.02 *(0.96)*	0.96 *(0.912)*	0.92 *(0.87)*	0.85 *(0.81)*
1998-2030	40.66 *(38.53)*	33.62 *(31.86)*	32.45 *(30.76)*	31.60 *(29.95)*	30.07 *(28.50)*
Cumulative Savings:		7.04 *(6.67)*	8.20 *(7.78)*	9.06 *(8.59)*	10.58 *(10.03)*
Percent of Base:		17.3%	20.2%	22.3%	26.0%

Table 5.16 U.S. Energy Consumption for Freezers, EJ (Quads) Primary

Year	Base Case	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
1990	0.414 *(0.392)*				
1993	0.357 *(0.338)*				
1998	0.265 *(0.251)*	0.264 *(0.250)*	0.262 *(0.248)*	0.261 *(0.247)*	0.260 *(0.246)*
2000	0.245 *(0.232)*	0.241 *(0.228)*	0.235 *(0.223)*	0.233 *(0.221)*	0.231 *(0.219)*
2015	0.211 *(0.200)*	0.193 *(0.183)*	0.160 *(0.152)*	0.145 *(0.137)*	0.131 *(0.124)*
2030	0.236 *(0.224)*	0.216 *(0.205)*	0.177 *(0.168)*	0.157 *(0.149)*	0.140 *(0.133)*
1998-2030	7.394 *(7.008)*	6.915 *(6.554)*	6.054 *(5.738)*	5.629 *(5.335)*	5.265 *(4.990)*
Cumulative Savings:		0.479 *(0.454)*	1.340 *(1.270)*	1.765 *(1.673)*	2.129 *(2.018)*
Percent of Base:		6.5%	18.1%	23.9%	28.8%

5.3.3 Annual Installations

Table 5.17 shows projected changes in installations as a result of standards.

Table 5.17 Cumulative Installations of Refrigerators and Freezers (Millions)

1998-2030	Base	Trial Standard Level 1	2	3	4
Refrigerators	286.6	284.5	283.8	282.8	280.7
Freezers	67.0	66.5	65.6	62.9	61.4
Total	353.6	351.1	349.4	345.7	342.1
Change from Base					
Refrigerators		-2.1	-2.9	-3.8	-5.9
Freezers		-0.5	-1.4	-4.1	-5.6
Total		-2.5	-4.2	-7.9	-11.6
Percent Change					
Refrigerators		-0.7%	-1.0%	-1.3%	-2.1%
Freezers		-0.7%	-2.0%	-6.2%	-8.4%
Total		-0.7%	-1.2%	-2.2%	-3.3%

Source: LBL-REM.

5.3.4 Appliance Prices

Projections of the purchase prices for new refrigerators and freezers in 1990 dollars are shown in Table 5.18 and Table 5.19.

Table 5.18 Average Purchase Price for New Refrigerators (1990$ per Unit)

Year	Base	Trial Standard Level 1	2	3	4
1990	626.8				
1993	619.1				
1998	623.3	673.4	692.0	710.3	751.0
2000	623.5	673.5	692.2	710.4	751.1
2015	624.2	674.0	692.8	711.0	751.6
2030	624.9	674.6	693.4	711.6	752.2

Source: LBL-REM.

Table 5.19 Average Purchase Price for New Freezers (1990$ per Unit)

Year	Base	Trial Standard Level 1	2	3	4
1990	353.4				
1993	377.5				
1998	378.5	391.9	417.0	457.8	481.9
2000	378.5	391.9	417.0	457.8	481.9
2015	379.7	392.5	417.1	457.8	481.9
2030	379.7	392.5	417.1	457.9	481.9

Source: LBL-REM.

5.3.5 Net Present Values (NPV)

The NPV 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 (1998-2030) 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.

Tables 5.20.a through 5.20.c show positive NPV (reduced costs) to society for all trial standard levels. Tables 5.20.a through Table 5.20.c show the results when calculated with 10 % real discount rate, 7% real discount rate, and 4% real discount rate, respectively. The ratio of benefits to costs ranges from 1.89 (standard 4 for freezers) to 3.66 (standard 1 for freezers).

Table 5.20.a Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 10% Real)

	Trial Standard Level			
	1	2	3	4
Refrigerator				
Benefit (Energy)	5.36	6.20	6.81	7.82
Cost (Equipment)	1.96	2.68	3.38	4.93
Net Present Value = Benefit - Cost	3.40	3.52	3.42	2.89
Ratio: Benefit/Cost	2.74	2.31	2.01	1.59
Freezer				
Benefit (Energy)	0.37	0.99	1.16	1.35
Cost (Equipment)	0.12	0.35	0.69	0.88
Net Present Value = Benefit - Cost	0.25	0.65	0.47	0.48
Ratio: Benefit/Cost	3.04	2.87	1.69	1.55
Total: Refrigerators and Freezers				
Benefit (Energy)	5.73	7.19	7.97	9.17
Cost (Equipment)	2.08	3.03	4.07	5.81
Net Present Value = Benefit - Cost	3.65	4.17	3.89	3.37
Ratio: Benefit/Cost	2.75	2.37	1.96	1.58

Source:LBL-REM.

Table 5.20.b Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 7% Real)

	Trial Standard Level			
	1	2	3	4
Refrigerator				
Benefit (Energy)	10.89	12.61	13.84	15.91
Cost (Equipment)	3.23	4.42	5.58	8.12
Net Present Value = Benefit - Cost	7.66	8.19	8.26	7.78
Ratio: Benefit/Cost	3.37	2.85	2.48	1.96
Freezer				
Benefit (Energy)	0.73	1.99	2.33	2.72
Cost (Equipment)	0.20	0.57	1.13	1.44
Net Present Value = Benefit - Cost	0.53	1.42	1.20	1.29
Ratio: Benefit/Cost	3.66	3.50	2.06	1.89
Total: Refrigerators and Freezers				
Benefit (Energy)	11.62	14.6	16.17	18.63
Cost (Equipment)	3.43	4.99	6.71	9.56
Net Present Value = Benefit - Cost	8.19	9.61	9.46	9.07
Ratio: Benefit/Cost	3.39	2.93	2.41	1.95

Source: LBL-REM.

Table 5.20.c Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 4% Real)

	Trial Standard Level			
	1	2	3	4
Refrigerator				
Benefit (Energy)	24.61	28.51	31.29	35.97
Cost (Equipment)	5.73	7.86	9.91	14.44
Net Present Value = Benefit - Cost	18.88	20.65	21.38	21.53
Ratio: Benefit/Cost	4.29	3.63	3.16	2.49
Freezer				
Benefit (Energy)	1.59	4.42	5.19	6.08
Cost (Equipment)	0.35	1.00	2.00	2.55
Net Present Value = Benefit - Cost	1.24	3.42	3.19	3.53
Ratio: Benefit/Cost	4.54	4.42	2.60	2.38
Total: Refrigerators and Freezers				
Benefit (Energy)	26.2	32.93	36.48	42.05
Cost (Equipment)	6.08	8.86	11.91	16.99
Net Present Value = Benefit - Cost	20.12	24.07	24.57	25.06
Ratio: Benefit/Cost	4.31	3.72	3.06	2.48

Source: LBL-REM.

5.4 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 refrigerators and freezers. For each sensitivity case, the results for the trial standards level are compared to the corresponding base-case run and the differences are tabulated.

5.4.1 Sensitivity Analysis of the Base Case

The sensitivity cases selected are defined as follows:

1 Lower Energy Price. Assume lower energy prices by using energy prices from the Low Economic Growth Case Scenario in the *Annual Energy Outlook 1994*.

2 Higher Energy Price. Assume higher energy prices by using energy prices from the High Economic Growth Case Scenario in the *Annual Energy Outlook 1994*.

3. 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.

4. 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.

5. High Equipment Efficiency. Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.

The results of these five sensitivity cases are presented in the following tables. Table 5.21 and Table 5.22 show how the average price varies. Table 5.23 and Table 5.24 show the differences in UEC or efficiency. The first line of these tables give 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 5.21 Average Purchase Price of New Refrigerators (1990$)

Year:	1990	1998	2000	2015	2030
Reference	627	623	624	624	625
1	627	623	623	624	625
2	627	623	623	624	625
3	627	535	535	536	536
4	627	686	687	687	688
5	627	631	637	718	752

Table 5.22 Average Purchase Price of New Freezers (1990$)

Year:	1990	1998	2000	2015	2030
Reference	353	379	379	380	380
1	353	379	379	380	380
2	353	379	379	380	380
3	353	342	342	342	342
4	353	417	417	417	418
5	353	383	389	452	482

Table 5.23 Average Unit Energy Consumption of New Refrigerators (kWh/a)

Year:	1990	1998	2000	2015	2030
Reference	857	647	647	647	646
1	857	647	647	647	647
2	857	647	647	646	646
3	857	647	647	646	646
4	857	647	647	647	647
5	857	618	596	451	424

Table 5.24 Average Unit Energy Consumption of New Freezers (kWh/a)

Year:	1990	1998	2000	2015	2030
Reference	595	491	491	474	474
1	595	491	491	474	474
2	595	491	491	474	474
3	595	474	474	474	474
4	595	491	491	491	474
5	595	472	454	337	307

Tables 5.25 and 5.26 shows results for cumulative energy consumption. The sensitivity analysis of product shipments is given in Table 5.27. Table 5.28 shows the net present values. The first line of Tables 5.25 through 5.28 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 5.25 Cumulative Energy Consumption of Refrigerators During the Period 1998-2030, EJ (Quads) Primary

	Base Case		Standard Level 1		Difference	
Reference	40.656	*(38.534)*	33.617	*(31.863)*	7.039	*(6.671)*
1	40.671	*(38.549)*	33.624	*(31.869)*	7.047	*(6.680)*
2	40.678	*(38.517)*	33.610	*(31.856)*	7.068	*(6.661)*
3	41.064	*(38.921)*	33.912	*(32.142)*	7.152	*(6.779)*
4	40.330	*(38.225)*	33.298	*(31.560)*	7.032	*(6.665)*
5	33.717	*(31.958)*	32.055	*(30.382)*	1.662	*(1.576)*

Table 5.26 Cumulative Energy Consumption of Freezers During the Period 1998-2030, EJ (Quads), Primary

	Base Case		Standard Level 1		Difference	
Reference	7.39	*(7.01)*	6.92	*(6.55)*	0.48	*(0.45)*
1	7.45	*(7.06)*	6.94	*(6.58)*	0.51	*(0.48)*
2	7.35	*(6.96)*	6.89	*(6.53)*	0.46	*(0.44)*
3	7.55	*(7.16)*	7.16	*(6.74)*	0.44	*(0.42)*
4	7.28	*(6.90)*	6.71	*(6.36)*	0.57	*(0.54)*
5	6.15	*(5.83)*	6.11	*(5.79)*	0.04	*(0.04)*

Table 5.27 Cumulative Shipments of Refrigerators and Freezers During the Period 1998-2030 (Millions)

	Refrigerator			Freezer		
	Base	Level 1	Difference	Base	Level 1	Difference
Reference	286.62	284.54	2.08	67.00	66.54	0.47
1	286.74	284.64	2.10	67.42	66.94	0.48
2	286.49	284.43	2.06	66.53	66.10	0.44
3	290.43	287.90	2.53	69.87	69.61	0.27
4	283.64	280.75	2.89	64.06	63.43	0.62
5	283.18	282.65	0.52	63.93	63.91	0.02

Table 5.28 Total Net Present Value to Consumers for Refrigerators and Freezers Sold during the Period 1998-2030 (Discounted to 1990 at 7% Real)

	Net Present Value (Billion 1990$)		
Case	Refrigerator	Freezer	Total
Reference	7.66	0.53	8.19
1	6.83	0.51	7.34
2	8.59	0.56	9.15
3	6.72	0.50	7.22
4	6.92	0.58	7.50
5	1.98	0.07	2.05

Source: LBL-REM.

REFERENCES

1. U.S. Department of Commerce, Bureau of the Census. 1983. *1980 Census of Population and Housing*, Washington, D.C.
2. U.S. Department of Energy, Energy Information Administration. 1994. *Annual Energy Outlook 1994*, DOE/EIA-0383(94), January. Washington, D.C.
3. U.S. Department of Commerce, Bureau of the Census. 1994. *Housing Starts*, July. Washington, D.C.
4. U.S. Department of Commerce, Bureau of Economic Analysis. 1981-1987. *Survey of Current Business*. Washington, D.C.
5. U.S. Department of Energy. 1994. *Monthly Energy Review*, DOE/EIA-0035(94/06), June. Washington, D.C.
6. U.S. Department of Energy, Energy Information Administration, Office of Energy Markets and End Use. 1990. *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 1990*. DOE/EIA-0321(90), February. Washington, D.C.

CHAPTER 6. IMPACTS OF STANDARDS ON MANUFACTURERS

This chapter describes estimates of the impacts of standards on manufacturers of refrigerators and freezers. These estimates are based on the Lawrence Berkeley Laboratory Manufacturer Analysis Model (LBL-MAM), which consists of the LBL-Manufacturer Impact Model and the Government Regulatory Impact Model developed by Arthur D. Little Consulting Company. The LBL-MAM collects into one spreadsheet all calculations necessary to determine the impact of standards on an industry's profitability and scale of operation. A complete description of the LBL-MAM and its inputs and outputs for the two industries analyzed is included in Appendix C.

This chapter begins with a profile of the refrigerator and freezer industries. Next, we give an overview of the analysis with some notes about interpreting the results of the analysis. The items covered include long-run impacts, short-run impacts, impacts as a function of firm size, and sensitivity analysis. The final sections describe the impacts of various standards levels on manufacturers of refrigerators and freezers, respectively.

6.1. INDUSTRY PROFILE

This section begins by examining housing starts and appliance saturation rates, followed by a brief description of market shares, then a discussion of mergers and acquisitions in these industries. Finally we present a comparison of price indices for these industries.

6.1.1. Demand

Units Shipped and Housing Starts

Figure 6.1 shows annual refrigerator and freezer shipments and housing starts between 1961 and 1990. The figure shows a strong correlation between housing starts and refrigerator sales. Although the changes in refrigerator shipments are not entirely due to changes in new housing starts, housing starts may be used to predict shipments of refrigerators (and most other major appliances) for two reasons. First, almost every new house requires a new set of appliances, so fluctuations in housing starts tend to cause fluctuations in shipments of most common appliances. Second, housing starts are a good indicator of the strength of the economy as a whole. A healthy new housing market is likely to correspond to a healthy economy, and a healthy economy encourages replacement and discretionary purchases of appliances.

Other factors, such as age of the current stock of appliances, purchase price, fuel costs, consumer income, and climate conditions, have varying degrees of importance in determining shipments of the various appliances covered by the National Appliance Energy Conservation Act of 1987 (NAECA). The LBL-REM uses some of these factors in predicting appliance shipments in the base and new standards cases. The LBL-MAM uses some of the LBL-REM estimates in its analysis of financial impacts on manufacturers.

As expected, refrigerators and freezers show a strong correlation with housing starts. Several interesting points emerge from these graphs. We see that there has been a fairly steady decline in freezer shipments since 1979 while shipments of refrigerators have generally risen since a strong dip in 1982 corresponding to the significant national recession of that period.

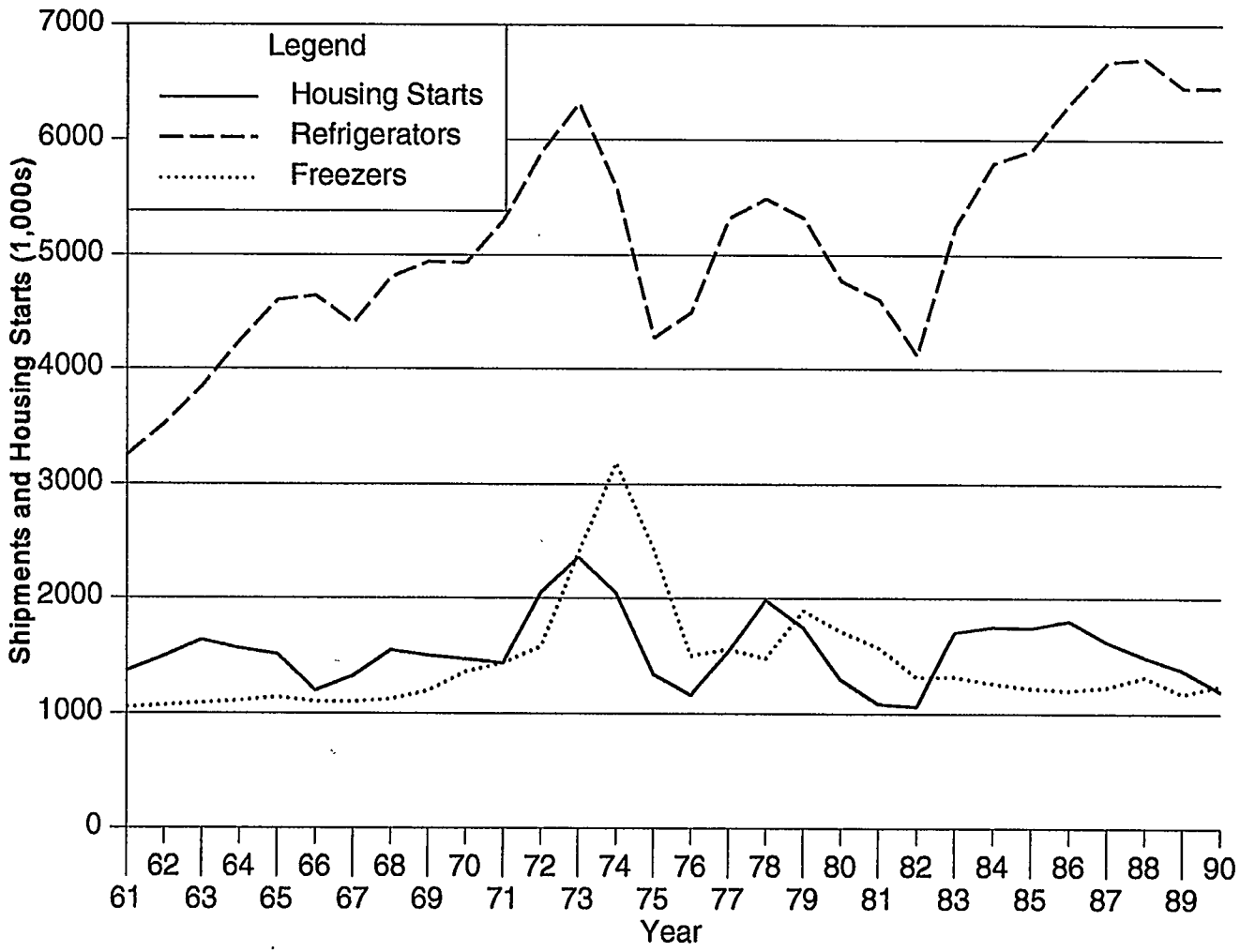

Figure 6.1 Refrigerator and freezer shipments compared to housing starts

Appliance Saturation Rates

The saturation rate is the percentage of residences that own a particular appliance. Table 6.1 lists the saturation rates for refrigerators and freezers in selected years during the past 28 years. Note that the data do not reflect the fact that some residences have more than one appliance of a particular type. In general, if most residences own an appliance but few have more than one unit, we expect that the appliance will have a relatively low elasticity of demand. This is usually explained by such appliances being considered necessities. This observation corresponds with the lower price elasticity of refrigerators relative to freezers.

Table 6.1. Market Saturations

Product	1963 %	1973 %	1978 %	1983 %	1988 %	1991 %
Refrigerators	99.1	99.9	99.9	99.9	99.9	99.9
Freezers	24.0	31.0	40.0	42.8	42.0	33.0

Source: *Appliance,* September 1992

6.1.2. Supply

Market concentration

Market concentration is the extent to which market share is controlled by the largest firms in an industry. Table 6.2 shows market concentration percentages for the two, four, and five largest producers in each industry.

Market concentration plays a part in the analysis because it may indicate the existence of market power[1] in a particular industry. Firms with the largest market shares may have some market power, a factor that affects the markups used by these firms both in the base case and the standards case.

[1]Market power is the ability to set price within a limited range. More technically, it is the freedom that results from facing a demand curve that is not infinitely elastic. This means that if price is raised by some small amount, sales will not fall to zero, and if price is lowered by some small amount, sales will not become essentially infinite.

Table 6.2 Percent of Market Controlled by the Largest Producers of the Two Products

	Number of Companies		
Product	**Top Two %**	**Top Four %**	**Top Five %**
Refrigerators	60	89	97
Freezers	86	95	†

†Market share data for only the top four firms. "Others" comprise 5% of the market.
Source: *Appliance,* September 1992

Figures 6.2 and 6.3 give a picture of the manufacturer market shares for refrigerators and freezers, respectively. We can see that the market for both products are characterized by high industrial concentrations.

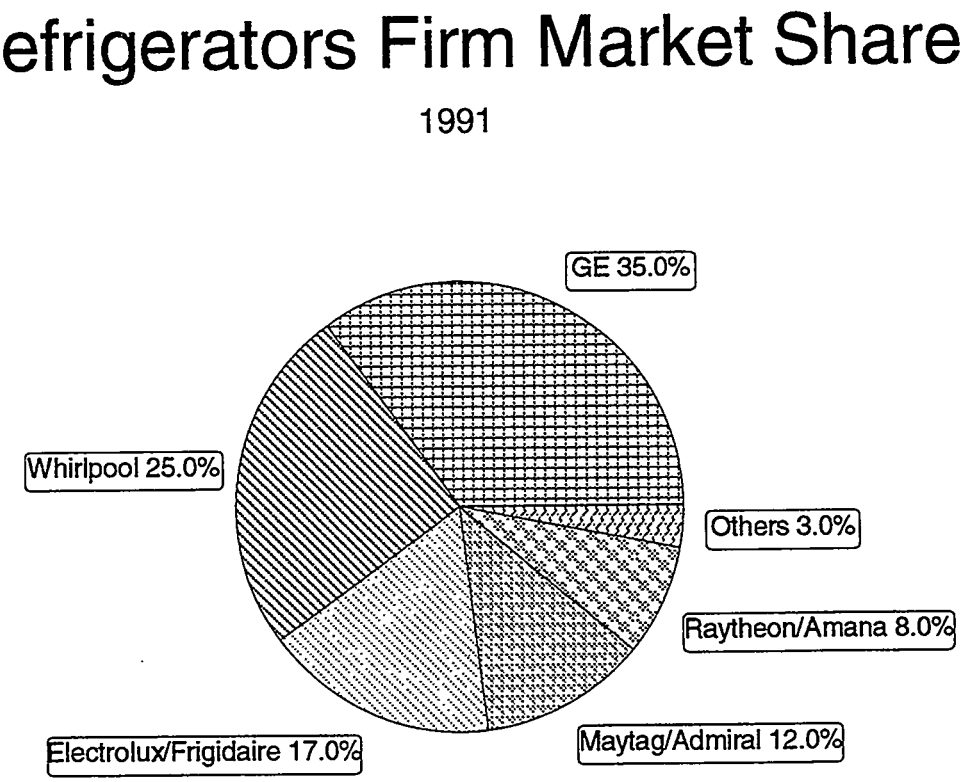

Figure 6.2 Refrigerator share of market

Source: *Appliance,* September 1992

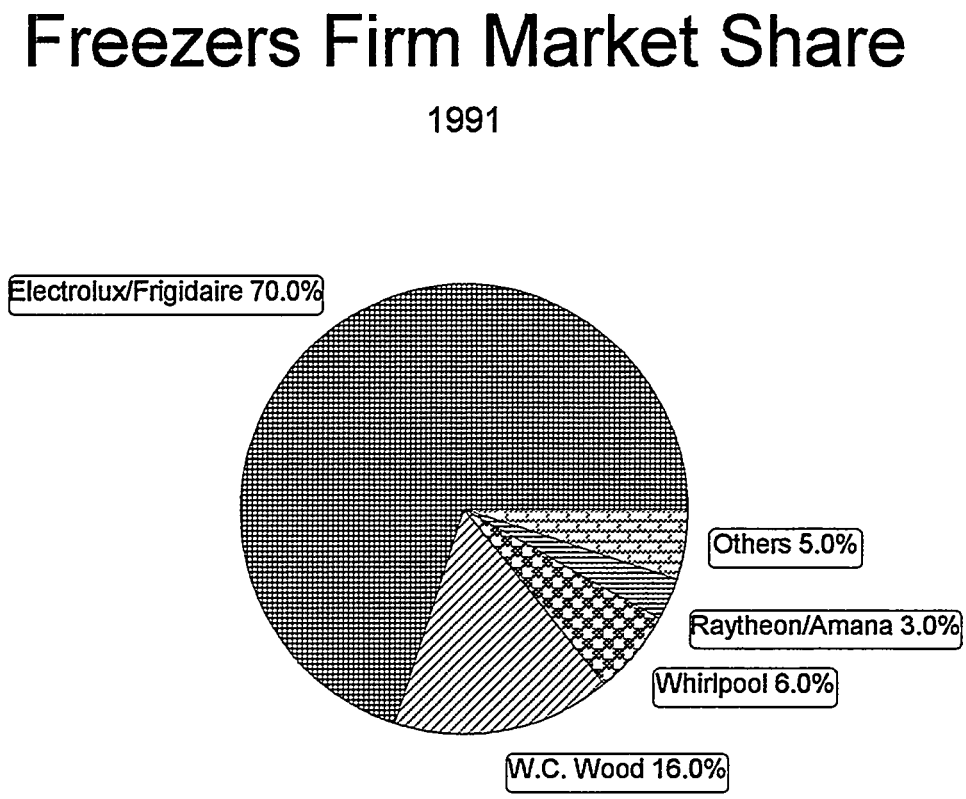

Figure 6.3 Freezer share of market

Source: *Appliance*, September 1992

Mergers and Acquisitions

The appliance manufacturing industry has had a continuing history of consolidation. Mergers and acquisitions have two purposes. First, they produce large corporations with the financial resources and stability to be successful in a competitive market. Second, mergers and acquisitions mean manufacturers can have a complete line of home appliances. This product diversification allows firms to offer a complete set of appliances to consumers, an important feature in the builder market. There is also increasing worldwide competition in the major appliance market, so mergers or acquisitions are likely to continue. Table 6.3 is a partial list of major acquisitions of appliance manufacturers.

Table 6.3 Major Mergers and Acquisitions

Buyer	Purchase	Year
Whirlpool	Heil-Quaker	1964
Raytheon Co.	Amana Refrigeration, Inc.	1965
White Consolidated Inc.	Franklin Appliance Div. (Studebaker Corp.)	1967
White Consolidated Inc.	Kelvinator Appliance Div. (American Motor Corp.)	1968
Emerson Electric Co.	In-Sink-Erator	1968
Magic Chef, Inc.	Gaffers & Sattler	1968
Magic Chef, Inc.	Dixie-Narco, Inc.	1968
Magic Chef, Inc.	Johnson Corp.	1971
AB Electrolux (Sweden)	Eureka	1974
Rockwell International	Admiral Co.	1974
White Consolidated Inc.	Westinghouse Electric Corp.'s Major Appliance Operations	1975
Caloric Corp. (Raytheon)	Glenwood Range Co.	1978
White Consolidated Inc.	Philco Appliance Business (Ford Motor Co.)	1979
White Consolidated Inc.	Frigidaire Appliance Business (General Motors Corp.)	1979
Magic Chef, Inc.	Admiral Div. (Rockwell)	1979
Carrier	Jenn-Air	1979
Raytheon Co.	Modern Maid Co.	1979
Raytheon Co.	Speed Queen (McGraw Edison)	1979
United Technologies Corp.	Carrier	1979
AB Electrolux (Sweden)	Tappan	1981

Table 6.3 Acquisitions of Appliance Manufacturers (Cont'd).

Buyer	Purchase	Year
Dart & Kraft	Hobart Corp.	1981
Magic Chef, Inc.	Revco	1981
Maytag Co.	Hardwick Stove	1981
Maytag Co.	Jenn-Air (Carrier/United Techn)	1982
Hobart (Dart & Kraft)	Chambers Corp. (Rangaire Corp.)	1983
Magic Chef, Inc.	Toastmaster	1983
Admiral (Magic Chef)	Warwick Manufacturing Co.	1985
Chicago Pacific Corp.	The Hoover Co.	1985
Masco Corp.	Thermador-WasteKing (NI Ind.)	1985
AB Electrolux (Sweden)	White Consolidated Industries	1986
Maytag Co.	Magic Chef, Inc.	1986
Chicago Pacific Corp.	Rowenta Group (West Germany) (Allegheny Int'l and Rothmans Deutschland GmbH)	1986
Whirlpool Corp.	Kitchen-Aid Division (Dart & Kraft, Inc.)	1986
General Electric Co.	RCA	1986
Inter-City Gas Corp. (Canada)	Heil-Quaker Home Systems, Inc. (Whirlpool)	1986
Emerson Electric Co.	Kitchen-Aid dishwashing manufacturing facility (Whirlpool)	1986
White Consolidated Ind. (Electrolux)	Design & Manufacturing Corp.	1987
Thomson S.A. (France)	GE/RCA consumer electronics	1988
Toastmaster Div.	Mgt. team buys division from Maytag Co.	1988
Speed Queen	Holiday-Hammond	1988
Whirlpool Corp.	Roper Corp.'s brand name	1988
General Electric Co.	Roper Corp.'s physical assets (inc. manufacturing facilities)	1988
Maytag Co.	Merger with Chicago Pacific Corp.	1988
Fedders	Emerson Quiet Kool	1990
Hayward Pools	ComfortZone	1991

6.1.3. Prices

Appliance prices have, on average, risen more slowly than aggregate indexes measuring consumer and producer prices. The appliance industry has a long history of price stability even through business cycle fluctuations. Despite increased energy and component prices during the 1970s and 1980s, the industry has, through increased productivity, kept price increases lower than increases in the Consumer Price Index (CPI). In recent years, the industry has made a strong push toward automation to keep costs down, spending hundreds of millions of dollars to automate production facilities. Figure 6.4 shows the Producer Price Index (PPI) for all commodities and for household appliances for the years 1977 to 1991.

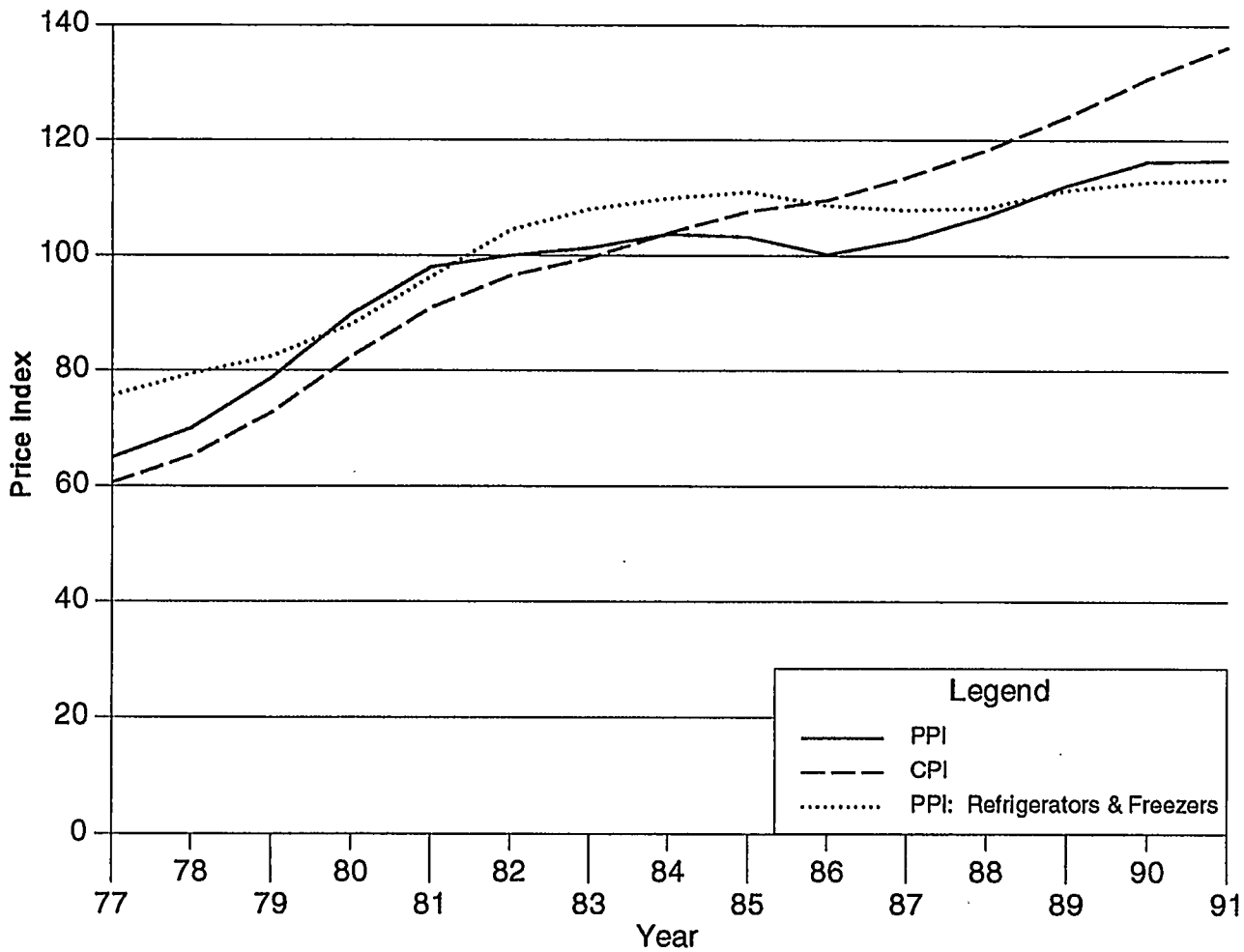

Figure 6.4 PPI and CPI Indices
Source: U.S. Bureau of Labor Statistics, October 1994.

6.2. IMPACTS ON THE MANUFACTURERS OF REFRIGERATORS AND FREEZERS

6.2.1. Long-Run Impacts

Refrigerators and freezers were analyzed at four different trial standards levels. In each case it is assumed that the standards would be just stringent enough to induce manufacturers to use all engineering design options up through the one listed as achieving the desired energy efficiency. For a complete description of these design options, see the Engineering Analysis in Chapter 3.

Qualitative Analysis

The appliance manufacturing industries (including refrigerator and freezer manufacturing) is characterized by economies of scale. The presence of economies of scale means that for the purpose of price determination there are fixed costs. These are estimated to be about 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. Because of this markup, 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 through its effect on sales. If standards induce an increase in fixed cost, 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 (i.e., by making refrigerators more attractive and thereby increasing demand). The model calculates that these effects, when combined, will tend to increase typical firm return on equity (ROE) at levels 1 and 4 and decrease profits at levels 2 and 3. The model also calculates that these effects for each standard level will tend to increase industry net present value.

Quantitative Analysis

Tables 6.4 and 6.5 are referred to as the long-run output tables and they summarize the essential outputs from the LBL-MAM using the primary scenario for refrigerator and freezers, respectively. Four other scenarios are summarized and discussed in the sensitivity section, 6.1.4. The first column in the output table gives the value of the output variables in the base case. This case represents the current state of the industry. Each of the next four columns shows the estimated state of the industry if one of the four trial standards levels were to be implemented.

Each column of an output table gives the estimated values of the five most important output variables. Under each of these five values can be found two percentages. The upper percentage tells how much the variable has changed from the base case, while the lower percentage gives the standard error of the variable's estimated value. For all variables except ROE and net income, the change is given as a percentage change. For ROE and net income a simple difference is given.

Tables 6.6 and 6.7 present the results of industry net present value analysis using an industry

net cash flow model. Industry net present value is an alternate method of analyzing the impact of standards. The two measures of ROE and industry net present value are theoretically identical although in practice, small differences may arise.

Once the above interpretations are understood, the results of the model concerning the long-run impact of standards on the refrigerator industry can be read from the various output tables. However, two points should be noted. First, higher standards levels may tend to increase profitability because higher standards generally entail higher costs which, depending on their nature, may increase markups by mor than the incremental increase in costs. Second, uncertainty in the output variables increases at higher standards levels, approximately in proportion to the size of the change.

Table 6.4 Refrigerator: Primary Scenario – Long-Run

	Base	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	1.34	1.32	1.32	1.31	1.29
% change		-1.41%	-2.01%	-2.62%	-3.98%
S.E.		2.83%	3.11%	3.45%	5.22%
Price	$447.05	$485.42	$499.24	$513.09	$545.12
% change		8.58%	11.68%	14.77%	21.94%
S.E.		2.70%	3.34%	4.24%	7.32%
Revenue (in $M)	600.21	642.55	656.83	670.86	702.75
% change		7.05%	9.43%	11.77%	17.08%
S.E.		3.17%	3.81%	4.71%	7.29%
Net Income (in $M)	38.42	40.32	40.50	41.03	44.16
Difference		1.90	2.08	2.61	5.74
S.E.		2.91	4.42	6.21	8.65
ROE	7.31%	7.36%	7.18%	7.15%	7.72%
Difference		0.04%	-0.13%	-0.16%	0.41%
S.E.		0.45%	0.75%	1.00%	1.57%

Table 6.5 Freezer: Primary Scenario – Long-Run

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.25	0.24	0.24	0.23	0.22
% change		-0.91%	-2.91%	-6.83%	-8.93%
S.E.		2.73%	6.71%	8.82%	10.61%
Price	$225.30	$233.77	$249.31	$274.58	$290.22
% change		3.76%	10.66%	21.87%	28.82%
S.E.		1.51%	3.50%	7.93%	8.45%
Revenue (in $M)	55.25	56.81	59.36	62.74	64.82
% change		2.81%	7.44%	13.55%	17.32%
S.E.		2.56%	6.74%	11.40%	13.75%
Net Income ($M)	3.54	3.59	3.61	3.60	3.90
Difference		0.05	0.07	0.06	0.36
S.E.		0.24	0.50	1.59	1.23
ROE	7.30%	7.33%	7.08%	6.74%	7.51%
Difference		0.03%	-0.22%	-0.56%	0.20%
S.E.		0.40%	0.78%	2.86%	2.28%

Table 6.6 Refrigerators: Industry Net Present Values

	Base	Level 1	Level 2	Level 3	Level 4
SHIPMENTS (UNITS)	6.71	6.50	6.43	6.38	6.37
Difference		-0.22	-0.28	-0.34	-0.35
% Change		-3.23%	-4.18%	-5.00%	-5.18%
PRICE ($ UNIT)	$447.05	$523.29	$546.01	$566.46	$573.01
Difference		76.24	98.97	119.41	125.96
% Change		17.06%	22.14%	26.71%	28.18%
TOTAL REVENUES ($000,000)	3001.07	3399.37	3512.33	3612.44	3647.32
Difference		398.30	511.26	611.37	646.25
% Change		13.27%	17.04%	20.37%	21.53%
PROFIT AFTER TAX ($M)	115.24	115.24	290.88	321.92	233.03
Difference		0.00	175.64	206.68	117.79
% Change		0.00%	152.41%	179.35%	102.21%
NET CASH FLOW ($M)	92.73	151.52	181.46	195.48	100.66
Difference		58.79	88.72	102.75	7.93
% Change		63.40%	95.68%	110.80%	8.55%
INDUSTRY VALUE ($M)	772.77	829.80	835.91	846.18	924.42
Difference		57.02	63.14	73.41	151.65
% Change		7.38%	8.17%	9.50%	19.62%

Table 6.7 Freezers: Industry Net Present Values

	Base	Level 1	Level 2	Level 3	Level 4
SHIPMENTS (UNITS)	1.23	1.21	1.19	1.14	1.11
Difference		-0.01	-0.04	-0.09	-0.12
% Change		-1.20%	-3.04%	-6.98%	-9.85%
PRICE ($ UNIT)	$225.30	$235.32	$250.05	$275.55	$296.76
Difference		10.02	24.75	50.25	71.46
% Change		4.45%	10.99%	22.30%	31.72%
TOTAL REVENUES ($M)	276.27	285.10	297.31	314.32	328.06
Difference		8.83	21.03	38.04	51.78
% Change		3.19%	7.61%	13.77%	18.74%
PROFIT AFTER TAX ($M)	10.61	10.61	13.59	17.20	16.31
Difference		0.00	2.98	6.59	5.70
% Change		0.00%	28.12%	62.13%	53.75%
NET CASH FLOW ($M)	8.54	7.82	7.94	8.66	5.44
Difference		-0.72	-0.59	0.12	-3.10
% Change		-8.42%	-6.93%	1.45%	-36.32%
INDUSTRY VALUE ($M)	71.14	73.17	75.44	79.32	85.73
Difference		2.03	4.30	8.17	14.59
% Change		2.86%	6.04%	11.49%	20.50%

6.2.2. Short-Run Impacts

In the short run, capacity may not adjust as needed to meet the predicted long-run change in demand resulting from standards. This could have either of the following consequences: If standards cause a decrease in demand, stiffer-than-normal short-run price competition will result and price will fall below its long-run level, lowering profits. If standards cause an increase in demand, there will be less short-run price competition than normal and price and profits will increase.

The business cycle presents the refrigerator and freezer manufacturing industries (indeed all durable goods industries) 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 1.6% fall in the price of refrigerator-freezers; a 10% demand increase has the reverse effect. This effect is taken into account as described in Section 2.3.4.2 and is used to produce a short-run version of the output table that is displayed in Table 6.6 and Table 6.7. For reasons that are explained in 2.3.4.2, the short-run change has been overestimated. Thus all values for change in Tables 6.6 and 6.7 should be viewed as somewhat too large in absolute value. The short-run impact on profit is also displayed in the Monte Carlo module.

6.2.3. Impact as a Function of Firm Size

As described in section 6.1.2, the refrigerator and freezer manufacturing industries are dominated by several large firms along with a number of smaller firms that make up a very small segment of the market. Typically, in these (and other similar) industries, average cost decreases with increasing firm size. Thus, the industry has economies of scale, and large firms (to the extent that their facilities are modernized) have lower average costs than small firms. This fact, coupled with increasing competitive pressures of the national market (e.g., foreign competition, etc.), 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 smaller firms tend to have less resources and capacity to weather economic adversity, any decrease in average profitability is more likely to seriously affect 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 standpoint of competitiveness, a decrease in average profitability could speed up the consolidation process, further reducing the number of firms. An increase in average profitability could help maintain the current level of competition. Either effect may well be temporary because in the long run the number of firms should be determined by the industry's cost structure and the relationship between a single firm's elasticity of demand and the number of competing firms.

Table 6.8 Refrigerator: Primary Scenario – Short-Run

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	1.34	1.32		1.31	1.29
% change		-1.35%	-1.92%	-2.50%	-3.80%
Price	$447.05	$484.3	$497.65	$510.99	$541.78
% change		8.34%	11.32%	14.30%	21.19%
Revenue (in $M)	600.211	641.48	655.31	668.91	600.78
% change		6.88%	9.18%	11.44%	16.59%
Net Income (in $M)	38.42	37.91	34.65	33.45	40.38
Difference		-0.51	-3.77	-4.97	1.96
ROE	7.31%	6.92%	6.15%	5.83%	7.06%
Difference		-0.40%	-1.17%	-1.48%	-0.25%
S.E.		0.87%	1.10%	1.28%	2.12%

Table 6.9 Freezer: Primary Scenario – Short-Run

		Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.25	0.24	0.24	0.23	0.23
% change		-0.85%	-2.70%	-6.29%	-8.18%
Price	$225.30	$233.44	$248.23	$271.85	$286.48
% change		3.61%	10.18%	20.66%	27.16%
Revenue (in $M)	55.26	56.77	59.24	62.48	64.51
% change		2.73%	7.20%	13.07%	16.75%
Net Income (in $M)	0.04	3.56	3.16	2.50	3.38
Difference		1.88%	-38.29%	-103.88%	-15.53%
ROE	7.30%	7.26%	6.19%	4.67%	6.51%
Difference		-0.04%	-1.11%	-2.63%	-0.79%
S.E.		0.53%	1.10%	3.06%	14.15%

6.2.4. Sensitivity Analysis for Refrigerators and Freezers

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

Alternative Scenarios

The sensitivity analysis shows that price elasticities and discount rates play significant roles in determining the output of the model. The price elasticity is an industry elasticity as opposed to a single-firm elasticity. This means it measures the effect on demand of a change in price by all firms for all refrigerators or freezers. The estimates of standard errors which 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, four alternative scenarios have been used.

The four scenarios are: The "high industry price elasticity" scenario where the industry price elasticity (IPE) is -1. The "low industry price elasticity" scenario changes IPE to 0. The "high discount rate" scenario increases the discount rate three times. The "low discount rate scenario" sets the discount rate at 10% of its value in the primary scenario. Tables 6.10, 6.11, 6.12 and 6.13 show the results of running these scenarios for the refrigerator industry, and Tables 6.14, 6.15, 6.16 and 6.17 show the results for the freezer industry.

Sensitivity Charts

Tables 6.18 and 6.19 list the sensitivities of ROE to the control panel inputs. To construct the tables, each control variable is first set to its normal value, then one is increased in absolute value by one standard error, and the change in profit is recorded. Next, the variable is returned to its normal value and the next variable is tested. Since each variable has its own standard error, the sensitivity reported in the table measures both how sensitive the model is to a change in the variable, and how uncertain the variable's value is. Note that the change in profit is simply the difference between long-run ROE and base-case ROE. For a complete explanation, see Section 6.1.4

As can be seen from the tables, 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 consumer discount rate of appliance energy savings (RD), and 3) the current proportion of long-run fixed costs (FCA). No variable may be singled out as most important because importance varies with standards level. Why these three variables are important, and why their importance changes from one level to the next, is discussed below.

The industry price elasticity (IPE) determines consumer reaction to the price increase imposed by standards. This variable gains its importance not through any effect on pricing (which is determined only by the single-firm price elasticity), but because it translates a price increase into a decrease in sales, and any change in sales directly influences profit. Because of fixed costs, a fall in demand causes a greater reduction in revenue than in variable costs, and, consequently, a loss in profit. Probably the most important reason for the model's high sensitivity to IPE is IPE's

uncertainty.[2] Because the estimates were made quite some time ago, we view the estimated value of IPE as being highly uncertain and as a result, we assigned it an uncertainty of 100%.[3]

[2]The original source of elasticities was Oak ridge National Laboratory and are documented in DOE/CE-0029, Consumer Products Efficiency Standards Economic Analysis Document, U.S. Department of Energy, March 1982. These estimates were further checked against historical shipments by the LBL-REM analysis.

[3]This means its standard error equals its mean value.

Table 6.10 Refrigerators: High IPE Scenario

	Base	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	1.34	1.28	1.26	1.24	1.19
% change		-4.17%	-5.91%	-7.64%	-11.48%
S.E.		1.92%	2.19%	2.26%	3.71%
Price	$447.05	$485.42	$499.24	$513.09	$545.12
% change		8.58%	11.68%	14.77%	21.94%
S.E.		3.06%	3.68%	3.98%	7.41%
Revenue (in $M)	598.90	623.21	629.32	634.83	646.49
% change		4.06%	5.08%	6.00%	7.95%
S.E.		0.79%	0.96%	1.06%	1.95%
Net Income (in $M)	38.25	37.83	36.76	36.04	37.10
Difference		-0.43	-1.49	-2.21	-1.15
S.E.		2.40	3.40	4.16	5.55
ROE	7.30%	7.10%	6.77%	6.59%	6.97%
Difference		-0.20%	-0.52%	-0.71%	-0.32%
S.E.		0.49%	0.67%	0.81%	1.08%

Table 6.11 Refrigerators: Low IPE Scenario

	Base	Level	Level	Level	Level
Shipments (in Mil)	1.34%	1.34	1.34	1.34	1.34
% change		-0.00%	-0.00%	-0.00%	-0.00%
S.E.		0.00%	0.00%	0.00%	0.00%
Price	$447.05	$485.42	$499.24	$513.09	$545.13
% change		8.58%	11.68%	14.77%	21.94%
S.E.		2.73%	3.28%	4.10%	7.24%
Revenue (in $M)	600.87	652.44	671.02	689.63	732.68
% change		8.58%	11.68%	14.77%	21.94%
S.E.		2.73%	3.28%	4.09%	7.24%
Net Income (in $M)	38.51	41.60	42.44	43.63	47.91
Difference		3.09	3.93	5.13	9.41
S.E.		2.80	4.04	5.13	10.10
ROE	7.32%	7.48%	7.38%	7.42%	8.08%
Difference		0.16%	0.06%	0.10%	0.76%
S.E.		0.44%	0.65%	0.81%	1.51%

Table 6.12 Refrigerators: High Discount Rate Scenario

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	1.34	1.32	1.31	1.30	1.28
% change		-1.73%	-2.36%	-2.99%	-4.38%
S.E.		0.61%	0.73%	0.85%	1.33%
Price	$447.14	$486.31	$500.30	$514.29	$546.61
% change		8.76%	11.89%	15.02%	22.25%
S.E.		2.85%	3.53%	4.37%	7.43%
Revenue (in $M)	600.10	641.40	655.57	669.56	701.44
% change		6.88%	9.25%	11.58%	16.89%
S.E.		2.12%	2.60%	3.23%	5.40%
Net Income (in $M)		40.77	41.03	41.63	44.98
Difference		2.30	2.56	3.17	6.51
S.E.		2.67	4.24	6.20	8.59
ROE	7.32%	7.46%	7.30%	7.28%	7.90%
Difference		0.14%	-0.02%	-0.04%	0.58%
S.E.		0.47%	0.76%	1.08%	1.46%

Table 6.13 Refrigerators: Low Discount Rate Scenario

	Base	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	1.35	1.42	1.426	1.42	1.42
% change		4.81%	5.12%	5.12%	4.69%
S.E.		0.83%	0.86%8	1.10%	1.82%
Price	$446.26	$477.62	$490.00	$502.61%	$532.07
% change		7.03%	9.80%7	12.63%	19.23%
S.E.		2.83%	2.87%5	3.76%	6.54%
Revenue (in $M)	603.41	676.91	696.47%	714.37%	753.20
% change		12.18%	15.42%	18.39%	24.82%
S.E.		2.08%	2.09%	2.70%	4.61%
Net Income (in $M)	38.29	39.10	39.28%9	39.59	40.98
Difference		0.82	0.99	1.30	2.69
S.E.		281.48	312.49%	334.81%	276.55%
ROE	7.24%	6.70%	6.50%	6.41%	6.61%
Difference		-0.54%	-0.74%	-0.82%	-0.63%
S.E.		0.51%	0.55%	0.58%	0.48%

Table 6.15 Freezers: High IPE Scenario

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.25	0.24	0.23	0.21	0.20
% change		-1.82%	-5.74%	-13.19%	-17.06%
S.E.		1.11%	2.59%	3.78%	5.15%
Price	$225.30	$233.77	$249.31	$274.58	$290.22
% change		3.76%	10.66%	21.87%	28.82%
S.E.		1.37%	4.37%	6.91%	9.67%
Revenue (in $M)	55.23	56.27	57.61	58.43	59.01
% change		1.88%	4.31%	5.80%	6.84%
S.E.		0.18%	0.92%	1.56%	1.98%
Net Income (in $M)	3.54	3.52	3.38	2.99	3.19
Difference		-0.01	-0.16	-0.54	-0.35
S.E.		0.07	0.53	0.69	0.68
ROE	7.30%	7.25%	6.81%	5.93%	6.63%
Difference		-0.04%	-0.49%	-1.37%	-0.67%
S.E.		0.16%	1.32%	1.47%	1.43%

Table 6.14 Freezers: Low IPE Scenario

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.25	0.25	0.25	0.25	0.25
% change		-0.00%	-0.00%	-0.00%	-0.00%
S.E.		0.00%	0.00%	0.00%	0.00%
Price	$225.30	$233.77	$249.31	$274.58	$290.22
% change		3.76%	10.66%	21.87%	28.82%
S.E.		1.19%	3.09%	6.05%	9.32%
Revenue (in $M)	55.28	57.36	61.17	67.37	71.21
% change		3.76%	10.66%	21.87%	28.82%
S.E.		1.19%	3.09%	6.05%	9.31%
Net Income (in $M)	3.54	3.66	3.85	4.26	4.68
Difference		0.12	0.31	0.72	1.14
S.E.		0.08	0.27	0.76	0.88
ROE	7.30%	7.40%	7.35%	7.50%	8.33%
Difference		0.10%	0.05%	0.20%	1.02%
S.E.		0.14%	0.46%	1.23%	1.34%

Table 6.16 Freezers: High Discount Rate Scenario

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.25	0.24	0.24	0.23	0.22
% change		-1.29%	-3.69%	-7.63%	-9.78%
S.E.		0.55%	1.10%	2.11%	2.74%
Price	$225.32	$234.03	$249.89	$275.40	$291.22
% change		3.86%	10.91%	22.22%	29.24%
S.E.		1.38%	2.99%	7.07%	9.95%
Revenue (in $M)	55.24	56.63	59.00	62.36	64.41
% change		2.52%	6.81%	12.90%	16.61%
S.E.		0.77%	1.63%	3.82%	5.31%
Net Income (in $M)	3.54	3.60	3.63	3.64	3.96
Difference		0.06	0.09	0.10	0.42
S.E.		0.11	0.31	0.84	1.11
ROE	7.31%	7.38%	7.18%	6.86%	7.69%
Difference		0.07%	-0.12%	-0.45%	0.38%
S.E.		0.24%	0.6%	1.65%	2.19%

Table 6.17 Freezers: Low Discount Rate Scenario

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments	0.25	0.26	0.28	0.27	0.27
% change		6.09%	13.42%	11.07%	11.30%
S.E.		0.74%	1.90%	3.27%	4.71%
Price	$225.10	$231.67	$244.62	$268.05	$282.28
% change		2.92%	8.67%	19.08%	25.40%
S.E.		1.37%	2.92%	5.84%	8.85%
Revenue (in	55.61	60.72	68.55	73.55	77.62
% change		9.19%	23.35%	32.26%	39.57%
S.E.		0.73%	1.49%	2.61%	3.73%
Net Income	3.56	3.80	4.16	4.24	4.34
Difference		0.24	0.60	0.68	0.78
S.E.		0.16	0.28	0.40	0.29
ROE	7.29%	7.21%	7.05%	6.80%	7.00%
Difference		-0.08%	-0.25%	-0.49%	-0.29%
S.E.		0.32%	0.56%	0.72%	0.54%

Table 6.18 Refrigerators: Sensitivity of ROE to a 1 S.E. Change in Control Variables

Control Variables			Possible Standards Levels			
Name	Value	Change	1	2	3	4
IPE	-0.24	-0.55	-0.002	-0.003	-0.004	-0.005
RD	1.37	3.14	0.001	0.001	0.001	0.002
ECC	0.07	0.08	-0.000	-0.000	-0.000	-0.000
EP	0.01	0.02	0.000	-0.000	-0.000	0.000
FCA	0.10	0.16	0.002	0.003	0.004	0.006
F1X	0.20	0.35	-0.001	-0.003	-0.004	-0.001
CC.N	41.23	50.26	-0.000	-0.001	-0.001	-0.000
dVC.N	32.76	43.94	0.001	0.001	0.001	0.002
ro.N	0.00	0.30	-0.002	-0.002	-0.003	-0.005
SRPR	0.16	0.59	0.000	0.000	0.000	0.000

Table 6.19 Freezers: Sensitivity of ROE to a 1 S.E. Change in Control Variables

Control Variables			Possible Standards Levels			
Name	Value	Changed	1	2	3	4
IPE	-0.43	-0.99	-0.001	-0.004	-0.010	-0.011
RD	1.60	3.68	0.001	0.001	0.001	0.002
ECC	0.07	0.08	-0.000	-0.000	-0.001	-0.000
EP	0.01	0.02	-0.000	-0.000	-0.000	0.000
FCA	0.10	0.16	0.001	0.002	0.004	0.005
F1X	0.20	0.35	-0.000	-0.002	-0.005	-0.001
CC.N	0.18	0.22	-0.000	-0.001	-0.002	-0.000
dVC.N	8.06	10.80	0.000	0.001	0.000	0.001
ro.N	0.00	0.30	-0.001	-0.002	-0.005	-0.007
SRPR	0.16	0.59	0.000	0.000	0.000	0.000

The consumer discount rate (RD) shows a large sensitivity for exactly the same reason as IPE. In both cases, this sensitivity changes from standard level to standard level because price increase and operating cost decrease change from level to level. The percent of fixed costs (FCA) is important because of its role in the model and the uncertainty of its measurement. It determines LBL-MAM's estimate of the firm's markup over variable cost, which, in turn, determines the firm's ability to pass on various mixtures of fixed and variable cost. (For a full explanation, see Sections 2.3.4 and C.2.1.)

Monte Carlo Analysis

The Monte Carlo approach is described in Section 6.1.4, and the standard errors it generates are reported in the output tables. This section examines four runs in more detail: two for refrigerators and two for freezers.

Tables 6.20 to 6.23 show the control panel from two Monte Carlo runs for refrigerators and freezers, which were selected because they showed a decrease in long-run ROE. (All Monte Carlo Runs were done for standard level 1.) In both of the refrigerator Monte Carlo runs, the primary factor affecting the results was IPE, the industry's price elasticity, which was randomly chosen more than two standard deviations beyond its estimated value. In both freezer runs, the primary factor affecting the results was also IPE.

It should also be noted that the discount rate plays a lesser but supporting role in the outcome of the various scenarios.

Table 6.20 Refrigerator Monte Carlo Runs

		Input Value	Cntrl	Vari-ation	Progrm Value	Name
Price Elasticity		-0.24	1.82	100.00%	-1.09	IPE
Consumer Discount Rate		136.50%	28.79%	100.00%	173.48%	RD
Equity Cost of Capital		0.068	-0.57	10.00%	0.0642	ECC
Economic Profit		0.005	-0.64	1.00%	-0.001	EP
L-R Fixed Part of Costs & Assets		0.10	1.44	50.00%	0.20	FCA
L-R Fixed Part of 1-X Cap. Cost		0.20	1.05	60.00%	0.36	F1X
One-Time Capital Costs		41.23	1.99	20.00%	61.09	CC.N
Unit Variable Cost Increase		32.76	1.26	30.00%	47.38	dVC.N
Elasticity Curve Parameter		0.00	1.35	30.00%	0.40	ro.N
Short-Run Price Response to Demand		0.16	-0.32	76.43%	0.10	SRPR
	NAECA	NEW		PREVIOUS	NEW	
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN	
Shipments	1.34	1.20	-10.08%	-3.98%	1.22	
Price	$446.86	$499.24	11.72%	21.94%	$494.49	
Revenue (in $M)	597.49	600.26	0.46%	17.08%	602.58	
Net Income	32.45	21.44	-1100.89%	573.74%	16.77	
ROE	6.20%	4.14%	-2.06%	0.41%	3.24%	
			Trys =	419		

Table 6.21 Refrigerator Monte Carlo Runs

CONTROL FACTORS		Input Value	Cntrl	Vari-ation	Progrm Value	Name
Price Elasticity		-0.24	2.83	100.00%	-2.53	IPE
Consumer Discount Rate		136.50%	-0.97	100.00%	60.84%	RD
Equity Cost of Capital		0.068	-1.691	10.00%	0.0574	ECC
Economic Profit		0.005	1.0566	1.00%	0.0156	EP
L-R Fixed Part of Costs & Assets		0.10	1.54	50.00%	0.21	FCA
L-R Fixed Part of 1-X Cap. Cost		0.20	1.63	60.00%	0.49	F1X
One-Time Capital Costs		41.23	0.14	20.00%	42.39	CC.N
Unit Variable Cost Increase		32.76	0.62	30.00%	39.25	dVC.N
Elasticity Curve Parameter		0.00	0.69	30.00%	0.21	ro.N
Short Run Price Response to Demand		0.16	-1.30	76.43%	0.03	SRPR
	NAECA	NEW		PREVIOUS	NEW	
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN	
Shipments	1.34	1.23	-8.41%	-1.41%	1.24	
Price	$446.77	$487.66	9.15%	8.58%	$486.61	
Revenue (in $M)	600.29	600.09	-0.03%	7.05%	603.58	
Net Income	38.24	27.76	-10.48	1.90	26.15	
ROE	7.27%	5.36%	-1.91%	0.04%	5.05%	
			Trys =	695		

Table 6.22 Freezer Monte Carlo Runs

CONTROL FACTORS		Input Value	Cntrl	Vari-ation	Progrm Value	Name
Price Elasticity		-0.43	2.43	100.00%	-3.24	IPE
Consumer Discount Rate		160.00%	104.61%	100.00%	382.26%	RD
Equity Cost of Capital		0.068	-1.449	10.00%	0.0589	ECC
Economic Profit		0.005	1.6701	1.00%	0.0217	EP
L-R Fixed Part of Costs & Assets		0.10	-0.03	50.00%	0.10	FCA
L-R Fixed Part of 1-X Cap. Cost		0.20	-0.05	60.00%	0.19	F1X
One-Time Capital Costs		0.18	-1.19	20.00%	0.14	CC.N
Unit Variable Cost Increase		8.06	2.31	30.00%	15.88	dVC.N
Elasticity Curve Parameter		0.00	1.14	30.00%	0.34	ro.N
Short-Run Price Response to Demand		0.16	-0.40	76.43%	0.09	SRPR
	NAECA	NEW		PREVIOUS	NEW	
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN	
Shipments	0.24	0.20	-18.18%	-8.93%	0.21	
Price	$225.24	$240.44	6.75%	28.82%	$237.34	
Revenue (in $M)	54.94	47.98	-12.66%	17.32%	50.11	
Net Income	3.86	2.46	-139.84%	36.23%	2.42	
ROE	8.00%	5.91%	-2.09%	0.20%	5.81%	
			Trys =	40		

Table 6.23 Freezer Monte Carlo Runs

FREEZER ANALYSIS		Input		Vari-	Progrm	
CONTROL FACTORS		Value	Cntrl	ation	Value	Name
Price Elasticity		-0.43	2.03	100.00%	-2.34	IPE
Consumer Discount Rate		160.00%	0.07	100.00%	169.97%	RD
Equity Cost of Capital		0.07	0.09	10.00%	0.07	ECC
Economic Profit		0.01	0.35	1.00%	0.01	EP
L-R Fixed Part of Costs & Assets		0.10	1.51	50.00%	0.20	FCA
L-R Fixed Part of 1-X Cap. Cost		0.20	-1.51	60.00%	0.09	F1X
One-Time Capital Costs		0.18	-0.43	20.00%	0.17	CC.N
Unit Variable Cost Increase		8.06	0.34	30.00%	8.90	dVC.N
Elasticity Curve Parameter		0.00	1.61	30.00%	0.48	ro.N
Short Run Price Response to Demand		0.16	0.95	76.43%	0.55	SRPR
	NAECA	NEW		PREVIOUS	NEW	
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN	
Shipments	0.24	0.23	-4.58%	-0.91%	0.24	
Price	225.23	233.12	3.51%	3.76%	230.56	
Revenue (in $M)	55.16	54.48	-1.24%	2.81%	55.45	
Net Income	3.71	3.11	-59.93%	5.35%	3.03	
ROE	7.66%	6.57%	-1.10%	0.03%	6.40%	
			Trys =	57		

CHAPTER 7. IMPACTS OF STANDARDS ON ELECTRIC UTILITIES

7.1 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. In this chapter, an attempt is made to quantify these four effects. 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. In addition to this chapter, more details on methodology may be found in Appendix D.

7.2 AVOIDED ENERGY AND AVOIDED RELIABILITY COSTS

Consider the four effects listed in the above section. Effect (1) results in a cost saving to the utility usually called fuel cost savings. Effects (2) and (3) together are here called capacity cost savings. The fuel cost savings depend on fuel price forecasts. The capacity cost savings contain the costs avoided when 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 can be used to value electricity savings from the societal perspective. Figure 7.1 shows a summary of the these two cost components for the case of refrigerators, refrigerator-freezers, and freezers.

7.3 PEAK LOAD AND CAPACITY REDUCTIONS

Table 7.1 shows the peak load reduction for each test level. The base case peak load in the second column represents coincident peak load of all three appliances in this type. The total peak demand and the peak demand reductions are calculated using the appropriate conservation load factors, a T&D loss factor of 1.075, and estimates of energy consumption calculated using the LBL-REM. The capacity savings shown in Table 7.2 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 residential refrigeration range from 0.49 to 0.84 GW in 2000, and from 3.92 to 6.65 GW in 2030. Capacity savings range up to 7.99 GW.

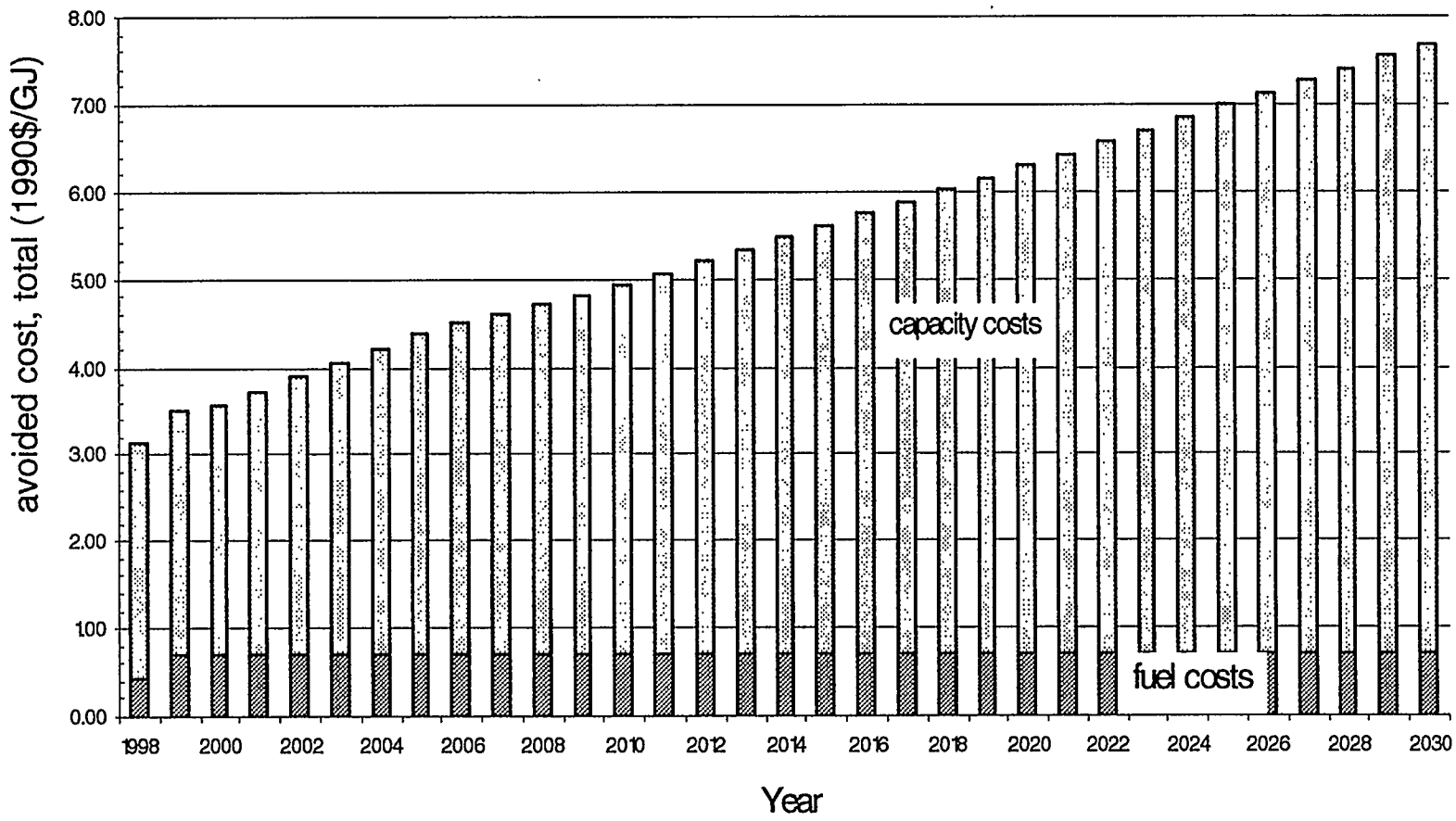

Figure 7.1 Total utility avoided costs: refrigeration.

Table 7.1 Peak Demand Reductions (GW) - Refrigerators, Refrigerator-Freezers, and Freezers

Year	Peak (GW)	Level 1	Level 2	Level 3	Level 4
1998	17.1	0.17	0.20	0.24	0.28
1999	16.7	0.32	0.42	0.47	0.55
2000	16.4	0.49	0.64	0.72	0.84
2001	16.1	0.66	0.85	0.96	1.13
2002	15.8	0.85	1.08	1.22	1.44
2003	15.5	1.02	1.29	1.47	1.73
2004	15.3	1.20	1.52	1.73	2.03
2005	15.1	1.38	1.75	1.99	2.34
2006	14.9	1.57	1.99	2.25	2.65
2007	14.7	1.75	2.23	2.52	2.96
2008	14.6	1.93	2.45	2.78	3.26
2009	14.5	2.12	2.69	3.05	3.58
2010	14.4	2.31	2.94	3.33	3.91
2011	14.4	2.51	3.18	3.60	4.22
2012	14.4	2.67	3.41	3.86	4.52
2013	14.4	2.85	3.62	4.10	4.82
2014	14.5	3.00	3.81	4.33	5.07
2015	14.6	3.14	3.99	4.52	5.31
2016	14.7	3.26	4.15	4.71	5.53
2017	14.8	3.37	4.28	4.86	5.70
2018	15.0	3.45	4.39	4.98	5.85
2019	15.1	3.53	4.48	5.08	5.96
2020	15.2	3.57	4.54	5.16	6.05
2021	15.4	3.62	4.59	5.22	6.13
2022	15.5	3.66	4.65	5.28	6.20
2023	15.7	3.69	4.69	5.32	6.25
2024	15.8	3.72	4.72	5.36	6.31
2025	16.0	3.75	4.77	5.42	6.37
2026	16.1	3.79	4.82	5.47	6.43
2027	16.2	3.82	4.86	5.52	6.47
2028	16.4	3.86	4.90	5.56	6.55
2029	16.5	3.88	4.94	5.61	6.59
2030	16.7	3.92	4.99	5.67	6.65

Table 7.2 Capacity Savings (GW) - Refrigerators, Refrigerator-Freezers, and Freezers

Year	Level 1	Level 2	Level 3	Level 4
1998	0.12	0.15	0.17	0.20
1999	0.39	0.50	0.56	0.66
2000	0.59	0.76	0.86	1.01
2001	0.79	1.02	1.15	1.35
2002	1.02	1.29	1.47	1.73
2003	1.22	1.55	1.77	2.07
2004	1.44	1.83	2.07	2.43
2005	1.65	2.10	2.39	2.81
2006	1.88	2.39	2.70	3.18
2007	2.10	2.68	3.02	3.55
2008	2.32	2.94	3.34	3.91
2009	2.55	3.22	3.65	4.30
2010	2.78	3.53	4.00	4.69
2011	3.01	3.81	4.32	5.06
2012	3.21	4.09	4.63	5.42
2013	3.42	4.35	4.92	5.78
2014	3.60	4.58	5.19	6.09
2015	3.77	4.79	5.42	6.37
2016	3.91	4.98	5.65	6.63
2017	4.04	5.14	5.83	6.83
2018	4.14	5.27	5.97	7.02
2019	4.23	5.38	6.10	7.15
2020	4.29	5.45	6.19	7.27
2021	4.35	5.51	6.26	7.35
2022	4.39	5.58	6.33	7.44
2023	4.43	5.63	6.39	7.50
2024	4.46	5.67	6.43	7.57
2025	4.50	5.73	6.50	7.64
2026	4.55	5.78	6.56	7.71
2027	4.59	5.83	6.62	7.77
2028	4.63	5.88	6.68	7.86
2029	4.66	5.93	6.73	7.91
2030	4.70	5.99	6.81	7.99

7.4 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 7.2 shows annual revenue losses undiscounted over time for all 4 standard levels, and Table 7.3 shows the same data. Cumulative net revenue losses for refrigeration range from $15 to 26 billion (1990 dollars).

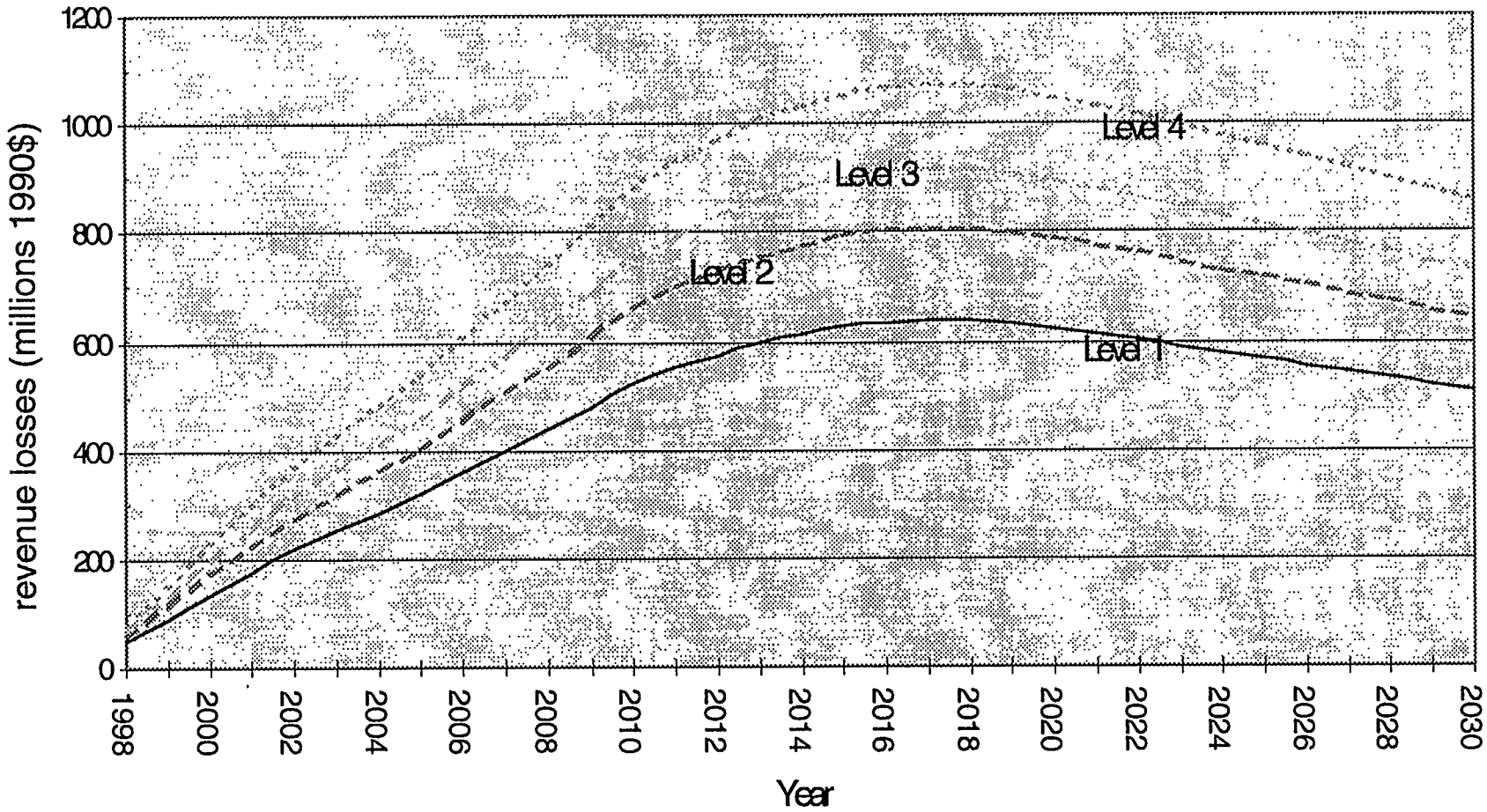

Figure 7.2 Revenue reductions and avoided costs for refrigerators.

Table 7.3 shows utility revenue losses, assuming no regulatory adjustment. If rather than the perpetual net revenue loss, rate adjustment is made without a lag, rates will be increased over the base case forecast and utilities will cease to lose revenue. If the net revenue loss is entirely recovered from the residential sector, rates would rise the most under level 4 in 2016 by a 0.108 ¢/kWh increase. The biggest percentage impact is in 2015 when residential rates are predicted to increase by 1.1%. By the end of the forecast period in 2030, under level 4, the percentage impact has eroded to 0.7%.

Table 7.4 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 7.3 Net Revenue Losses - Refrigerators, Refrigerator-Freezers, Freezers (million 1990$)

Year	Level 1	Level 2	Level 3	Level 4
1998	50	61	72	82
1999	89	115	128	151
2000	134	174	196	229
2001	174	225	254	298
2002	218	276	312	368
2003	252	320	364	426
2004	286	363	411	483
2005	317	402	457	537
2006	359	455	515	606
2007	399	508	573	674
2008	438	555	631	740
2009	480	608	689	812
2010	523	664	753	883
2011	552	700	793	930
2012	575	732	830	972
2013	598	759	859	1010
2014	612	779	884	1036
2015	625	795	900	1058
2016	632	805	914	1072
2017	636	808	917	1076
2018	635	807	915	1075
2019	631	802	909	1066
2020	622	791	897	1053
2021	613	777	883	1037
2022	602	765	868	1020
2023	590	749	851	999
2024	577	734	832	979
2025	566	720	817	960
2026	554	705	800	940
2027	543	689	783	919
2028	532	675	766	902
2029	519	659	749	880
2030	507	646	734	861
totals	**15459**	**19621**	**22258**	**26134**

Table 7.4 Present Value of Revenue Losses - Refrigerators, Refrigerator-Freezers, and Freezers (million 1990$)

Regulatory Lag	1	2	3	4
None	0	0	0	0
1998-2002	397	507	574	673
1998-2030	4515	5738	6508	7640

For refrigerators, refrigerator-freezers, and freezers, the present value of net lost revenues may range from $0.4 to 0.7 billion for a five-year lag, and would be as large as $7.6 billion if the regulators did not make adjustments. The present values over the period 1998 to 2030 also represent the rate increases needed over this period to compensate for lost revenues, assuming that regulators adjust immediately.

7.5 SENSITIVITY ANALYSIS

Tables 7.5 and 7.6 show the peak-demand reductions and capacity savings for the sensitivity cases defined in Section 5.4. Table 7.7 shows the present value of net lost revenues for the same sensitivity cases. The assumptions for the sensitivity cases are the same as those for previous tables.

Table 7.5 Peak Demand Reduction (GW)

Year	Case 1	Case 2	Case 3	Case 4	Case 5
2000	0.49	0.49	0.49	0.49	0.36
2010	2.33	2.30	2.33	2.33	0.96
2020	3.60	3.56	3.61	3.62	0.59
2030	3.94	3.92	3.99	3.99	0.07

Table 7.6 Capacity Reduction (GW)

Year	Case 1	Case 2	Case 3	Case 4	Case 5
2000	0.59	0.59	0.59	0.59	0.43
2010	2.79	2.76	2.79	2.79	1.15
2020	4.32	4.27	4.35	4.35	0.71
2030	4.73	4.70	4.79	4.79	0.09

Table 7.7 Present Value of Net Lost Revenues

Regulatory Lag	Case 1	Case 2	Case 3	Case 4	Case 5
none	0	0	0	0.49	0
1998-2003	375	414	397	396	280
1998-2030	3321	5839	4547	4551	1536

APPENDIX A. ENGINEERING ANALYSIS
ERA COMPUTER SIMULATION PROGRAM AND MANUFACTURE COST DATA

A.1 INTRODUCTION

The simulation model for household refrigerators and freezers is composed of two submodels: a cabinet heat load calculation routine and a refrigeration unit performance analysis. The results from the cabinet heat load calculation are supplied automatically to the refrigeration unit analysis model to predict the performance of the refrigerator or freezer being analyzed. The simulation model was developed by Arthur D. Little (ADL), and the following sections, which describe these submodels and their capabilities, are taken from a detailed report on the model. Specific computer operation information is also contained in the ADL report [1].

A.2 CABINET LOADS MODEL (CAB.EXE)

Five basic R/F configurations are described: 1) top-mount refrigerator/freezer, 2) side-by-side refrigerator/freezer, 3) bottom-mount refrigerator/freezer, 4) chest freezer, and 5) upright freezer. Design parameters considered are: external dimensions, internal volumes, insulation system geometry and resistivities, mullion dimensions and resistivity, compressor cabinet dimensions and insulation design, gasket heat leaks, cabinet section control temperatures, environmental conditions, door opening schedules, and ancillary electrical energies.

The cabinet loads program breaks down the steady-state heat loads by component as well as by compartment. Note that the fan heat inputs are not yet considered in the thermal loads budget: they are treated as a correction to the refrigeration capacity by the cycle program and are related to the compressor run-time.

The major heat flows present in the cabinet are considered, including the effects of edge losses associated with vacuum insulation panels. The most significant uncertainties in the modeled loads are associated with the gaskets (conduction and an unknown infiltration), penetrations of the insulation system, and moisture input.

A.2.1 Wall Heat Loads

The major heat load on the cabinet results from heat conduction across the walls comprising the cabinet, with convection boundary conditions. Calculation of the conduction heat flow is based on the following assumptions:

- steady heat flow, with fixed thermal properties characterizing each wall;
- constant heat transfer coefficients;
- fixed inside and outside temperatures;
- one-dimensional heat transfer (longitudinal heat flow is neglected).

Corrections to the simple 1-D heat flow analyses are made for:

- corner and edge effects (to account for different outside and inside surface areas);
- composite structures, such as foam and vacuum panel sandwich constructions.

The overall heat flow across a wall of the cabinet can be written:

$$Q_w = (UA)_w (T_r - T_c)$$

where

U = overall heat transfer conductance
A = wall area (inside surface)
T_r = room temperature
T_c = cabinet temperature

The expression UA is composed of inside and outside film coefficients and areas, cabinet insulation properties, and correction factors for corners and edges:

$$UA = \frac{1}{1/h_0 A_0 + 1/U_w A_i + 1/h_i A_i}$$

where

h_i, h_0 = film coefficients, inside and outside surfaces
A_i, A_0 = surface areas, inside and outside cabinet

The wall conductance is the sum of the conductance across a plane, with corrections for the additional heat flow along the edges and at the corners:

$$U_w A_i = \frac{kA_i}{x} + 0.54k\sum l_i + 0.14nkt$$

where

x = thickness of wall (ft)
k = thermal conductivity (Btu/hr-ft-°F)
l = inside edge length (ft)
t = average insulation thickness (ft)
n = number of corners

The above equation gives the wall conduction in English units (Btu/hr-ft^2-°F;); the edge and corner correction factors assume the same units since this is the form in which they were first published.

The equations in this section are applied to all surfaces, including the mullion between the freezer and fresh-food section, and the doors. Note that some average thermal conductivity, *k,* is assumed for the wall.

The values assumed for the inside and outside free convective surface heat transfer coefficients (including radiative heat transfer effects are:

$$h_o = 8.35 W/m^2 \cdot {}^\circ C (1.47 Btu/hr-ft^2-{}^\circ F)$$

$$h_i = 5.68 W/m^2 \cdot {}^\circ C (1.00 Btu/hr-ft^2-{}^\circ F)$$

A.2.2 Gasket Model

The gasket model assumes that the rate of heat input is a linear function of the gasket path length (door perimeter) and the room-cabinet temperature difference. In actuality, the rate of heat leak may be influenced by fan operation and may vary according to the tightness of fit.

A detailed finite element analysis carried out by the University of Kentucky has shown that the major paths for heat flow are along the cabinet flange and the door flange, with a lesser amount through the gasket itself. Because of the complexity of the heat flows in this region, ERA relies on the user to specify realistic values for the heat loss coefficient, rather than attempting to model the gasket region itself. Typical values for heat loss are provided in the Help menu.

A.2.3 Anti-Sweat Heat

Anti-sweat heat may be applied along the front surface of the cabinet and across the front face of the mullion. It may be supplied from electrical resistance heater wires, hot gas leaving the compressor prior to entering the condenser, or heat from the refrigerant leaving the condenser.

If electric heater wires are used, standard closed-door rating tests normally require that the refrigerator performance be measured with the heaters on and then with the heaters off. The rating is based on the average of these tests. As a short-cut analytical approach, the user may assume that the DOE test conditions are equivalent to measuring performance with half the anti-sweat heat input. Operation of the heaters is continuous, not dependent on the behavior of the refrigeration system.

If hot gas from the compressor output line, or heat from the condenser liquid line, is used for door flange and/or mullion heating, the net heat input will be dependent upon the compressor run-time. This is modelled by specifying the value for refrigerant line anti-sweat heat input equal to that used for switchable electric heat in the on-position. For example, if a 6 W electric heater (average of 3 W in simulation of the DOE test condition) is replaced by liquid line heat, the user should specify 6 W of refrigerant line heat. Since refrigerant line heat is not "switchable" the total heat input will be larger than the average heat input corresponding to the DOE test conditions.

ERA will calculate the on-cycle heat removal required from the refrigerant line heater to supply the cycle-averaged specified heat input. For example, if a cycle-average heat input of 6 W is specified and the duty cycle is 45%, the on-cycle heat removal must be 6/ 0.45 = 13.3 W. If this would result in an overcooling of the refrigerant line, ERA will issue a warning message in the summary output (ERA.OUT). Then the user must reduce the specified refrigerant line heat and replace the amount reduced with switchable electric heat. Hence, in some situations the mullion may receive anti-sweat from a liquid line and from a (smaller) electric heater at the same time.

A.3 REFRIGERATION CYCLE ANALYSIS AND ENERGY USE (ERACYC.EXE)

Four cycle configurations are described in the ADL report: 1) standard single evaporator cycle 2) Lorenz cycle with refrigerant mixtures, 3) dual-loop system employing two independent refrigeration cycles, one for each compartment, and 4) dual evaporator cycle, with two evaporators connected in series, normally employing a pure refrigerant. The first cycle only is described here.

Standard Single Evaporator Cycle - The fresh-food section and freezer section temperatures are specified. Air damper control is assumed to achieve these temperatures. The analysis involves calculation of the temperature of the air mixing from the two compartments as it approaches the evaporator. For example, if cabinet temperatures of 3.3°C (38°F) and -15°C (5°F) are specified for the two compartments, the mixed air temperature inlet to the evaporator will be about -11°C (12°F), depending on the ratio of the cabinet loads and the evaporator refrigerant temperature.

A.3.1 Cycle Model Solution Procedure

ERACYC.EXE is an iterative solver that starts with initial guesses for the refrigerant mass flow rate and the refrigerant temperatures at the exits of the condenser and evaporator. A converged solution is reached when a global energy balance for the entire refrigeration system is satisfied while satisfying local energy balances and heat transfer relationships for each system component. A schematic diagram of a single evaporator system, along with refrigerant state points is shown in Figure A-1. The refrigerant state points are defined in Table A-1.

Table A-1 Summary of Refrigerant State Point Locations

1	compressor inlet
2	compressor outlet
3	condenser inlet
4	refrigerant dew point within condenser
5	refrigerant bubble point within condenser
6	condenser exit
7	inlet to interchanger
8	outlet from interchanger
9	inlet to evaporator
10	refrigerant dew point within evaporator
11	outlet from evaporator

A.3.2 Map-Based Compressor Model

The map-based compressor model uses actual compressor map data applicable to a particular compressor. The user inputs data points for compressor capacity and motor power input as a function of evaporating and condensing temperatures. This data must be at the standard rating condition in which the temperature of the vapor exiting the evaporator (and entering the compressor), the liquid exiting the condenser, and the ambient are all at 32°C (90°F).

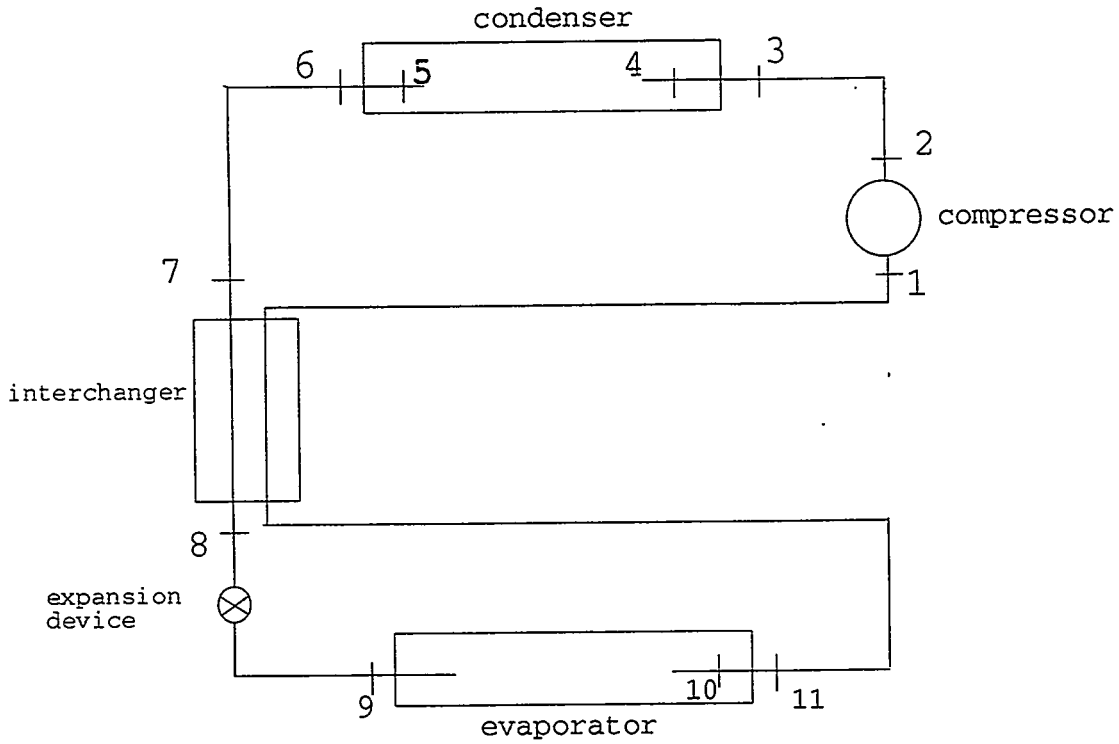

Figure A-1. Schematic diagram of a single evaporator system

A.3.3 Matching Evaporator Capacities and Cabinet Loads

The overall analysis of daily energy use takes place in four steps:

Step 1:	Calculate cabinet loads assuming fixed cabinet temperatures;
Step 2:	Calculate cycle parameters for given cabinet air temperature;
Step 3:	Perform adjustments to match cabinet loads and evaporator capacity;
Step 4:	Calculate compressor run-time and the net energy consumption.

The method for matching the capacities and loads depends on the refrigeration cycle and the control option. This is discussed below for the single evaporator-single compressor cycle.

A.3.3.1 Single Evaporator Cycle

The single evaporator cycle uses an air baffle arrangement to deliver cool air to both compartments from the single evaporator, located in the back of the freezer compartment. It is assumed that the user has properly set the baffle, or that an electronically controlled baffle is used to deliver the necessary air to each compartment to simultaneously meet the two cabinet loads at the assumed setpoints.

The cooling rate of each compartment is given by:

$$Q_{FF} = mC_p f(T_{FF} - T_{out})$$

$$Q_{FZ} = mC_p (1-f)(T_{FZ} - T_{out})$$

where

mC_p	=	mass flow-specific heat of air across the evaporator
f	=	fraction of air going to fresh-food compartment
T_{out}	=	temperature of air leaving the evaporator coil
T_{in}	=	temperature of air entering the evaporator coil

The inlet temperature of the coil, and the net evaporator capacity, must satisfy:

$$T_{in} = fT_{FF} + (1-f)T_{FZ}$$

The equations are solved simultaneously to determine the fraction of air going to the fresh-food section (typically 10-15%) and the inlet air temperature to the evaporator.

$$Capacity = mC_p(T_{in} - T_{out})$$

A.4 ENERGY CONSUMPTION MODEL

The relationship between the hourly total cabinet heat loads (the refrigeration requirement at the evaporators), and the instantaneous capacity of the refrigeration cycle establishes the compressor run-time (duty cycle = fraction of the hour that the compressor operates to meet the load):

Duty = Cabinet_Load/(Evaporator_Capacity Fan_Power)

Cabinet_Load = Duty*Fan_On_Cabinet_Load + (1.0 - Duty)* Fan_Off_Cabinet_Load

where

Duty = Calculated duty cycle (0 to 1)

Fan_On_Cabinet_Load = Cabinet load during compressor operation

Fan_Off_Cabinet_Load = Cabinet load during compressor off-cycle

The underlying assumption is that the thermal transients in the cabinet and in the refrigeration cycle are small. That is, it is assumed that the cabinet temperature is either relatively constant over the complete cycle, or that the sensible heat corresponding to temperature swings between the compressor on-cycle and off-cycle conditions is small. The equations above link the time-averaged cabinet loads to the *instantaneous* capacity of the refrigeration system.

Once the duty cycle is determined, the energy consumption terms are easily calculated:

Compressor energy use = Compressor power times the duty cycle

Fan energy use = Fan power times the duty cycle

Electronics (variable speed motor) = Electronics losses times the duty cycle

Heaters and controls = Specified hourly total values

Defrost energy = Net electrical input corresponding to heat of fusion of the moisture

condensing on the cold evaporator. (Note that it is assumed that moisture will not freeze on a fresh-food evaporator in the dual loop cycle, the Lorenz cycle, or the dual evaporator cycle.)

Total Electrical Energy Use = Sum of above components

A.5 COST DATA FOR REFRIGERATORS AND FREEZERS

This appendix contains manufacturer costing data for several product classes of refrigerator-freezers and freezers. The costs are divided into materials, labor, burden, shipping, tooling, building and equipment, and research and development. This data was obtained from manufacturers of refrigerator-freezers, freezers, compressors and motors. The costs for vacuum panel insulation was derived from "Vacuum Panel and Thick Wall Foam Insulation for Refrigerators: Cost Estimates for Manufacturing and Installation", Waldron, J.M. , prepared for US EPA Global Change Division, EPA Project No. X818749-01-0, October 1992. For compacts, the material, labor, burden, and shipping is aggregated together into "incremental production cost" as it was not possible to disaggregate them. All costs are incremental on the pervious design option and do not include wholesale or retail markups. Tables A.2 through A.10 show the manufacturing cost data. The right hand column shows the cumulative manufacturing cost for each design level. This is the cost to achieve the design option shown plus all the other design options preceding it.

Table A.2 Manufacturing Cost (1992$) Breakdown Top Mount Auto Defrost Refrigerator-Freezer (Adjusted Volume = 606.0 L [*21.4 ft*^{3}])

Level	Design Option	Unit Cost Impact ($) Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment and Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incremental Mfr Cost	Cumulative Mfr Cost
1	0 + 5.45 EER Compressor	11.06	0.00	0.00	0.00	11.06	0.00	0	0	0.00	11.06	11.06
2	1 + Reduce Condenser Motor Power	4.50	0.00	0.00	0.00	4.50	0.00	0	0	0.00	4.50	15.56
3	2 + Add 1/2" Insulation to Doors	2.31	0.13	0.18	0.48	3.10	6134.00	11,873	1,835	0.52	3.62	19.18
4	3+ Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0.00	0	0	0.00	6.50	25.68
5	4 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	641.00	0	561	0.06	0.81	26.49
6	5 + Add 1/2" Insulation to Walls	5.51	0.08	0.07	2.83	8.49	26451.00	88,954	9,695	2.86	11.35	37.84
7	6 + Reduce Gasket Heat Leak	2.50	0.08	0.17	0.00	2.75	1671.00	4,773	1,357	0.22	2.97	40.81
8	7 + Add 1" Insulation to Doors	2.28	0.07	0.13	0.54	3.02	203.00	4,462	406	0.09	3.11	43.93
9	8 + Add 1" Insulation to Walls	6.49	0.12	0.10	1.45	8.16	2706.00	47,454	0	0.73	8.89	52.82
10	9+ Increase Condenser Area	1.13	0.48	1.11	0.00	2.72	2876.00	25,959	1,285	0.54	3.26	56.08
11	10 + Adaptive Defrost	6.91	0.05	0.10	0.00	7.06	590.00	0	1,015	0.09	7.15	63.23
12	11 + Increase Evaporator Area	1.33	0.08	0.07	0.33	1.81	14330.00	21,556	6,731	1.30	3.11	66.34
13	7 + Increase Evaporator Area	1.33	0.08	0.07	0.33	1.81	14330.00	21,556	6,731	1.30	3.11	43.92
14	14 + Increase Condenser Area	1.13	0.48	1.11	0.00	2.72	2876.00	25,959	1,285	0.54	3.26	47.18
15	15 + Adaptive Defrost	6.91	0.05	0.10	0.00	7.06	590.00	0	1,015	0.09	7.15	54.33
16	2+ Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0.00	0	0		9.50	25.06
17	16 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	641.00	0	561	0.06	0.81	25.87
18	17 + Reduce Gasket Heat Leak	2.50	0.08	0.17	0.00	2.75	1671.00	4,773	1,357	0.22	2.97	28.84
19	18 + Increase Evaporator Area	1.33	0.08	0.07	0.33	1.81	14330.00	21,556	6,731	1.30	3.11	31.95
20	19 + Increase Condenser Area	1.13	0.48	1.11	0.00	2.72	2876.00	25,959	1,285	0.54	3.26	35.21
21	20 + Vacuum Panels on Walls & Doors	46.75	0.00	0.00	0.00	46.75	0.00	0	0	0.00	46.75	81.96
22	21 + Adaptive Defrost	6.91	0.05	0.1	0	7.06	590	0	1015	0.09	7.15	89.11

Table A.3 Manufacturing Cost (1992$) Breakdown Top Mount Auto Defrost Refrigerator-Freezer with Through-The-Door Features (Adjusted Volume = 726.8 L [25.7 ft^3])

Level	Design Option	Unit Cost Impact: Incremental Product Cost: Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's): Depreciable: Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incremental Mfr Cost	Cumulative Incremental Mfr Cost
	BASELINE											
1	0 + Reduce Condenser Motor Power	4.50	0.00	0.00	0.00	4.50	0	0	0	0.00	4.50	4.50
2	1+ Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0	0	0	0.00	6.50	11.00
3	2 + 5.60 EER Compressor	6.75	0.00	0.00	0.00	6.75	0	0	0	0.00	6.75	17.75
4	3 + Reduce Load for TAD Features	1.40	0.03	0.10	0.00	1.53	1620	4800	650	9.59	11.12	28.87
5	4 + Adaptive Defrost	7.24	0.00	0.00	0.00	7.24	350	0	343	2.05	9.29	38.17
6	5 + Add 1" Insulation to Doors	5.27	0.27	0.42	1.03	6.99	4590	9300	1371	22.23	29.22	67.39
7	6 + Reduce Gasket Heat Leak	3.50	0.13	0.25	0.00	3.88	1163	2528	379	5.88	9.76	77.15
8	7 + Add 1" Insulation to Walls	12.10	0.13	0.12	3.38	15.73	19850	86350	7220	135.22	150.95	228.10
9	8 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	533	0	467	2.92	3.67	231.77
10	9 + Increase Condenser Area	1.33	0.73	1.66	0.00	3.72	2333	20000	533	22.04	25.76	257.53
11	10 + Increase Evaporator Area	1.50	0.13	0.10	0.44	2.17	11650	17525	4920	57.26	59.43	316.96
12	5 + Reduce Gasket Heat Leak	3.50	0.13	0.25	0.00	3.88	1163	2528	379	5.88	9.76	47.92
13	12 + Add 1/2" Insulation to Doors	2.65	0.17	0.24	0.64	3.70	4590	9300	1360	22.19	25.89	73.82
14	13 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	533	0	467	2.92	3.67	77.49
15	14 + Add 1/2" Insulation to Walls	5.90	0.08	0.07	2.44	8.49	17600	58300	7220	109.36	117.85	195.34
16	15 + Increase Condenser Area	1.33	0.73	1.66	0.00	3.72	2333	20000	533	22.04	25.76	221.10
17	16 + Increase Evaporator Area	1.50	0.13	0.10	0.44	2.17	11650	17525	4920	57.26	59.43	280.54
18	4 + VI to Walls and Doors	49.22	0.00	0.00	0.00	49.22	0	0	0	0.00	49.22	78.09
19	18 + Adaptive Defrost	7.24	0.00	0.00	0.00	7.24	350	0	343	2.05	9.29	87.39
20	19 + Reduce Gasket Heat Leak	3.50	0.13	0.25	0.00	3.88	1163	2528	379	5.88	9.76	97.14
21	20 + Increase Condenser Area	1.33	0.73	1.66	0.00	3.72	2333	20000	533	22.04	25.76	122.90
22	21 + Increase Evaporator Area	1.50	0.13	0.10	0.44	2.17	11650	17525	4920	57.26	59.43	182.34

Table A.4 Manufacturing Cost (1992$) Breakdown Side-by-Side Auto Defrost Refrigerator-Freezer without Through-The-Door Features (Adjusted Volume = 737.8 L [*26.1 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incremental Mfr Cost	Cumulative Incremental Mfr Cost
	BASELINE											
1	0 + 5.60 EER Compressor	9.61	0.00	0.00	0.00	9.61	0.00	0.00	0.00	0.00	9.61	9.61
2	1+ Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0.00	0.00	0.00	0.00	6.50	16.11
3	2 + Reduce Condenser Motor Power	4.50	0.00	0.00	0.00	4.50	0.00	0.00	0.00	0.00	4.50	20.61
4	3 + Adaptive Defrost	5.24	0.05	0.09	0.00	5.38	155.00	212.00	446.00	0.30	5.68	26.29
5	4 + Add 1" Insulation to Walls	11.84	0.13	0.12	5.74	17.83	25910.00	96107.00	8164.00	22.18	40.01	66.30
6	5 + Enhanced Evaporator HT Surface	0.86	0.05	0.09	0.00	1.00	904.00	226.00	1816.00	1.24	2.24	68.54
7	6 + Add 1" Insulation to Doors	4.83	0.20	0.31	1.22	6.56	4401.00	13390.00	2096.00	3.83	10.39	78.93
8	7 + Reduce Gasket Heat Leak	2.57	0.08	0.17	0.00	2.82	11985.00	3401.00	1764.00	4.98	7.80	86.73
9	8 + Increase Condenser Area	1.13	0.08	0.07	0.59	1.87	4571.00	5593.00	2277.00	3.17	5.04	91.77
10	4 + Add 1/2" Insulation to Walls	5.88	0.08	0.07	2.09	8.12	23232.00	53316.00	8164.00	16.93	25.05	51.34
11	10 + Enhanced Evaporator HT Surface	0.86	0.05	0.09	0.00	1.00	904.00	226.00	1816.00	1.24	2.24	53.58
12	11 + Add 1/2" Insulation to Doors	2.36	0.13	0.18	0.83	3.50	4401.00	8927.00	1610.00	3.12	6.62	60.20
13	12 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	275.00	485.00	566.00	0.43	1.18	61.38
14	13 + Increase Condenser Area	1.13	0.08	0.07	0.59	1.87	4571.00	5593.00	2277.00	3.17	5.04	66.42
15	14 + Reduce Gasket Heat Leak	2.57	0.08	0.17	0.00	2.82	11985.00	3401.00	1764.00	4.98	7.80	74.22
16	4 + Increase Condenser Area	1.13	0.08	0.07	0.59	1.87	4571.00	5593.00	2277.00	3.17	5.04	31.33
17	16 + Enhanced Evaporator HT Surface	0.86	0.05	0.09	0.00	1.00	904.00	226.00	1816.00	1.24	2.24	33.57
18	17 + Vacuum Panel Insulation in W & D	51.55	0.00	0.00	0.00	51.55	0.00	0.00	0.00	0.00	51.55	85.12
19	18 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	275.00	485.00	566.00	0.43	1.18	86.30
20	19 + Reduce Gasket Heat Leak	2.57	0.08	0.17	0.00	2.82	11985.00	3401.00	1764.00	4.98	7.80	94.10

Table A.5 Manufacturing Cost (1992$) Breakdown Side-by-Side Auto Defrost Refrigerator-Freezer with Through-The-Door Features (Adjusted Volume - 740.9 L [*26.2 ft*^{3}])

		Unit Cost Impact				Incr'l Prod	Investment & Expense (in $1000's)			Investment	Net	Cumulative
		Incremental Product Cost				Cost	Depreciable		Expensed	& Expense	Incremental	Incremental
Level	Design Option	Mat'l	Labor	Burden	Ship	Subtotal	Tooling	Bldg & Eq	R & D	Subtotal	Mfr Cost	Cost
0	BASELINE											
1	0 + Add 1/2" Insulation to Doors	2.23	0.09	0.08	0.42	2.82	2543	3519	1583	1.50	4.32	4.32
2	1 + 5.60 EER Compressor	6.75	0.00	0.00	0.00	6.75	0	0	0	0.00	6.75	11.07
3	2 + Reduce Condenser Motor Power	4.50	0.00	0.00	0.00	4.50	0	0	0	0.00	4.50	15.57
4	3 + Increase Evaporator Area	1.27	0.08	0.07	0.00	1.42	953	397	1322	0.78	2.20	17.77
5	4 + Increase Condenser Area	1.17	0.08	0.07	0.00	1.32	2270	5619	1436	1.55	2.87	20.64
6	5 + Add 1" Insulation to Doors	2.20	0.01	0.00	0.36	2.57	0	4483	114	0.40	2.97	23.61
7	6 + Reduce TAD Features Load	1.67	0.00	0.00	0.00	1.67	2860	45	1589	1.31	2.98	26.58
8	7 + Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0	0	0	0.00	6.50	33.08
9	8 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	393	393	458	0.30	1.05	34.14
10	9 + Add 1" Insulation to Walls	11.37	0.13	0.12	3.00	14.62	19149	91487	3944	13.30	27.92	62.06
11	10 + Reduce Gasket Heat Leak	2.57	0.08	0.17	0.00	2.82	15279	3817	1901	4.67	7.49	69.55
12	11 + Adaptive Defrost	4.17	0.05	0.09	0.00	4.31	170	170	284	0.17	4.48	74.02
13	5 + Reduce TAD Features Load	1.67	0.00	0.00	0.00	1.67	2860	45	1589	1.31	2.98	23.62
14	13 + Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0	0	0	0.00	6.50	30.12
15	14 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	393	393	458	0.30	1.05	31.17
16	15 + Add 1/2" Insulation to Walls	5.67	0.08	0.07	2.00	7.82	16595	53950	3944	9.74	17.56	48.73
17	16 + Adaptive Defrost	4.17	0.05	0.09	0.00	4.31	170	170	284	0.17	4.48	53.20
18	17 + Reduce Gasket Heat Leak	2.57	0.08	0.17	0.00	2.82	15279	3817	1901	4.67	7.49	60.69
19	0 + Increase Evaporator Area	1.27	0.08	0.07	0.00	1.42	953	397	1322	0.78	2.20	2.20
20	19 + 5.60 EER Compressor	6.75	0.00	0.00	0.00	6.75	0	0	0	0.00	6.75	8.95
21	20 + Reduce Condenser Motor Power	4.50	0.00	0.00	0.00	4.50	0	0	0	0.00	4.50	13.45
22	21 + Increase Condenser Area	1.17	0.08	0.07	0.00	1.32	2270	5619	1436	1.55	2.87	16.31
23	22 + Reduce TAD Features Load	1.67	0.00	0.00	0.00	1.67	2860	45	1589	1.31	2.98	19.29
24	23 + Improve Evaporator Fan Efficiency	0.75	0.00	0.00	0.00	0.75	393	393	458	0.30	1.05	20.35
25	24 + Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0	0	0	0.00	6.50	26.85
26	25 + Adaptive Defrost	4.17	0.05	0.09	0.00	4.31	170	170	284	0.17	4.48	31.32
27	26 + VI on Doors and Walls	51.32	0.00	0.00	0.00	51.32	0	0	0	0.00	51.32	82.64
28	27 + Reduce Gasket Heat Leak	2.57	0.08	0.17	0.00	2.82	15279	3817	1901	4.67	7.49	90.13

Table A.6 Manufacturing Cost (1992$) Breakdown Bottom Mount Auto Defrost Refrigerator-Freezer (Adjusted Volume = 686.0 L [*24.2 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incremental Mfr Cost	Cumulative Incremental Cost
0	BASELINE											
1	0 + Reduce Evaporator Motor Power	6.50	0.00	0.00	0.00	6.50	0	0	0	0.00	6.50	6.50
2	1 + 5.60 EER Compressor	6.75	0.00	0.00	0.00	6.75	0	0	0	0.00	6.75	13.25
3	2 + Reduce Condenser Motor Power	4.50	0.00	0.00	0.00	4.50	0	0	0	0.00	4.50	17.75
4	3 + Add 1" Insulation to Walls	10.00	0.00	0.00	3.00	13.00	1977	2090	1526	11.72	24.72	42.47
5	4 + Add 1/2" Insulation to Doors	1.85	0.14	0.12	0.13	2.24	441	288	527	3.18	5.42	47.89
6	5 + Reduce Gasket Heat Leak	2.50	0.08	0.17	0.00	2.75	50	200	306	1.41	4.16	52.05
7	6 + Add 1" Insulation to Doors	1.70	0.01	0.01	0.05	1.77	175	3502	0	3.02	4.79	56.83
8	7 + Adaptive Defrost	5.05	0.10	0.19	0.00	5.34	100	0	486	2.04	7.38	64.21
9	8 + Increase Evaporator Area	1.40	0.13	0.10	0.00	1.63	500	0	576	3.28	4.91	69.12
10	9 + Increase Condenser Area	1.13	0.48	1.11	0.00	2.72	1200	2600	576	6.80	9.52	78.64
11	3 + Add 1/2" Insulation to Doors	1.85	0.14	0.12	0.13	2.24	441	288	527	3.18	5.42	23.17
12	11 + Add 1/2" Insulation to Walls	5.15	0.13	0.10	1.00	6.38	1977	1160	1526	11.02	17.40	40.57
13	12 + Reduce Gasket Heat Leak	2.50	0.08	0.17	0.00	2.75	50	200	306	1.41	4.16	44.73
14	13 + Improve Evaporator Fan Efficiency	0.50	0.00	0.00	0.00	0.50	150	0	250	1.27	1.77	46.50
15	14 + Increase Evaporator Area	1.40	0.13	0.10	0.00	1.63	500	0	576	3.28	4.91	51.41
16	15 + Adaptive Defrost	5.05	0.10	0.19	0.00	5.34	100	0	486	2.04	7.38	58.80
17	16 + Increase Condenser Area	1.13	0.48	1.11	0.00	2.72	1200	2600	576	6.80	9.52	68.31
18	3 + Reduce Gasket Heat Leak	2.50	0.08	0.17	0.00	2.75	50	200	306	1.41	4.16	21.91
19	18 + VI Insulation to Walls and Doors	42.36	0.00	0.00	0.00	42.36	0	0	0	0.00	42.36	64.27
20	19 + Increase Evaporator Area	1.40	0.13	0.10	0.00	1.63	500	0	576	3.28	4.91	69.18
21	20 + Adaptive Defrost	5.05	0.10	0.19	0.00	5.34	100	0	486	2.04	7.38	76.56
22	21 + Improve Evaporator Fan Efficiency	0.50	0.00	0.00	0.00	0.50	150	0	250	1.27	1.77	78.33
23	22 + Increase Condenser Area	1.13	0.48	1.11	0.00	2.72	1200	2600	576	6.80	9.52	87.85

Table A.7 Manufacturing Cost (1992$) Breakdown Upright Auto Defrost Freezer (Adjusted Volume = 716.3 L [25.3 ft^3])

Level	Design Option	Unit Cost Impact Incremental Product Cost				Incr'l Prod Cost	Investment and Expense (in $1000's)			Investment & Expense	Net Incr'l	Cumulative Incr'l
							Depreciable		Expensed			
		Mat'l	Labor	Burden	Ship	Subtotal	Tooling	Bld & Eq	R & D	Subtotal	Mfr Cost	Mfr Cost
1	0+ Reduce Evaporator Fan Motor Power	6.50				6.50					6.50	6.50
2	1 + 5.60 EER Compressor	6.75				6.75					6.75	13.25
3	2+ Evaporator Enhanced HT Surface	1.52	0.00	0.00	0.00	1.52	500	50	200	1.09	2.61	15.86
4	3 + Add 1" Insulation to Walls	7.60	0.20	0.18	4.63	12.61	7960	14900	3100	23.23	35.84	51.70
5	4 + Reduce Gasket Heat Leak	1.70	0.00	0.00	0.00	1.70	100	0	50	0.24	1.94	53.63
6	5+ Add 1" Insulation to Door	2.65	0.15	0.13	0.93	3.86	1530	4000	650	5.07	8.93	62.56
7	6 +Condenser Hot Gas for Anti-Sweat Heat	2.50	0.50	0.40	0.00	3.40	5000	5000	4000	17.12	20.52	83.08
8	7 +Adaptive Defrost	7.25	0.00	0.00	0.00	7.25	300	0	300	1.03	8.28	91.35
9	8 + Increase Condenser Area	3.00	0.63	1.10	0.38	5.11	1100	250	275	2.11	7.22	98.57
10	3 + Reduce Gasket Heat Leak	1.70	0.00	0.00	0.00	1.70	100	0	50	0.24	1.94	17.80
11	10 + Add 1/2" Insulation to Walls	4.03	0.13	0.10	3.00	7.26	6610	13300	3100	20.81	28.07	45.87
12	11 + Add 1/2" Insulation to Door	1.45	0.14	0.12	0.88	2.59	1430	4000	650	4.94	7.53	53.39
13	12 + Increase Condenser Area	3.00	0.63	1.10	0.38	5.11	1100	250	275	2.11	7.22	60.61
14	13 +Condenser Hot Gas for Anti-Sweat Heat	2.50	0.50	0.40	0.00	3.40	5000	5000	4000	17.12	20.52	81.13
15	14 +Adaptive Defrost	7.25	0.00	0.00	0.00	7.25	300	0	300	1.03	8.28	89.40
16	2 + Vacuum Panel Insulation to Walls & Door	33.77	0.00	0.00	0.00	33.77	0	0	0	0.00	33.77	47.02
17	16 + Reduce Gasket Heat Leak	1.70	0.00	0.00	0.00	1.70	100	0	50	0.24	1.94	48.96
18	17+ Evaporator Enhanced HT Surface	1.52	0.00	0.00	0.00	1.52	500	50	200	1.09	2.61	51.57
19	18 + Condenser Hot Gas for Anti-Sweat Heat	2.50	0.50	0.40	0.00	3.40	5000	5000	4000	17.12	20.52	72.08
20	19 +Adaptive Defrost	7.25	0.00	0.00	0.00	7.25	300	0	300	1.03	8.28	80.36
21	20+ Increase Condenser Area	3.00	0.63	1.10	0.38	5.11	1100	250	275	2.11	7.22	87.58

Table A.8 Manufacturing Cost (1992$) Breakdown Upright Manual Defrost Freezer
(Adjusted Volume = 685.4 L [*24.2 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incr'l Mfr Cost	Cumulative Incr'l Mfr Cost
	BASELINE											
1	0 + Foam Insulation to Door	1.82	0.00	0.00	0.00	1.82	0	0	0	0.00	1.82	1.82
2	1 + 5.15 EER Compressor	5.25	0.00	0.00	0.00	5.25	0	0	0	0.00	5.25	7.07
3	2 + Enhanced Condenser HT Surface	0.80	0.00	0.00	0.00	0.80	0	0	2	0.00	0.80	7.87
4	3+ Reduce Gasket Heat Leak	1.75	0.50	0.00	0.00	2.25	100	0	52	0.08	2.33	10.20
5	4 + Add 1" Insulation to Door	2.91	0.00	0.00	1.50	4.41	1350	4590	510	1.58	5.99	16.19
6	5 + Add 1" Insulation to Walls	10.01	0.00	0.00	4.25	14.26	6330	13180	2010	5.97	20.23	36.43
7	6 + Increase Evaporator Area	3.77	0.00	0.00	0.00	3.77	375	50	167	0.28	4.05	40.48
8	4 + Add 1/2" Insulation to Door	1.63	0.00	0.00	1.00	2.63	1240	4550	510	1.53	4.16	14.36
9	8 + Add 1/2" Insulation to Walls	5.76	0.00	0.00	2.25	8.01	5460	13180	2010	5.60	13.61	27.97
10	9 + Increase Evaporator Area	3.77	0.00	0.00	0.00	3.77	375	50	167	0.28	4.05	32.03
11	4 + Vacuum Panel Insulation in Walls & Door	30.65	0.00	0.00	0.00	30.65	0	0	0	0.00	30.65	40.85
12	11 + Increase Evaporator Area	3.77	0.00	0.00	0.00	3.77	375	50	167	0.28	4.05	44.91

Table A.9 Manufacturing Cost (1992$) Breakdown Chest Manual Defrost Freezer (Adjusted Volume = 723.1 L [25.5 ft^3])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incr'l Mfr Cost	Cumulative Incr'l Mfr Cost
	BASELINE											
1	0 + Add 1/2" Insulation to Walls	4.16	0.00	0.00	3.75	7.91	2300	3300	652	1.12	9.03	9.03
2	1 + Add 1" Insulation to Walls	3.16	0.00	0.00	2.70	5.86	250	3750	300	0.50	6.36	15.38
3	2 + 4.56 EER Compressor	5.52				5.52					5.52	20.90
4	3 + 4.95 EER Compressor	5.25				5.25					5.25	26.15
5	4 + Add 1" Insulation to Door	1.86	0.00	0.00	1.00	2.86	1824	5100	824	1.22	4.08	30.23
6	5 + Reduce Gasket Heat Leak	1.70	0.00	0.00	0.00	1.70	145	0	50	0.06	1.76	31.99
7	6 + Increase Evaporator Area	1.93	0.00	0.00	0.00	1.93	300	25	150	0.14	2.07	34.06
8	7 + Enhanced Condenser HT Surface	15.28	0.00	0.00	0.00	15.28	120	200	75	0.08	15.36	49.42
9	1 + 4.56 EER Compressor	5.52	0.00	0.00	0.00	5.52	0	0	0	0.00	5.52	14.55
10	9 + 4.95 EER Compressor	5.25	0.00	0.00	0.00	5.25	0	0	0	0.00	5.25	19.80
11	10 + Reduce Gasket Heat Leak	1.70	0.00	0.00	0.00	1.70	145	0	50	0.00	1.76	21.55
12	11 + Add 1/2" Insulation to Door	1.03	0.00	0.00	1.00	2.03	1250	4360	650	0.06	2.97	24.53
13	12 + Increase Evaporator Area	1.93	0.00	0.00	0.00	1.93	300	25	150	0.94	2.07	26.59
14	13 + Enhanced Condenser HT Surface	15.28	0.00	0.00	0.00	15.28	120	200	75	0.14	15.36	41.95
15	0 + 4.56 EER Compressor	5.52	0.00	0.00	0.00	5.52	0	0	0	0.08	5.52	5.52
16	15 + 4.95 EER Compressor	5.25	0.00	0.00	0.00	5.25	0	0	0	0.00	5.25	10.77
17	16 + Vacuum Panel Insulation on Walls & Door	30.82	0.00	0.00	0.00	30.82	0	0	0	0.00	30.82	41.59
18	17 + Reduce Gasket Heat Leak	1.70	0.00	0.00	0.00	1.70	145	0	50	0.06	1.76	43.35
19	18 + Increase Evaporator Area	1.93	0.00	0.00	0.00	1.93	300	25	150	0.14	2.07	45.42
20	19 + Enhanced Condenser HT Surface	15.28	0.00	0.00	0.00	15.28	120	200	75	0.08	15.36	60.77

Table A.10 Manufacturing Cost (1992$) Breakdown Compact Manual Defrost Refrigerator-Freezer (Adjusted Volume = 46.19 L [*1.6 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incr'l Mfr Cost	Cumulative Incr'l Mfr Cost
	BASELINE											
1	0 + Enhanced Condenser HT Surface	0.40	0.00	0.00	0.00	0.40	0.00	0	10	0.00	0.40	0.40
2	1 + Enhanced Evaporator HT Surface	0.60	0.00	0.00	0.00	0.60	0.00	0	10	0.00	0.60	1.01
3	2 + Reduce Gasket Heat Leak	1.00	0.00	0.00	0.00	1.00	0.00	0	10	0.00	1.00	2.01

Table A.11 Manufacturing Cost (1992$) Breakdown Compact Auto Defrost Refrigerator-Freezer (Adjusted Volume = 104.7 L [*3.7 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incr'l Mfr Cost	Cumulative Incr'l Mfr Cost
	BASELINE											
1	0 + 3.55 EER Compressor	2.10	0.00	0.00	0.00	2.10	0.00	0	0	0	2.10	2.10
2	1 + Reduce Condenser Fan Motor Power	4.50	0.00	0.00	0.00	4.50	0.00	0	0	0	4.50	6.60

Table A.12 Manufacturing Cost (1992$) Breakdown Compact Chest Manual Defrost Freezer (Adjusted Volume = 2.54.1 L [*9.0 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incr'l Mfr Cost	Cumulative Incr'l Mfr Cost
	BASELINE											
1	0 + 4.30 EER Compressor	2.79	0.00	0.00	0.00	2.79	0	0	0	0.00	2.79	2.79
2	1 + Add 1" Insulation to Walls	12.77	0.00	0.00	0.00	12.77	5500	8000	900	14.00	26.77	29.56
3	2 + Add 1" Insulation to Door	3.73	0.00	0.00	0.00	3.73	1800	4000	800	6.47	10.20	39.77
4	3 + Reduce Gasket Heat Leak	2.27	0.00	0.00	0.00	2.27	175	0	125	0.56	2.83	42.59

Table A.13 Manufacturing Cost (1992$) Breakdown Compact Upright Auto Defrost Freezer (Adjusted Volume = 2.58.0 L [*9.1 ft*^{3}])

Level	Design Option	Unit Cost Impact Incremental Product Cost Mat'l	Labor	Burden	Ship	Incr'l Prod Cost Subtotal	Investment & Expense (in $1000's) Depreciable Tooling	Bld & Eq	Expensed R & D	Investment & Expense Subtotal	Net Incr'l Mfr Cost	Cumulative Incr'l Mfr Cost
	BASELINE											
1	0 + 4.70 EER Compressor	9.34	0.00	0.00	0.00	9.34	0.00	0	0	0.00	9.34	9.34
2	1 + Enhanced Condenser HT Surface	1.00	0.00	0.00	0.00	1.00	0.00	0	10	0.07	1.07	10.41
3	2 + Reduce Gasket Heat Leak	1.00	0.00	0.00	0.00	1.00	0.00	0	10	0.07	1.07	11.48

REFERENCES

1. Merriam R., Verone A., Feng H., "*EPA Refrigerator Analysis (ERA) Program: User's Manual Version 1.0*", Arthur D. Little Inc., March 1993, Cambridge, MA. 02140.

APPENDIX B. FORECASTING MODELS

B.1 LBL RESIDENTIAL ENERGY MODEL

B.1.1 Overview

The LBL Residential Energy Model (LBL-REM) provides projections of the important characteristics of the residential appliance market. The LBL-REM utilizes a database of significant determinants of the current residential appliance market, as well as parameters characterizing market decisions that will affect the energy consumption of future appliances. This appendix describes the LBL-REM, the types of data it uses, the calculations it performs, and the results the LBL-REM provides.

The LBL-REM projects numbers of households by house type, energy-related building shell characteristics, average energy efficiency of appliances, fraction of households owning each appliance, usage behavior, and turnover of appliances. These characteristics are projected for each year from 1980 to 2030.

The LBL-REM combines these factors to project energy consumption and expenditures by fuel type for each end use, and monetary expenditures for equipment (both replacement and new installations) and for fuels. The results are reported in several formats, for convenience, including: annual energy consumption and expenditures, annual equipment shipments, cumulative energy consumption and expenditures over a period (e.g., from policy implementation date to the end of the projection period), and net present values of equipment and energy expenditures, discounted and summed over time.

The basic equation in the simulation model that defines residential use of fuel *i* for end use *k* in housing type *m* during year *t* is:

$$Q_t^{ikm} = STOKC_t^{m} \times C_t^{ikm} \times EU_t^{ikm} \times U_t^{ik} \times TI_t^{ikm} \qquad \text{(B.1)}$$

where *STOKC* is the stock of occupied housing units, *C* is the saturation (percent of households with this equipment): *EU* is the unit energy consumption, *U* is the usage behavior factor, and *TI* is the thermal integrity factor (for space conditioning only).

Households respond to changes in operating expenses in three different ways. In the short run (see B.1.6, "Usage Behavior"), they change the way they operate existing equipment and structures (e.g., lower winter thermostat settings). In the long run, they also change equipment by switching from one fuel to another (see B.1.5, "Market Shares"), by improving the efficiency of their equipment (e.g., purchasing a water heater with more jacket insulation (see B.1.4, "Equipment Efficiency"), or both. Thus, the elasticity of demand for a particular fuel with respect to the price of

that fuel can be separated into three elements–a usage elasticity (E_u), a technical efficiency elasticity (E_e), and an equipment/fuel choice (market share) elasticity (E_{ms}):

$$E = E_u + E_e + E_{ms} \tag{B.2}$$

B.1.2 Housing

The model performs calculations for three house types, (i) single family homes, (ii) multi-family homes, and (iii) mobile homes. Inputs for housing information includes annual projections of occupied households and housing starts.

B.1.2.1 Occupied Households

The number and type of occupied households for the base year (1980) are from the 0.1% Public Use MicroSample (PUMS) of the 1980 Decennial Census. Projection of occupied households by house type from 1992 to 2010 is obtained from DOE/EIA's *Annual Energy Outlook 1994*. The stock of households is interpolated in years 1981 to 1991. Household figures after 2010 are obtained by extrapolation using the growth rate from 1990 to 2010 as given in the *Annual Energy Outlook 1994*.

B.1.2.2 Housing Starts

Figures for past (1980-1989) housing starts by house type come from the Bureau of Census' *Housing Starts*. Projections (1990-2010) come from the *Annual Energy Outlook 1994*. Housing starts in later years (2011-2030) are extrapolated using the projected annual growth rates from 1990 to 2010.

B.1.3 Building Shell Thermal Integrity

The equation used in the LBL-REM to represent the thermal performance/cost tradeoff for structures is:

$$\frac{TIN}{TIN_O} = \frac{TINF}{TIN_O} + \left[\frac{TBETA}{TBETA+C}\right]^{TALFA} \left[1 - \frac{TINF}{TIN_O}\right] \tag{B.3}$$

where *TIN* is the thermal performance (relative heating energy normalized to 1980 existing houses); *C* is the change in the initial cost of the structure due to the change in *TIN*; and *TINF, TALFA*, and *TBETA* are parameters.

Table B.1 shows values of the parameters $TINF/TIN_0$, *TALFA*, and *TBETA*.

Table B.1 Parameters of Thermal Integrity/Cost Curves by House Type

	$TINF/TIN_0$	TALFA	TBETA
Single Family	0.25	11.14	26717
Multi-Family	0.24	6.87	6067
Mobile Homes	0.34	7.56	9931

The thermal integrity factor (TI) is the relative energy consumption corresponding to a set of building shell characteristics (e.g., ceiling insulation, floor insulation, glazing, floor insulation, infiltration rate), associated with an incremental cost (C). For space heating, it is calculated from the relationship each year to minimize the life-cycle cost, given current energy prices, using a discount rate consistent with historical market tradeoffs. The thermal integrity factor for air conditioning depends on, and differs from, the thermal integrity factor for heating.

Thermal integrity is largely irrelevant in the analysis of refrigerators, refrigerator-freezers, and freezers. The only interaction between energy consumption of these products and the building shell characteristics is through internal loads generated by these products. Those internal loads interact with space-conditioning requirements.

B.1.4 Equipment Efficiency

The LBL-REM projects the average efficiency or unit energy consumption for a new unit purchased in each future year. The method involves characterization of historical market behavior, in the form of market discount rate. The observed average efficiency of the unit purchased is characterized as a function of the range of designs available from manufacturers, equipment prices (set by manufacturers and distributors), current residential fuel prices, and trade-off decisions made by purchasers (including homebuilders, contractors, landlords, and homeowners). The range of available designs and their prices are from the Engineering Analysis. Historical average efficiencies are reported by industry trade associations. Taking the average efficiency of units purchased as the minimum life-cycle cost defines the market discount rate. The average efficiency in future years is projected based on the range of engineering designs available (characterized by unit price and efficiency) and projected residential energy prices, given the market discount rate.

B.1.5 Market Shares

The number of potential purchasers is calculated for two markets: housing starts and potential replacement/retrofit in existing housing. Total product sales for each year are determined by applying market share elasticities to projected equipment price, operating expense, and income to determine the fraction of potential purchasers who will actually purchase the product.

The market share elasticities are constant over the projection period. The market shares for each product in future years are given in Chapter 5, Table 5.8. The percent share for each class in future years is assumed to be the same as that in 1992 and is shown in Table B.2.

Table B.2 Percent Share of Each Class of Refrigerators and Freezers

	Single Family	Multi-Family	Mobile Home
Refrigerator			
Top Mount Auto no TTDF	62.2%	75.2%	76.9%
Top Mount Auto with TTDF	1.1%	1.3%	1.4%
Bottom Mount Auto	1.3%	0.8%	0.5%
Side-by-Side Auto no TTDF	9.5%	4.6%	4.9%
Side-by-Side Auto with TTDF	12.4%	6.0%	6.5%
Compact Manual Defrost	13.6%	12.0%	9.7%
Total	100.0%	100.0%	100.0%
Freezer			
Upright Manual	39.3%	35.7%	29.9%
Upright Auto	12.9%	11.8%	9.9%
Chest Manual	47.8%	52.4%	60.2%
Total	100.0%	100.0%	100.0%

B.1.6 Usage Behavior

The usage elasticities for refrigerators, refrigerator-freezers, and freezers are assumed to be zero.

B.1.7 Equipment Turnover

Chapter 5 shows average equipment lifetimes. These lifetimes are assumed to be constant over the projection period. The retirement functions (the percent of products which survives, as a function of years after purchase) are shown in Table B.3.

Table B.3 Survival Function of Refrigerators and Freezers

Age (year)	Refrigerator	Compact	Freezer
1 to 4	100%	100%	100%
5	100%	97%	100%
6	100%	92%	100%
7	100%	85%	100%
8	100%	76%	100%
9	100%	66%	100%
10	100%	55%	100%
11	100%	45%	100%
12	100%	34%	100%
13	97%	24%	100%
14	92%	15%	100%
15	85%	8%	100%
16	76%	3%	100%
17	66%	0%	100%
18	55%	0%	100%
19	45%	0%	42%
20	34%	0%	26%
21	24%	0%	13%
22	15%	0%	2%
23	8%	0%	0%
24	3%	0%	0%
25 to 30	0%	0%	0%

B.1.8 Outputs

The LBL-REM produces annual projections of:

- number of houses in stock by house type;
- housing starts by house type;
- thermal integrity factors for stock and new houses by house type;
- average unit energy consumption of new units sold (by class and by end use/fuel);
- average unit equipment price of new units sold (by class and by end use/fuel);
- fraction of existing houses having each end use;
- fraction of new houses having each end use;
- usage behavior factor, by end use/fuel;
- fuel consumption by housing type, by fuel, and total by end use;
- total equipment expenditures by end use; and
- total fuel expenditures.

The LBL-REM produces cumulative values for a period (1998-2030):

- fuel use by end use and fuel type;
- discounted fuel expenditures by end use and fuel type;
- discounted equipment expenditures; and
- discounted total (fuel and equipment) expenditures.

The LBL-REM produces cumulative values for new units purchased in a period (1998-2030):

- discounted fuel expenditures by end use and fuel type;
- discounted equipment expenditures by end use and fuel type;
- discounted total (fuel and equipment) expenditures by end use and fuel type;
- units installed by end use and fuel type; and
- total discounted life-cycle expenditures per unit by end use and fuel type.

Product types usually correspond to end uses.

B.1.9 Changes Since Previous Technical Support Document

The principal changes since the previous Technical Support Document in 1989 are:

(1) The set of clases being analyzed has changed for refrigerators: partial defrost has been removed and compacts added.
(2) The set of design options, efficiencies, and cost data have changed (see Chapter 4).
(3) Occupied household and housing start projections have been revised to agree with *Annual Energy Outlook 1994* (see Chapter 5).
(4) Energy price projections have been updated to *Annual Energy Outlook 1994* (see Chapter 5).
(5) Historial shipments of refrigerators and freezers have been updated.
(6) Marginal saturations for refrigerators and freezers have been calibrated so that results of market saturation from LBL-REM are consistent with historical saturations from DOE/EIA's *Household Energy Consumption and Expenditures (RECS)*, 1984, 1987, and 1990.
(7) A consistent set of market discount rates is used in calculating market shares and in forecasting equipment efficiencies.

B.2. LBL-REM INPUT DATA: REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS.

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 refrigerators, refrigerator-freezers, and freezers.

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 "EF of standard." For example, for standards taking effect in 1998, change "first year for standard = 2031" to "first year for standard = 1998" and enter the appropriate maximum EF value in the line "EF of standard."

REFRIGERATOR

```
total saturation              = 1.40
elec price multiplier         = 1.06
gas price multiplier          = 1.00
ncalc                         = 2
ndr1 (1, read drate & curve)  = 0
nv1 (# of eun inputs)         = 1
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
   16.05    0.00    0.00    0.00    0.00                                ** SF **
   16.05    0.00    0.00    0.00    0.00                                ** MF **
   16.05    0.00    0.00    0.00    0.00                                ** MB **

---------- Purchase price of a reference unit ($1990) -------------------------
       1       2       3       4       5
  585.91    0.00    0.00    0.00    0.00                                ** SF **
  531.44    0.00    0.00    0.00    0.00                                ** MF **
  543.55    0.00    0.00    0.00    0.00                                ** MB **

---------- Relative UEC and Capacity of a reference unit to a stock unit -------
       1       2       3       4       5
.6989729    1.00    1.00    1.00    1.00                              ** re   **
    1.00    1.00    1.00    1.00    1.00                              ** recap**

----- Base Year Saturations - c70 - (Source: RECS 81 Stock, Jim Hanford)
       1       2       3       4       5       6
   1.170    0.00    0.00    0.00    0.00   0.230                        ** SF **
   1.020    0.00    0.00    0.00    0.00   0.380                        ** MF **
   1.030    0.00    0.00    0.00    0.00   0.370                        ** MB **

---------- Marginal Saturations for Replacement Units - cn(m=1) ----------------
       1       2       3       4       5       6
   1.360    0.00    0.00    0.00    0.00   0.040                        ** SF **
   1.100    0.00    0.00    0.00    0.00   0.300                        ** MF **
   0.830    0.00    0.00    0.00    0.00   0.570                        ** MB **

----- Marginal Saturations for New Houses - cn(m=2) - (RECS 81 New Homes,
Hanford)
       1       2       3       4       5       6
   1.170    0.00    0.00    0.00    0.00   0.230                        ** SF **
   1.020    0.00    0.00    0.00    0.00   0.380                        ** MF **
   1.030    0.00    0.00    0.00    0.00   0.370                        ** MB **

----- Historical Shipments (from 1980 to 1951) Source: AHAM Domestic (excl.
export)
 1 Refrigerators
   4.772   5.323   5.494   5.323   4.493   4.269   5.580   6.318   5.890   5.308
   4.930   4.940   4.804   4.396   4.639   4.599   4.239   3.848   3.521   3.246
   3.241   3.530   2.907   3.125   3.451   3.918   3.358   3.405   3.330   3.801

----- Retirement Function (from age 1 to 30 years) ---- (MTSC, same as 8 prod)
all i
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- Average Life Times (by fuel type i) --------------------------------
       1       2       3       4       5
    19.0     0.0     0.0     0.0     0.0
```

```
---------- Operating Cost Elasticities (for 5 fuel types and income) -----------
       1       2       3       4       5       6
   -.024    0.00    0.00    0.00    0.00    1.00                          /* j=1 */
    0.00    0.00    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 */
    0.10    0.00    0.00    0.00    0.00   -0.50                          /* j=6 */

----- Discount rate for calculating Equipment Price Elasticity
       1       2       3       4       5
   1.365    0.00    0.00    0.00    0.00                                  /* j=1 */
    0.00    0.00    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
   -0.05    0.00    0.00    0.00    0.00                                  /* j=1 */
    0.00    0.00    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 */
    0.02    0.00    0.00    0.00    0.00                                  /* j=6 */

---------- Historical Relative Energy Use (eun) for New Units ------------------
   i   1    1981    1982    1983    1984    1985    1986    1987    1988    1989
  1990
   1   0    1.26    1.24    1.21    1.19    1.15    1.16    1.10    1.05    0.99
  0.93

---------- Historical Usage Factors for Existing Units -------------------------
   i   1    1980    1981    1982    1983    1984    1985    1986    1987    1988
  1989    1990
   1   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 refrig      =    1

===============================================================================
product type id#             =    1
product name                 = Refr (Refrigerator)
end-use id#                  =    5
fuel type id#                =    1
number of classes            =   11

---------- the 1st class -------------------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = TF-A (Top Mount A/D w/o ttd)
discount rate                = 1.26
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   11.20   11.20
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    6.12    6.30    6.47    6.75    6.89    6.95    7.66    7.83    8.06    8.51
  8.91    9.36

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
```

```
  1991     1992
   517.     558.     576.     585.     579.     573.     574.     579.     582.     584.
  577.     569.

---------- Adjusted volumes (1981-2015) (81-87 AHAM, 1988-2015 Baseline) (changed
from 20.80 to 21.41)
   20.08    20.24    20.39    20.30    20.37    20.28    20.41    20.54    20.45    20.62
   20.53    20.79    21.41    21.41    21.41    21.41    21.41    21.41    21.41    21.41
   21.41    21.41    21.41    21.41    21.41    21.41    21.41    21.41    21.41    21.41
   21.41    21.41    21.41    21.41    21.41

---------- Fraction of market share (1981-2015)
l = 1
   0.539    0.539    0.539    0.539    0.539    0.539    0.539    0.539    0.539    0.539
   0.539    0.618    0.618    0.618    0.618    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000
l = 2
   0.655    0.655    0.655    0.655    0.655    0.655    0.655    0.655    0.655    0.655
   0.655    0.749    0.749    0.749    0.749    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000
l = 3
   0.676    0.676    0.676    0.676    0.676    0.676    0.676    0.676    0.676    0.676
   0.676    0.766    0.766    0.766    0.766    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000

----- Retirement Function (from age 1 to 30 years)
   .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000
   .0000    .0000    .0270    .0530    .0730    .0880    .0990    .1060    .1080    .1060
   .0990    .0880    .0730    .0530    .0270    .0000    .0000    .0000    .0000    .0000

---------- UEC (Kwh) & Purchase Price ($1990) data (scaled price at 1993 standard
to ELCAP 93, same as no CFC baseline)
   Price      Kwh (scaled to 16.0*21.41+355 (93 stds) / 683.0 (design that meet
93 std)
  508.22    967.2
  515.32    858.9
  518.07    803.6
  524.44    760.9
  535.93    729.2
  554.67    697.6
  562.66    676.1
  580.40    650.6
  613.84    628.1
  633.15    607.7
  652.59    594.4
  713.69    526.0

---------- Shipment Distribution (source: none)
     Kwh    Units
   11.20     132.
   11.60      87.
   12.00      74.
   12.40      48.
   12.80      36.
   13.20      25.
   13.50      13.
   13.80      17.
   14.40      31.
   14.70       5.

---------- the 1st class (no CFCs)----------------------------------------------
class id#                    =    99 avg life= 19.0
```

```
class name                    = TF-A (Top Mount A/D w/o ttd)
discount rate                 = 1.26
last year of historical info = 1992
first year for standard       = 1993 2016
EF  of standard               =   11.20   11.20
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    6.12    6.30    6.47    6.75    6.89    6.95    7.66    7.83    8.06    8.51
  8.91    9.36

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    517.    558.    576.    585.    579.    573.    574.    579.    582.    584.
  577.    569.

---------- Adjusted volumes (1981-2015) (81-87 AHAM, 1988-2015 Baseline)
   20.08   20.24   20.39   20.30   20.37   20.28   20.41   20.54   20.45   20.62
   20.53   20.79   21.41   21.41   21.41   21.41   21.41   21.41   21.41   21.41
   21.41   21.41   21.41   21.41   21.41   21.41   21.41   21.41   21.41   21.41
   21.41   21.41   21.41   21.41   21.41

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.618   0.618   0.618   0.618   0.618
   0.618   0.618   0.618   0.618   0.618   0.618   0.618   0.618   0.618   0.618
   0.618   0.618   0.618   0.618   0.618
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.749   0.749   0.749   0.749   0.749
   0.749   0.749   0.749   0.749   0.749   0.749   0.749   0.749   0.749   0.749
   0.749   0.749   0.749   0.749   0.749
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.766   0.766   0.766   0.766   0.766
   0.766   0.766   0.766   0.766   0.766   0.766   0.766   0.766   0.766   0.766
   0.766   0.766   0.766   0.766   0.766

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh (baseline set to met 1993 stds)
  554.67  697.60
  572.89  620.13
  580.39  594.45
  586.46  572.43
  597.37  543.07
  598.69  539.40
  618.88  495.37
  623.89  484.36
  628.99  477.02
  635.06  469.69
  647.23  458.68
  700.69  421.98

---------- Shipment Distribution (source: none)
     Kwh   Units
   11.20    132.
```

```
   11.60      87.
   12.00      74.
   12.40      48.
   12.80      36.
   13.20      25.
   13.50      13.
   13.80      17.
   14.40      31.
   14.70       5.

---------- the 2nd class -------------------------------------------------------
class id#                      =   99 avg life= 19.0
class name                     = TFAI (Top Mount A/D with ttd)
discount rate                  = 1.21
last year of historical info = 1992
first year for standard        = 1993 2016
EF  of standard                =   11.11   11.11
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    6.12    6.30    6.47    6.75    6.89    6.95    7.66    7.83    8.06    8.51
  8.91    9.36

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    877.    947.    978.    993.    982.    973.    975.    982.    996.   1009.
 1011.   1012.

---------- Adjusted volumes (1981-2015) (changed from 20.80 to 25.68) (
   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68
   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68
   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68
   25.68   25.68   25.68   25.68   25.68

---------- Fraction of market share (1981-2015)
l = 1
   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.046
   0.046   0.011   0.011   0.011   0.011   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 2
   0.056   0.056   0.056   0.056   0.056   0.056   0.056   0.056   0.056   0.056
   0.056   0.013   0.013   0.013   0.013   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 3
   0.058   0.058   0.058   0.058   0.058   0.058   0.058   0.058   0.058   0.058
   0.058   0.014   0.014   0.014   0.014   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data (scaled price to 1993 ELCAP,
assume 93 std to match baseline)
   Price     Kwh (scale kWh to 17.6*25.68+391 (93 std) / 746 (design meeting 93
stds))
 1015.94  1141.3
 1023.98  1011.3
```

```
 1027.08   944.7
 1035.58   890.4
 1047.28   843.0
 1063.61   802.3
 1073.12   772.9
 1093.51   734.5
 1131.69   709.6
 1155.25   687.0
 1179.23   672.3
 1242.11   593.2

---------- Shipment Distribution (source: none)
     Kwh   Units
   11.30      1.
   11.80      6.
   12.30      2.
   12.90      2.
   13.40     18.

---------- the 2nd class (no CFCs)-----------------------------------------------
class id#                     =   99 avg life= 19.0
class name                    = TFAI (Top Mount A/D with ttd)
discount rate                 = 1.21
last year of historical info = 1992
first year for standard       = 1993 2016
EF  of standard               =   11.11   11.11
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    6.12    6.30    6.47    6.75    6.89    6.95    7.66    7.83    8.06    8.51
  8.91    9.36

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    877.    947.    978.    993.    982.    973.    975.    982.    996.   1009.
 1011.   1012.

---------- Adjusted volumes (1981-2015) (81-87 AHAM, 1988-2015 Baseline)
   20.08   20.24   20.39   20.30   20.37   20.28   20.41   20.54   20.45   20.62
   20.53   20.79   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68
   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68   25.68
   25.68   25.68   25.68   25.68   25.68

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.011   0.011   0.011   0.011   0.011
   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011   0.011
   0.011   0.011   0.011   0.011   0.011
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.013   0.013   0.013   0.013   0.013
   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
   0.013   0.013   0.013   0.013   0.013
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.014   0.014   0.014   0.014   0.014
   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.014   0.014
   0.014   0.014   0.014   0.014   0.014

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
```

```
   .0000    .0000    .0270    .0530    .0730    .0880    .0990    .1060    .1080    .1060
   .0990    .0880    .0730    .0530    .0270    .0000    .0000    .0000    .0000    .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price      Kwh
 1047.28   795.37
 1054.28   759.58
 1064.55   723.79
 1075.37   703.91
 1095.56   672.09
 1108.98   656.18
 1125.59   648.23
 1170.26   628.34
 1173.99   624.37
 1398.91   568.69
 1463.07   556.76
 1553.36   552.78
 1359.22   516.99

---------- Shipment Distribution (source: none)
     Kwh    Units
   11.30       1.
   11.80       6.
   12.30       2.
   12.90       2.
   13.40      18.

---------- the 3rd class ----------------------------------------------------
class id#                     =   99 avg life= 19.0
class name                    = BF-A (Bottom Mount Auto Defrost)
discount rate                 = 1.13
last year of historical info = 1992
first year for standard       = 1993 2016
EF  of standard               =   11.20   11.20
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors  (81-92 AHAM)
    1981     1982     1983     1984     1985     1986     1987     1988     1989     1990
  1991     1992
    5.93     6.02     6.10     6.12     6.36     6.49     7.28     7.45     7.68     7.78
  8.26     8.69

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981     1982     1983     1984     1985     1986     1987     1988     1989     1990
  1991     1992
     734.     793.     818.     831.     822.     814.     815.     822.     836.     849.
  849.     848.

---------- Adjusted volumes (1981-2015)
   22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80
   22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80
   22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80    22.80
   22.80    22.80    22.80    22.80    22.80

---------- Fraction of market share (1981-2015)
l = 1
   0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013    0.013
   0.013    0.013    0.013    0.013    0.013    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000
l = 2
   0.008    0.008    0.008    0.008    0.008    0.008    0.008    0.008    0.008    0.008
   0.008    0.008    0.008    0.008    0.008    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000
```

```
l = 3
   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
   0.005   0.005   0.005   0.005   0.005   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
  854.65   970.0
  862.87   876.0
  866.07   820.0
  873.97   778.0
  887.27   730.0
  908.95   697.0
  918.50   670.5
  938.58   635.0
  977.28   612.0
 1002.18   592.0
 1049.99   572.0
 1087.65   446.5

---------- Shipment Distribution (source: none)
     Kwh   Units
   13.10      5.
   14.50      3.
   14.90      3.

---------- the 3rd class (no CFCs)-----------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = BF-A (Bottom Mount Auto Defrost)
discount rate                = 1.13
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   11.53   11.53
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors  (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    5.93    6.02    6.10    6.12    6.36    6.49    7.28    7.45    7.68    7.78
  8.26    8.69

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    734.    793.    818.    831.    822.    814.    815.    822.    836.    849.
  849.    848.

---------- Adjusted volumes (1981-2015)
   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24
   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24
   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24   24.24
   24.24   24.24   24.24   24.24   24.24

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.013   0.013   0.013   0.013   0.013
   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013   0.013
   0.013   0.013   0.013   0.013   0.013
```

```
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.008   0.008   0.008   0.008   0.008
   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008   0.008
   0.008   0.008   0.008   0.008   0.008
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.005   0.005   0.005   0.005   0.005
   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005   0.005
   0.005   0.005   0.005   0.005   0.005

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
  908.95  714.81
  919.42  669.62
  930.31  624.43
  937.68  603.89
  952.58  587.46
  997.33  534.05
 1007.85  521.73
 1013.85  517.62
 1028.91  509.40
 1047.39  497.08
 1066.10  484.75
 1076.66  443.67

---------- Shipment Distribution (source: none)
     Kwh   Units
   13.10      5.
   14.50      3.
   14.90      3.

---------- the 4th class ----------------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = SS-A (Side-by-Side w/o ttd)
discount rate                = 1.73
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   11.20   11.20
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors  (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    5.93    6.02    6.10    6.12    6.36    6.49    7.28    7.45    7.68    7.78
  8.26    8.69

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    854.    922.    951.    966.    956.    947.    948.    956.    989.   1022.
 1027.   1031.

---------- Adjusted volumes (1981-2015)
   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10
   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10
   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10   24.10
   24.10   24.10   24.10   24.10   24.10

---------- Fraction of market share (1981-2015)
```

```
l = 1
   0.084   0.084   0.084   0.084   0.084   0.084   0.084   0.084   0.084   0.084
   0.084   0.094   0.094   0.094   0.094   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 2
   0.041   0.041   0.041   0.041   0.041   0.041   0.041   0.041   0.041   0.041
   0.041   0.046   0.046   0.046   0.046   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 3
   0.045   0.045   0.045   0.045   0.045   0.045   0.045   0.045   0.045   0.045
   0.045   0.049   0.049   0.049   0.049   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
  954.86   1164.
  963.84   1000.
  967.38    938.
  978.38    880.
  993.26    863.
 1017.63    827.
 1028.77    803.
 1055.08    763.
 1098.09    737.
 1126.49    697.
 1154.19    672.
 1230.10    599.

---------- Shipment Distribution (source: none)
     Kwh   Units
   11.20     31.
   11.60      7.
   12.00     16.
   12.60     12.
   13.00      7.
   13.30      6.
   13.70      2.
   14.20      2.

---------- the 4th class (no CFCs)----------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = SS-A (Side-by-Side w/o ttd)
discount rate                = 1.73
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   11.77   11.77
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors  (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    5.93    6.02    6.10    6.12    6.36    6.49    7.28    7.45    7.68    7.78
  8.26    8.69

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
```

```
   854.    922.    951.    966.    956.    947.    948.    956.    989.   1022.
 1027.   1031.

---------- Adjusted volumes (1981-2015)
   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07
   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07
   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07   26.07
   26.07   26.07   26.07   26.07   26.07

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.094   0.094   0.094   0.094   0.094
   0.094   0.094   0.094   0.094   0.094   0.094   0.094   0.094   0.094   0.094
   0.094   0.094   0.094   0.094   0.094
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.046   0.046   0.046   0.046   0.046
   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.046   0.046
   0.046   0.046   0.046   0.046   0.046
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.049   0.049   0.049   0.049   0.049
   0.049   0.049   0.049   0.049   0.049   0.049   0.049   0.049   0.049   0.049
   0.049   0.049   0.049   0.049   0.049

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
 1055.08  761.19
 1074.35  699.75
 1087.44  662.20
 1096.56  641.72
 1107.94  624.66
 1162.41  559.80
 1165.75  552.98
 1179.64  539.32
 1181.76  535.91
 1191.21  529.08
 1204.72  518.84
 1242.66  501.77

---------- Shipment Distribution (source: none)
     Kwh   Units
   12.00     16.
   12.60     12.
   13.00      7.
   13.30      6.
   13.70      2.
   14.20      2.

---------- the 5th class ----------------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = SSAI (Side-by-Side with ttd)
discount rate                = 2.01
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   10.01   10.01
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors  (81-92 AHAM)
```

```
    1981     1982     1983     1984     1985     1986     1987     1988     1989     1990
  1991     1992
    5.93     6.02     6.10     6.12     6.36     6.49     7.28     7.45     7.68     7.78
  8.26     8.69

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981     1982     1983     1984     1985     1986     1987     1988     1989     1990
  1991     1992
    973.    1050.    1084.    1101.    1089.    1078.    1081.    1089.    1104.    1119.
 1121.    1123.

---------- Adjusted volumes (1981-2015)(modified to 26.18 from 31.90
   26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18
   26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18
   26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18    26.18
   26.18    26.18    26.18    26.18    26.18

---------- Fraction of market share (1981-2015)
l = 1
   0.120    0.120    0.120    0.120    0.120    0.120    0.120    0.120    0.120    0.120
   0.120    0.123    0.123    0.123    0.123    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000
l = 2
   0.059    0.059    0.059    0.059    0.059    0.059    0.059    0.059    0.059    0.059
   0.059    0.060    0.060    0.060    0.060    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000
l = 3
   0.064    0.064    0.064    0.064    0.064    0.064    0.064    0.064    0.064    0.064
   0.064    0.065    0.065    0.065    0.065    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000

----- Retirement Function (from age 1 to 30 years)
   .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000
   .0000    .0000    .0270    .0530    .0730    .0880    .0990    .1060    .1080    .1060
   .0990    .0880    .0730    .0530    .0270    .0000    .0000    .0000    .0000    .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh (Kwh scale by 16.3*26.18+527 (93 std)/ 1040 (design at 1993 std
orig. UEC)
 1099.07  1375.6
 1106.30  1181.2
 1109.15  1109.6
 1121.62  1040.9
 1133.47  1017.0
 1151.89   981.2
 1161.51   953.7
 1183.60   907.9
 1217.91   875.8
 1241.91   828.1
 1265.09   797.8
 1338.56   711.6

---------- Shipment Distribution (source: none)
     Kwh    Units
   10.20      45.
   10.80      25.
   11.20      16.
   11.60      13.
   12.00      27.
   12.60      19.
   13.00      12.
   13.30       2.
```

```
   14.00       8.
   14.30       2.

---------- the 5th class (no CFCs)----------------------------------------------
class id#                      =   99 avg life= 19.0
class name                     = SSAI (Side-by-Side with ttd)
discount rate                  = 2.01
last year of historical info = 1992
first year for standard        = 1993 2016
EF  of standard                =   10.02   10.02
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors  (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    5.93    6.02    6.10    6.12    6.36    6.49    7.28    7.45    7.68    7.78
  8.26    8.69

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    973.   1050.   1084.   1101.   1089.   1078.   1081.   1089.   1104.   1119.
 1121.   1123.

---------- Adjusted volumes (1981-2015)
   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18
   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18
   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18   26.18
   26.18   26.18   26.18   26.18   26.18

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.123   0.123   0.123   0.123   0.123
   0.123   0.123   0.123   0.123   0.123   0.123   0.123   0.123   0.123   0.123
   0.123   0.123   0.123   0.123   0.123
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.060   0.060   0.060   0.060   0.060
   0.060   0.060   0.060   0.060   0.060   0.060   0.060   0.060   0.060   0.060
   0.060   0.060   0.060   0.060   0.060
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.065   0.065   0.065   0.065   0.065
   0.065   0.065   0.065   0.065   0.065   0.065   0.065   0.065   0.065   0.065
   0.065   0.065   0.065   0.065   0.065

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060   .1080   .1060
   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
 1161.51  799.93
 1167.53  768.41
 1177.67  725.06
 1184.25  697.48
 1187.02  685.66
 1191.30  669.89
 1194.88  654.13
 1204.73  634.43
 1206.17  630.49
 1236.84  583.20
 1243.55  571.38
```

```
 1253.12  555.62
 1294.50  516.21

---------- Shipment Distribution (source: none)
     Kwh   Units
   10.20     45.
   10.80     25.
   11.20     16.
   11.60     13.
   12.00     27.
   12.60     19.
   13.00     12.
   13.30      2.
   14.00      8.
   14.30      2.

---------- the 6th class (no CFCs)-------------------------------------------
class id#                     =   99 avg life= 11.3
class name                    = SD-M (Manual Defrost)
discount rate                 = 1.95
last year of historical info = 1992
first year for standard       = 1993 2016
EF  of standard               =    1.86    1.86
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    1.89    1.89    1.89    1.89    1.89    1.89    1.89    1.89    1.89    1.89
  1.89    1.89

---------- Historical Price (from CPI-ref/frz and ELCAP, see ref-hist-price.wk1)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    156.    156.    156.    156.    156.    156.    156.    156.    156.    156.
  156.    156.

---------- Adjusted volumes (1981-2015)
    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63
    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63
    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63    1.63
    1.63    1.63    1.63    1.63    1.63

---------- Fraction of market share (1981-2015)
l = 1
   0.170   0.170   0.170   0.170   0.170   0.170   0.170   0.170   0.170   0.170
   0.170   0.135   0.135   0.135   0.135   0.135   0.135   0.135   0.135   0.135
   0.135   0.135   0.135   0.135   0.135   0.135   0.135   0.135   0.135   0.135
   0.135   0.135   0.135   0.135   0.135
l = 2
   0.151   0.151   0.151   0.151   0.151   0.151   0.151   0.151   0.151   0.151
   0.151   0.120   0.120   0.120   0.120   0.120   0.120   0.120   0.120   0.120
   0.120   0.120   0.120   0.120   0.120   0.120   0.120   0.120   0.120   0.120
   0.120   0.120   0.120   0.120   0.120
l = 3
   0.123   0.123   0.123   0.123   0.123   0.123   0.123   0.123   0.123   0.123
   0.123   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097
   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097
   0.097   0.097   0.097   0.097   0.097

----- Retirement Function (from age 1 to 30 years)
   .0000   .0000   .0000   .0000   .0270   .0530   .0730   .0880   .0990   .1060
   .1080   .1060   .0990   .0880   .0730   .0530   .0270   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
```

---------- UEC (Kwh) & Purchase Price ($1990) data (scale baseline from 277.20 to 321)

Price	Kwh
156.20	315.00
156.58	308.06
157.28	301.13
158.64	295.29

---------- Shipment Distribution (source: none)

Kwh	Units
3.5	1.0

FREEZERS

```
total saturation              = 1.00
elec price multiplier         = 1.06
gas price multiplier          = 1.00
ncalc                         = 2
ndr1 (1, read drate & curve)  = 0
nv1 (# of eun inputs)         = 1
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
   15.10    0.00    0.00    0.00    0.00                                ** SF **
   15.10    0.00    0.00    0.00    0.00                                ** MF **
   15.10    0.00    0.00    0.00    0.00                                ** MB **

---------- Purchase price of a reference unit ($1990) -------------------------
       1       2       3       4       5
  352.69    0.00    0.00    0.00    0.00                                ** SF **
  350.35    0.00    0.00    0.00    0.00                                ** MF **
  346.41    0.00    0.00    0.00    0.00                                ** MB **

---------- Relative UEC and Capacity of a reference unit to a stock unit -------
       1       2       3       4       5
.5366281    1.00    1.00    1.00    1.00                             ** re   **
    1.00    1.00    1.00    1.00    1.00                             ** recap**

---------- Base Year Saturations - c70 ----------------------------------------
       1       2       3       4       5       6
   0.496    0.00    0.00    0.00    0.00   0.504                        ** SF **
   0.098    0.00    0.00    0.00    0.00   0.902                        ** MF **
   0.315    0.00    0.00    0.00    0.00   0.685                        ** MB **

---------- Marginal Saturations for Replacement Units - cn(m=1) ----------------
       1       2       3       4       5       6
   0.490    0.00    0.00    0.00    0.00   0.510                        ** SF **
   0.190    0.00    0.00    0.00    0.00   0.810                        ** MF **
   0.360    0.00    0.00    0.00    0.00   0.640                        ** MB **

---------- Marginal Saturations for New Houses - cn(m=2) -----------------------
       1       2       3       4       5       6
   0.520    0.00    0.00    0.00    0.00   0.480                        ** SF **
   0.090    0.00    0.00    0.00    0.00   0.910                        ** MF **
   0.300    0.00    0.00    0.00    0.00   0.700                        ** MB **

---------- Historical Shipments (from 1980 to 30 years back) -------------------
 1 Freezers
   1.757   1.941   1.521   1.598   1.541   2.457   3.219   2.415   1.577   1.436
   1.359   1.195   1.125   1.100   1.100   1.140   1.110   1.090   1.070   1.050
   1.045   1.205   1.101   0.925   0.975   1.100   0.990   1.090   1.140   1.050

---------- Retirement Function (from age 1 to 30 years) ------------------------
all i
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0250   .1030   .1360   .1550   .1620   .1550
   .1360   .1030   .0250   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- Average Life Times (by fuel type i) ---------------------------------
       1       2       3       4       5
    19.0     0.0     0.0     0.0     0.0

---------- Operating Cost Elasticities (for 5 fuel types and income) -----------
       1       2       3       4       5       6
```

```
 -.0450    0.00    0.00    0.00    0.00    0.20                          /* j=1 */
   0.00    0.00    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 */
   0.30    0.00    0.00    0.00    0.00   -0.10                          /* j=6 */

---------- Discount rate for calculating Equipment Price Elasticities -----------
       1       2       3       4       5
   1.60    0.00    0.00    0.00    0.00                                  /* j=1 */
   0.00    0.00    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
  -0.05    0.00    0.00    0.00    0.00                                  /* j=1 */
   0.00    0.00    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 */
   0.02    0.00    0.00    0.00    0.00                                  /* j=6 */

---------- Historical Relative Energy Use (eun) for New Units ------------------
   i   1    1981    1982    1983    1984    1985    1986    1987    1988    1989
  1990
   1   0    1.18    1.17    1.16    1.13    1.13    1.08    1.03    0.98    0.93
  0.88

---------- Historical Usage Factors for Existing Units -------------------------
   i   1    1980    1981    1982    1983    1984    1985    1986    1987    1988
  1989    1990
   1   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 freezer      =    1

=============================================================================
product type id#              =    2
product name                  = Frzr (Freezer)
end-use id#                   =    6
fuel type id#                 =    1
number of classes             =    6

---------- the 1st class -------------------------------------------------------
class id#                     =   99 avg life= 19.0
class name                    = UP-M (Upright Manual)
discount rate                 =1.081
last year of historical info = 1992
first year for standard       = 1993 2016
EF  of standard               =   17.21   17.21
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
   10.89   11.14   11.38   11.51   11.56   12.07   12.60   12.61   13.86   14.15
 13.95   13.73

---------- Adjusted volumes (1981-2015) (81-92 AHAM) (changed from 26.10 to
24.22)
   27.31   26.99   26.66   26.57   26.71   26.85   26.95   26.76   26.05   26.32
   25.35   24.80   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22
```

```
   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22
   24.22   24.22   24.22   24.22   24.22

---------- Fraction of market share (1981-2015)
l = 1
   0.322   0.322   0.322   0.322   0.322   0.322   0.322   0.322   0.322   0.322
   0.322   0.325   0.325   0.325   0.325   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 2
   0.287   0.287   0.287   0.287   0.287   0.287   0.287   0.287   0.287   0.287
   0.287   0.293   0.293   0.293   0.293   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 3
   0.233   0.233   0.233   0.233   0.233   0.233   0.233   0.233   0.233   0.233
   0.233   0.241   0.241   0.241   0.241   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000

---------- Retirement Function (from age 1 to 30 years) ------------------------
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0250   .1030   .1360   .1550   .1620   .1550
   .1360   .1030   .0250   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh (kWh scaled with 10.3*24.22+264 / 544 (design meeting 93 stds)
  359.55   733.4
  364.73   664.5
  372.91   572.0
  379.63   513.5
  391.12   482.3
  398.43   461.6
  415.86   427.6
  438.78   406.8
  446.21   392.7
  503.01   323.7

---------- Shipment Distribution (source: none)
      EF   Units
   18.00     43.
   18.90      5.
   20.30     24.

---------- the 1st class (no CFCs)---------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = UP-M (Upright Manual)
discount rate (orig 1.91)    = 1.91
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   17.21   17.21
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-90 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
   10.89   11.14   11.38   11.51   11.56   12.07   12.60   12.61   13.86   14.15
 13.95   13.73

---------- Adjusted volumes (1981-2015) (81-92 AHAM)
   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22
   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22
   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22   24.22
   24.22   24.22   24.22   24.22   24.22
```

---------- Fraction of market share (1981-2015)

l = 1

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.325	0.325	0.325	0.325	0.325
0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325
0.325	0.325	0.325	0.325	0.325					

l = 2

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.293	0.293	0.293	0.293	0.293
0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293	0.293
0.293	0.293	0.293	0.293	0.293					

l = 3

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.241	0.241	0.241	0.241	0.241
0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241	0.241
0.241	0.241	0.241	0.241	0.241					

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

.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	.0250	.1030	.1360	.1550	.1620	.1550
.1360	.1030	.0250	.0000	.0000	.0000	.0000	.0000	.0000	.0000

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

Price	Kwh
379.63	482.94
382.40	424.31
391.50	361.15
392.91	353.78
397.07	343.30
405.29	328.00
431.33	302.51
438.66	301.38
460.72	277.87

---------- Shipment Distribution (source: none)

EF	Units
18.00	43.
18.90	5.
20.30	24.

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

class id# = 99 avg life= 19.0
class name = UP-A (Upright Auto Defrost)
discount rate =1.218
last year of historical info = 1992
first year for standard = 1993 2016
EF of standard = 12.02 12.02
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
8.03	8.23	8.43	8.58	9.50	9.44	9.57	9.31	9.47	10.41

1991	1992
10.43	10.38

---------- Adjusted volumes (1981-2015) (81-92 AHAM)

30.12	30.58	31.03	30.20	29.91	28.24	27.53	27.52	26.93	29.36
29.14	28.82	25.30	25.30	25.30	25.30	25.30	25.30	25.30	25.30
25.30	25.30	25.30	25.30	25.30	25.30	25.30	25.30	25.30	25.30
25.30	25.30	25.30	25.30	25.30					

---------- Fraction of market share (1981-2015)

l = 1

0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
0.072	0.107	0.107	0.107	0.107	0.000	0.000	0.000	0.000	0.000

```
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 2
   0.064   0.064   0.064   0.064   0.064   0.064   0.064   0.064   0.064   0.064
   0.064   0.097   0.097   0.097   0.097   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 3
   0.052   0.052   0.052   0.052   0.052   0.052   0.052   0.052   0.052   0.052
   0.052   0.080   0.080   0.080   0.080   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000

---------- Retirement Function (from age 1 to 30 years) ------------------------
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0250   .1030   .1360   .1550   .1620   .1550
   .1360   .1030   .0250   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
  429.67   979.0
  435.09   899.0
  443.65   824.0
  451.11   763.0
  463.13   719.0
  464.24   709.0
  472.73   659.0
  491.67   626.0
  539.00   600.0
  564.80   596.0
  573.97   524.0
  625.84   461.0

---------- Shipment Distribution (source: none)
      EF   Units
   12.10      2.
   12.80      6.
   13.20      2.
   13.80      9.

---------- the 2nd class (no CFCs)---------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = UP-A (Upright Auto Defrost)
discount rate                =1.218
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   12.03   12.03
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
    8.03    8.23    8.43    8.58    9.50    9.44    9.57    9.31    9.47   10.41
 10.43   10.38

---------- Adjusted volumes (1981-2015) (81-92 AHAM)
   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31
   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31
   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31   25.31
   25.31   25.31   25.31   25.31   25.31

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.107   0.107   0.107   0.107   0.107
```

```
   0.107   0.107   0.107   0.107   0.107   0.107   0.107   0.107   0.107   0.107
   0.107   0.107   0.107   0.107   0.107
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.097   0.097   0.097   0.097   0.097
   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097   0.097
   0.097   0.097   0.097   0.097   0.097
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.080   0.080   0.080   0.080   0.080
   0.080   0.080   0.080   0.080   0.080   0.080   0.080   0.080   0.080   0.080
   0.080   0.080   0.080   0.080   0.080

---------- Retirement Function (from age 1 to 30 years) ------------------------
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0250   .1030   .1360   .1550   .1620   .1550
   .1360   .1030   .0250   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price      Kwh
  451.11   759.24
  462.88   711.14
  475.19   674.62
  479.23   667.96
  482.61   663.32
  534.23   610.00
  549.14   598.12
  561.29   587.98
  590.83   559.87
  605.25   548.57
  600.65   483.94

---------- Shipment Distribution (source: none)
      EF    Units
   12.10       2.
   12.80       6.
   13.20       2.
   13.80       9.

---------- the 3rd class -------------------------------------------------------
class id#                      =   99 avg life= 19.0
class name                     = CH-M (Chest Manual Defrost)
discount rate                  =2.107
last year of historical info = 1992
first year for standard        = 1993 2016
EF  of standard                =   21.14   21.14
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
   11.82   11.87   11.91   12.31   12.04   12.84   14.41   14.46   15.48   15.67
 15.92   15.63

---------- Adjusted volumes (1981-2015) (81-92 AHAM) (modified to 25.55 from
22.50)
   23.95   23.80   23.65   23.88   22.38   22.82   21.84   21.24   20.55   20.20
   20.96   20.01   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55
   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55
   25.55   25.55   25.55   25.55   25.55

---------- Fraction of market share (1981-2015)
l = 1
   0.455   0.455   0.455   0.455   0.455   0.455   0.455   0.455   0.455   0.455
   0.455   0.395   0.395   0.395   0.395   0.000   0.000   0.000   0.000   0.000
```

```
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 2
   0.491   0.491   0.491   0.491   0.491   0.491   0.491   0.491   0.491   0.491
   0.491   0.430   0.430   0.430   0.430   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000
l = 3
   0.548   0.548   0.548   0.548   0.548   0.548   0.548   0.548   0.548   0.548
   0.548   0.486   0.486   0.486   0.486   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000

---------- Retirement Function (from age 1 to 30 years) ------------------------
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0250   .1030   .1360   .1550   .1620   .1550
   .1360   .1030   .0250   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh
  326.19   681.0
  328.57   600.0
  335.79   539.0
  339.78   501.0
  350.88   471.0
  356.57   441.0
  372.68   420.0
  394.68   376.0
  433.44   358.0

---------- Shipment Distribution (source: none)
      EF   Units
   13.30      1.
   17.50      1.
   18.30     10.
   19.70      6.
   20.90      3.
   21.70     13.
   22.10     14.

---------- the 3rd class (no CFCs)---------------------------------------------
class id#                    =   99 avg life= 19.0
class name                   = CH-M (Chest Manual Defrost)
discount rate                =2.107
last year of historical info = 1992
first year for standard      = 1993 2016
EF  of standard              =   21.14   21.14
conversion (Kwh-MMBTU&usage) = .003412

---------- Historical energy factors (81-92 AHAM)
    1981    1982    1983    1984    1985    1986    1987    1988    1989    1990
  1991    1992
   11.82   11.87   11.91   12.31   12.04   12.84   14.41   14.46   15.48   15.67
 15.92   15.63

---------- Adjusted volumes (1981-2015) (81-92 AHAM)
   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55
   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55
   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55   25.55
   25.55   25.55   25.55   25.55   25.55

---------- Fraction of market share (1981-2015)
l = 1
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.395   0.395   0.395   0.395   0.395
```

```
   0.395   0.395   0.395   0.395   0.395   0.395   0.395   0.395   0.395   0.395
   0.395   0.395   0.395   0.395   0.395
l = 2
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.430   0.430   0.430   0.430   0.430
   0.430   0.430   0.430   0.430   0.430   0.430   0.430   0.430   0.430   0.430
   0.430   0.430   0.430   0.430   0.430
l = 3
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000
   0.000   0.000   0.000   0.000   0.000   0.486   0.486   0.486   0.486   0.486
   0.486   0.486   0.486   0.486   0.486   0.486   0.486   0.486   0.486   0.486
   0.486   0.486   0.486   0.486   0.486

---------- Retirement Function (from age 1 to 30 years) ------------------------
   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000   .0000
   .0000   .0000   .0000   .0000   .0250   .1030   .1360   .1550   .1620   .1550
   .1360   .1030   .0250   .0000   .0000   .0000   .0000   .0000   .0000   .0000

---------- UEC (Kwh) & Purchase Price ($1990) data
   Price     Kwh (Baseline changed to meet 1993 standard)
  356.57  441.05
  375.77  394.03
  373.15  392.91
  383.04  357.21
  392.49  328.47
  395.69  324.43
  402.12  318.14
  405.89  315.67
  434.39  307.59
  467.53  284.02

---------- Shipment Distribution (source: none)
      EF   Units
   21.70     13.
   22.10     14.
```

APPENDIX C. LBL MANUFACTURER ANALYSIS MODEL

C.1 OVERVIEW OF LBL MANUFACTURER ANALYSIS MODEL

C.1.1 Purpose

The Lawrence Berkeley Laboratory Manufacturer Analysis Model (LBL-MAM) collects into one spreadsheet all the calculations necessary to determine the impact of a change in appliance efficiency standards on an industry's profitability and scale of operation. The spreadsheet design makes it possible to quickly analyze the effects of uncertainties in input values and to efficiently incorporate new data into the calculations. The model has a control panel, which makes the analysis of uncertainty particularly straightforward for nine of the model's crucial inputs. Through this panel, the model provides the user not only with the best estimates of financial impacts, but also with the uncertainty of these estimates and a sensitivity analysis attributing that uncertainty to certain input variables.

C.1.2 The Economic Approach

The impact of efficiency standards on manufacturers depend on the interaction of four factors: (1) the costs imposed by the change in standards, (2) the price elasticity of a single typical firm, (3) the industry's price elasticity of demand, and (4) the consumer market discount rate for energy savings for a product (which are used to obtain industry operating cost elasticity). The LBL-MAM integrates and analyzes these four factors as they apply to a single typical firm.

A change in standards will generally create three types of costs for a firm. First, variable costs of goods sold (VCGS) will be affected by new parts and labor requirements. Second, some engineering will be required to design, test, and plan the manufacturing of new products. And third, new products often require re-tooling and new equipment (capital) costs. The incorporation of VCGS is straightforward, but engineering and capital costs must be amortized to be converted from one-time costs to annual costs for a typical-year model.

Markups from manufacturing costs to ex-factory prices depend on the single-firm price elasticity. Because it is difficult to find data on single-firm price elasticities, the LBL-MAM infers them from the firm's fixed costs and return on equity (ROE). The markup is over variable cost and not fixed; hence it must be greater than one if a firm with fixed costs is to recover its fixed costs and turn a profit.

The industry has two elasticities of interest: its price elasticity and its operating cost elasticity. Although individual firms must calculate according to their own elasticities of demand, it is ultimately the industry elasticities that determine the level of demand experienced by each firm. This apparent paradox arises because the model assumes that all firms are profit-maximizers and thus respond in essentially the same way to the imposition of standards. Because of this assumption, all firms change the prices and operating costs of their appliances by the same amount (i.e., the

industry acts in unison). When this happens, sales for each firm are determined by the industry elasticities.

C.1.3 Measures of Impact

The LBL-MAM computes three primary and several secondary measures of impact. The three primary measures, ROE, industry net present value, and net income are presented because they can each move in opposite directions. For instance, if net income increases, but assets and thus equity increase by a greater percentage, ROE will decline. If the decline is large, the net effect will be viewed as negative, but if a small decrease in a healthy ROE is accompanied by a large increase in net income, the net effect might be viewed as positive. Other outputs of the model are total shipments, price, revenues, and average wholesale price. These variables help explain the origins of changes in the primary inputs.

C.1.4 Methodology

How standards are implemented in the model

Generally, a change in standards affects the model in three distinct ways. Standards require additional investment, raise production costs, and affect revenue.

The most obvious investment induced by standards is the purchase of new plant and equipment. This cost is first evaluated from engineering data and then amortized by taking into account the life of the investment, the timing of the expenditures, tax laws, and the cost of funds. An additional (and sometimes larger) investment is made as old inventory is replaced with more expensive new units. The model assumes that previous inventory ratios are maintained. A third form of investment tracked by LBL-MAM is the change in the transactions demand for cash that accompanies a change in revenues.

Increased costs of production are modeled by coupling changes in unit costs with changes in product shipments. Changes in unit costs come from engineering data and shipments data come from LBL-REM.

Revenue is affected both by price and shipments. Price is determined by computing the markup over long-run marginal costs, and then using the markup to determine an optimal price. Shipments (demand) is determined by price elasticities and consumer market discount rates, coupled with the standards-induced changes in price and operating costs.

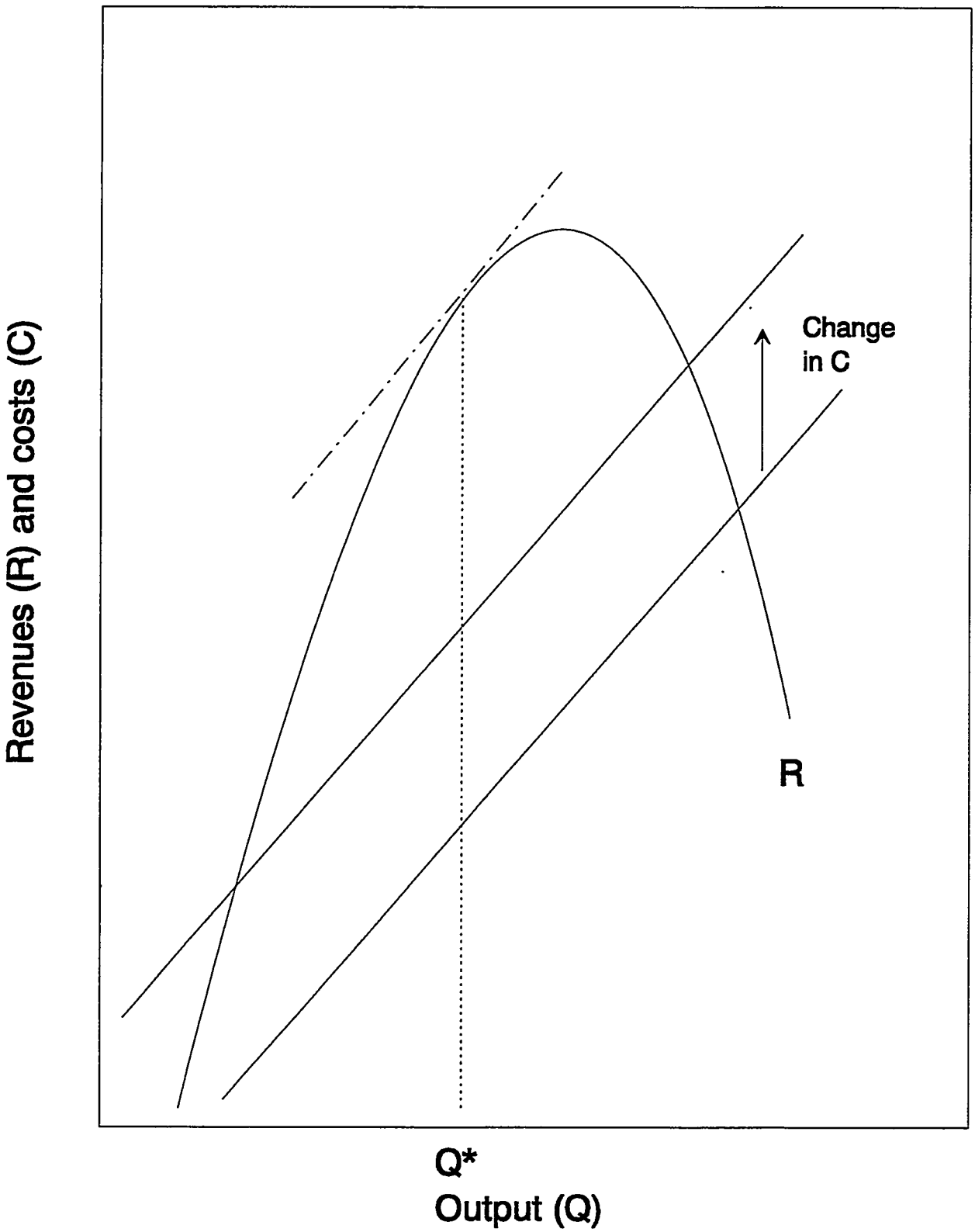

Figure C.1 Profit maximization and fixed costs

Typical-year approach

The LBL-MAM uses a "typical-year" approach rather than a dynamic approach. This approach models a "typical year" for the industry both in the base case and in the new standards case. The year chosen for the model is the fourth year after the imposition of standards, and is selected because it is believed to be long enough to capture any major impacts from the standard, such as profitability changes or firm entry into or exit from the industry.

Use of prototypical firms

Because the engineering and financial data for most firms are proprietary, LBL-MAM models a prototypical firm. A prototypical firm is a hypothetical firm that is representative of the industry. In many cases, this firm must be thought of as representing an autonomous division of a larger firm. Prototypical firms are defined by parameters that are important for determining the impacts of standards and are consistent with data for the portion of the industry they represent. Important parameters used in the model include the cost structure of the firms, profitability ratios, relative costs of complying with new standards, and marketing strategies.

Product segmentation

The LBL-MAM assumes that the product market is segmented. Thus, different products have different markups. In general, it is found that appliance manufacturers are able to charge different markups for products that have different characteristics. They can charge higher markups on products that have desirable characteristics (e.g., refrigerators with automatic defrost features, or water heaters with heat pumps, etc.). Products without such desirable features are generally bought in larger quantities at lower prices by consumers who are more price-conscious, and thus the markups for these products are lower. The per-unit profits made by manufacturers for these different products may differ significantly.

C.2 STRUCTURE OF THE LBL-MAM

C.2.1 Economic Theory and Assumptions

The basic question that LBL-MAM must answer is: how much of the cost increases caused by standards can be passed through to consumers? If less than the normal pass-through occurs, profits will suffer, while an above normal pass-through will increase profits. To answer this question precisely, it is necessary to compute a markup; but, before that, a more intuitive understanding of the relevant economics will be useful.

In economics, costs are often divided into fixed and marginal components where fixed costs are just what their name suggests and marginal costs are the costs of producing an additional unit of output. Three points are true in general of these cost distinctions:

1. Under perfect competition, price equals marginal cost.

2. Under imperfect competition (i.e., where the market is characterized by a downward-sloping demand curve) price equals marginal cost times a markup.

3. In neither case do fixed costs affect the calculation of price.[1]

The first point may be understood by assuming for a moment that it is false and that price is higher than marginal cost. In this case, each firm concludes that it is profitable to increase production (since under perfect competition each firm knows that as an individual firm its own output has no effect on price). As a result, prices would certainly fall. If price is below marginal cost, the reverse argument holds, so, in either case, price will inevitably change until it equals marginal cost. The second point is derived in the next section. The third point is most easily understood by examining Figure C.1, which shows a revenue curve and two total-cost curves that differ only in their fixed components.

How will a firm respond to an increase in fixed cost (represented by the upward shift displayed in the cost curve)? Since the firm wishes to maximize the difference between cost and revenue, it chooses the optimal output Q*. This choice is clearly independent of the shift in fixed cost, but once output is determined, the demand curve will dictate the price at which that output can be sold. A change in fixed cost has no effect on the demand curve and thus no effect on price.

The separation of costs into fixed and variable must be done with an eye to the time horizon under consideration, because many (if not most) costs that are fixed in the short run become variable in the long run. Three distinct time horizons are useful: the short run, the long run, and the very long run. In the short run, the productive capacity of the firms in the industry remains fixed. In the long run, capacity may be adjusted, but the number of firms remains constant. In the very long run, firms may enter or leave the industry, with the result that an individual firm's market power, as measured by its price elasticity of demand, may change. Thus, in the very long run, markup may change.

In the long run, price is a markup over long-run marginal cost, while in the short run, price is a markup over short-run marginal cost. Since in the long run, capital is considered a marginal cost, how can the two pricing rules be reconciled? If a firm finds that its long-run plans have been realized (in other words, if the market conditions are those that it foresaw at the time it planned its present capacity), then long- and short-run marginal costs will be equal. This is possible because although capital is not included as a short-run cost, there are other costs that are short-run cost but not

---

[1]Two legitimate interpretations may be given to this mathematical result. The first is that given the demand function, marginal cost determines price and fixed costs are not passed on. The second is that one may argue that fixed costs indirectly determine the elasticity of demand, and thereby the markup over marginal cost. Thus fixed costs are indirectly passed on through the markup of marginal cost. The mechanism providing this indirect link is the following: if fixed costs are not covered, then economic profits will be negative and some firms will leave the industry; this will reduce competition and thus reduce each firm's elasticity of demand. Conversely, if fixed costs are more than covered, positive economic profits will induce entry and elasticity and markup over marginal cost will be reduced.

long-run costs. These are the costs associated with an increase in output beyond the planned long-run capacity level. If a plant is running optimally, output has been pushed to the point that short-run marginal costs equal long-run marginal costs; otherwise a different size plant would have been more profitable.

The next section gives a theoretical overview of the LBL-MAM, followed by a derivation of some important results and a review of their application to the long-run model. Finally, we discuss the short-run part of the model.

Theory and the LBL-MAM

From our discussions with the industries involved and industry consultants, we know that in appliance manufacturing, unit cost decreases as quantity decreases. Therefore, we know that there are fixed costs in the production of appliances. Consequently, each producing firm does not face an infinite elasticity of demand because a small increase in price charged will not result in a 100% loss of sales (because the increase in price would induce entry of new competitors). As a result, we know that the appliance-manufacturing industry is not perfectly competitive. As a result, the LBL-MAM models typical firms as having a combination of fixed and variable costs, and as facing a demand curve with finite elasticity.

The next section derives the equations relating markup, fixed costs, variable cost, and economic profit. These relationships are part of standard economic theory, hence these derivations are included for the convenience of the reader and not as an explanation of any theoretical results new to this study. One exception to this disclaimer is the discussion on oligopsony power and the "effective" number of firms. There is no generally accepted theory on how to model a market characterized by significant market concentration on both the seller's and the buyer's side. As a result, we developed an approach that is discussed in greater detail below.

Derivation of markup

To begin the derivation of the markup equation, assume that firms maximize economic profit, where economic profit is revenue minus economic cost, and economic cost includes the cost of equity and all taxes. Economic costs © are assumed to be linear functions of output (Q) and revenues (R):

$$C = \beta_0 + \beta_1 Q \qquad \text{(C.1)}$$

Although cost is written as a linear function of output, this is not essential; a non-linear cost function would give a mathematically equivalent, but more difficult to express, result.[2]

---

[2] If we assume that cost is an arbitrary function of Q, $C(Q, R)$, our final result, will differ only in that the two types of cost (β_0 and β_1) will be replaced by $C - Q\,(dC / dQ)$ and dC / dR, respectively.

Next, make the standard economics assumption that firms maximize economic profit *(R-C)*. Since the cost of capital is included in economic cost, a firm with an ROE equal to the cost of capital will find its economic profit to be zero. If, however, a firm can earn a higher ROE, it is assumed that it will, in which case *R-C* will be positive. The firm can maximize profit by picking either a quantity to produce *(Q)* or, equivalently, a price to sell it at, but it cannot choose both. The following computations assume that profit is maximized with respect to Q. This gives the following first-order condition:

$$\frac{d}{dQ}(R-C)=0 \tag{C.2}$$

This equation completes the description of the supply-side assumptions. The demand side is described by an elasticity of demand which may vary, but which at the market equilibrium takes the value *e*. Elasticity of demand is the percentage change in demand caused by a 1% change in price *P*, and consequently is negative. Mathematically, this is expressed as follows:

$$\frac{dQ}{dP} \cdot \frac{P}{Q} = e \tag{C.3}$$

All necessary assumptions have now been made, so all that remains are some mathematical manipulations. From the two supply assumptions, and denoting dR/dQ by R' and dP/dQ by P', we have:

$$\frac{d}{dQ}\left[R - \beta_0 - \beta_1 Q \right] = 0 \tag{C.4}$$

By definition:

$$R' = \beta_1 \tag{C.5}$$

$$R = P \cdot Q \tag{C.6}$$

$$R' = \frac{P}{\frac{dQ}{dP}\,\frac{P}{Q}} + P \tag{C.7}$$

$$R' = P' \cdot Q + P \tag{C.8}$$

$$R' = \frac{P}{e} + P \tag{C.9}$$

$$R' = \frac{P}{e} + P \tag{C.10}$$

$$P = \frac{e}{1+e}\beta_1 \tag{C.11}$$

In this last equation, price is a simple markup over marginal cost and may be found in any standard text on industrial organization. Now we define the markup:

$$\mu = \frac{e}{1+e} \tag{C.12}$$

Note that because the own-price elasticity *(e)* is negative, μ is greater than 1. Of course if $e \leq = -1$, then μ is undefined, since the firm makes more profit the less it sells.

A small rearrangement of Eq. C.12 provides a simpler look at the markup equation:

$$P = \mu\beta_1 \tag{C.13}$$

Price formation can be explained as follows: marginal costs are marked up by μ and fixed costs are not passed on at all.

It is now easy to derive another representation of μ which is used in the calibration stage of the LBL-MAM to estimate μ from Eq. C.1:

$$(R-C) = R - \beta_0 - \beta_1 \cdot Q \tag{C.14}$$

Using Eq. C.5:

$$R = P \cdot Q = \mu \beta 1 Q \tag{C.15}$$

so

$$(R-C) = \mu \beta_1 Q - \beta_0 - \beta_1 Q \tag{C.16}$$

and

$$(R-C) = (\mu - 1)\beta_1 Q - \beta_0 \tag{C.17}$$

Finally,

$$\mu = 1 + \frac{(R-C) + \beta_0}{\beta_1 Q} \tag{C.18}$$

This equation shows that markup is economic income *(R-C)* plus fixed costs, all over total variable cost. The calibration calculations of the long-run module uses a simple variation of this equation in which $\beta_1 Q$ is replaced by $C\text{-}\beta_0 0$, and the relation, $R\text{-}C = EP$, where EP is economic profit, is used twice. The new form of the equation is:
Markup is determined by revenue, economic profit, and fixed costs. Generally, it has been found that

$$\mu = 1 + \frac{EP + \beta_0}{R - EP - \beta_0} \tag{C.19}$$

fixed costs are large relative to economic profit, so the numerator is controlled largely by the fixed cost. Thus, markup is primarily determined by the size of fixed cost relative to revenue.

Oligopsony Power and the "Effective Number of Firms

From an evaluation of the analyzed industries (for instance, see Chapter 6, Industry Profile section), we see that the market structures of the industries are oligopolies and model them accordingly. However, the situation is further complicated by the fact that the demand side of the market is also heavily concentrated due to the presence of large retailers who have a great deal of

market power.[3] In other words, we have an oligopoly facing an oligopsony. Consequently, the standard oligopoly model needs to be modified. Unfortunately, there is no standard theory on how to model an industry with such a market structure. After examining the evidence of oligopsony, an outline will be made to show how we incorporate this into the model.

The rise of large retailers in the home appliance industry is a relatively recent phenomenon. They are generally defined as multi-market large-volume retailers, which includes firms such as Sears, Montgomery Ward, Circuit City, and Highland. For example, the home appliance retail share of Sears and Montgomery Ward alone has been estimated to be about 30% for various products. One indication of this oligopsony power is that if theoretical markups based on the actual number of firms in the industry are estimated, we find that the markups are much too large relative to what we observe in the market.

We address both the problems of oligopsony and of "over-estimated" markups by assuming that the low observed markup is the result of oligopsony power and is an indication of the strength of that power. Since a firm's markup is directly related to the elasticity of the demand it faces, we can find the single-firm demand elasticity that corresponds to the observed markup. This same elasticity is also implied by the industry elasticity and a Cournot oligopoly with some hypothetical number of firms. This allows us to compute the hypothetical or what we refer to as the "effective" number of firms from the observed markup. We then model the industry as if it were a Cournot oligopoly facing a competitive, not oligopolistic, demand for its product, but we use the "effective" number of firms rather than the actual number of firms to reflect the impact of the oligopsony. The effect of this is to reduce the market power of the individual firm to agree with our observation of markup. Although the reduced market power is a consequence of specifying too many firms, and not of modeling oligopsony, we believe that it provides a good first-order approximation to the actual market structure and provides a way around the intractable problem of modeling a market with imperfectly competitive demand and supply sides.

We now show how markup is computed from economic profit and fixed costs, and how the "effective" number of firms is computed from markup and industry demand elasticity. A well-known result for a Cournot oligopoly is:

$$e = NF \cdot e_i \tag{C.20}$$

where:

e	=	the firm elasticity of demand,
e_i	=	the industry elasticity of demand, and
NF	=	number of firms.

[3]The increasing concentration on the demand side of the market also agrees with comments by the home appliance industry in comments for these and other appliances. For instance, see AHAM, "Statement by AHAM to the Department of Energy on Notice of Proposed Rulemaking on Energy Efficiency Standards for Clothes Dishwashers, Clothes Washers and Clothes Dryers," CE-RM-88-101, October 10, 1989.

We can solve for *NF* if the two elasticities are known. We have an estimate of e_i and can estimate *e* as follows. From Eq. C.5, we know that:

$$e=\frac{\mu}{1-\mu} \tag{C.21}$$

Thus, we can find the markup, μ, in Eq. C.21 from Eq. C.4, if we know marginal cost *c*. Marginal cost can be found from the firm's return on equity, its fixed costs, and the following price identity: $\pi/Q=P-c+FC/Q$, where *FC* is fixed cost. This is just a restatement of the definition of economic profit, which is revenue minus costs. Noting that revenue, *R*, equals $P\bullet\ Q$, we have:

$$\mu = \frac{P}{c} = \frac{P}{P-\frac{FC}{Q}-\frac{\pi}{Q}} = \frac{R}{R-FC-\Pi} \tag{C.22}$$

This gives a formula for markup μ based on our most easily observed variables. Solving Eqs. C.9 and C.10 for *e*, we can now find the number of firms, *NF*:

$$NF=\frac{\mu}{e_i\cdot(1-\mu)} \tag{C.23}$$

We find that given two elasticities estimated from actual data, *NF* is higher than the actual number of firms observed.

To summarize, we first look at a typical firm's profit and fixed costs. In order to recover fixed costs, a firm must mark up over variable costs, and if it can mark up enough, it will make above "normal" ROE. From these considerations, we find its markup. The markup indicates a firm's industry demand elasticity and the effective number of firms in the industry. We use it in subsequent calculations.

The base case

In the *long-run model module*, the calibration case is immediately followed by long-run calculations for the state of the industry in 1996 provided that the 1990 NAECA standards are unmodified. These calculations use the markup that is based on the one just calculated and modified in keeping with the assumption that demand elasticity with respect to life-cycle cost is constant. The modified markup is calculated as in Eq. C.5 but from a modified price elasticity. The new price elasticity is obtained as follows. First, the original price and operating cost elasticities are used to determine a life-cycle cost and an elasticity with respect to that cost. A demand curve with constant

life-cycle cost elasticity is then computed. It takes this form:

$$Q = a \cdot (P + ff \cdot F)^B \tag{C.24}$$

where P is price, F is operating (fuel) cost, ff is the fuel-cost factor, and B is the elasticity with respect to life-cycle cost. Then price and fuel cost are changed from the calibration case to either the base case or a long-run case. These changes shift the division of demand elasticity between the price and operating cost. In particular, the price elasticity is given by:

$$e = \frac{B \cdot P}{P + ff \cdot F} \tag{C.25}$$

As price increases as a fraction of life-cycle cost, the price elasticity increases.

The added costs to meet standards are divided into two categories: capital, and parts and labor. Capital costs come in two varieties, tooling and equipment. These are not currently separated by the model because we do not have separate data from the manufacturers. Since the chief economic difference between these two is their expected life, the LBL-MAM, in its amortization procedure, uses an intermediate value for the lifetime of new capital. This procedure takes a one-time capital expense and converts it to an annual expense, taking into account the cost of debt and equity, the tax laws, the lifetime of the capital, and the age of any capital being replaced.

Once the cost of capital has been annualized, it must be divided into fixed and variable parts. The fixed part is then added to β_0, while the remainder is divided by Q and added to β_1.

Since there are undoubtedly some economies of scale when parts are purchased, the LBL-MAM provides for a division of the cost of parts and labor between the fixed and variable categories. However, the savings generated by buying an additional 100,000 units above an initial million, for example, will generally be so small that the cost of parts and labor will be referred to as a variable cost and thus can be thought of as being added directly to β_1.

Once base case costs have been assigned, price is easily computed from Eq. C.4, by using the price elasticity calculated as described above. With the new price in hand, sales (Q) can be computed from price and operating-cost elasticities. Revenue is now just $R=P \bullet Q$, and economic income is just R-C. Assets are those of the calibration case plus the new capital resulting from 1993 Standards, and equity is computed from the debt-to-equity ratio. This calculation of equity is the last essential calculation for the base case.

The long-run analysis: changed standards

The analysis of the long-run effect of a change in standards from their 1993 Standards level is essentially the same as the analysis of the base case. New costs are divided between fixed and

variable categories in the same way and added to the base case costs. From there, the calculation proceeds in exactly the same way as above.

C.2.2 Structural Assumptions

The cost structure. Costs are assumed to have two components: fixed and proportional to quantity.

$$EC = FC + MCq \cdot Q$$

The asset structure. Assets are assumed to have the same two components.

$$A = A0 + Aq \cdot Q$$

Demand elasticity. The demand elasticity with respect to life-cycle cost experienced by a single firm is assumed to be independent of price and operating cost over the relevant region. This means that if the industry raises price, the percentage change in demand caused by a 1% change in price remains the same as before the price increase.

Optimizing behavior. A firm is assumed to maximize revenue minus economic cost *(R-EC).*

Debt-to-equity ratio. The debt-to-equity ratio is assumed to remain constant while the firm finances any investment necessary to meet standards. It is generally assumed that firms have some *D/E* ratio that they consider optimal, and there is no reason for standards to change this figure.

Amortization of capital costs. It is assumed that the one-time capital cost is to be amortized over its life (typically seven years), that its cost is the weighted average after-tax cost of capital, and that depreciation is straight-line over the tax life.

Structure of cost resulting from changes in standards. Engineering costs, if they are separated from capital costs, are assumed to be entirely fixed. The cost of capital is assumed to be partly fixed and partly variable (proportional to shipments). Parts and labor are assumed to be variable costs.

C.2.3 Description of Modules

The LBL-MAM is a Lotus 1-2-3 spreadsheet that is organized into 13 modules. A flowchart depicting the main linkages between the various modules appears in Figure C.2, and a brief description of each is given below. Starting with subsection C.2.3.1, each panel is given a full description.

MAM Modules and Primary Routes of Data Flow

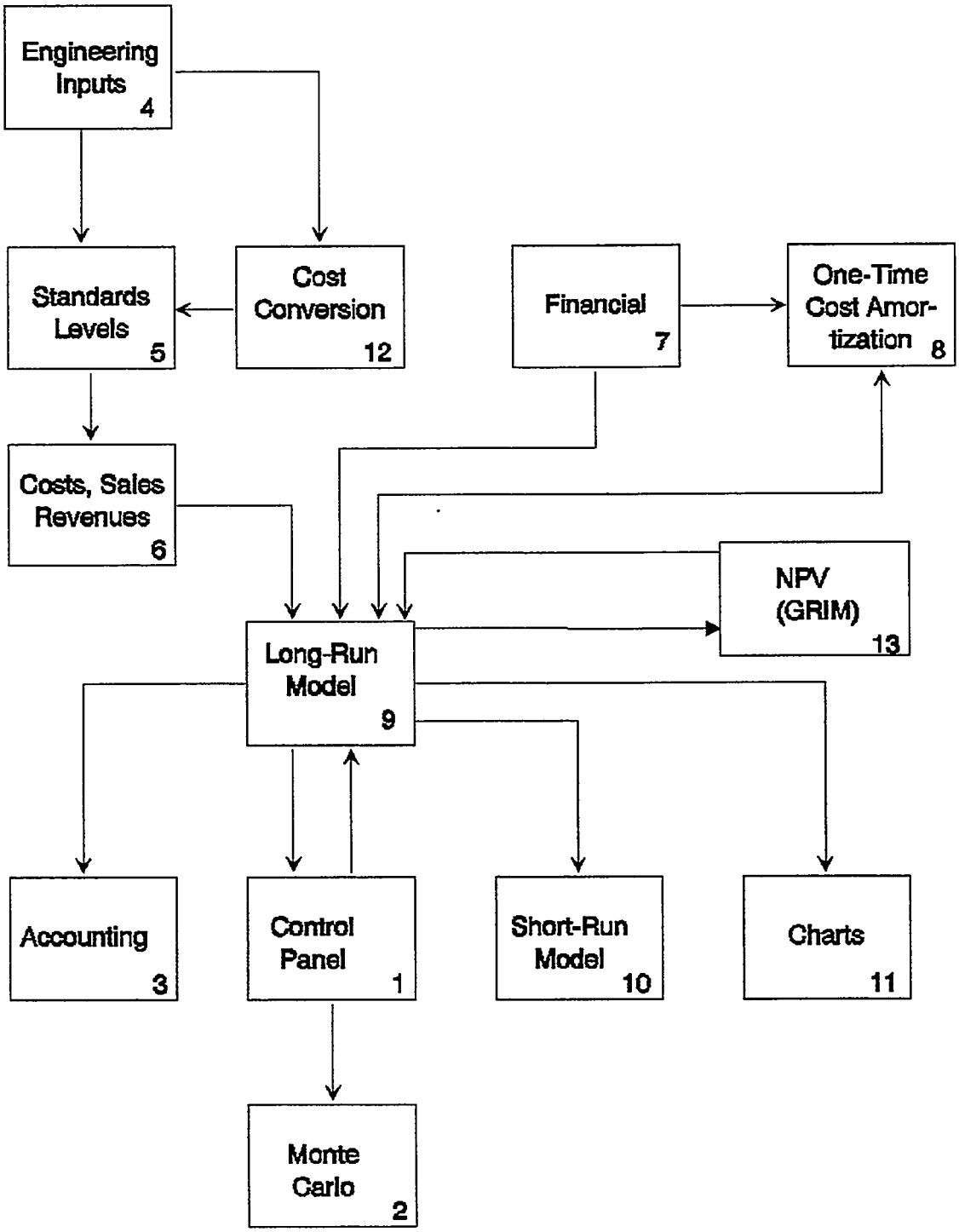

Figure C.2 LBL-MAM modules and primary routes of data flow

1. *Control Panel.* This module displays nine key variables and their control factors, plus a summary of crucial results. The control factors are normally set to one, but can be changed to test the model's reaction to any of the control variables. The change in results is immediately displayed in the lower part of the control panel.

2. *Monte Carlo.* The nine control variables can be selected randomly from probability distributions determined by the variables' standard errors and median (estimated) values. The Monte Carlo module is designed to record many such runs and display the mean value and standard deviation of six outputs: percentage change in price, sales, revenue, and net income, plus the change in ROE in the long and short runs.

3. *Accounting.* The Accounting module gives a summary, in the form of a simplified income statement, of the financial impact of standards on the firm. In addition, a summary of the financial impacts of standards from an economic point of view is shown at the bottom of the page.

4. *Engineering Inputs.* The Engineering Inputs module accepts as input raw engineering data that are used elsewhere in the model for the impacts analysis. These data include incremental variable costs, capital costs, engineering costs, and changes in unit energy consumption for the products being analyzed.

5. *Standards Levels.* The Standards Levels module provides the same data as the Engineering Inputs module, except that the data have been processed by the LBL-REM and/or the "Cost Conversion" module (12) and are presented for the standards levels being analyzed.

6. *Costs, Sales, and Revenues.* This module uses prices, markups, market shares, and industry shipment levels to compute variable cost of goods sold and revenues for a single prototypical firm. Changes in operating cost, capital cost, and engineering expense are also computed here.

7. *Financial.* The Financial module computes the weighted average cost of capital and a factor describing how costs depend on revenues.

8. *One-Time Cost Amortization.* The One-Time module derives amortized costs from the one-time capital cost and one-time engineering expense associated with the imposition of new standards.

9. *Long-Run Model.* This module does most of the economic calculations. Its calibration phase estimates the markup over variable cost, which is used to estimate new prices once standards have been imposed. These prices are then used to compute sales, and, from sales, all other descriptive variables.

10. *Short-Run Model.* This module modifies the price computed by the Long-Run module in order to take into account the possible short-run effects of excess capacity. An estimate of the responsiveness of price to changes in demand during the business cycle is combined with the change in demand predicted by the Long-Run model.

11. *Sensitivity and Profit Charts.* This module produces two charts. The first shows how profit is affected by a one-standard-deviation change in each of the control variables. These changes are all made with the standards level set to its middle value. The second chart shows how profits change as the standards level is changed, but all control variables are kept at their base value.

12. *Engineering-to-Standards Cost Conversion.* This module weights the costs given by the Engineering Inputs module in proportion to the number of products of a particular design that will be produced at any given standards level and thereby generates the costs for that level. These costs appear in the Standards Level module.

13. *Industry Net Present Value.* This module estimates the impacts of standards using an industry net present value approach. This module's functionality is exactly that of the externally developed Government Regulatory Impact Model (GRIM). See C.2.3.13 for more details.

C.2.3.1 Control Panel

The control panel displays the nine most important input variables of the model and allows the user to easily adjust them. These variables are described below. The *Input Values* are the best available estimates of the relevant variables.

The control panel has one control for each input variable. The controls, found in the column labeled *Cntrl*, allow the *Input Values* to be modified to become the *Model Values* before they are used by the model. The controls work as follows: when a control is set to zero, its *Input Value* becomes a *Model Value* without any adjustment. When a control is set to 1, its *Input Value* is increased (in absolute value) by approximately one standard deviation to become a *Model Value*. Because the error distributions associated with the *Input Values* are not normal, they are not changed by exactly one standard deviation when the control is set to plus or minus 1. A control value of ± 1 actually changes an *Input Value* by an amount sufficient to make it just as unlikely as a point that is one standard deviation from the mean using a normal distribution. Consider an *Input Value* that is known to be strictly positive and have a mean of 5 and a standard deviation of 3. Setting its control to -2, which would otherwise change its value to -1 (an impossibility) actually only changes it to some small but positive value. This value would be just as unlikely as a point -2 in a normal distribution.

The *Variation* column shows either the standard deviation of an input variable if the variable is normally distributed, or the coefficient of variation *(S.D./mean)* if the input variable is non-normal.

At the bottom of the control panel is a short output summary, which shows the five key output variables: *shipments, price, revenue, net income*, and *ROE*. The first column gives the output values in the base case. The second column assumes some particular change in standards and gives long-run values—that is, values that would hold after capacity adjustments (by about 1999). The

third column gives the percentage change from the base case to the new standards case for each of the five key output variables. The fourth column, labeled *Previous Change*, simply lists the results of the previous run to use as a comparison with the results of the current run. The fifth column lists the results from the short-run part of the model (i.e., the estimated output values for the period immediately after the imposition of the new standards).

The following is a list of the nine key input variables that appear as control factors in the Control Panel module:

1. The industry's price elasticity of demand (IPE),
2. The consumer discount rate (RD),
3. The market cost of capital financed through equity (ECC),
4. Economic profit: the industry's ROE minus normal ROE (EP),
5. The long-run fixed part of costs and assets (FCA),
6. The long-run fixed part of one-time costs and assets (F1X),
7. One-time capital costs resulting from the change in standards (CC.L),
8. Variable cost of goods sold after the change in standards (dVC.L), and
9. The short-run price response to demand (SRPR).

C.2.3.2 The Monte Carlo Module

This module estimates the standard errors of the six most important output variables by randomly choosing the nine control variables in accordance with estimates of their standard errors, running the model, and recording the six output variables. This procedure is repeated up to 400 times. Afterwards, the mean and standard deviations of the 400 computed values of each output variable are computed and displayed near the top of the Monte Carlo module. The top row, labeled *Value*, is the most recently computed random set of outputs.

The first four output variables are the percent change resulting from standards, in output *(Q)*, price *(P)*, revenue *(R)*, and net income *(NI)*. The last two variables are changes in long- and short-run return on equity (ROE).

C.2.3.3 The Accounting Module

The Accounting Summary consists of a simplified income statement that is presented in standard form, along with several key financial ratios and figures that highlight the firm's financial position. The income statement and financial ratios are presented for the calibration case and base cases that include the impact of the 1993 Standards, and a new standards case that lists the firm's financial results under the new standards being analyzed. Thus, the financial impacts of the new standards are easily seen by comparing the two new standards scenarios. To highlight the results, a final column in the accounting summary indicates the percentage change from the base case to the new standards case.

Table C.1 Accounting Module

Item	Formula
Earnings Before Interest and Taxes	EBIT = Revenue – Total Expenses
Total Expenses	Does not include interest or taxes
Interest	(Interest rate *mb* Debt ratio *mb* Assets) – Interest earned on "Cash" assets
Taxes	(EBIT – Interest) *mb* Tax rate
Net Income	EBIT – Interest – Taxes
Gross Margin	1 – (Variable Cost of Goods Sold/Revenue)
Return on Sales	Net Income/Revenue
Return on Assets (ROA)	(EBIT – Taxes – (Tax rate *mb* Interest))/Assets This calculation eliminates interest tax shield
Return on Equity (ROE)	Net Income/Equity

A second table at the bottom of the Accounting Summary page lists financial data for the firm using figures that are necessary for an economic analysis. Note that the assets and expenses are broken down into two categories: fixed and proportional to quantity produced. These proportionalities have economic significance when the price markup is computed, and for that reason they are reported separately in the economic analysis.

Note that "one-time" *(1-X)* in the Accounting module refers to expenses incurred because of the change in standards.

C.2.3.4 The Engineering Inputs Module

The Engineering Inputs module receives all the engineering costing data and energy consumption data for the product classes being analyzed. The data include the incremental variable cost and change in unit energy consumption for each design option. They also include the one-time engineering expense and capital costs incurred in meeting the new standards; the module assigns these costs to design options and product classes where appropriate or necessary. The various components of the module are described below:

1. *Increment in additional UVC (Unit Variable Cost)*: Engineering input data. Each "increment" is measured relative to the previous engineering design. The numbers refer to 1992 dollars per unit produced and are displayed only to the nearest whole dollar.

2. *Additional UVC above Level 0 cost (VCS.E):* "Additional" UVC is measured relative to the calibration case, which is shown as level 0. In other words, this table is a cumulative version of the above "incremental" table.

3. *Annual unit energy consumption per year*: For electric appliances, these engineering input data are the energy use per year measured in kilowatt hours.

4. *Capital costs:* These engineering input data are given on a per-unit basis amortized (with zero interest) over three, seven, or fifteen years depending on the type of capital costs.

5. *Additional capital cost (above Level 0 Cost)*: This row translates the amortized capital costs into total one-time capital costs. The numbers refer to 1990 dollars per unit produced.

6. *Total capital and engineering costs (CCEE.E):* The top row of this matrix is the sum of the columns in the "additional capital cost" matrix. Thus the *CCEE.E* matrix gives the combined added capital cost for all classes of an appliance. The maximum number (from the highest level) in this row is called *MxCC* and is used to assign engineering expenses to the levels as follows:

$$EE_i = EE{:}CC \cdot MxCC \cdot CC_i$$

where *EE:CC* is the ratio of total engineering expense to total capital cost, and EE_i and CC_i are expenses for level "*I*." The *CCEE.E* matrix contains the capital and engineering costs that are used as inputs to the rest of the model. The Long-Run module calculates the average prices for all classes and for each level.

C.2.3.5 The Standards Levels Module

The Standards Levels module provides the same information as the Engineering Inputs module except that instead of listing the cost and energy data for various engineering design options, it lists the data for the various standards levels being analyzed.

The data that appear in the three REM panel tables—VCS.R, KWS.R and CCEE.R—may correspond exactly to some specific engineering levels or, if it has been determined that the manufacturer, when faced with certain standard levels, would use a mixture of engineering designs, then the "Engineering-to-Standards Module" appropriately averages the engineering data and places the results in the three REM tables. The exact mixtures of engineering options are determined by the LBL-REM.

The top section of this module allows the user to determine what standards will be analyzed in a particular run. The module is used interactively by the user, who can choose "levels" LEV.B and LEV.N, which correspond to the Base case and Long-Run case, respectively. The bottom numbers in the "LevIn" matrix determine whether these levels will refer to "standards levels" or "engineering designs." The top numbers specify the exact level or design.

The values in the "LevIn" matrix determine what values are placed in the bottom two matrices when the model is run. For example if in "LevIn," LEV.B = 4 and SlE.B = 0, then the columns of VCB, KWB, CCB, and EEB will contain data for the fourth engineering design option. Changing SlE.B from 0 to 1 would cause all of these data to be replaced with data for the fourth standards level.

C.2.3.6 The Costs, Sales, and Revenue Module

This module has two functions. First, it provides the Long-Run Model module with several inputs; these are averages. Second, it uses many of the data from the input pages and processes these data into prices, quantities sold, and revenue. These intermediate output data are then used in the financial and economic summaries to give output results, which are used for the analysis of the impact of standards. Table C.2 lists the equations that are used in the Costs, Sales, and Revenue module.

In the new standards case, the variables are named with a ".N" suffix instead of a ".B" suffix. The "Totals" row gives the weighted average change in UVC *(dVC.B),* the weighted average change in price, the new weighted average price *(P.B),* the firm's total revenues ($\sum$ *(Ri), R.B*), the weighted average change in operating costs (*OC%.B*), and the total firm shipments (*Q.B*). *P.B, Q.B* and *R.B* are actually computed in the Long-Run module.

The first stage in this module is setting up the calibration case, which uses known information about industry shipments, product class market shares, prototypical firm market shares, markups for each of the product classes, and baseline unit variable costs to calculate the prototypical firm's shipments for each product class, its cost of goods sold, and its revenue. Also calculated are a weighted-average unit variable cost, selling price, and markup. Markup is calculated from data on the ratio between the highest and lowest markups (*ratio*) and the typical markup (*mid*).

Table C.2 Equations Used in the Costs, Sales, and Revenue Module

Item	Calibration Case Formula or Definition
Size	Prototypical firm market share
Industry Shipments	Annual industry shipments for a product class
Relative Shipments (Q%)	Product class market share (product class units sold/total units sold)
Shipments (Q.1)	Product class shipments for a prototypical firm
Price (P.1)	Retail price/retail market
Revenue (R.1)	Price *mb* Shipments
Markup (M.1)	1 ÷ (*P*.1 - *BB*)/*AA*
Unit Variable Cost (UVC.1)	*P*.1/*M*.1
Weighted UVC	UVC *mb* Relative Shipments (Q%)
Weighted Change in UVC	Change in UVC *mb* Relative shipments (Q%)
Weighted Change in Price	Change in Price *mb* Relative shipments (Q%)
Weighted Change in Price	Wghtd dp=q%**M*.1 mb Change in UVC
Mark.B	(P.B-P)/∑*Wghtd dP*
New Price (Pi.B)	P.1 ÷*Mark.B*M. Imb Change in* UVC
Operating Cost Ratio	1998 UEC/1992 UEC
New Shipments (Qi.B)	Operating Cost Ratio *mb* Relative Shipments (Q%)
New Revenue (Ri.B)	Q%*Q.B
Weighted Operating Cost Ratio	Pi.B * Qi.B

The next stage in the Cost, Sales, and Revenue Module calculates the changes necessary to produce the base case and the new standards case.[4] The calibration case is used as a base, and the changes in unit variable cost and unit energy consumption are fed in from the REM panel. From this input, new unit variable costs and prices are calculated for each of the product classes. The model then uses known price elasticities and discount rates to calculate changes in shipments for each of the trial standards level cases. For each of the standards cases, the model calculates the firm's new shipments, revenue, and the weighted-average change in unit variable cost and price.

[4] The base case allows the analysis of intermediate standards or other alternate standards analysis scenarios in addition to the new standards case scenarios. For the purposes of this analysis of refrigerators and freezers, the base case is identical to the calibration case.

The manufacturer markup listed in the panel is used to calculate the baseline model prices, but it is *not* used in calculating the manufacturer prices for the new standards levels. In these cases, LBL-MAM uses an economic markup to determine prices.[5] This markup is on *economic* variable costs, which are a broader category than the typical business definition of variable costs. The markup varies depending on price elasticities, discount rates, and changes in prices and operating costs at different standards levels. Thus, prices at different standards levels do not exactly reflect the manufacturer cost times the manufacturer markup.

C.2.3.7 The Financial Module

The Financial module lists the financial characteristics of the prototypical firm being analyzed. Some of the inputs are used to calculate intermediate outputs of financial characteristics of the firm. The financial inputs and intermediate outputs are then used elsewhere in the model when the impacts of standards are calculated.

Several variables in the Financial module are non-standard and thus require explanation. First, in order to make the model adjustable to a particular point in time when the size of the firm may be different from what it was in the year in which the data were collected, some of the inputs are listed as ratios proportional to revenue. For instance, the historical ratio between depreciable assets and revenues for the refrigerator and freezer manufacturing industries (called *DA:R*) is 0.22. This is used by the model to compute a value for depreciable assets at some typical year in the future after standards have changed by multiplying *DA:R* by revenue in that year.

Table C.3 Financial Module

Item	Formula
Depreciation (DR:R = Depreciable assets as a percentage of revenues	Average depreciation rate × DR:R
Pre-Tax Equity Cost of Capital (PECC)	Equity Cost of Capital/(1 - Tax Rate)
Weighted Average Cost of Capital (WACC)	(Debt ratio *mb* Interest rate) + (Equity ratio *mb* PECC)
After-Tax WACC	WACC *mb* (1 - Tax rate)
Return on Equity (ROE) (ECC = Equity Cost of Capital) (This ROE figure is the expected ROE for a prototypical firm.)	After-Tax ECC + Economic Profit

A complication may occur if a value changes in proportion to revenue between now and the typical year, but under standards it is expected that a portion of the value will remain proportional to revenue while a portion of the value will not change with revenues because of the change in standards (i.e., it is "fixed"). In this case, that value is analyzed as having a "variable" and a "fixed" component, where "variable" and "fixed" are used with respect to a change in standards.

[5]For a thorough description of how markups are derived and used in LBL-MAM, see Appendix C.2.1.

C.2.3.8 The One-Time Cost Amortization Module

Crucial to this analysis are the capital cost and engineering expense that the industry will incur because of the change in standards. This module takes as input from the Engineering Inputs Module the estimate of the total value of these two one-time expenses and reduces these one-time expenses to annual expenses. To annualize (or "amortize") these costs, the module takes into account the expected life of the new capital, the tax life of the investment, the weighted average cost of capital, and the timing of the investment relative to any capital that is being replaced.

The amortized engineering expense and capital cost are calculated for the change from the calibration case to whatever standards case is under consideration. Also, the average value (over the amortization period) of the new capital is computed.

The calculations are based on the following model of investment: new capital will be paid for according to the *CC SCHEDULE*, and engineering costs will be expended according to the *EE SCHEDULE*. These schedules give expenditures for the four years previous to 1998; these expenditures are assumed to occur at the middle of each year. They are assumed to be financed by debt and equity in the firm's normal debt-to-equity ratio. Tax benefits will accrue over the tax life of the capital. Some part (0%–10%) of the capital expenditure is assumed to be for new plant and equipment that do not take the place of anything in existence; the remainder is assumed to replace inadequate existing equipment. The replaced equipment is assumed to have had the same potential lifetime (L) as the replacing equipment and is assigned a certain age. If the new equipment replaces old equipment that would soon have needed replacing anyway, savings are included at the time the natural replacement would have occurred.

The computed annualized cost tells what constant real dollar payment would need to be made each year in order that at the end of the capital's useful life all of the issued debt could have been paid off, and all of the issued equity could have been repurchased.[6] Since standards are assumed to last indefinitely, new capital will need to be purchased at the end of this cycle; but of course the next cycle starts with a clean slate and repeats the same process we have just described. This process can repeat indefinitely with no change in amortized payments.

This procedure overestimates the burden to the firm in two ways. First, engineering costs should actually be lower, possibly zero, in the second cycle. Second, because industry is constantly improving the efficiency of product lines, lines would undoubtedly be much nearer to meeting the standards by the beginning of the second cycle. Thus, much of the capital equipment re-installed at the end of the first capital's lifetime would have been a normal expense by this date (around 2001).

For the interested reader, the details of the calculation method are given in Table C.4.

---

[6] Of course tax benefits are counted toward eliminating debt and equity.

Table C.4 One-Time Cost Amortization Module

Item	Definition	Formula
DR [ER]		Debt [Equity] / (Debt + Equity)
T	Tax rate (36%)	
ECC	Equity cost of capital	
PECC	Pre-tax ECC	*ECC*/(1 - T)
WACC	Weighted average CC	*DR*I + ER * PECC*
ATWACC	After-tax WACC	*WACC** (1 - *T*)
ATR	Continuous ATWACC	ln(1 + *ATWACC*)
CCi	Capital cost I years before standards	
EEi	Engineering expense I years before standards	
WCCi	(see 1-X Cost module)	CCi * exp (ATR * I)
WEEi	(see 1-X Cost module)	EEI * exp (ATR * I)
LTC	(see 1-X Cost module)	Sum of WCCi over 4 years
LTE	(see 1-X Cost module)	Sum of WEEi over 4 years
EMRT		exp (-ATR*TL)
EMRL		exp (-ATR*L)
BN	"Tax benefit rate"	T/TL
RTL	Remaining tax life	max (TL - AGE, 0)
PVD	Present value of depreciation	- BN * (1 -EMRT)/ATR
OCS	Old capital savings	- (1 - %NC) * exp (-ATR * (L - AGE))
OCTL	Old capital tax loss	(1 - %NC) * BN * (1 - EMRT)/ATR
TBS	Tax benefit from scrapping	-RTL * BN * (1 - %NC)
PVCC	Present value of CC	1 + PVD + OCS + OCTL +TBS
APVCC	Adjusted for lead timer	PVCC * LTC
CCLF	CC amortization factor	ATR * APVCCC/(1 - EMRL)
EELF	EE amortization factor	LTE * (1 - T) * ATR/(1 - EMRL)
AFB	(see One-Time Cost module)	$\frac{1 - ATR * L * EMRL/(1 - EMRL)}{1 - EMRL}$
AFC	(see One-Time Cost module)	$\frac{1 - ATR * TL * EMRT/(1 - EMRT)}{1 - EMRL}$
B:T	(see One-Time Cost module)	(1 - EMRT)/(ATR/BN + 1 - EMRT)
AFF	Average asset factor	B:T * AFB + (1 - B:T) * AFC

Table C.4 should be read in conjunction with the One-Time Cost Amortization module. Note that the calculations are all done with continuous interest and discount rates, which makes it necessary to convert *ATWACC* to a continuous equivalent cost of capital *(ATR)* by taking the natural log of *(1 + ATWACC)*. The continuous rate is equivalent to, and for small rates it is numerically close to, the annual rate. The continuous time formula for the present value of $Y received *t* years in the future is $Y^{exp(rt)}$, where *r* is the discount rate and *exp* denotes exponentiation. For a constant stream of income at $Y per year for *L* years, the present value is $Y \cdot (1 - exp(-rL))/r$.

The most important output of this module is the amortized cost factor *CCLF*, which is constructed by summing the following five present values: (1) The initial cost, which is normalized to 1 in order to produce a cost factor instead of an actual cost. (2) The present value of the tax benefit from straight-line depreciation of the initial cost. (3) Present value of savings from not replacing old capital at the end of its normal life if it has already been replaced with new capital to meet standards. (4) The tax benefit from the one-time depreciation of the old capital when it is scrapped. (5) The loss of tax benefit from the old capital after it has been scrapped. The sum is then adjusted for the fact that investment must start before the implementation of standards. All that is left to do now is to convert from a present value to an equivalent constant stream of payments that continues for the lifetime of the capital. The formula for this equation is shown in Table C.4.

Because capital depreciates, its average value is lower than its initial value. In order to derive the factor *AAF*, by which the initial value should be multiplied to arrive at the average value, it is necessary to account for the exact path by which the capital depreciates. Since the value of a piece of capital is, at any time, simply the present value of its future income stream, the value of the depreciated capital as a function of time can be found from the stream of income that the capital will generate. If that stream has a constant flow for a period of *T* years, then the depreciated value of a unit of capital is:

$$DF(t) = \frac{1-e^{-r(T-t)}}{1-e^{-rT}}$$

Now if that capital is held for a period of *L* years, it is logical to ask what the average value of the asset is over the *L* years. Because of discounting, a unit of capital now should weigh more heavily than a unit of capital later. This is properly taken into account by requiring the following equivalence:

$$PV(DF(t)) = PV(AAV)$$

where *PV()* is the *L*-year present value operator, and *AAV* is the average asset value corresponding to *DF(t)*. This equation can be solved for *AAV*, to find the following:

$$AAV = \frac{1}{1-e^{-rL}}\left[1-\frac{rT\ e^{-rT}}{1-e^{-rT}}\right]$$

This would be the end of the problem—*AAV* would be the sought-for average asset factor—except for the fact that the asset of interest does not generate a constant stream of income for *T* years before falling to zero for the remaining *L-T* years. Instead the income stream of interest is made up of *T* years of constant tax benefit and *L* years of (roughly) constant production by the capital. Each of these streams separately fits the description of the problem that has been solved. The solution to this new problem is just the average of the solutions for the two separate problems. For example, if 20% of the total stream is tax benefit that comes to an end after *T* years, while the

remaining 80% continues for the full L years, then the AAF of this combined stream should be 20% of the way from the tax-benefit asset factor to the production asset factor.

The variable $B{:}T$ gives the fraction of the total stream made up of tax benefits. The factors AFB and AFC are the average asset factors for tax benefits and the productive income of capital respectively, and AAF is the weighted average of these two using $B{:}T$ as the weight for AFB.

At the bottom of the One-Time Cost Amortization module are found the capital and engineering cost for the base and long-run levels, and the coefficients of variation associated with each. The three factors just derived, $CCLF$, $EELF$, and AAF, can be applied to CC, EE, and again CC, respectively (for either the base case or long-run case), to derive the three "amortized" outputs.

C.2.3.9 The Long-Run Model Module

The Long-Run Model module is the heart of the LBL-MAM. It does all of the computations concerning a typical firm's behavior. It proceeds in three stages. The calibration stage uses data on present costs and profit to estimate the firm's markup. The second stage estimates the industry's current situation. The third estimates a typical firm's situation with more stringent standards. A detailed discussion of the economic assumptions and results used by this section may be found in C.2.1.

Notation. The following naming conventions have been followed with the variables in the Long-Run Model module and generally throughout the LBL-MAM. The suffixes .F and .Q, are used with variables that measure an asset or a cost that is fixed or proportional to sales, respectively. The suffixes .B and .N refer to the base case and the new trial standards, respectively. A combined suffix such as .BF has the natural interpretation (i.e., a fixed variable in the base case). The most important variable names in the Long-Run Model module are A for assets, TC for total cost excluding taxes and the cost of equity, EC for economic cost (including taxes and equity), EI for economic income, and $\mu 1$ for markup above marginal cost, $\mu - 1$.

Calibration. The calibration stage estimates a typical firm's markup over unit variable costs using the following basic economic equation:

$$\text{Markup} = \frac{\text{(Fixed Cost + Economic Profit)}}{\text{Variable Cost}}$$

(In this equation, fixed and variable cost are components of total cost and are not per-unit costs.) *Economic Profit* is the difference between ROE and the equity cost of capital, both of which are obtained by observation. *Fixed* and *Variable Costs* must be deduced from accounting data and from information on economies of scale in the industry.

Assets and costs in the calibration stage are both represented as proportions of revenue, so firm size is irrelevant. This means, for instance, that fixed and marginal costs are not given as dollars and dollars per unit, but instead, total fixed and total marginal costs are described as a fraction of revenue.

Depreciable assets are divided between fixed and marginal according to the input parameter *FCA,* the "fixed part of costs and assets." Inventories are classified as marginal assets, while cash and receivables are classified as proportional to revenue.

Now consider total costs (i.e., those that are tax-deductible). *FCA* is also used to determine the proportion of fixed (total) costs in revenues. All other costs are marginal, and their amount is deduced from the firm's rate of economic profit.

Because the costs so far are tax-deductible, but revenue is taxable, economic fixed costs are given by the following formula:

$$EC.F = (1-T) \cdot TC.F + A.F \cdot ER \cdot ECC$$

where T is the tax rate, ER is the ratio of equity to assets, and ECC is the cost of assets. In principle, we could now estimate marginal economic cost ($EC.Q$) directly and use this value to finish our analysis. However, because costs cannot be measured accurately enough, there could be considerable error in the implied value of economic profit and thus in markup. (Typically a 5% error in total estimated cost will cause a 10% error in implied economic profit.) It is much better to deduce marginal economic cost from economic profit, because economic profit is relatively well-known. This approach gives us the equation for economic marginal cost:

$$EC.Q = 1 - EC.F - EC.R - EP \cdot ER \cdot A{:}R$$

where EP is the rate of economic profit, and $A{:}R$ is the ratio of total assets to revenue.

Now the markup is easily computed using the formula given at the beginning of this section on calibration and the model is ready to analyze the base level of standards.

The base case. The base case is an analysis of what may happen in the current period. The variables in both the base case and the new standards case give fixed costs and assets in dollars and variable costs in dollars per unit.

As we noted earlier, total costs are the same as the calibration case unless we are analyzing the impact of any possible interim standards. In that case, that new variable costs due to the interim standard are added into $TC.Q$. Economic costs are computed from A and TC as before, except for

the addition of amortized capital costs (*LCC*), which are divided between fixed and variable according to the input parameter *F1X*, and amortized engineering expenses *(LEE),* which are counted as entirely fixed.

The new standards case. The case of changes in standards is handled exactly as the base case, except that new values of *DVC* (the change in variable cost), *LA, LCC*, and *LEE* are used.

The remaining descriptive variables. For the calibration case, most of the remaining descriptive variables, *Q, P, R, UVC, TC, A*, and *ROE* are known because they are inputs or have been computed. The others are obtained as follows:

$$\text{Variable Cost of Goods Sold} = \text{VCGS} = \text{UVC} \cdot \text{Q}$$

$$\text{Interest, Not 1X} = \text{IC} = \text{I} \cdot \text{DR} \cdot \text{A} - \text{C:R} \cdot \text{R} \cdot (\text{I} - \text{ICash})$$

$$\text{Pre-interest Cost} = \text{PIC} = \text{TC} - \text{IC}$$

$$\text{Pre-tax Cost} = \text{PTC} = \text{TC}$$

$$\text{Taxes} = \text{TAX} = (\text{R} - \text{TC}) \cdot \text{T}$$

$$\text{Equity} = \text{EQ} = \text{ER} \cdot \text{A}$$

$$\text{Economic Income} = \text{EI} = \text{NI} - \text{EQ} \cdot \text{ECC} \text{ and}$$

$$\text{Net Income} = \text{NI} = \text{R} - \text{TC} - \text{TAX}$$

$$\text{Return on Equity} = \text{ROE} = \text{ECC} + \frac{\text{EI}}{\text{EQ}}$$

For the base case the above formulas hold with the exception of the one for *NI*, but several other descriptive variables must be computed. Their formulas follow:

$$\text{Q.B} = \text{Q} \cdot \text{LCC}^{(\text{PE}+\text{ICE})}$$

$$\text{P.B} = (\mu 1 + 1) \cdot \text{EC.BQ}$$

$$\text{R.B} = \text{Q.B} \cdot \text{P.B}$$

$$\text{UVC.B} = \text{UVC} + \text{DVC.B}$$

$$\text{VCGS.B} = \text{UVC.B} \cdot \text{Q.B}$$

$$1X\ \text{depreciation} = X1D.B = CC.\frac{B}{L}$$

$$1X\ \text{interest} = X1I.B = LA.B \cdot DR \cdot I \cdot LTC$$

$$1X\ \text{equity cost} = X1I.B = LA.B \cdot ER \cdot ECC$$

$$1X\ \text{tax benefit} = X1T.B = LCC.B + LEE.B - X1D.B - X1I.B - X1E.B$$

$$IC.B = I \cdot DR \cdot (A.B - LA.B) - C{:}R \cdot R.B \cdot (1 - ICASH)$$

$$PIC.B = TC.B + X1D.B - IC.B$$

$$PTC = TC.B + X1D.B + X1I.B$$

$$NI = R - TC - TAX - LCC.B - LEE.B$$

$$ROE.B = NI.B/EQ.B$$

In the formula for *Q.B* above, *LCC* stands for life-cycle cost. This formula is equivalent to the more general one used in the model when the shape parameter (*ro*) for the demand function is set to one. Setting *ro* to one simply implements the assumption of constant demand elasticity with respect to life-cycle cost. All of the descriptive variables for the changed standards (long-run) case are computed in exactly the same way as the corresponding variables in the base case.

C.2.3.10 The Short-Run Model Module

During a recession an appliance manufacturing industry will typically face a substantial decline in demand for its product, which will usually cause increased price competition within the industry, with a consequent fall in price. By regressing price on quantity sold and on a time trend, we can estimate the industry's "short-run price response to demand" *(SRPR)*. The LBL-MAM uses this variable as an input to the Short-Run Model module. From *SRPR*, the short-run impact calculation proceeds as follows. Assume for explanatory purposes that demand has fallen because of the change in standards. From *SRPR* compute the implied fall in price resulting from this unexpected drop in demand. At this new price level, compute a new level of demand that will necessarily be a little higher at the new lower price than at the previous higher price. Now take the new estimate of the level of (and change in) demand resulting from standards and repeat the calculations. After five or fewer repetitions of these calculations, our estimates will converge to a stable answer. At this point, the price correction exactly agrees with the estimated fall in demand, and the estimated demand agrees with the price. At no other values of price and quantity would this be true.

Once price and quantity are known, all other variables are easily computed using procedures

that have already been described.

C.2.3.11 Sensitivity Charts Module

This module produces a chart which shows how profit is affected by a one-standard deviation change in each of the Control Panel variables. These changes are all made with the standards level set to its middle value.

C.2.3.12 Engineering-to-Standards Cost Conversion Module

This module weights the costs given by the engineering analysis for each design option in proportion to the number of appliances of a particular design that will be produced at any given standards level and thereby generates the costs for that level. These costs appear in the Standards Level Module.

C.2.3.13 Industry Net Present Value Module

The LBL-MAM includes the current version of the Government Regulatory Impact Model (GRIM) ver. 1.2 to calculate the impact of standards on industry net present values. The integration of this externally developed model into the LBL-MAM required the resolution of a number of issues. These are covered in more detail in Section C.2.6.

C.2.4 Model Inputs

C.2.4.1 Input Generating Assumptions

Many of the necessary input data are not publicly available and so have been estimated from available data or estimated from averages of subjective estimates made by industry representatives. This section describes the various origins of LBL-MAM's data.

Cost data. All cost data are provided by the Engineering Analysis.

Elasticities and discount rates: Industry price elasticity and consumer discount rates are supplied by the LBL-REM.

Financial data. Financial data are collected from publicly available sources such as Value Line, Standard and Poor's, Moody's, and company reports. The data are often for firms whose operations in the industry under consideration are only part of the firm's total business operations. It is assumed that the relevant division is similar to the firm as a whole.

Amortization data. In order to amortize the one-time costs associated with new standards, the life of new capital is broken down into three groups with different amortization periods. They are: tooling (7 years), building and equipment (15 years), and research and development (3 years).

These categories and their amortization lifetimes have been designated as such by several manufacturers as the period used in their own amortization calculations. Other values relating to such issues as taxation are displayed in the spreadsheet and are generally derived from historical discussions with industry representatives. The timing of engineering and capital costs come from the Engineering Analysis.

Fixed and marginal costs and assets. Some costs increase in proportion to shipments, and some are fixed. Industry representatives indicate that the bulk of costs and assets are proportional to shipments. The specific values are shown in the Control Panel.

The following sections list and describe the inputs used by the model.

C.2.4.2 Control Factors in the Control Panel

Industry price elasticity. Industry price elasticity measures the way a change in the average industry price for a product will affect the industry's shipments. For example, if the price of a product increases 4% and shipments drop 2% as a result, the price elasticity is -0.5. Because standards will cause the prices of products to increase, this input is obviously crucial in determining the impact of standards on manufacturers.

Consumer discount rate. The consumer market discount rate is a measure of how much consumers value the operating cost savings from energy efficient design options. In the model, it serves a role similar to that of industry operating cost elasticity which measures the effect of a change in operating costs for a product on the industry's shipments of that product. For example, if operating costs of a product decrease 10% and shipments increase 1% as a result, the operating cost elasticity is -0.1. Because standards mandate more efficient products that will have lower operating costs, this input is important in determining the impact of standards on manufacturers.

Equity cost of capital. This is the rate of return expected by equity shareholders. This figure is in real terms (i.e., with inflation subtracted). It is an after-tax rate, which means that it is the rate of return the company must earn for its shareholders after its taxes have been accounted for. Data values come from calculations using standard finance equations and public financial data.

Economic profit. Economic profit is the profit earned by a firm above its expected return on equity. In other words, it is the profit earned after all costs are taken into account, including the cost of equity (the market rate of return). A firm makes economic profit only when it has some degree of market power.

Long-run fixed part of costs and assets. This figure is the portion of all costs and assets that is fixed over time, that is, which does not vary with quantity sold or with revenue. It is expressed as a percent of the base case costs and assets. From an economic standpoint, this figure is important for determining the impact of standards on manufacturers.

Long-run fixed part of one-time capital cost. This figure is the portion of one-time capital costs that is fixed in the long run. Although all capital costs are normally considered fixed in the short run, this portion of the capital costs is spent regardless of the output capacity of the tooling purchased. The other portion of one-time capital costs varies proportionally with the output capacity of the new equipment.

One-time capital costs. Some of the design options used to meet the increased efficiencies mandated by the new standards require additional capital investment in the form of retooling, new equipment, or other capital expenditures. The "one-time capital costs" figure represents the capital costs expended to meet a specific standard being analyzed; this number covers all products in a product type and is an input from the Engineering Inputs module.

Unit variable cost increase. This number is the shipment-weighted average increase in unit variable costs incurred by the manufacturer in meeting the new standards. The incremental variable cost includes raw materials, direct labor, purchased parts, and increased transportation costs. This number is an input from the Costs, Sales, and Revenues module.

Short-run price response to demand (SRPR). When industry demand falls by Y%, price will, in the short run, fall by *SRPR mb* Y%. This response is expected to die out within a few years, and Y% should be less than 20% when *SRPR* is used.

C.2.4.3 Engineering Data

Incremental unit variable cost. The incremental unit variable costs are the variable costs associated with design options that increase a product's energy efficiency. This input differs from the variable cost increase input for the Control Panel (Section C.2.3.1) in that it lists incremental variable costs for each design option for each product class of the product type being analyzed, rather than a single shipments-weighted average number. The increased variable cost includes costs such as raw materials, direct labor, purchased parts, and increased transportation costs. The data also come in the form of a table that lists the incremental variable cost for each product class for each of the standards levels being analyzed.

Unit energy consumption (UEC). Unit energy consumption is the annual energy cost (in dollars) of a product. The input data come in the form of a table that lists the UEC for each product class for each design option (and standards level) being analyzed. Electricity is measured in kilowatt hours per annum (kWh/a).

Engineering expense. This is the total engineering expense associated with producing more energy-efficient products within a product type. The input is given as a table listing the engineering expenses to reach each of the various design options and standards levels being analyzed. The engineering expense also varies depending on the size of the manufacturer. If more than one size of manufacturer is being analyzed for a product type, then the data for all firm sizes are included.

Capital costs. Some of the design options used to meet the increased efficiencies mandated by the new standards require additional capital investment in the form of retooling, new equipment, or other capital expenditures. This input is given as a table listing the cost associated with each design option that requires a capital expenditure. The input is also given in a table listing the total capital expenditure for the design options used to reach each of the various standards levels being analyzed. The capital cost input covers all product classes within a product type, unless noted otherwise. The one-time capital costs resulting from standards generally vary with the size of the manufacturer. If more than one size of manufacturer is being analyzed for a product type, then input data for all sizes being analyzed are included.

C.2.4.4 Costs, Sales, and Revenues

Industry shipments. Industry shipments are annual shipments for all classes of the product type being analyzed. These inputs are actual data for a calibration and base case and long-run estimates for each of the new standards levels being analyzed. The long-run shipments estimates are based on projected product price increases and product price elasticities and market discount rates which are based on forecasts provided by the LBL-REM.

Product class market shares. Each of the classes within a product type has a "market share" of the shipments for that product type. For example, upright automatic defrost freezers account for the bulk of all freezer shipments. The product class market share combined with the total industry shipments give a breakdown of annual shipments by product class.

Manufacturer market share. Each of the prototypical firms in the analysis is assigned a market share appropriate to that segment of the industry. For example, five large refrigerator manufacturers may each be assigned a 20% market share. The manufacturer market share, combined with the total industry shipments, gives a firm's annual shipments. This figure, combined with the product class market shares, gives a typical firm's annual shipments for each product class.

Markups. The markup is the figure used by the manufacturer to determine the firm's selling price for a particular product. It is an increase over the unit variable cost of that product, and it covers overhead, capital costs, and profit. In some industries, manufacturers use different markups on different product classes. The markup input lists the markup used for each class in the product type being analyzed.

Initial prices. This input is the baseline manufacturer's selling price per unit for each product class. Added to the baseline unit price are the incremental costs of reaching the higher efficiency levels required by standards.

Energy price. This figure is the price ratio of a 1992 kWh to a 1998 kWh taken from the LBL-REM; energy price is used to calculate the change in operating cost from the calibration case to the base case (*OC%.B*) and to the new standards case (*OC%.N*).

C.2.4.5 Financial Inputs

Rates of financial costs:

After-tax equity cost of capital. This input is explained in Section C.2.3.8, Control Panel.

Interest rate on debt. This is the interest rate paid by a corporation on its debt. This figure is in real terms (i.e., with inflation subtracted), and is the yield of corporate bonds with a Moody's rating comparable to ratings in the industry being analyzed.

Interest lost on cash. Companies hold a portion of their current assets in the form of cash in bank accounts, marketable securities, and other liquid holdings, all lumped under the term "cash." This category of assets has a cost associated with it because of the cost of the debt and equity associated with all assets. However, companies manage their cash accounts very well and are able to earn interest each day on the cash they are not using that day. The interest earned on the cash accounts tends to be low, since the investment is only overnight and varies from day to day. The interest earned is lower than the cost of the capital used to form the asset. Thus, the cash account costs the company money but the cost is lower than for any of the company's other assets.

Rate of depreciation. This figure is the rate of depreciation on fixed assets for a typical firm in the industry. It is obtained by assuming straight-line depreciation and an average tax life of eight years for the firm's fixed assets. It is then revised by analyzing actual depreciation data from the industry under consideration.

Tax rate. This rate is the average tax rate faced by an industry in 1996. It is based on past data and recent revisions to the tax law.

Assets and costs as a percent of revenue:

Cash. Companies hold a portion of their current assets in the form of cash in bank accounts, marketable securities, and other liquid holdings, all lumped under the term "cash." In the model, this input is expressed as a percent of total revenue.

Inventory and receivables. This figure represents the inventory and receivables assets, expressed as a percent of total revenue. Inventory includes raw materials owned by the company, work in process, and finished goods that have not yet been shipped. Receivables refers to goods that have already been sold and shipped by the firm for which the firm has not yet been paid, but is instead owed money.

Depreciable assets. This figure represents the net depreciable, or fixed, assets of the firm, expressed as a percent of revenue. Depreciable assets are tooling, equipment, production facilities, and other goods that have an original lifetime of longer than one year and thus are depreciated over several years rather than expensed in one year.

General and administrative expenses (G&A). This figure represents the general and administrative and selling expenses for the firm, expressed as a percent of revenue. It is the "overhead" of the company. In the model, this figure does not include engineering, since engineering expense is treated separately because of its relevance for analyzing the financial impact of standards on manufacturers.

Engineering. This figure represents the annual engineering expenses for a firm, apart from the engineering expenses induced by standards, expressed as a percent of revenue. The engineering expense associated with meeting the standards appears on the Costs and Assets of the One-Time Investment page of the model.

Fixed and variable costs:

Fixed part of all costs and depreciable assets. This input is explained in the Control Panel section of C.2.4.2.

Fixed part of one-time capital cost. This input is explained in the Control Panel section of C.2.4.2.

Other financial inputs:

Economic profit. This input is explained in C.2.4.2.

Debt-to-equity ratio. All of a firm's assets are paid for either by debt or by equity. The debt-to-equity ratio is used in calculating a firm's weighted average cost of capital. It is also associated with the risk factor of the firm and affects how much money a firm is able to borrow and at what interest rate, so it is important in the analysis of the impacts of standards.

Markup on a typical model. This figure is the markup used by a firm in determining the manufacturer's selling price. It is the markup used on the unit variable cost of a typical product in the industry being analyzed.

Ratio of highest to lowest markup. In some industries, manufacturers use different markups on different product classes. If such a situation exists in the industry being analyzed, this ratio indicates the range of markups used.

Costs and assets of one-time investment:

One-time capital cost's life. This input is the productive life of the equipment purchased to meet the standards, expressed in years. The number is also used as the period of time over which the one-time costs induced by standards are amortized.

One-time capital cost's tax life. This input is the tax life of the equipment purchased to meet the standards, expressed in years.

Percent additional one-time capital. Meeting standards may require both the addition of new capital that replaces nothing, and the replacement of old capital that has become inadequate. This variable tells what percent of new capital is additional rather than for replacement.

Age of old (replaced) capital. This input gives the age, in years, of the old capital that gets replaced because of the new standards. Under standards, some old equipment will get scrapped before the end of its productive life and replaced by new equipment. Depending on the age of the replaced capital, tax and/or economic consequences are factored into the calculations of the cost of the new equipment.

One-time capital cost and engineering expense schedules. The one-time capital cost and engineering expense schedules are inputs that list the costs incurred over time for preparations to meet the new standards. The capital costs and the engineering expenses are listed together in a table. A percentage of the total cost of each of these categories is attributed to each year before the standards go into effect, because that is when these expenses will occur. These cost schedules allow the model to be more accurate in calculating the present value of the amortized costs, rather than assuming that the costs all occur when the standards go into effect.

C.2.5 Model Outputs

C.2.5.1 Control Panel Outputs

The Control Panel outputs are the summary outputs of the model. This output section enables the reader or model user to see at a glance the main short-run and long-run impacts of standards on a few key variables: shipments, price, revenue, net income, and return on equity.

For each of the five variables listed above, the Control Panel output table lists the base case number, the new long-run number, and the percentage change between the two. The table also lists the percentage changes for these variables from the most recent previous run for comparison purposes. The last column in the output table lists the short-run results for each of the variables.

The base case values refer to the current state of the industry. The long-run numbers are the model's estimates for these variables when new trial standards are implemented and after manufacturers have had time to adjust to the changes and find new optimal selling prices and production quantities. The short-run numbers are the model's estimates of impacts on manufacturers in the short run, before they have time to find a new optimum.

Shipments. Shipments are the total units sold by a prototypical firm in a given year, expressed in millions of units. The shipments variable is the sum of shipments for all product classes within a product type. Shipments data are calculated on the Costs, Sales, and Revenues page.

Price. Price is the shipments-weighted average of the manufacturer's selling prices for the different classes within the product type being analyzed. Price data are calculated on the Costs, Sales, and Revenues page.

Revenue. Revenue is the amount of money received by the manufacturer for the products it has sold. It is the sum of the revenue for each of the product classes being sold by the manufacturer and it is expressed in millions of dollars. It can also be calculated by multiplying the annual shipments times the shipments-weighted average price. Revenue data are calculated on the Costs, Sales, and Revenues page.

Net income. Net income is the after-tax profit made by the company, expressed in millions of dollars. Net income and the associated return-on-equity are primary measures of a company's financial performance. In LBL-MAM, net income is calculated in the Accounting Summary.

Return on equity (ROE). Net income is a dollar amount that varies in part simply because of a firm's size, and ROE adjusts for different-sized companies by giving net income as a proportion of stockholders' equity. It is the return an investor makes on his investment in the stock of a particular company. ROE is calculated in the Accounting Summary.

C.2.5.2 Accounting Summary Outputs

Net income. See the Control Panel section above for a description of net income. In the Accounting Summary, net income is expressed in thousands of dollars rather than millions.

Gross margin. Gross margin shows, on a percentage basis, how much revenue remains after the variable cost of goods sold is accounted for: $GM = (R - VCGS)/R$.

Return on sales. Return on sales is net income as a percentage of revenue.

Total assets. Total assets is the sum of all of the prototypical firm's assets. This includes cash, inventory, and receivables; depreciable assets; and in the case of new standards, the one-time assets acquired to meet the standards.

Return on assets. Return on assets is the total return on the debt and equity portions of a firm's assets. It is a measure of how productively a firm's assets are being used. The interest paid on debt instruments and the net income that belongs to equity shareholders are the returns on the firm's assets. The returns are divided by the total assets of the firm to calculate return on assets.

Equity. Equity is the portion of a firm's assets owned by the stockholders of the firm. It is the difference between a firm's assets and its liabilities. In this model it is calculated by multiplying the equity percentage obtained from the debt-to-equity ratio times the total assets figure.

Return on equity (ROE). See the Control Panel section above for a description of ROE.

C.2.5.3 Economic Analysis Outputs

The economic analysis outputs give a clear and concise picture of what is going on in the company from an economic standpoint. Most of the outputs show up in the other two outputs sections. Shipments, price, and revenue are discussed in the Control Panel section. The total assets number is calculated in the Accounting Summary section, and the economic analysis output breaks down total assets into three categories: cash, inventories, and depreciable assets. Expenses are looked at from an economic point of view rather than an accounting one. Thus expenses are broken down into fixed expenses and expenses that vary with the quantity produced.

C.2.5.4 Monte Carlo Outputs

The Monte Carlo Outputs section lists the results of six key measures of impact when the Monte Carlo option is used. For key input variables, the Monte Carlo option randomly generates values around the best available estimates of their true values. As a result, the outputs vary from run to run, and the model can calculate means and standard deviations for the key measures of impact. It is then possible to bound the estimates of impacts and attribute a degree of certainty to them.

The Monte Carlo Outputs section is a table that lists for each variable the value of the current iteration, the mean of all the iterations done in the current run, and the standard deviation of the results. It then lists in chronological order the results of all the iterations done in the current run.

The measures of impacts are percentage change in shipments, percentage change in price, percentage change in revenue, percentage change in net income, and percentage point change in ROE for both the long-run analysis and the short-run analysis. See the Control Panel section (Section C.2.3.1) for a more complete description of each of these outputs.

C.2.5.5 Retail Prices

One important role of LBL-MAM is to provide estimates of retail prices of appliances at different standards levels for the LBL-REM and the Life-Cycle Cost analysis. The primary input for the retail price calculation in LBL-MAM is MAM's estimates of manufacturer prices. The manufacturer prices are derived from base manufacturer costs, engineering production costs, and appropriate manufacturer markups for each product. The base manufacturer cost is derived from current retail price data for appropriate product classes (e.g., manual defrost refrigerators). These prices are divided by both the retail markup for the product and the wholesale (manufacturer) markup. This calculation is described in more detail in the description of the Costs, Sales, and Revenue module (Section C.2.3.6).

The model generates a matrix of manufacturers' selling prices for each product class at each standards level. These manufacturers prices are then multiplied by an estimate of the manufacturer-to-retail markup appropriate for the product class. This gives the estimated retail price.

C.2.6 Development and Integration of the Industry NPV Module

During 1991-1993, three industry trade associations[7] contracted with the Arthur D. Little consulting firm to develop a model that presents industry impacts using industry net present value (NPV) as an impact variable. Their model was named the Government Regulatory Impact Model (GRIM). The latest version of this model is version 1.2 and was released in April 1993. Since NPV is theoretically identical to ROE as an impact measure, the U.S. Department of Energy decided to include the GRIM as part of the analysis. Hence the entire GRIM ver. 1.2 model is integrated into the LBL-MAM.

As a result, if the reader were to use the cost, price, and shipments inputs that were used in the LBL-MAM for input to a standalone version of GRIM, they will obtain the same answer. There has been no modification of the GRIM's functionality as part of the integration.

C.2.6.1 The Integration and Cost Iteration Process

The integration of GRIM presented three major issues: They were:

- The GRIM model's programming did calculate the net cash flows well, however there is no price-estimation algorithm (i.e., there is no mechanism to forecast price). The model assumes that price and shipments inputs will be supplied from some external forecasting source.

- The GRIM has a cost analysis structure such that it uses annual costs and revenues to compute annual cash flows and then calculates a net present value of the industry based on those cash flows. On the other hand, while the LBL-MAM recognizes different costs in different years for its demand function and price-formation algorithm, it "levelizes" these costs before it calculates price and quantity. Hence in integrating the two models, the costs in the two approaches need to be converted such that both approaches recognize the same costs.

- There are several categories of costs that GRIM calculates as fixed ratios of revenues. Hence there are several categories of costs that are higher in GRIM than in the LBL-MAM.

---

[7]The Association of Home Appliance Manufacturers, Gas Appliance Manufacturers Association, and Air-Conditioning and Refrigeration Institute.

The absence of a price-formation algorithm in GRIM was solved by using the demand function and price formation algorithm that was developed in the LBL-MAM. This entailed the following:

I. Since the cost structure of GRIM is different from that of LBL-MAM, the costs for both modules need to be translated into the same basis. As a result, a "cost levelization" methodology was developed to translate the format of the GRIM-style costs into MAM-style costs. (There is no change of the amount of costs, just how the costs are represented as necessary for input to the cost analyses of the two modules.)

ii. In the absence of GRIM-style cost inputs from the industry, we take the baseline per-unit cost inputs of materials, labor and overhead costs, along with baseline per-unit price and shipments (supplied by the Engineering Analysis), and constructed a GRIM cost input table. These same basic cost inputs are also used in the LBL-MAM.

iii. Using this cost input table, the LBL-MAM is run to estimate price and shipments for the new standards case.

iv. The price and shipments estimated by LBL-MAM are then input to the GRIM module, and the GRIM module is run to generate its results. Because several of the cost assumptions in the GRIM module are proportional to revenue, the costs for several major cost categories (i.e., variable cost of goods sold, capital costs, working capital, and selling and general administration costs) will change from the original inputs.

v. The LBL-MAM then compares the costs used in the LBL-MAM that supplied the inputs to the GRIM module and the resulting costs from the GRIM module. These differences are incorporated back into the LBL-MAM costs via "cost comparison factors" (defined below). The LBL-MAM is then run again to generate new price and shipments estimates based on these revised costs.

vi. This iterative process is repeated until the cost differences between the major cost categories used in the GRIM module and that of the LBL-MAM run that generated the inputs is equal to zero.

vii. After convergence has been obtained, the final industry net present value results from the GRIM module are reported.

The data flows and linkages between the LBL-MAM, the GRIM module, and the cost comparison factors used to link the modules are illustrated in Figures C.3 and C.4.

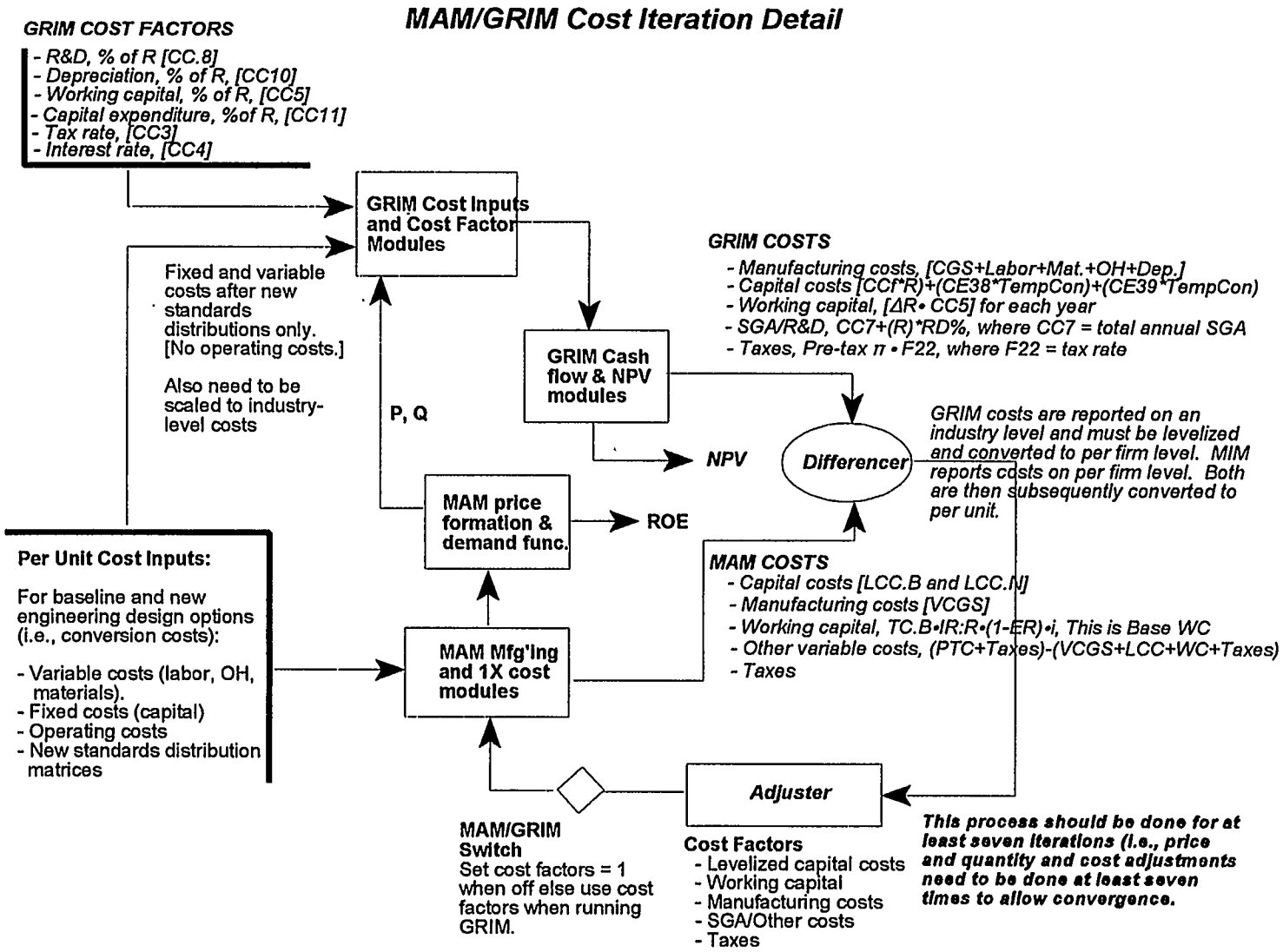

Figure C.3 LBL-MAM and GRIM integration overview

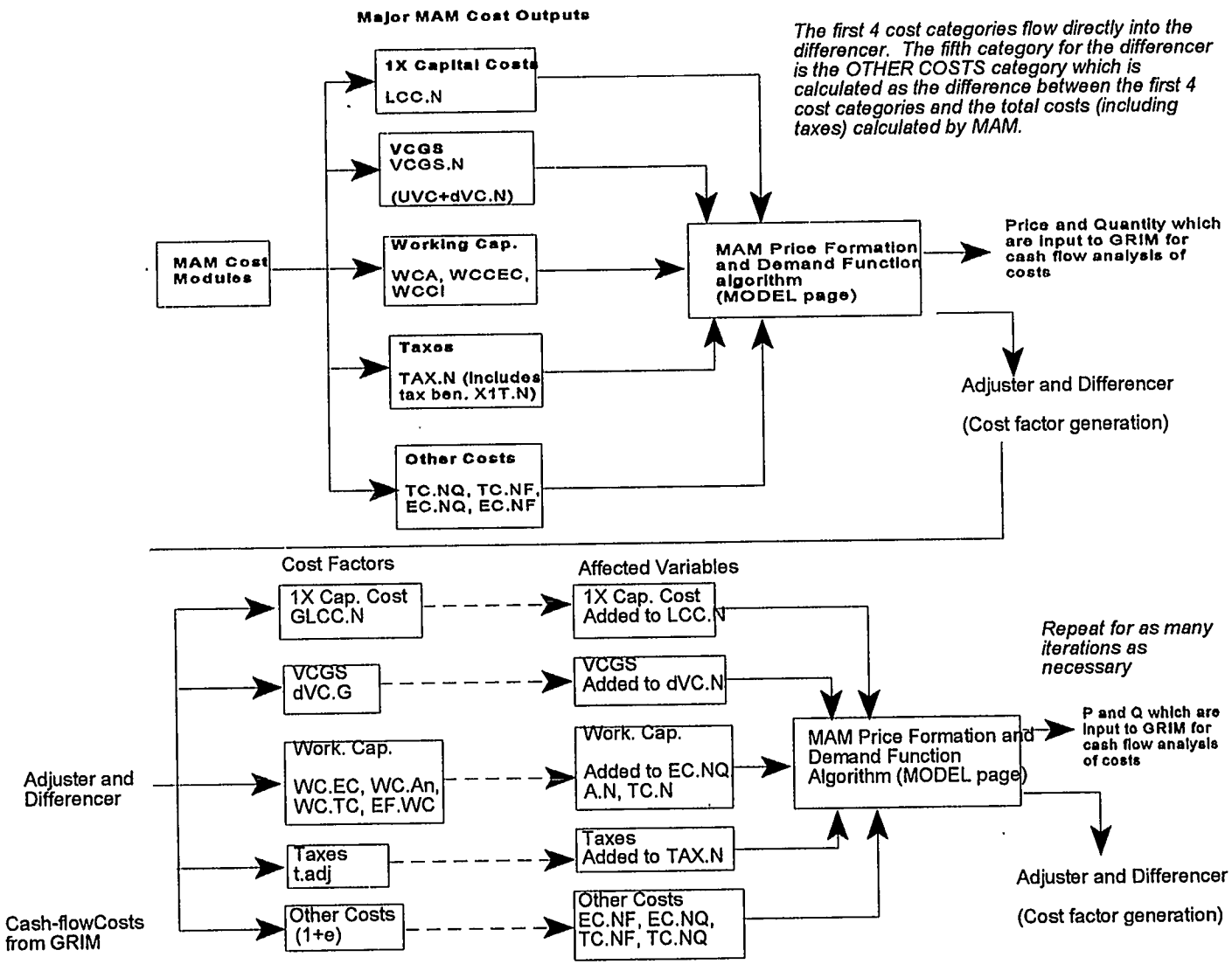

Figure C.4 Cost comparison factors and their relationships

Cost Comparison Factors

Since the cost structure in the MAM and GRIM modules may differ due to the differing assumptions in the two models, cost comparison factors are used in the integration of the two models to properly align and adjust their costs. For instance, if the GRIM assumptions resulted in a lower capital maintenance expense, the initial GRIM cost assumption would be adjusted by a cost comparison factor.

In this section, we discuss each of the Comparison Factors in the MAM MODEL page that are used for the adjustment of MAM and GRIM, why they are needed, and how they are implemented in the model.

Levelized Capital Costs (LCC):

GRIM's assumptions of the level of capital maintenance expense is higher than MAM's. Hence an initial adjustment is needed to align the costs between the two approaches. Further, GRIM's level of capital expenditure is a fixed percentage of revenues, hence when quantity changes (e.g., when other cost adjustments are made), LCC will change.

MAM already computes per unit levelized capital costs for new standards (LCC.N) in the model. Hence we create a new variable, GLCC.N, which is the per unit difference between MAM and GRIM, which we add to LCC.N. Further, we need to take GLCC.N into account for tax effects and new assets. Hence we also add GLCC.N to the tax effects of one-time capital cost (LCC.TN) and assets due to one-time capital costs (LA.N) variable calculations.

Manufacturing Costs:

Manufacturing costs are the sum of materials, labor, and overhead costs. In MAM, this is the Variable Cost of Goods Sold (VCGS.N) variable. In GRIM, it is the same three cost inputs, but it also includes depreciation. However in GRIM, depreciation is only included for the purpose of tax calculation and it is netted out later in the cash flow calculation. Since it plays no role in the NPV calculation (aside from taxes), we do not include it in the Manufacturing Costs calculation.

The baseline per unit costs of materials, labor, and overhead are inputs into the models. But in the post-standards case, the GRIM Overhead cost component has a portion that varies with

shipments.[8] Since shipments will vary when other adjustments are made, overhead costs and consequently Manufacturing Costs will change.

In MAM, the per unit cost of new standards is calculated in the change in variable cost variable, dVC.N0. Hence we created a new variable, dVC.G where we input the per unit difference in manufacturing costs which is added to dVC.N0.

Working Capital:

In GRIM, working capital is a fixed percentage of revenues. Since revenues are likely to change as a result of other cost adjustments, an adjustment for working capital is needed. In Appendix A, we already have a method by which working capital is taken into account in the model so we can handle the working capital adjustments similarly.

Hence there is a variable, WC.EC, that is the sum of the per unit differences in working capital costs from each iteration. WC.EC is added to the variable part of economic costs, EC.NQ.

Next the total differences in working capital assets are calculated as:

$$WC.AN = \frac{WC.EC_i \cdot Q_{io}}{ATR}$$

where ($WC.EC_i \bullet Q_{io}$) is the sum of each per unit difference times the Q.N from that respective iteration. ATR is the after-tax weighted cost of capital. WC.AN is then added to new standards assets, A.N.

The total "accounting" cost of working capital is:

$$WC.TC = WC.AN \cdot (1 - ER) \cdot i$$

where ER is the equity ratio and I is the interest rate. However, as we mentioned earlier, to facilitate convergence with GRIM, we assume (1 - ER) = 1.. WC.TC is added to total costs in the new standards case, TC.N.

Finally, from an accounting cost standpoint, WC.TC will probably be less than total cost of working capital. Hence to facilitate convergence, we define one more "extra factor" variable:

---

[8]The GRIM Overhead formula is $OH = OH_b + (OH_f \cdot Q.N)$, where OH_b is the baseline Overhead cost, OH_f is the per unit difference between Overhead costs in the pre- and post-standards case, and Q.N is shipments in the post-standards case.

$$EF.NC = (WC.AN \cdot ATR) - WC.TC$$

where (WC.AN •ATR) is the total costs of working capital and WC.TC is the accounting portion recognized earlier. EF.NC is also added to TC.N.

Adjustment for Other Variable Costs (MAM) and SGA/R&D (GRIM):

MAM contains Other Variable Costs which are the variable portion of fixed costs such as capital costs.[9] GRIM also contains explicit variable costs for selling and general administration expense and research and development. These GRIM costs are a fixed percentage of revenue and thus are variable costs also. Since they are both relatively close in size, both are variable costs, and both are cost categories which are not in the other model, we align these two costs.

Some iteration will be necessary because the GRIM costs are a proportion of revenue. And so as other cost adjustments are made, revenue will change and hence these costs will change.

When we align these costs, we want to affect both the accounting and the economic costs. The accounting costs are defined as:

$$TC.N = TC.NF + (TC.NQ) \cdot Q.N$$

where TC.N is total costs in the new standards case, TC.NF is the total fixed part of costs, TC.NQ is the per unit variable part of costs, and Q.N is shipments. These accounting costs are important in the determination of financial variables such as Net Income, Taxes, and ROE.

Economic costs are defined as:

$$EC.N = EC.NF + (EC.NQ \cdot Q.N)$$

where EC.N is total economic costs, EC.NF is the total fixed part of economic costs, EC.NQ is the per unit variable part of economic costs, and Q.N is shipments. Economic costs are important for the determination of price.

Since the MODEL page calculates fixed and variable costs separately and the cost components are used as inputs to other areas of the models, we define a factor, e, which will be applied to each of the cost components. Hence we will have:

---

[9]This is because in MAM, even fixed costs such as capital costs are considered to have a variable portion in the long run.

$$TC.NF \bullet (1 + e), \quad TC.NQ \bullet (1 + e), \quad EC.NF \bullet (1 + e), \quad EC.NQ \bullet (1 + e)$$

Generally, the MAM Other Variable Costs need to be scaled up to align with the GRIM SGA/R&D costs.

We can derive a formula as follows. We want to find a formula for a factor that does the following:

$$OTHER_{mam} + TC.N \cdot (e) = SGA_{grim}$$

where $OTHER_{mam}$ is MAM Other Variable Costs, TC.N is total costs, e is the adjustment factor, and SGA_{grim} is GRIM SGA/R&D costs.

Solving for e, we have:

$$e = \frac{SGA_{grim} - OTHER_{mam}}{TC.N}$$

Thus, in the model, we input the per unit values for SGA_{grim}, $OTHER_{mam}$, and TC.N. We scale each of the per unit values to firm values by multiplying by Q.N and then calculating e. (For successive iterations, e is the sum of the individual calculations.)

Cost Levelization

Most costs in the GRIM are annualized costs and are thus in the same format as those of the LBL-MAM. However, there are two types of costs which will differ from year to year. These are:

- *Conversion costs:* In GRIM, conversion costs are broken into two types: design costs and capital costs, which are incurred in the three years leading up to standards in the SG&A and Capital Expenditure categories, respectively.

- *Working capital:* Working capital is incurred as a one-time cost when there is a change in revenue as in the first year of standards when price and quantity changes.

To convert these "one-times" costs into continuous, annualized costs, we "levelize" them via the following procedures:

I.. If they are standards costs incurred in years prior to standards, future value them to the first year of standards. This may be accomplished by the following formula where the total future value C_o is:

$$C_o = \sum C_{t-n} \cdot (1+r)^n$$

To derive the formula for levelized costs (L) from the future valued costs (C_o), we perform the following:

$$\sum_{n=0}^{\infty} \frac{L}{(1+r)^n} = C_o$$

$$L + \frac{L}{1+r} + \ldots = C_o$$

$$C_o \approx L + \frac{L}{1+r} + \ldots = (C_o - L) \cdot 1 + r$$

$$\frac{C_o}{1+r} = C_o - L$$

$$L = C_o - \frac{C_o}{1+r} = \frac{C_o(1+r) - C_o}{1+r} = \frac{r}{1+r} C_o$$

C.3 INPUT DATA AND DATA DEVELOPMENT FOR REFRIGERATORS AND FREEZERS

The Lawrence Berkeley Laboratory Manufacturer Analysis Model (LBL-MAM) 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. In this appendix, we provide an overview and description of the LBL-MAM along with a description of the economic theory and a discussion of each of the model's modules. We conclude with the LBL-MAM input data and model runs for the analysis of refrigerators, refrigerator-freezers, and freezers.

C.3.1 Engineering Cost Data

The source of the engineering data is the Engineering Analysis described in Chapter 3. The sources of data include manufacturers of these products, discussions with industry consultants, and other studies. The engineering data inputs used in the model consist of several components:

1. The incremental unit variable cost for each of the design options that increases the efficiency of the appliance (e.g., 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 for each design option requiring capital expenditures.

The engineering input data are also listed for each standards level being analyzed (a base case and standards levels 1 through 4 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-MAM 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 Chapter 3.

C.3.2. Industry Market Data

Industry Shipments

These data include annual industry shipments for the base case and the long-run shipments for each of the standards levels. The base case shipments figure is based on statistics from the Association of Home Appliance Manufacturers.

Price Elasticities and Market Discount Rates

Price elasticities and market discount rates determine the effect on shipments of changes in appliance price and operating expense. For refrigerators and freezers, the price elasticities are estimated to be -0.24 and -0.43, respectively. (These are derived from long-run equipment ownership market share elasticities in E. Hirst and J. Carney, "The ORNL Engineering-Economic Model of Residential Energy Use," ORNL/CON-24, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1978.)

The market discount rates supplied to the LBL-REM were 137% for refrigerators and 160% for freezers. These market discount rates were calculated using the relationship of retail prices and unit energy consumption by design option from the Engineering Analysis, by the method described in H. Ruderman, M.D. Levine, and J.E. McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," in The Energy Journal 8 (1), 1987.

Product Class Market Share

Each of the product classes has a share of the total market for refrigerators, refrigerator-freezers, and freezers and the market share, or unit sales, for each product class is an input to the model.

Markups

Manufacturers charge different markups over variable cost for different product classes, resulting in different profit margins for different product classes. For refrigerators, refrigerator-freezers, and freezers, the estimated markup is 1.37. The source is based on historical information collected from the previous analysis of refrigerators, refrigerator-freezers, and freezers as noted in DOE/CE-0277.[10]

Initial prices

The 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 LBL and Elrick and Lavidge's ELCAP refrigerator retail price database.

Energy price

This figure is the ratio of the price of a 1992 kWh to a 1998 kWh. The source is the LBL-REM. Industry market data appear on the Cost, Sales, and Revenues page of the model.

C.3.3 Financial Input Data

Financial Inputs

The financial inputs for refrigerators, refrigerator-freezers, and freezers are summarized in Tables C.1 to C.4.

Table C.5 Rates of Financial Costs

Variable	Value	Source
After-tax equity cost of capital[†]	6.8%	MAM calc. from public financial data[‡]
Interest rate on debt[‡]	2.5%	MAM calc. from public financial data
Interest lost in cash[‡]	1.0%	MAM calc. from public financial data
Rate of depreciation	17.7%	Public financial data
Tax rate★	36%	Tax law

[†]Cost of capital and interest rate are *real* rather than nominal
[‡]Public financial data include data from Value Line, Standard and Poors, Moody's, individual company annual reports, and economic reports.
★We adopted the 36% discount used by Arthur D. Little and the trade associations in their development of the Government Regulatory Impact Model.

[10]*Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces,* U.S. Department of Energy, DOE/CE-0277, November 1989.

Table C.6 Other Financial Data

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]

[1]Industry sources include consultants under contract to LBL and discussions with industry representatives.

Table C.7 Fixed, Variable, and Revenue-Related Cost Split

Variable	Value	Source
Fixed part of costs and depr. assets	10%	Industry sources
Fixed part of one-time capital costs	20%	Industry sources
Economic profit	0.5%	MAM est. from financial data
Debt/equity ratio	25%	Public financial data
Markup on typical model:	1.37	Industry sources
Ratio of highest to lowest markup:	2.00	Industry sources

Table C.8 One-Time Costs

Variable	Value	Source
One-time capital cost's life	8 years	Industry sources
One-time capital cost's tax life	6 years	MAM calculation
Percent additional 1-X capital	50%	MAM 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.3.4 LBL-MAM Inputs and Outputs Showing the Primary Scenario

Table C.9 Refrigerators and Refrigerator-Freezers

Control Panel

REFRIGERATOR ANALYSIS CONTROL FACTORS		Input Value	Cntrl	Vari- ation	Program Value	Name
Price Elasticity		-0.24	0.00	100.00%	-0.24	IPE
Consumer Discount Rate		136.50%	0.00	100.00%	136.50%	RD
Equity Cost of Capital		0.068	0.00	10.00%	0.068	ECC
Economic Profit		0.005	0.00	1.00%	0.005	EP
L-R Fixed Part of Costs & Assets		0.1	0.00	50.00%	0.1	FCA
L-R Fixed Part of 1-X Cap. Cost		0.2	0.00	60.00%	0.2	F1X
One-Time Capital Costs		41.22911	0.00	20.00%	41.229	CC.N
Unit Variable Cost Increase		32.76064	0.00	30.00%	32.761	dVC.N
Elasticity Curve Parameter		1.00e-09	0.00	30.00%	1e-09	ro.N
Short Run Price Response to Demand		0.157	0.00	76.43%	0.157	SRPR
	NAECA	NEW		PREVIOUS	NEW	
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN	
Shipments	1.34	1.32	-1.41%	-1.41%	1.32	
Price	$447.05	$485.42	8.58%	8.58%	$484.31	
Revenue (in $M)	600.21	642.55	7.05%	7.05%	641.48	
Net Income	38.42	40.32	189.84%	189.84%	37.91	
ROE	7.31%	7.36%	0.04%	0.04%	6.92%	
			Trys =	696		

Table C.10 Refrigerators and Refrigerator-Freezers

The Monte Carlo Module

MCarlo	34638.466		34638.466		Std Level =	1

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.

				Secnds/iteration =		0.52
				Iterations to go =		0
	REFRIGERATORS			Sample Size =		400
		%dQ	%dP	%dR	dNI	dROE.N
curr	Value	-0.014084	0.0858358	0.0705424	1.8983656	0.0004447
forms	Means	0.0468128	0.1948861	0.2496357	2.3575719	-0.006894
	Stnd. Dev	0.0182349	0.0654268	0.0460506	2.7655265	0.0047659
		0.0492519	0.1832469	0.2415241	2.0321106	-0.006141
		0.0598734	0.135382	0.2033613	5.8274362	0.0004573
		0.0389828	0.2210777	0.2686788	3.6103273	-0.009024
		0.0581056	0.1410957	0.2073997	7.4310855	0.0005207
		0.0622631	0.1436192	0.2148245	2.9238012	-0.004341
		-0.011095	0.4171937	0.4014697	4.6672799	-0.006691
		0.0525182	0.1737491	0.2353924	2.0848527	-0.006147
		0.0546169	0.1759447	0.2401712	-3.366527	-0.015151
		0.0182345	0.2990608	0.3227485	4.6849254	-0.004656
		0.0421123	0.2162732	0.2674932	-1.715598	-0.016386
		0.0764235	0.1021145	0.186342	1.3767257	-0.008158
		0.0478598	0.1810217	0.2375452	6.0588773	-0.002343
		0.0205793	0.2920161	0.3186049	4.4271591	-0.003956
		0.0430152	0.2066369	0.2585407	1.7172744	-0.007919
		0.063701	0.133694	0.2059115	0.8733107	-0.008579
		0.0598132	0.1577684	0.2270182	-2.150263	-0.014278
		0.0962526	0.0602721	0.1623261	-19.24219	-0.043832
		0.0528181	0.1755053	0.2375932	2.0392402	-0.005384
		0.0701778	0.1145506	0.1927674	-0.223491	-0.011376

Table C.11 Refrigerators and Refrigerator-Freezers

The Accounting Module

	CALIBRATION	BASE	NEW	CHANGE
Revenue	596.32	600.21	642.55	0.07
Expenses				
Cost of Goods Sold	401.96	405.45	439.23	0.08
Selling & G & A	100.30	101.84	101.45	-0.00
Engineering	7.16	7.27	7.25	-0.00
Depreciation	24.29	24.29	24.29	NA
1-X Depreciation	0.00	0.12	5.15	NA
Total Expenses	533.71	538.96	577.37	0.07
Earnings Before Interest & Taxes	62.61	61.25	65.12	0.06
Interest	2.86	1.20	1.20	-0.00
Earnings Before Taxes	59.75	60.05	63.92	0.06
Taxes	21.51	21.65	24.20	0.12
Net Income	38.24	38.41	39.72	0.03
Gross Margin	0.33	0.32	0.32	-0.02
Return on Sales	0.06	0.06	0.06	-0.03
Total Assets	654.76	656.85	685.14	0.04
Return on Assets (w/intrst taxed)	0.06	0.06	0.06	-0.05
Equity	523.81	525.48	548.11	0.04
Return on Equity	0.07	0.07	0.07	-0.06

ECONOMIC ANALYSIS

INCOME	CALIBRATION	BASE	NEW	CHANGE
Shipments	1.34	1.34	1.32	-0.01
Price	443.66	447.05	485.42	0.09
Revenue	596.32	600.21	642.55	0.07
EXPENSE (W/ INTEREST)				
Fixed Costs	59.63	59.63	59.63	0.00
Variable Costs (w/ Q)	476.94	480.35	78.94	-0.84
Total Expenses	536.57	539.98	138.57	-0.74
ASSETS				
Cash	138.35	138.19	136.25	-0.01
Inventories	382.84	382.42	377.03	-0.01
Depreciable	133.58	136.24	171.86	0.26
Total Assets	654.76	656.85	685.14	0.04

Table C.12 Refrigerators and Refrigerator-Freezers

The Engineering Inputs Module

VCS.E Additional UVC. (Above Level 0 cost). Cumulative costs directly from engineering inputs.

CLS	0	1	2	3	4	5	6	7	8	9	10
0	$0.00	$11.06	$15.560	$18.66	$25.16	$25.91	$34.40	$37.15	$40.17	$48.33	$51.05
1	$0.00	$4.50	$11.00	$17.75	$19.28	$26.52	$33.51	$37.39	$53.12	$53.87	$57.59
2	$0.00	$9.61	$16.11	$20.61	$25.99	$43.82	$44.82	$51.38	$54.20	$56.07	$34.11
3	$0.00	$2.82	$9.57	$14.07	$15.49	$16.81	$19.38	$21.05	$27.55	$28.30	$42.92
4	$0.00	$6.50	$13.25	$17.75	$30.75	$32.99	$35.74	$37.51	$42.85	$44.48	$47.20

Operating Costs: $/Yr

KWS.E	0	1	2	3	4	5	6	7	8	9	10
TM no ttd	61.68	54.57	52.31	50.37	47.79	47.47	43.59	42.62	41.66	39.07	38.43
TM with	69.99	66.84	63.69	61.94	59.14	57.74	54.59	53.89	45.85	45.5	44.8
SS no ttd	66.99	61.58	58.27	56.47	54.97	45.66	45.06	42.95	41.75	41.15	49.26
SS with ttd	70.39	67.62	63.81	61.38	60.34	58.95	57.56	56.18	54.44	54.1	46.81
BM	62.9	58.93	54.95	53.14	45.91	44.1	43.02	41.57	40.49	39.77	39.04

INCREMENTAL PER UNIT, DEPRECIATED INVESTMENT COSTS

Tooling Costs Depreciated Over 5 Years

Capital cost / unit / 5 Depreciated Per Unit Incremental Investment Costs

	0	1	2	3	4	5	6	7	8	9	10
TM no ttd	0	0	0	0.243	0	0.025	1.047	0.066	0.008	0.107	0.114
TM with	0	0	0	0	3.611	0.78	10.23	2.592	44.24	1.188	5.2
SS no ttd	0	0	0	0	0.048	8.032	0.28	1.364	3.715	1.417	7.201
SS with ttd	0	0.602	0	0	0.225	0.537	0	0.677	0	0.093	4.531

Table C.12 (Continued)

BM	0	0	0	0	4.441	0.991	0.112	0.393	0.225	1.123	2.695
Class 6	0	0	0	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0	0	0	0
	Building and Equipment Depreciated Over 15 Years										
	Capital cost / unit / 15			Depreciated Per Unit Incremental Investment Costs							
	0	1	2	3	4	5	6	7	8	9	10
TM no ttd	0	0	0	0.157	0	0	1.174	0.063	0.059	0.626	0.343
TM with	0	0	0	0	3.566	0	6.91	1.878	64.15	0	14.86
SS no ttd	0	0	0	0	0.022	9.93	0.023	1.384	0.351	0.578	5.509
SS with ttd	0	0.278	0	0	0.031	0.443	0.354	0.004	0	0.031	7.215
BM	0	0	0	0	1.565	0.216	0.15	2.622	0	0	1.947
Class 6	0	0	0	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0	0	0	0
	R&D Costs			Depreciated Per Unit Incremental Investment Costs							
	0	1	2	3	4	5	6	7	8	9	10
TM no ttd	0	0	0	0.121	0	0.037	0.64	0.09	0.027	0	0.085
TM with	0	0	0	0	2.415	1.274	5.093	1.408	26.82	1.735	1.98
SS no ttd	0	0	0	0	0.23	4.218	0.938	1.083	0.911	1.176	4.218
SS with ttd	0	0.624	0	0	0.521	0.566	0.045	0.627	0	0.181	1.555
BM	0	0	0	0	5.713	1.973	1.146	0	1.819	2.156	2.156
Class 6	0	0	0	0	0	0	0	0	0	0	0

Table C.12 (Continued)

CC.E	Total Additional CC./7 (Above Level 0 cost.):					Depreciated Per Unit Cumulative					
CLS	0	1	2	3	4	5	6	7	8	9	10
0	0.00	0.00	0.00	0.52	0.52	0.58	3.44	3.66	3.76	4.49	5.03
1	0.00	0.00	0.00	0.00	9.59	11.65	33.88	39.76	174.98	177.90	199.94
2	0.00	0.00	0.00	0.00	0.30	22.48	23.72	27.55	32.53	35.70	17.23
3	0.00	1.50	1.50	1.50	2.28	3.83	4.23	5.53	5.53	5.84	19.14
4	0.00	0.00	0.00	0.00	11.72	14.90	16.31	19.32	21.36	24.64	31.44
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TOTAL ADD.E	0	1	2	3	4	5	6	7	8	9	10
TM no ttd	0	0	0	3.968	3.968	4.209	29.23	30.79	31.8	41.84	47.86
TM with	0	0	0	0	1.414	1.553	4.605	5.419	28.1	28.3	32.88
SS no ttd	0	0	0	0	0.163	26.2	26.79	30.77	34.2	36.68	17.11
SS with ttd	0	1.529	1.529	1.529	2.063	3.928	4.848	5.747	5.747	5.995	28.91
BM	0	0	0	0	2.607	3.459	3.912	3.947	4.672	5.607	6.681
Class 6	0	0	0	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0	0	0	0

	Total										
CCEE.E	0	1.529	1.529	5.497	10.22	39.35	69.38	76.67	104.5	118.4	133.4

Table C.12 (Continued)

VCS.E

CLS	12	13	14	15	16	17	18	19	20	21	22
0	$59.92	$38.96	$41.68	$48.74	$22.06	$22.81	$25.56	$27.37	$30.09	$76.84	$83.90
1	$30.40	$34.10	$34.85	$43.34	$47.06	$49.23	$68.50	$75.74	$79.62	$83.34	$85.51
2	$38.61	$39.36	$41.23	$44.05	$27.86	$28.86	$80.41	$81.16	$83.98	$0.00	$0.00
3	$50.05	$18.48	$24.98	$25.73	$33.55	$37.86	$40.68	$1.42	$8.17	$12.67	$13.99
4	$26.37	$29.12	$29.62	$31.25	$36.59	$39.31	$20.50	$62.86	$64.49	$69.83	$70.33

KWS.E	12	13	14	15	16	17	18	19	20	21	22
TM no ttd	37.13	41.98	41.33	40.36	49.41	49.08	48.11	47.47	46.82	38.1	37.13
TM with	57.04	55.29	54.94	50.04	48.99	48.65	48.3	47.25	46.55	45.85	45.5
SS no ttd	47.46	47.16	46.56	45.66	54.07	53.47	45.36	45.06	44.16	0	0
SS with ttd	44.73	57.56	55.83	55.48	51.32	50.28	48.89	69.01	64.85	62.42	61.03
BM	47	45.91	45.55	44.83	43.74	42.66	52.06	41.94	41.21	40.13	39.77

INCREMENTAL PER UNIT, DEPRECIATED INVESTMENT COSTS

	12	13	14	15	16	17	18	19	20	21	22
TM no ttd	0.567	0.567	0.114	0.023	0	0.025	0.066	0.567	0.114	0	0.023
TM with	2.592	10.23	1.188	39.23	5.2	25.97	0	0.78	2.592	5.2	25.97
SS no ttd	1.364	0.085	1.417	3.715	1.417	0.28	0	0.085	3.715	0	0
SS with ttd	0.04	0.677	0	0.093	3.926	0.04	3.615	0.225	0	0	0.537
BM	4.441	0.112	0.337	1.123	0.225	2.695	0.112	0	1.123	0.225	0.337
Class 6	0	0	0	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0	0	0	0

Table C.12 (Continued)

	12	13	14	15	16	17	18	19	20	21	22
TM no ttd	0.285	0.285	0.343	0	0	0	0.063	0.285	0.343	0	0
TM with	1.878	6.91	0	43.31	14.86	13.02	0	0	1.878	14.86	13.02
SS no ttd	0.922	0.05	0.578	0.351	0.578	0.023	0	0.05	0.351	0	0
SS with ttd	0.013	0.004	0	0.031	4.255	0.013	0.301	0.031	0	0	0.443
BM	0.869	0.15	0	0	0	1.947	0.15	0	0	0	0
Class 6	0	0	0	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0	0	0	0
	12	13	14	15	16	17	18	19	20	21	22
TM no ttd	0.444	0.444	0.085	0.067	0	0.037	0.09	0.444	0.085	0	0.067
TM with	1.408	5.052	1.735	26.82	1.98	18.28	0	1.274	1.408	1.98	18.28
SS no ttd	0.832	0.292	1.176	0.911	1.176	0.938	0	0.292	0.911	0	0
SS with ttd	0.112	0.627	0	0.181	1.555	0.112	0.75	0.521	0	0	0.566
BM	5.713	1.146	0.936	2.156	1.819	2.156	1.146	0	2.156	1.819	0.936
Class 6	0	0	0	0	0	0	0	0	0	0	0

CC.E

CLS	12	13	14	15	16	17	18	19	20	21	22
0	6.42	4.96	5.50	5.59	0.00	0.06	0.28	1.58	2.12	2.12	2.21
1	17.52	39.72	42.64	152.00	174.04	231.31	9.59	11.65	17.52	39.56	96.83
2	21.59	22.02	25.19	30.17	3.47	4.71	4.71	5.14	10.12	0.00	0.00
3	23.97	5.13	5.13	5.44	15.18	15.34	20.01	0.78	0.78	0.78	2.32
4	14.20	15.61	16.88	20.16	22.21	29.00	1.41	1.41	4.69	6.73	8.00

Table C.12 (Continued)

5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL ADDITIONAL CC * 7 MATRIX											
ADD.E	12	13	14	15	16	17	18	19	20	21	22
TM no ttd	56.7	39.31	45.34	45.66	0	0.24	1.801	10.32	16.35	16.35	16.67
TM with	2.367	5.417	5.617	22.24	26.81	33.63	1.414	1.553	2.367	6.94	13.76
SS no ttd	20.68	20.95	23.44	26.87	2.651	3.24	3.24	3.505	6.935	6.935	6.935
SS with ttd	33.24	4.827	4.827	5.076	19.97	20.1	24.3	0.534	0.534	0.534	2.399
BM	3.459	3.912	4.305	5.24	5.964	7.039	0.453	0.453	1.388	2.113	2.505
Class 6	0	0	0	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0	0	0	0
CCEE.E	116.4	74.42	83.52	105.1	55.4	64.25	31.21	16.37	27.57	32.87	42.27
VCS.E											
CLS	23	24	25	26	27	28					
0	0	0	0	0	0	0					
1	0	0	0	0	0	0					
2	0	0	0	0	0	0					
3	$15.66	16.41	22.91	27.22	78.54	81.36					
4	$73.05	0	0	0	0	0					
KWS.E	23	24	25	26	27	28					
TM no ttd	0	0	0	0	0	0					
TM with	0	0	0	0	0	0					
SS no ttd	0	0	0	0	0	0					

Table C.12 (Continued)

SS with ttd	59.99	59.64	57.56	56.52	46.81	45.43
BM	39.04	0	0	0	0	0

INCREMENTAL PER UNIT, DEPRECIATED INVESTMENT COSTS

	23	24	25	26	27	28
TM no ttd	0	0	0	0	0	0
TM with	0	0	0	0	0	0
SS no ttd	0	0	0	0	0	0
SS with ttd	0.677	0.093	0	0.04	0	3.615
BM	2.695	0	0	0	0	0
Class 6	0	0	0	0	0	0
Class 7	0	0	0	0	0	0
Class 8	0	0	0	0	0	0

	23	24	25	26	27	28
TM no ttd	0	0	0	0	0	0
TM with	0	0	0	0	0	0
SS no ttd	0	0	0	0	0	0
SS with ttd	0.004	0.031	0	0.013	0	0.301
BM	1.947	0	0	0	0	0
Class 6	0	0	0	0	0	0
Class 7	0	0	0	0	0	0
Class 8	0	0	0	0	0	0

Table C.12 (Continued)

	23	24	25	26	27	28
TM no ttd	0	0	0	0	0	0
TM with	0	0	0	0	0	0
SS no ttd	0	0	0	0	0	0
SS with ttd	0.627	0.181	0	0.112	0	0.75
BM	2.156	0	0	0	0	0
Class 6	0	0	0	0	0	0

CC.E

CLS	23	24	25	26	27	28
0	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00
3	3.63	3.94	3.94	4.10	4.10	8.77
4	14.80	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00

TOTAL ADDITIONAL CC * 7 MATRIX

ADD.E	23	24	25	26	27	28
TM no ttd	16.67	16.67	16.67	16.67	16.67	16.67
TM with	13.76	13.76	13.76	13.76	13.76	13.76
SS no ttd	6.935	6.935	6.935	6.935	6.935	6.935
SS with ttd	3.298	3.547	3.547	3.672	3.672	7.871
BM	3.58	3.58	3.58	3.58	3.58	3.58

Table C.12 (Continued)

Class 6	0	0	0	0	0	0
Class 7	0	0	0	0	0	0
Class 8	0	0	0	0	0	0
CCEE.E	44.24	44.49	44.49	44.61	44.61	48.81

Table C.13 Refrigerators and Refrigerator-Freezers

The Standards Level Module

LevIn	prev	LEV.B	lev.N	Eng: Levels = 0...12	0 ...	25	No. of Eng. Levs.
	-1	0	1	REM: -1='87 0='96	-1 ...	4	No. of Stds
	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=1987	0=1996	1	2	3	4	5	6
TM no ttd	0	2.916	37.15	38.96	48.74	83.9	0	0
TM with ttd	0	2.371	34.85	43.34	49.23	85.51	0	0
SS no ttd	0	2.172	20.61	39.36	44.05	83.98	0	0
SS with ttd	0	3.64	16.93	33.55	40.68	81.36	0	0
BM	0	2.735	19.99	29.62	39.31	73.05	0	0

KWS.R Kw Hrs /Yr

LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6
TM no ttd	61.68	59.86	42.62	41.98	40.36	37.13	0	0
TM with ttd	69.99	68.33	54.94	50.04	48.65	45.5	0	0
SS no ttd	66.99	65.77	56.47	47.16	45.66	44.16	0	0
SS with ttd	70.39	67.78	58.87	51.32	48.89	45.43	0	0
BM	62.9	61.23	51.7	45.55	42.66	39.04	0	0

CC.R

LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6
TM no ttd	0	0.012	3.663	4.959	5.591	2.209	0	0
TM with ttd	0	0	42.64	152	231.3	96.83	0	0
SS no ttd	0	0	0	22.02	30.17	10.12	0	0
SS with ttd	0	0.848	3.891	15.18	20.01	8.768	0	0
BM	0	0	3.179	16.88	29	14.8	0	0

ADD.R: ADD'L CAPITAL COST *7

LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6
TM no ttd	0	0.094	30.79	39.31	45.66	16.67	0	0
TM with ttd	0	0	5.617	22.24	33.63	13.76	0	0
SS no ttd	0	0	0	20.95	26.87	6.935	0	

Table C.13 (Continued)

SS with ttd	0	0.843	3.972	19.97	24.3	7.871	0	0
BM	0	0	0.852	4.305	7.039	3.58	0	0
Class 6	0	0	0	0	0	0	0	0
Class 7	0	0	0	0	0	0	0	0
Class 8	0	0	0	0	0	0	0	0
CCEE.R								
LEVEL -->	-1=1987	0=1996	1	2	3	4	5	6
Cumltv CC	0	0	0	0	0	0	0	
	0	0.937	41.23	106.8	137.5	48.81	0	0

Table C.14 Refrigerators and Refrigerator-Freezers

The Costs, Sales, and Revenue Module

Ratio of highest to lowest markup:	ratio.0	2	ratio.cv	0.2
Typical markup over UVC	mid.0	0.38	mid.cv	0.2
Size of firm as % of industry	size.0	0.2		

CALIBRATION CASE

	Indst Ship. IQ	Relatv Ship. Q%	Ship. Q.1	Price P.1/Range	Rev. R.1	m.1	UVC.1	Weighted UVC
TM no ttd	5.05	0.75	1.01	355.56	359.20	1.38	257.65	193.65
TM with ttd	0.09	0.01	0.02	712.44	12.79	1.66	428.54	5.72
SS no ttd	0.65	0.10	0.13	561.21	72.42	1.54	363.77	34.92
SS with ttd	0.85	0.13	0.17	835.62	141.27	1.76	474.78	59.72
BM	0.09	0.01	0.02	597.99	10.65	1.57	380.43	5.04
TOTAL·S	6.72	0.20	1.34	443.66	596.32	1.48	0.20	299.06
	TS.0	Q.CV	Q.0	P.0	596.32		P.CV	299.06

BASE	Rule-of-Thb d P	Rule-of-Thb Price		Pi.B	Op Cost Ratio	Weightd OpCst-R	Qi.B	Ri.B
TM no ttd	4.04	362.88	16.45	358.79	0.97	0.73	1.01	362.07
TM with ttd	3.94	12.84	0.28	715.62	0.98	0.01	0.02	12.83
SS no ttd	3.35	72.77	1.45	564.01	0.98	0.09	0.13	72.70
SS with ttd	7.60	142.40	9.76	840.38	0.96	0.12	0.17	141.92
BM	4.30	10.71	0.33	601.38	0.97	0.01	0.02	10.70
	0.05	601.60	28.27	447.05	600.21	-0.03	1.34	600.21
	Alpha.B	Sum P (2)	3.00	P.B	Sum(Ri)	OC%.B0	Q.B	R.B

NEW STANDARDS CASE

	Rule-of-Thb d P	Rule-of-Thb Price		Pi.N	% Chng Op Cost	Weightd OpCst-R	Qi.N	Ri.N
TM no ttd	55.31	408.78	3043.74	400.50	0.69	0.52	0.99	398.47
TM with ttd	114.65	14.62	232.31	782.55	0.79	0.01	0.02	13.83
SS no ttd	31.80	75.36	128.49	589.59	0.84	0.08	0.13	74.93
SS with ttd	35.27	145.00	207.16	866.68	0.84	0.11	0.17	144.30
BM	35.42	11.11	22.00	629.16	0.82	0.01	0.02	11.03
TOTAL	0.00	654.87	3633.70	485.42	642.55	-0.27	1.32	642.55
	Alpha.N	Sum P (2)	3.00	P.N	Sum(Ri)	OC%.N0	Q.N	R.N

Table C.15 Refrigerators and Refrigerator-Freezers

The Financial Module

DESCRIPTION (FINANCE PAGE)	RANGE NAME	INPUT VALUE	RANGE NAME	C.V.
RATES OF COST				
After Tax Equity Cost of Capital	ECC.0	0.07	ECC.CV	0.10
Interest Rate on Debt	I.0	0.03	I.CV	1.00
Interest Lost on Cash	ICash.0	0.01	ICASH.CV	1.00
Rate of Depreciation	Dep.0	0.18		
Tax Rate	T.0	0.36	T.CV	0.20
ASSETS and COSTS as a PERCENT of REVENUE				
Cash	C:R.0	0.23	C:R.CV	1.00
Inventory & Receivables	IR:R.0	0.64	IR:R.CV	0.27
Depreciable Assets	DA:R.0	0.22	DA:R.CV	0.37
G & A	G&A.0	0.17	G&A.CV	0.40
Engineering	Eng	0.01		
FIXED AND VARIABLE COST SPLIT				
Fixed Part of All Costs & Depr Assets	FCA.0	0.10	FCA.CV	0.50
Fixed Part of 1-X Capital Cost	F1X.0	0.20	F1X.CV	0.60
OTHER				
Economic Profit	EP.0	0.01	EP.CV	0.01
Debt to Equity ratio	DER.0	0.25	DER.CV	0.43
Markup on typical model	"mid	0.38		
Ratio of highest to lowest markup	"ratio	2.00		
OUTPUT	NAME	VALUE		
Depreciation	DRR	0.04		
G&A to Overhead Ratio	G:O	0.93		
Engineering to Overhead Ratio	E:O	0.07		
Debt Ratio	DR	0.20		
Equity Ratio	ER	0.80		
Pre-Tax Equity Cost of Capital*	PECC	0.11		
Weighted Average Cost of Capital	WACC	0.09		
After Tax WACC	ATWACC	0.06		
Return on Equity	ROE	0.07	'ROE.0	0.00

Table C.16 Refrigerators and Refrigerator-Freezers

The One-Time Cost Amortization Module

		L	8	years	
Tax life of existing capital		TL	6	years	
Age of existing capital		AGE	1	years	
Percent of 1X capital that is add-on (as opposed		%NC	0.5		
COMPUTATIONS					
DESCRIPTION		NAME	VALUE		
Continuous After-Tax WACC		ATR	0.0560022		
Weighted CC Lead-Time	0	0.28757	0.5438162		0.26
Cumulative CC Lead-Time Factors		LTC.0	1.0913863		
exp(-ATR*TL)		EMRT	0.7146137		
exp(-ATR*L)		EMRL	0.6388935		
Rate of tax benefit	3.2968	BN	0.06		
Remaining tax life		RTL	5	years	
Tax Benefit Rate: (1-%NC)*BN		BEN	0.03		
Discount factor: @exp(-ATR*(L-(TL-RTL)))		DIS	0.6756938		
Loss of tax benefit on portion of existing capital with remaining tax life		LEC1	0.1308295		
Loss of tax benefit on discounted existing capital expenditure in the future		LEC2	0.1032997		
LEVELIZED CC			GROSS CC		TAX EFF
Initial Cost			1		
Tax Benefit of Straight-Line Depreciation					0.305759
Savings from not replacing existing Capital later			-0.337847		
Loss of Tax Benefit from existing Capital					-0.23413
Present Value of CC:			0.6621531		0.07163
Adjusted for Capital			0.7226648		0.078176
Levelized Tax Benefit:					0.004584
LEVELIZED CC		CCLF	0.1120744		0.016708
					CCLTF
AVERAGE ASSET					
Asset Factor for Any New		AFB	0.5741736		
Average Asset Factor for		AAF	0.2870868		

Table C.16 (Continued)

INPUT

NEW CAP. COST:	CC.B0	0.9374833
1996 CHANGE	CC.N	41.229109
COEFFICIENTS OF	CCL.CV	0.2
	CC.B.CV	0.25

OUTPUT

	BASE CASE		NEW STNDS	
Levelized 1-X CC: Gross	LCC.B	0.1050679	LCC.N	4.62073
Levelized 1-X CC: Tax	LCC.TB	0.0156634	LCC.TN	0.688852
Levelized 1-X CC: Net	LCC.NB	0.0894045	LCC.NN	3.931878
Levelized 1-X Assets	LA.B	0.2691391	LA.N	11.83633

Table C.17 Refrigerators and Refrigerator-Freezers

The Long-Run Model Module

CALIBRATION CASE		A.F	A.Q	A:R	A
	Assets -->	0.02	1.08	1.10	654.76
	Costs except taxes	TC.F	TC.Q	TC:R	536.57
	and equity -->	0.10	0.80	0.90	536.57
		EC.F	EC.Q	EC:R	593.70
	Economic costs -->	0.07	0.57	1.00	593.70
	Economic Income			EI:R	0.00
	Markup (mu - 1)			0.12	0.12
	Price Leader's elasticity of demand:				-9.19
BASE		A.BF	A.BQ		A.B
	Assets	13.36	477.20		656.85
		TC.BF	TC.BQ		TC.B
	Costs except taxes	59.63	357.77		540.04
		EC.BF	EC.BQ		EC.B
	Economic costs	38.89	255.10		596.07
	Total Working Capital Correction Assets	WCA.B	2.52		
	Working Capital Correction (Per Unit EC)	WCCEC.B	0.11		
	Total Working Capital Correction (Interest)	WCCI.B	0.06		
NEW		A.NF	A.NQ		A.N
	Assets	13.36	477.20		685.14
		TC.NF	TC.NQ		TC.N
	Costs except taxes	59.63	387.60		573.41
		EC.NF	EC.NQ		EC.N
	Economic costs	39.82	277.95		622.42
	Total Working Capital Correction Assets	WCA.N	28.27		
	Working Capital Correction (Per Unit EC)	WCCEC.N	1.18		
	Total Working Capital Correction (Interest)	WCCI.N	0.71		
					1.33

Table C.17 (Continued)

Assets	CAL		BASE		NEW	
Shipments	Q	1.34	Q.B	1.34	Q.N	1.32
Price	P	443.66	P.B	447.05	P.N	485.42
Revenue	R	596.32	R.B	600.21	R.N	642.55
Unit Var. Cost	UVC	299.06	UVC.B	301.98	UVC.N	331.82
V. Cost Goods Sold	401.96	401.96	VCGS.B	405.45	VCGS.N	439.23
1X tax benefit			X1T.B	0.02	X1T.N	0.69
Pre-tax cost	536.57	536.57	PTC.B	540.15	PTC.N	578.03
Taxes	21.51	21.51	TAX.B	21.65	TAX.N	24.20
Net Income	38.24	38.24	NI.B	38.42	NI.N	40.32
Economic Income	2.62	2.62	EI.B	2.69	EI.N	3.05
Equity	523.81	523.81	EQ.B	525.48	EQ.N	548.11
Retrn on Eqity	ROE	0.07	ROE.B	0.07	ROE.N	0.07

Table C.18 Refrigerators and Refrigerator-Freezers

The Short-Run Model Module

Short-Run "Supply Elasticity of Price":				SRQE.0	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	261.11		"P.N	$220.79	
UVC.S	$158.15		"Q.N		1.18
VCGS.S	187.10				
TC.S	267.02			ap	bp
TAX.S	-2.01	P=a+bQ		186.13	29.22
PTC.S	267.02		1.00	cq	dq
NI.S	-3.90	Q=c+dP		1.90	0.00
A.S	246.64				
EQ.S	197.31		P.S	220.70	
ROE.S	-1.98%		Q.S		1.18
		Check P		$220.70	
		Check Q			1.1831

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.19 Refrigerators and Refrigerator-Freezers

The Charts Module

CHARTS OF SENSITIVITY AND PROFIT FOR
REFRIGERATORS

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	-0.240	-0.552	-0.002	-0.003	-0.004	-0.005
RD	1.365	3.138	0.001	0.001	0.001	0.002
ECC	0.068	0.075	-0.000	-0.000	-0.000	-0.000
EP	0.005	0.015	0.000	-0.000	-0.000	0.000
FCA	0.100	0.160	0.002	0.003	0.004	0.006
F1X	0.200	0.348	-0.001	-0.003	-0.004	-0.001
CC.N	41.229	50.259	-0.000	-0.001	-0.001	-0.000
dVC.N	32.761	43.938	0.001	0.001	0.001	0.002
ro.N	0.000	0.300	-0.002	-0.002	-0.003	-0.005
SRPR	0.157	0.594	0.000	0.000	0.000	0.000

Table C.20 Refrigerators and Refrigerator-Freezers

Net Cash Flow Module

	GRIM Switch	0		1989	1990	1991	1992	1993	1994	1995	1996
Price/Unit				$447.05	$447.05	$447.05	$447.05	$447.05	$447.05	$447.05	$447.05
Unit Sales				6.7131	6.7131	6.7131	6.7131	6.7131	6.7131	6.7131	6.7131
Revenues				3001.1	3001.1	3001.1	3001.1	3001.1	3001.1	3001.1	3001.1
		New	Base								
	CGS	376.99	344.23	2310.8	2310.8	2310.8	2310.8	2310.8	2310.8	2310.8	2310.8
	Labor	47.981	44.705	300.11	300.11	300.11	300.11	300.11	300.11	300.11	300.11
	Material	253.3	227.99	1530.5	1530.5	1530.5	1530.5	1530.5	1530.5	1530.5	1530.5
	Overhead	61.176	56.999	382.64	382.64	382.64	382.64	382.64	382.64	382.64	382.64
	Depreciation	14.529	14.529	97.535	97.535	97.535	97.535	97.535	97.535	97.535	97.535
SG&A				510.18	510.18	510.18	510.18	510.18	510.18	528.18	535.38
	R&D			60.021	60.021	60.021	60.021	60.021	60.021	60.021	60.021
	Product Conversion			0	0	0	0	0	0	17.999	25.199
Profit Before Tax				180.06	180.06	180.06	180.06	180.06	180.06	162.07	154.87
Taxes				64.823	64.823	64.823	64.823	64.823	64.823	58.343	55.752
Net Income Before Financing				115.24	115.24	115.24	115.24	115.24	115.24	103.72	99.114
Cash Flow											
	Net Income			115.24	115.24	115.24	115.24	115.24	115.24	103.72	99.114
	Depreciation			97.535	97.535	97.535	97.535	97.535	97.535	97.535	97.535
	Change in Work Capital			0	0	0	0	0	0	0	0
Cash Flows from Operations				212.78	212.78	212.78	212.78	212.78	212.78	201.26	196.65
	Capital Expenditures (Cash used in invest)			-120	-120	-120	-120	-120	-120	-120	-120
	Conversion Expenditure			0	0	0	0	0	0	-181.3	-253.8
Cash Used in Investments				-120	-120	-120	-120	-120	-120	-301.3	-373.8
Net Cash Flow				92.733	92.733	92.733	92.733	92.733	92.733	-100	-177.2

Table C.20 Refrigerators and Refrigerator-Freezers (Continued)

1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
$447.0	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3	$523.3
6.71	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
3,001	3,399	3,399	3,399	3,399	3,399	3,399	3,399	3,399	3,399	3,399	3,399	3,399	3,399
2,311	2,504	2,504	2,504	2,504	2,504	2,504	2,504	2,504	2,504	2,504	2,504	2,504	2,504
300	312	312	312	312	312	312	312	312	312	312	312	312	312
1,531	1,645	1,645	1,645	1 645	1,645	1,645	1,645	1,645	1,645	1,645	1,645	1,645	1,645
383	400	400	400	400	400	400	400	400	400	400	400	400	400
98	146	146	146	146	146	146	146	146	146	146	146	146	146
539	518	518	518	518	518	518	518	518	518	518	518	518	518
60	68	68	68	68	68	68	68	68	68	68	68	68	68
29	0	0	0	0	0	0	0	0	0	0	0	0	0
151	378	378	378	378	378	378	378	378	378	378	378	378	378
54	136	136	136	136	136	136	136	136	136	136	136	136	136
97	242	242	242	242	242	242	242	242	242	242	242	242	242
97	242	242	242	242	242	242	242	242	242	242	242	242	242
98	146	146	146	146	146	146	146	146	146	146	146	146	146
0	68	0	0	0	0	0	0	0	0	0	0	0	0
194	320	388	388	388	388	388	388	388	388	388	388	388	388
-120.04	-168.38	-168.38	-168.38	-168.38	-168.38	-168.38	-168.38	-168.38	-168.38	-168.38	-168.38	-	-168.38
-290	0	0	0	0	0	0	0	0	0	0	0	0	0
(410)	(168)	(168)	(168)	(168)	(168)	(168)	(168)	(168)	(168)	(168)	(168)	(168)	(168)
(216)	152	219	219	219	219	219	219	219	219	219	219	219	219

Table C.21 Freezers

The Control Panel

FREEZER ANALYSIS		Input		Vari-	Progrm	
CONTROL FACTORS		Value	Cntrl	ation	Value	Name
Price Elasticity		-0.43	0	1	-0.43	IPE
Consumer Discount Rate		160.00%	0.00%	100.00%	160.00%	RD
Equity Cost of Capital		0.068	0	0.1	0.068	ECC
Economic Profit		0.005	0	0.01	0.005	EP
L-R Fixed Part of Costs & Assets		0.1	0	0.5	0.1	FCA
L-R Fixed Part of 1-X Cap. Cost		0.2	0	0.6	0.2	F1X
One-Time Capital Costs		0.18	0	0.2	0.18	CC.N
Unit Variable Cost Increase		8.055883	0	0.3	8.0559	dVC.N
Elasticity Curve Parameter		1.00e-09	0	0.3	1e-09	ro.N
Short Run Price Response to Demand		0.157	0	0.7643	0.157	SRPR
	NAECA	NEW		PREVIOUS	NEW	
SUMMARY	BASE	L-RUN	CHANGE	CHANGE	S-RUN	
Shipments	0.25	0.24	-0.01	-0.07	0.24	
Price	$225.30	$233.77	$0.04	$0.22	$233.44	
Revenue (in $M)	55.25496	56.80911	0.0281	0.1355	56.766	
Net Income	3.538743	3.592276	0.0535	0.0636	3.5576	
ROE	0.073004	0.073275	0.0003	-0.006	0.0726	
			Trys =	58		
MAM/GRIM Cost Convergence Factor Status	0					

Table C.22 Freezers

The Monte Carlo Module

MONTE CARLO DETERMINATION OF STANDARD ERRORS OF ESTIMATES.

			Secnds/iteration =		0.46	0.46
			Iterations to go =		0	0
FREEZERS			Sample Size =		36	
	%dQ	%dP	%dR	dNI	dROE.N	dROE.S
Value	-0.02	0.03	0.02	0.05	0.00	-0.01
Means	-0.02	0.05	0.03	0.01	-0.00	-0.00
Stnd. Dev	0.05	0.07	0.02	0.17	0.00	0.01
	-0.02	0.03	0.02	0.05	0.00	-0.01
	0.01	0.03	0.04	-0.09	-0.00	-0.00
	-0.03	0.05	0.02	0.00	-0.00	-0.00
	0.01	0.03	0.03	0.01	-0.00	-0.00
	-0.01	0.03	0.01	-0.03	-0.00	-0.00
	0.02	0.06	0.08	0.29	0.00	0.01
	0.00	0.05	0.05	0.07	-0.00	0.00
	-0.01	0.05	0.04	0.30	0.00	-0.01
	-0.07	0.04	-0.03	-0.36	-0.00	-0.01
	-0.00	0.03	0.03	0.12	0.00	0.00
	0.03	0.02	0.06	0.20	0.00	0.00
	-0.07	0.06	-0.01	-0.23	-0.00	-0.01
	-0.02	0.04	0.03	0.06	0.00	-0.00
	-0.00	0.06	0.06	0.10	0.00	0.00
	-0.01	0.05	0.04	0.10	0.00	-0.00
	0.02	0.02	0.04	0.06	-0.00	0.00
	-0.02	0.05	0.03	0.08	0.00	-0.00
	-0.05	0.05	0.00	-0.09	0.00	-0.00
	-0.02	0.04	0.02	-0.05	-0.00	-0.00
	-0.00	0.02	0.02	0.03	-0.00	-0.00
	-0.01	0.03	0.02	0.03	-0.00	-0.00
	-0.01	0.04	0.03	0.02	-0.00	-0.00
	-0.00	0.02	0.02	0.12	0.00	0.00

Table C.23 Freezers

The Accounting Module

(All units are millions or millions of $ unless labeled with $ or %.)

	CALIBRATION	BASE	NEW	CHANGE
Revenue	55.12	55.26	56.81	0.03
Expenses				
Cost of Goods Sold	42.95	43.07	44.50	0.03
Selling & G & A	3.87	4.01	4.03	0.00
Engineering	0.28	0.29	0.29	0.00
Depreciation	2.25	2.25	2.25	NA
1-X Depreciation	0.00	0.00	0.02	NA
Total Expenses	49.34	49.62	51.08	0.03
Earnings Before Interest & Taxes	5.79	5.64	5.73	0.02
Interest	0.26	0.11	0.11	-0.02
Earnings Before Taxes	5.52	5.53	5.62	0.02
Taxes	1.99	1.99	2.03	0.02
Net Income	3.53	3.54	3.59	0.01
Gross Margin	0.22	0.22	0.22	-0.02
Return on Sales	0.06	0.06	0.06	-0.01
Total Assets	60.53	60.59	61.28	0.01
Return on Assets (w/intrst taxed)	0.06	0.06	0.06	0.01
Equity	48.42	48.47	49.02	0.01
Return on Equity	7.30%	7.30%	7.32%	2.18%

ECONOMIC ANALYSIS

	CALIBRATION	BASE	NEW	CHANGE
INCOME				
Shipments	0.25	0.25	0.24	-0.01
Price	224.66	225.30	233.77	0.04
Revenue	55.12	55.26	56.81	0.03
EXPENSE (W/ INTEREST)				

Table C.23 (Continued)

Fixed Costs	5.51	5.51	5.51	0.00
Variable Costs (w/ Q)	44.09	44.21	1.34	-0.97
Total Expenses	49.60	49.72	6.85	-0.86
ASSETS				
Cash	12.79	12.78	12.67	-0.01
Inventories	35.39	35.37	35.05	-0.01
Depreciable	12.35	12.43	13.56	0.09
Total Assets	60.53	60.59	61.28	0.01

Table C.24 Freezers

The Engineering Inputs Module

VCS.E — Additional UVC. (Above Level 0 cost). Cumulative costs directly from engineering inputs.

CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0.00	6.50	13.25	14.77	27.38	29.08	32.94	36.34	43.59	48.70	16.47	23.73	26.32
1	0.00	1.82	7.07	7.87	10.12	14.53	28.79	32.56	12.75	20.76	24.53	40.77	44.54
2	0.00	7.91	13.77	19.29	24.54	27.40	29.10	31.03	46.31	13.43	18.68	20.38	22.41

Operating Costs: $/Yr

KWS.E	0	1	2	3	4	5	6	7	8	9	10	11	12
Up - Auto	66.81	62.58	59.37	58.78	51.05	50.62	48.78	46.31	45.37	44.58	58.37	53.68	52.63
Up- Man	42.5	37.34	31.78	31.13	30.21	27.99	24.2	24.1	28.86	26.62	26.52	24.55	24.45
Chest	41.51	34.58	30.43	27.68	25.45	24.52	24.16	24.03	23.43	31.43	28.91	28.55	28

INCREMENTAL PER UNIT, DEPRECIATED INVESTMENT COSTS

Tooling Costs Depreciated Over 5 Years

Capital cost / unit / 5 — Depreciated Per Unit Incremental Investment Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12
Up - Auto	0	0	0	0.642	10.22	0.128	1.964	6.419	0.385	1.412	0.128	8.485	1.836
Up- Man	0	0	0	0	0.042	0.573	2.686	0.159	0.526	2.317	0.159	0	0.159
Chest	0	0.767	0.083	0	0	0.608	0.048	0.1	0.04	0	0	0.048	0.417

Building and Equipment Depreciated Over 15 Years

Capitai cost / unit / 15 — Depreciated Per Unit Incremental Investment Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12
Up - Auto	0	0	0	0.021	6.376	0	1.712	2.14	0	0.107	0	5.691	1.712
Up- Man	0	0	0	0	0	0.649	1.865	0.007	0.644	1.865	0.007	0	0.007
Chest	0	0.367	0.417	0	0	0.567	0	0.003	0.022	0	0	0	0.485

Table C.24 (Continued)

R&D Costs Depreciated Over 3 Years

Capital cost / unit / 3 Depreciated Per Unit Incremental Investment Costs

	0	1	2	3	4	5	6	7	8	9	10	11	12
Up - Auto	0	0	0	0.428	6.633	0.107	1.391	8.558	0.642	0.588	0.107	6.633	1.391
Up- Man	0	0	0	0.001	0.037	0.361	1.422	0.118	0.361	1.422	0.118	0	0.118
Chest	0	0.362	0.167	0	0	0.458	0.028	0.083	0.042	0	0	0.028	0.361

Total Cumulative Per Unit

CC.E Additional CC./7 (Above Level 0 cost.): Depreciated Per Unit C

CLS	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0.00	0.00	0.00	1.09	24.32	24.55	29.62	46.74	47.76	49.87	1.33	22.14	27.07
1	0.00	0.00	0.00	0.00	0.08	1.66	7.64	7.92	1.61	7.21	7.50	0.08	0.36
2	0.00	1.50	2.16	2.16	2.16	3.80	3.87	4.06	4.16	1.50	1.50	1.57	2.84
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
4	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

Total Weighted Undepreciated Cumulative Investment Costs

CCEE.E	0	1.25	2.11	2.261	7.483	10.35	15.93	18.95	14.69	16.52	6.97	6.102	8.689

VCS.E

CLS	13	14	15	16	17	18	19	20	21
0	31.43	34.83	42.08	47.02	48.72	50.24	53.64	60.89	66.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	24.34	39.62	5.52	10.77	41.59	43.29	45.22	60.50	0.00

KWS.E	13	14	15	16	17	18	19	20	21
Up-Auto	51.74	49.27	48.27	47.61	47.2	46.74	44.27	43.35	42.59
Up-Man	0	0	0	0	0	0	0	0	0
Chest	27.78	27.07	37.72	34.67	26.22	25.86	25.65	24.99	0

Table C.24 (Continued)

INCREMENTAL PER UNIT, DEPRECIATED INVESTMENT COSTS

	13	14	15	16	17	18	19	20	21
Up-Auto	1.412	6.419	0.385	0	0.128	0.642	6.419	0.385	1.412
Up-Man	0	0	0	0	0	0	0	0	0
Chest	0.1	0.04	0	0	0	0.048	0.1	0.04	0

	13	14	15	16	17	18	19	20	21
Up-Auto	0.107	2.14	0	0	0	0.021	2.14	0	0.107
Up-Man	0	0	0	0	0	0	0	0	0
Chest	0.003	0.022	0	0	0	0	0.003	0.022	0

	13	14	15	16	17	18	19	20	21
Up-Auto	0.588	8.558	0.642	0	0.107	0.428	8.558	0.642	0.588
Up-Man	0	0	0	0	0	0	0	0	0
Chest	0.083	0.042	0	0	0	0.028	0.083	0.042	0

CC.E

CLS	13	14	15	16	17	18	19	20	21
0	29.18	46.30	47.32	0.00	0.24	1.33	18.44	19.47	21.58
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	3.02	3.13	0.00	0.00	0.00	0.08	0.26	0.37	0.00
CCEE.E	9.109	11.99	9.392	0.149	0.179	0.368	3.263	3.462	3.787

Table C.25 Freezers

The Standards Level Module

LevIn	prev	LEV.B	lev.N	Eng: Levels = 0...12	0 ...
	-1	0	1	REM: -1='87 0='96	-1 ...
	1	1	1	1 ==> Stndrds	
	SIE	SIE.B	SIE.N	Esc = QUIT	

VCS.R Additional UVC by Level and Class. (Above Base cost.)

LEVEL -->	-1	0	1	2	3	4
Up-Auto	0	1.918	16.47	23.73	42.08	66
Up-Manual	0	0.346	1.82	12.75	24.53	44.54
Chest	0	0.411	10.77	20.38	39.62	60.5

KWS.R Kw Hrs /Yr

LEVEL -->	-1	0	1	2	3	4
Up-Auto	66.81	65.56	58.37	53.68	48.27	42.59
Up-Manual	42.5	41.52	37.34	28.86	26.52	24.45
Chest	41.51	41.25	34.67	28.55	27.07	24.99

CC.R

LEVEL -->	-1=1987	0=1996	1	2	3	4
Up-Auto	0	0	1.327	22.14	47.32	21.58
Up-Manual	0	0	0	1.611	7.499	0.365
Chest	0	0	0	1.572	3.125	0.366

Table C.26 Freezers

The Costs, Sales, and Revenue Module

Ratio of highest to lowest markup:	ratio.0	1.5	ratio.cv	0
Typical markup over UVC	mid.0	0.3	mid.cv	0
Size of firm as % of industry	size.0	0.2		

CALIBRATION CASE

	Indst Ship	Relatv Ship.	-------- Firm -------- Ship.	Price	Rev.			Weighted
	0.16	Q%	Q.1	P.1/Range	R.1	m.1	UVC.1	175.04
Up-Auto	0.16	0.13	0.03	268.52	8.37	1.30	206.55	26.23
Up-Man	0.47	0.38	0.09	225.97	21.30	1.28	176.06	67.63
Chest	0.60	0.49	0.12	212.25	25.46	1.28	166.05	81.18
TOTAL S	1.22	0.20	0.25	224.66	55.12	1.28	0.20	175.04
	IS.0	Q.CV	Q.0	P.0	R		P.CV	UVC

BASE CASE

	Rule-of-Thb d P	Rule-of-Thb Price		Pi.B	Op Cost Ratio	Weightd OpCst-R	Qi.B	Ri.B
Up-Auto	2.49	8.44	0.19	270.32	0.98	0.12	0.03	8.42
Up-Man	0.44	21.33	0.02	226.39	0.98	0.38	0.09	21.33
Chest	0.53	25.51	0.03	212.74	0.99	0.49	0.12	25.51
	0.112178	55.282481	0.25	225.30	55.26	-0.01	0.25	55.26
	Alpha.B	Sum P (2)	Sum (3)	P.B	Sum(Ri) check=R.B	OC%.B0	Q.B	R.B

NEW STANDARDS CASE

	Rule-of-Thb d P	Rule-of-Thb Price		Pi.N	% Chng Op Cost	Weightd OpCst-R	Qi.N	Ri.N
Up-Auto	22.79	8.99	16.03	286.72	0.87	0.11	0.03	8.85
Up-Man	2.34	21.31	0.51	228.26	0.88	0.34	0.09	21.31
Chest	13.77	26.85	22.51	224.34	0.84	0.41	0.12	26.65
TOTAL	0.01	57.15	39.05	233.77	56.81	-0.14	0.24	56.81
	Alpha.N	Sum P (2)	Sum (3)	P.N	Sum(Ri)	OC%.N0	Q.N	R.N

Table C.27 Freezers

The One-Times Cost Amortization Module

COSTS AND ASSETS OF ONE-TIME INVESTMENT

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	%NC	0.50	
(as opposed to replacement capital)			

COMPUTATIONS

DESCRIPTION		NAME	VALUE	
Continuous After-Tax WACC		ATR	0.06	
Weighted CC Lead-Time	0	0.28757	0.54	0.26
Cumulative CC Lead-Time		LTC.0	1.09	
exp(-ATR*TL)		EMRT	0.71	
exp(-ATR*L)		EMRL	0.64	
Rate of tax benefit	3.2968	BN	0.06	
Remaining tax life		RTL	5.00	years
Tax Benefit Rate:		BEN	0.03	
Discount factor:		DIS	0.68	
Loss of tax benefit on portion				
capital with remaining tax		LEC1	0.13	
Loss of tax benefit on				
capital expenditure in the		LEC2	0.10	
LEVELIZED CC			GROSS	TAX EFF
Initial Cost			1.00	
Tax Benefit of Straight-Line				0.31
Savings from not replacing			-0.34	
Loss of Tax Benefit from				-0.23
Present Value of CC:			0.66	0.07
Adjusted for Capital Lead			0.72	0.08
Levelized Tax Benefit: 1-X				0.00
LEVELIZED CC FACTOR		CCLF	0.11	0.02

Table C.27 (Continued)

AVERAGE ASSET FACTOR				
Asset Factor for Any New Cap.		AFB	0.57	
Average Asset Factor for		AAF	0.29	
INPUT				
NEW CAP. COST: 1987-96	CC.B0	0		
1996 CHANGE	CC.N	0.18		
COEFFICIENTS OF	CCL.CV	0.2		
	CC.B.CV	0.25		
OUTPUT-------	-------	--------	--------	------
	BASE CASE		NEW	
Levelized 1-X CC: Gross	LCC.B	0	LCC.N	0.02
Levelized 1-X CC: Tax Effects	LCC.TB	0	LCC.TN	0.00
Levelized 1-X CC: Net	LCC.NB	0	LCC.NN	0.02
Levelized 1-X Assets	LA.B	0	LA.N	0.05
		Fudge NEW	0.00	
		Fudge ORI	3.95	

Table C.28 Freezers

The Long-Run Model Module

CALIBRATION CASE		A.F	A.Q	A:R	A
	Assets -->	0.02	1.08	1.10	60.53
	Costs except taxes	TC.F	TC.Q	TC:R	TC
	and equity -->	0.10	0.80	0.90	49.60
		EC.F	EC.Q	EC:R	EC
	Economic costs -->	0.07	0.57	1.00	54.88
	Economic Income			EI:R	0.00
	Markup (mu - 1)			mu1	0.12
	Price Leader's elasticity of demand:				-9.19
BASE		A.BF	A.BQ		A.B
	Assets	1.23	241.65		60.59
		TC.BF	TC.BQ		TC.B
	Costs except taxes	5.51	180.27		49.73
		EC.BF	EC.BQ		EC.B
	Economic costs	3.60	128.54		54.96
	Total Working Capital Correction Assets	WCA.B	0.09		
	Working Capital Correction (Per Unit EC)	WCCEC.B	0.02		
	Total Working Capital Correction (Interest)	WCCI.B	0.00		
NEW		A.NF	A.NQ		A.N
	Assets	1.23	241.65		61.28
		TC.NF	TC.NQ		TC.N
	Costs except taxes	5.51	187.74		51.17
		EC.NF	EC.NQ		EC.N
	Economic costs	3.60	133.66		55.92
	Total Working Capital Correction Assets	WCA.N	1.27		
	Working Capital Correction (Per Unit EC)	WCCEC.N	0.29		
	Total Working Capital Correction (Interest)	WCCI.N	0.03		

Table C.28 (Continued)

Assets	-----CAL------		----BASE----		----NEW---	
Shipments	Q	0.25	Q.B	0.25	Q.N	0.24
Price	P	224.66	P.B	225.30	P.N	233.77
Revenue	R	55.12	R.B	55.26	R.N	56.81
Unit Var. Cost	UVC	175.04	UVC.B	175.62	UVC.N	183.09
V. Cost Goods Sold	VCGS	42.95	VCGS.B	43.07	VCGS.N	44.50
1X tax benefit			X1T.B	0.00	X1T.N	0.00
Pre-tax cost	PTC	49.60	PTC.B	49.73	PTC.N	51.19
Taxes	TAX	1.99	TAX.B	1.99	TAX.N	2.03
Net Income	NI	3.53	NI.B	3.54	NI.N	3.59
Economic Income	EI	0.24	EI.B	0.24	EI.N	0.26
Equity	EQ	48.42	EQ.B	48.47	EQ.N	49.02
Retrn on Eqity	ROE	7.30%	ROE.B	7.30%	ROE.N	7.33%

Table C.29 Freezers

The Short -Run Module

Short-Run "Supply Elasticity of Price":			SRQE.0	0.16
(Q/P)*dP/dQ				
Standard Error of SRQE			SRQE.SD	0.12
Random Value selected for this run:			SRQE	0.16
R.S	56.77	P.N	233.77	
UVC.S	183.09	Q.N		0.24
VCGS.S	44.52			
TC.S	51.17		ap	bp
TAX.S	2.02	P=a+bQ	197.06	149.58
PTC.S	51.19	0.98	cq	dq
NI.S	3.56	Q=c+dP	0.35	-0.00
A.S	61.28			
EQ.S	49.02	P.S	233.44	
ROE.S	0.07	Q.S		0.24
		Check P	233.45	
		Check Q		0.24

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.30 Freezers

The Charts Module

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	-0.430	-0.989	-0.001	-0.004	-0.010	-0.011
RD	1.600	3.679	0.001	0.001	0.001	0.002
ECC	0.068	0.075	-0.000	-0.000	-0.001	-0.000
EP	0.005	0.015	-0.000	-0.000	-0.000	0.000
FCA	0.100	0.160	0.001	0.002	0.004	0.005
F1X	0.200	0.348	-0.000	-0.002	-0.005	-0.001
CC.N	0.180	0.219	-0.000	-0.001	-0.002	-0.000
dVC.N	8.056	10.805	0.000	0.001	0.000	0.001
ro.N	0.000	0.300	-0.001	-0.002	-0.005	-0.007
SRPR	0.157	0.594	0.000	0.000	0.000	0.000

Table C.31 Freezers

The Financial Module

DESCRIPTION (FINANCE PAGE)	RANGE NAME	INPUT VALUE	RANGE NAME	C.V.
RATES OF COST				
After Tax Equity Cost of Capital	ECC.0	0.068	ECC.CV	0.1
Interest Rate on Debt	I.0	0.025	I.CV	1
Interest Lost on Cash	ICash.0	0.01	ICASH.CV	1
Rate of Depreciation	Dep.0	0.177		
Tax Rate	T.0	0.36	T.CV	0.2
ASSETS and COSTS as a PERCENT of REVENUE				
Cash	C:R.0	0.232	C:R.CV	1
Inventory & Receivables	IR:R.0	0.642	IR:R.CV	0.2719
Depreciable Assets	DA:R.0	0.224	DA:R.CV	0.3689
G & A	G&A.0	0.168	G&A.CV	0.4
Engineering	Eng	0.012		
FIXED AND VARIABLE COST SPLIT				
Fixed Part of All Costs & Depr Assets	FCA.0	0.1	FCA.CV	0.5
Fixed Part of 1-X Capital Cost	F1X.0	0.2	F1X.CV	0.6
OTHER				
Economic Profit	EP.0	0.005	EP.CV	0.01
Debt to Equity ratio	DER.0	0.25	DER.CV	0.4336
Markup on typical model	"mid	0.3		
Ratio of highest to lowest markup	"ratio	1.5		
OUTPUT	NAME	VALUE		
Depreciation	DRR	0.04		
G&A to Overhead Ratio	G:O	0.93		
Engineering to Overhead Ratio	E:O	0.07		
Debt Ratio	DR	0.20		
Equity Ratio	ER	0.80		
Pre-Tax Equity Cost of Capital*	PECC	0.11		
Weighted Average Cost of Capital	WACC	0.09		
After Tax WACC	ATWACC	0.06		
Return on Equity	ROE	0.07	'ROE.0	

Table C.32 Freezers

Cash Flow Analysis

FREEZER ANALYSIS			Base Year			Standards level 1				
GRIM Switch	0		1989	1990	1991	1992	1993	1994	1995	1996
Price/Unit			225.3	225.3	225.3	225.3	225.3	225.3	225.3	225.30
Unit Sales			1.2263	1.2263	1.2263	1.2263	1.2263	1.2263	1.2263	1.23
Revenues			276.27	276.27	276.27	276.27	276.27	276.27	276.27	276.27
	New	Base								
CGS	181.53	173.48	212.73	212.73	212.73	212.73	212.73	212.73	212.73	212.73
Labor	23.335	22.53	27.627	27.627	27.627	27.627	27.627	27.627	27.627	27.63
Material	121.12	114.9	140.9	140.9	140.9	140.9	140.9	140.9	140.9	140.90
Overhead	29.753	28.725	35.225	35.225	35.225	35.225	35.225	35.225	35.225	35.23
Depreciation	7.3222	7.3222	8.9789	8.9789	8.9789	8.9789	8.9789	8.9789	8.9789	8.98
SG&A			46.967	46.967	46.967	46.967	46.967	46.967	46.976	46.98
R&D			5.5255	5.5255	5.5255	5.5255	5.5255	5.5255	5.5255	5.53
Product Conversion			0	0	0	0	0	0	0.0097	0.01
Profit Before Tax			16.576	16.576	16.576	16.576	16.576	16.576	16.567	16.56
Taxes (Rate)			5.9675	5.9675	5.9675	5.9675	5.9675	5.9675	5.964	5.96
Net Income Before Financing			10.609	10.609	10.609	10.609	10.609	10.609	10.603	10.60
Cash Flow										
Net Income			10.609	10.609	10.609	10.609	10.609	10.609	10.603	10.60
Depreciation			8.9789	8.9789	8.9789	8.9789	8.9789	8.9789	8.9789	8.98
Change in Work Capital			0	0	0	0	0	0	0	0.00
Cash Flows from Operations			19.59	19.59	19.59	19.59	19.59	19.59	19.58	19.58
Capital Expenditures (Cash used in invest)			-11.05	-11.05	-11.05	-11.05	-11.05	-11.05	-11.05	-11.05
Conversion Expenditure			0	0	0	0	0	0	-0.025	-0.04
Cash Used in Investments			-11.05	-11.05	-11.05	-11.05	-11.05	-11.05	-11.08	-11.09
Net Cash Flow			8.54	8.54	8.54	8.54	8.54	8.54	8.51	8.49

73.174

Table C.33 Freezers

Cash Flow Analysis

1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
$225.30	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32	$235.32
1.23	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
276.27	285.10	285.10	285.10	285.10	285.10	285.10	285.10	285.10	285.10	285.10	285.10	285.10	285.10
212.73	220.16	220.16	220.16	220.16	220.16	220.16	220.16	220.16	220.16	220.16	220.16	220.16	220.16
27.63	28.27	28.27	28.27	28.27	28.27	28.27	28.27	28.27	28.27	28.27	28.27	28.27	28.27
140.90	146.75	146.75	146.75	146.75	146.75	146.75	146.75	146.75	146.75	146.75	146.75	146.75	146.75
35.23	36.15	36.15	36.15	36.15	36.15	36.15	36.15	36.15	36.15	36.15	36.15	36.15	36.15
8.98	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
46.98	47.14	47.14	47.14	47.14	47.14	47.14	47.14	47.14	47.14	47.14	47.14	47.14	47.14
5.53	5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70	5.70
0.02	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
16.56	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80
5.96	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41
10.60	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39
10.60	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39	11.39
8.98	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.58	18.88	20.38	20.38	20.38	20.38	20.38	20.38	20.38	20.38	20.38	20.38	20.38	20.38
-11.05	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06
-0.04	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
-11.09	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06	-11.06
8.49	7.82	9.32	9.32	9.32	9.32	9.32	9.32	9.32	9.32	9.32	9.32	9.32	9.32

APPENDIX D. ELECTRIC UTILITY IMPACT MODELING

D.1 INTRODUCTION

This appendix summarizes the methodology used to calculate utility avoided costs for energy savings that result from the imposition of appliance efficiency standards. The second section explains the conventions and background information used in the analysis, and the third and fourth sections explain the basis for valuing the energy and capacity savings of the standards. The goal of this analysis is to calculate the peak and capacity savings and the avoided cost of electricity saved. Avoided costs contain both the marginal fuel and marginal capacity value of each kWh saved by the proposed standards in each year of the period analyzed.

D.2 AVOIDED COST BACKGROUND AND CONVENTIONS

The analysis adopts the standard utility convention that the value of electricity savings, commonly called *avoided cost*, can be broadly separated into *energy* or variable cost savings and *capacity* or fixed cost savings. The variable impact measures the production costs avoided by reduced electrical generation. The largest variable component by far is the cost of the fuel not burned, but there are also avoided labor and variable operation and maintenance costs to be considered. The fixed component is intended to measure the benefit of reduced system load during peak periods. Since electricity cannot normally be stored at utility scales, one way to measure the cost avoided by a lower peak demand is to estimate the lowest possible cost of maintaining the cheapest generator available on hand year-around simply to generate the last peak kW demanded. By convention, this hypothetical generator is a low-cost gas turbine, and its capital cost per kW is called the *gas turbine proxy*. In addition to the generating capacity itself, lowering peak demand will also deliver a saving in the need for peak transmission and distribution (T&D) capacity, which should be included in the capacity savings.

An appliance standard analysis typically relies on disaggregation by National Electric Reliability Council (NERC) region of capacity savings and energy savings, followed by re-aggregation to the national level. Disaggregation is necessary because different regions need capacity at different times, and the relative energy savings attributable to each region for heating, cooling, and all other appliances vary substantially. For the purposes of calculating utility avoided costs, *heating appliances* are defined as electric heat pumps in heating mode and electric resistance heat, *cooling appliances* are defined as room and central air-conditioning plus heat pumps in cooling mode, and *baseload appliances* are defined as all other appliances affected by standards, including all residential refrigeration. Since the energy consumption of residential refrigeration varies little seasonally or regionally, unlike many prior appliance standards analyses covering heating or cooling appliances, only national averages are used in this analysis.

D.3 ENERGY COST SAVINGS

The energy value of load shape modifications is measured by the marginal cost of electricity, which depends on the variable cost of operating the power plants that will change their output in response to a change in load. This variable cost consists primarily of the cost of fuel for these marginal units. U.S. utilities are characterized by a substantial difference among the prices of fuels used to generate electricity on the margin. Marginal resources of a utility can be either more expensive oil and gas or less expensive non-oil-and-gas resources, typically coal or economy purchase of power generated by coal. Very low variable-cost nuclear or run-of-river hydro resources are usually base loaded and thus only rarely contribute to marginal energy costs. Even though the relative cost of natural gas as a generation fuel has decreased in recent years, and seasonal price fluctuations often make it cheaper than coal bought under long-term contract, this oil and gas fraction approach is still valid because gas-fired resources are more likely to be marginal because of their greater operating flexibility.

The relevant marginal cost is the cost of each marginal fuel weighted by the fraction of time each fuel is on the margin plus any variable operation and maintenance (O&M). Formally, this relationship can be simplified as follows:

$$\text{Marginal Cost} = OGF_m \cdot \text{Natural Gas Price} + NOGF_m \cdot \text{Coal Price} + \text{Variable O\&M}$$

To calculate the oil-and-gas fraction on the margin OGF_m, the total amount of oil- and gas-generated electricity is divided by the total forecasted amount of electricity generation from NERC data [1] to obtain the *total oil and gas fraction,* OGF_t. OGF_t can then be related to OGF_m with a simplified load-duration curve (LDC) for each region. Figure D.1 shows this LDC, where B' is the OGF_m. The non-oil-and-gas fraction ($NOGF_m$) is simply $1 - OGF_m$.

The purpose of the following derivation is to calculate the OGF_m (B'). First, note that

$$\tan\Omega = \frac{A}{B}$$

and B = 1.0, which implies that

$$A = B \tan\Omega = \tan\Omega$$

The normalized area of the triangle at the top of the LDC represents the fraction of total generation from oil and gas (OGF_t). Calculating the area of this triangle yields

$$OGF_t = 0.5A'B' = 0.5(B\Omega)B'$$

B' can thus be expressed as follows:

$$B' = OGF_m = \frac{2OGF_t^{1/2}}{(\tan\Omega)}$$

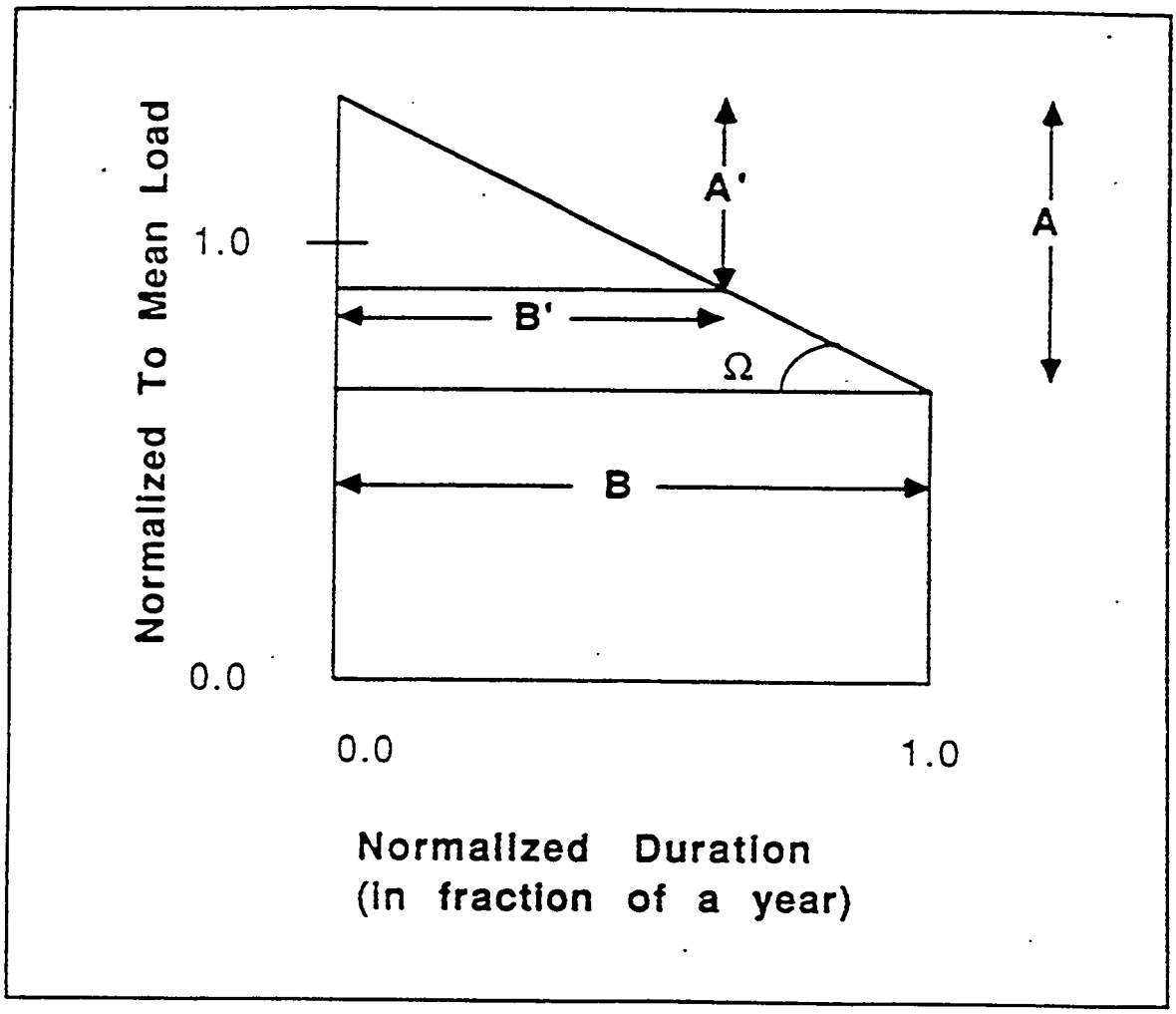

Figure D.1 Simplified load-duration curve

The appropriate value for $A = \tan \Omega$ is determined empirically: when $OGF_t \geq 0.4$, $OGF_m = 1.0$. The value of A must therefore be greater than or equal to 0.8. Note that when $A = 0.8$,

$$\text{Normalized peak demand} = 1.4 \cdot \text{mean load}$$

and

$$\text{Normalized minimum load} = 0.6 \cdot \text{mean load.}$$

A weighted-average marginal energy cost is determined for each of the NERC regions using the above formulas, and a national weighted-average marginal cost for heating and baseload energy savings is calculated using the regional fuel price multipliers and energy savings fractions described above. This approach assumes that the marginal oil-and-gas fractions remain constant over the analysis period.

For cooling energy savings, the appropriate marginal energy cost (MEC) will exceed the annual average MEC because the OGF_m is typically higher in summer than in winter. The annual average OGF_m is approximately 52% when calculated using the energy savings fractions for heating, cooling, and baseload energy. Cooling MECs are calculated using a national OGF_m of 60% to account for the seasonal differences in marginal fuel usage. Table D.1 shows the annual average OGF_m for each NERC region.

Table D.1 Utility Marginal OGFs, and Year of Capacity Need by NERC Region

NERC Region	Marginal OGF	Year Capacity is Needed
NPCC	0.88	now
MAAC	0.61	now
ECAR	0.16	now
MAIN	0.19	now
SPP	0.77	1999
SERC	0.47	now
ERCOT	0.92	1999
MAPP	0.15	1997
WSCC	0.55	1999
National Avg.	0.52	

The calculation of MECs in year j can be summarized as follows:

$$OGF_m = \sum_{i=1}^{N} ESF_i \cdot OGF_m^i$$

$$NOGF_m = 1 - OGF_m$$

$$EC_j = (OGF_m \cdot \text{gas price}_j + NOGF_m \cdot \text{coal price} + \text{Variable O\&M}) \cdot 1.06$$

where:

i denotes a particular NERC region,
ESF_i represents the energy savings fraction for region *i*, and
1.06 adjusts for transmission and distribution losses.

Variable O&M is calculated using references [2] and [3]. Average O&M (fixed and variable) for all fossil-fuel fired steam-electric power plants for investor-owned utilities in 1990 is reported in [5] as 0.5¢/kWh (in 1990 dollars). This can be split into fixed and variable components using [2]. The analysis uses the fraction of O&M that is variable for a supercritical coal steam unit (50%) and for a natural gas combustion turbine (20%), weights these by the appropriate marginal oil and gas fractions, and applies the resulting percentage (variable O&M as a percent of total O&M) to the total O&M (0.5¢/kWh). This calculation results in a variable O&M cost of 0.33¢/kWh or 0.27 $/EJ of resource energy (in 1990 dollars).

In keeping with industry practice, labor and other variable cost savings are ignored in this analysis. This practice has arisen first, because labor costs are very low relative to fuel and capital, and, second, because the regulatory treatment of labor cost recovery in the general rate case cycle makes savings difficult to estimate.

D.4 CAPACITY SAVINGS

D.4.1 Value of Capacity Savings

The value of capacity is the value associated with having additional generating capacity available to meet load increases. For utility systems with excess capacity, this value may be equal to or very close to zero. When capacity does have value, this value is commonly measured by the cost of the marginal investment a utility would make to expand system capacity, such as the purchase of a combustion turbine [4]. This investment adds reliability to the system *even if it never operates*, since it is ready to prevent outages if another generating unit fails. If the utility chooses to build another type of plant with higher capital costs (such as a baseload coal unit), it must be basing this choice on other considerations than meeting peak demand alone. Baseload coal plants, for example, can have lower operating costs than gas-fired generation and can be used to displace generators with higher variable cost per kWh. The additional capital cost of a coal plant is thus not related to capacity alone but to energy benefits as well [4]. The use of capacity valuation based on the gas turbine proxy, therefore, has a rationale behind it and is widespread in the industry.

The additional coal plant capital cost (sometimes called energy-related capital) is contained implicitly in the marginal energy cost described above. Consider a utility with a large number of

expensive oil and gas units on the margin and dwindling adjusted reserves. Such a utility would need capacity to preserve the system's reliability at an acceptable level. It would also benefit from installing a baseload unit that would reduce oil and gas consumption at the margin. This reduction in fuel costs compensates for expending capital in addition to the cost of a combustion turbine. A utility with coal on the margin a large fraction of the time would not have the same incentive and would probably install a combustion turbine to preserve reliability.

The utility will choose to have a baseload plant come on line when the present value of the energy-related capital cost of the plant is just equal to the PV of the reduction in fuel costs from the operation of the plant. The reduction in fuel costs and hence the incentive to build a baseload plant depend on the marginal oil and gas fraction. Thus, the marginal energy cost contains an avoided capital component in addition to an avoided fuel component.

The following two rules are applied to determine the value of capacity for the year 1998 based on DOE's interpretation of NERC data [5]:

1. If the NERC region is forecast to have an adjusted reserve margin larger than 5% of forecasted peak demand, there is no reliability value for capacity.[1]

2. If the NERC region is forecast to have a capacity deficiency (operating adjusted reserves of less than 5%), the capacity value for the combustion turbine is applied.

After 1998, DOE has not calculated adjusted reserve margins and it is assumed that every region will need capacity. Table D.1 shows the year that each region will need capacity based on these rules.

The calculations in this analysis follow standard industry practice developed for determining the value of reductions in peak load caused by cogenerators and other small power producers [5]. First, the present value of revenue requirements is calculated for a combustion turbine based on its capital cost ($400 per kW in 1987 dollars), a discount rate equal to the utility rate of disadvantage or ROD (10.0%), a fixed charge rate (13.0%),[2] a turbine lifetime of 25 years, and the assumption of straight-line depreciation. The calculation is repeated for each year of the analysis assuming no

---

[1] An equivalent rule of thumb for adequate reliability is that the overall reserve margin should equal about 20% of forecasted peak demand. *Adjusted reserves* are defined by DOE as [Planned Capacity + Net Power Transfers(in) - (Forced Outages + Scheduled Maintenance + Other Outages) - Forecasted Peak Demand]. *Overall reserves* are defined as [Planned Capacity + Net Power Transfers(in) - Forecasted Peak Demand [6]. This analysis does not account for the possibility that the standards could cause a significant change in a region's adjusted reserves, and hence change the date when capacity is needed.

[2] The estimates of ROD and fixed charge rate have been calculated based on current interest rates and the corporate tax rate (34%) adopted in the 1986 tax revisions. The standard utility capital structure from EPRI [2] is used (45% debt, 10% preferred stock, and 10% common stock). Nominal costs of capital are 10% for debt and preferred stock and 13.4% for common stock.

real capital cost escalation for the combustion turbine. Next, the present values are spread over time using an economic carrying charge (ECC). The ECC technique yields a current dollar stream of costs (escalating at an inflation rate of 5%) that has the same present value (when discounted at the ROD) as the original stream. A stream of costs that escalates at the inflation rate is also constant in real terms, so this technique *levelizes* the costs to some constant dollar value ($47.07 per kWa in 1990 dollars). This cost is then converted to dollars per kWh of electricity savings by the method detailed in the next section.

D.4.2 Amount of Capacity Savings

An analysis of the load shape impacts of improved efficiencies for residential appliances must consider both the magnitude and timing of the impacts relative to periods of high system loads because residential class load shape changes only have reliability value for the system when they coincide with times of high system loads. This relationship is approximated from modeling runs of the LBL Hourly and Peak Demand Model and two LBL utility case studies [6,7].

There are large but varying degrees of coincidence between residential peak loads and system peak loads. The case studies show that the average change in the 250 highest residential hourly loads is a reasonable measure of the system-level capacity value of appliance standards.

The results of these studies also indicated that load shape impacts, measured as a conservation load factor (CLF), vary in a predictable fashion across utility service territories. A conservation load factor is the annual average load savings divided by the peak savings of the conservation measure [8]. Peak savings are defined as the forecasted differences between the average of the highest 250 hourly loads before and after the appliance efficiency standards are implemented. The peak savings for residential appliances are calculated using the LBL Residential Hourly and Peak Demand Model [9].

Conservation load factors can be used to characterize the peak load impacts of heating, cooling, and baseload energy savings. More formally, a conservation load factor can be expressed as:

$$\text{CLF} = \frac{\text{Annual Load Savings}}{\text{Peak Load Savings}}$$

Multiplying both numerator and denominator by 8760 hours gives:

$$\text{Peak Load Savings} = \frac{\text{Annual Energy Savings}}{\text{CLF} \cdot 8760}$$

$$\text{CLF} \cdot 8760 = \frac{\text{Annual Energy Savings}}{\text{Peak Load Savings}}$$

The peak load savings can be expressed as a function of the annual energy savings and the CLF. Another useful form of this equation is as follows:

$$CLF = \frac{\text{Annual Energy Savings}}{\text{Peak Load Savings} \cdot 8760}$$

CLF · 8760 = kWh of energy savings needed to yield 1 kW of peak load savings.

The conservation load factor for residential refrigeration is 0.89. Since refrigeration loads do not vary significantly seasonally or regionally, the capacity saved by standards can be inferred directly using the CLF.

Therefore, the calculation of avoided capacity costs can be summarized in the following equation:

$$ARC_{Baseload,j} = \frac{\text{Capacity Value}}{CLF_{Baseload} \cdot 8760} \cdot 0.3 \cdot 1.2 \cdot \Sigma\ ESF_{Baseload,j}$$

where:

$ARC_{Baseload,j}$	= Avoided reliability costs in 1990 $/EJ in year j,
Capacity Value	= value of 1 kW of peak load savings in 1990 $/kWa,
0.3	= energy conversion efficiency including T&D losses,
$CLF_{Baseload}$	= conservation load factor for baseload appliances,
1.2	= reserve margin adjustment needed for adequate reliability,
$\Sigma ESF_{Baseload,j}$	= sum of baseload ESFs for regions that need capacity in year j.

Capacity savings are peak load savings for only those regions that need capacity in a given year. Load savings in regions that do not need capacity contribute to deferring capacity additions in future years, but this analysis does not account for the value of such deferrals.

Table D.2 Sums of Baseload Energy Savings Fractions for NERC Regions That Need Capacity

Year	Baseload ESF	Regions Needing Capacity
1998	0.596	6
1999	1.000	9
2000	1.000	9

D.4.3 Avoided Transmission and Distribution Capital Costs

Recently, utility planners have begun to account for capital costs of the T&D system that can be avoided by reductions in electricity use. There are a wide range of estimates of such costs, depending on the particular characteristics of the utility system and of the conservation programs and policies that lead to such reductions in electricity use. Krause *et al.* [10] review the most recent studies on this topic and settle on a range for T&D savings of from $10 to $40/kWa. Krause *et al.* also cite reasons why this range is probably too low and suggest that further work will probably raise these values. For example, they cite marginal T&D cost estimates of nine different utilities that (on average) totaled more than $100/kWa.

We adopt the lower end of Krause *et al.*'s range ($10/kWa) as our estimate for avoided T&D capital costs. We choose this lower bound estimate because of the substantial uncertainties in applying such estimates (which are derived at the level of individual utilities) in national analyses.

REFERENCES

1. North American Electric Reliability Council. 1990. *Electricity Supply and Demand for 1990-99.*

2. Electric Power Research Institute. 1989. *TAG-Technical Assessment Guide: Vol. I: Electricity Supply-1989.* EPRI P-6587-L. September 1989.

3. U.S. Department of Energy. 1992. *Electric Plant Cost and Power Production Expenses 1990.* Energy Information Administration. DOE/EIA-0455(90). June.

4. National Economic Research Associates. 1977. *How to Quantify Marginal Costs: Topic 4.*

5. U.S. Department of Energy. 1990. *Staff Report: Electric Power Supply and Demand for the Contiguous United States,* 1989-1998, DOE/IE-0008.

6. Eto, J., J. Koomey, J. McMahon, P. Chan. 1986. *Financial Impacts on Utilities of Load Shape Changes: The Nevada Power Company,* Lawrence Berkeley Laboratory Report LBL-21597.

7. Eto, J., J. Koomey, J. McMahon, P. Chan. 1986. *Financial Impacts on Utilities of Load Shape Changes: The Texas Utilities Electric Company,* Lawrence Berkeley Laboratory Report LBL-21598.

8. Koomey, J., A. H. Rosenfeld and A.K. Gadgil. 1990. Conservation Screening Curves to Compare Efficiency Investments to Power Plants. *Energy Policy.* vol. 18, no. 8. p. 774.

9. Verzhbinsky, G., H. Ruderman, and M. Levine. 1986. *The Residential Hourly and Peak Demand Model: Description and Validation,* Lawrence Berkeley Laboratory Report LBL-18698.

10. Krause, F., J.F. Bush and J.G. Koomey. 1992. *Incorporating Global Warming Risks in Power Sector Planning: A Case Study of the New England Region.* Lawrence Berkeley Laboratory LBL-30797 (vols. I and II). November, 1992.

APPENDIX E. SI UNIT CONVERSIONS

1.0 m^2	=	10.764 ft^2
1.0 L	=	1.0 $dm^3 = 10^{-3}\ m^3$
	=	0.035315 ft^3 = 0.423776 board ft.
	=	0.264172 U.S. gals.
1 EJ	=	0.947817 Quads
1 GJ	=	0.947817 MBtu
1 kJ	=	0.947817 Btu
1 t	=	1000 kg = 1 Mg
	=	2205 lbs. = 1.102 short tons
1 Btu/h·ft·°F	=	1.73 W/m·K
	=	0.144 Btu·inch/h·ft^2·°F

DOE/EE-

DRAFT ENVIRONMENTAL ASSESSMENT FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

July 1995

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

ENVIRONMENTAL ASSESSMENT FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

1. INTRODUCTION AND NEED FOR PROPOSED ACTION

This Environmental Assessment (EA) on the candidate energy conservation standards for refrigerators, refrigerator-freezers, and freezers was prepared pursuant to the National Environmental Policy Act of 1969 (NEPA), regulations of the Council on Environmental Quality, Title 40, Code of Federal Regulations, Parts 1500 through 1508. The candidate conservation standards are being proposed pursuant to the Energy Policy and Conservation Act, as amended by the National Energy Conservation Policy Act and the National Appliance Energy Conservation Act [1].

The EA presents the results of the associated environmental impacts from four energy conservation standards for this type of household appliance. 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 this type of product were finalized, i.e., the "no action" alternative.

The primary environmental concern addressed is atmospheric emissions from fossil-fueled electricity generation. Residential refrigeration is fueled almost entirely by electricity, and this standard is not expected to affect propane residential refrigeration, which is widely used only where grid power is unavailable. The design options for this appliance type result in decreased electricity use and, therefore, a reduction of power plant emissions. 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_2 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 gradually to raise the mean global temperature.

Although the quantity of raw materials used per appliance will remain relatively constant, in most scenarios increased initial cost is expected to decrease slightly the number of appliances sold, resulting in small decreases in raw materials used. The main effect of the appliance production decrease is reduced SO_2 emitted in steel production. That reduction is small, however, in comparison to the SO_2 decreases from fuel burning avoided at power plants. The contribution from steel production is not included in the estimates for net SO_2 decreases resulting from design changes in these products.

The effects on particulate emissions related to a standard-induced decrease in electricity generation would be minor compared to effects on decreases in SO_2, NO_x, and CO_2. For example, in 1984, power plants contributed only 7% of U.S. total particulate emissions as compared to contributions of 83% and 34% to total SO_2 and NO_x emissions, respectively. Though the reduction

in particulate emissions would be relatively small, any reduction would possibly be beneficial to improving the quality of surface water. Since the amount of particulates emitted would be decreased, it is very likely that less particulates would reach the surface water.

Reductions in particulate emissions accompanied by decreases in SO_2 and NO_x would have other beneficial effects on the environment. The resultant improvement to air quality and the decreased potential of acid rain formation would help improve the quality of wetlands and fish and wildlife as well as aid in the preservation of historical and archaeological sites. Reductions in NO_x emissions within warm urban areas is particularly beneficial because it is an urban smog precursor gas as well as an air pollutant in its own right.

2. METHODS OF ESTIMATING ENVIRONMENTAL IMPACTS

The greatest impacts of the proposed standards would be a reduction in electricity demand growth. The main environmental effects of power plants on air and water quality result from emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2). With the proposed standards lessening the need for electricity generation, power plant emissions would be reduced.

2.1 Baseline Emissions

The estimates of emissions of SO_2, NO_x, and CO_2 in Tables 4-7 are also expressed as a percentage of U.S. power plant emissions for the year under consideration. In the Service Report that accompanies the 1991 National Energy Strategy (NES) [2], the impact on power plant emissions as a result of revisions to Title V of the 1990 Clean Air Act Amendments, P. L. 101-549, are estimated.

NO_x emissions are required to be reduced by 1.8 Mt (2 million short tons) by the year 2000 under the legislation. However, no emissions cap exists for NO_x, and the goals of the legislation are implemented through command-and-control emissions rates that vary by fuel burned and type of boiler. Therefore, while NO_x emissions per kWh generated are expected to fall, they will fall less than emissions of SO_2. Also, it is less clear whether the Act's emissions reduction target will be met because enforcement is indirect. In this case, it is reasonable to report predicted reductions in physical NO_x emissions as a result of the appliance standards and that approach is adopted here.

The case of SO_2 emissions is more complex. The legislation calls for SO_2 emissions reductions in two phases. In the first phase of the planned reductions (beginning December 31, 1995 and carrying through the year 2000), electric utilities will have several options for reducing their SO_2 emissions to comply with the allowance constraints imposed by the provisions of the Clean Air Act. The major options are 1) to decrease their use of high emission units and increase the use of their clean units, 2) to switch units using high sulfur coal to low sulfur coal, 3) to retrofit plants emitting

at a high rate with emissions-reduction technologies (e.g., scrubbers), 4) to purchase allowances from other utilities who reduce their emissions below their permitted levels, and 5) to purchase power rather than generate it. Most utilities will make use of a combination of these options to minimize the cost of complying with the allowance constraints. Total SO_2 emissions by utilities cannot exceed 8.1 Mt (8.9 million short tons) after December 31, 2000.

In the second phase of the planned reductions (beginning December 31, 2000), the options available to electric utilities for maintaining the 8.1 Mt cap will broaden with the expected introduction of new, advanced generating technologies. However, during this period utilities are less able to reduce emissions by changing the way they utilize their plants. Since most plants will be fully utilized, there will be few opportunities for reducing emissions by decreasing the use of a high emission plant or for further fuel switching.

The adoption or non-adoption of the efficiency standard for this type of appliance will likely not affect the physical emissions of SO_2, which will hover near the ceiling. This is not to say that there is no SO_2 emissions benefit to be derived from the lowered electricity demand implied by appliance standards. Actual physical emissions will not be lowered, but the demand for SO_2 allowances by electricity generators will be reduced, resulting in lower allowance prices, and lower electric utility compliance costs. In other words, lowered generation is a costless contribution towards the SO_2 clean-up required by the Act. Estimating these effects as they reverberate through SO_2 allowance trading, however, is too ambitious for this analysis. Here, therefore, emissions reductions by weight are simply estimated and reported, as if the allowance trading market did not exist. Further, no effort is made to estimate the reduced compliance cost, which may ultimately benefit utility companies, their stockholders, or their ratepayers. The actual distribution of benefits depends upon the regulatory regime.

In the report accompanying the 1991 NES, two possible outcomes are presented, a flexible case and a restricted case, so that the effect of different levels of permitted trading of emission allowances can be evaluated. (The report does not go beyond this explanation in defining the differences between the two cases.) As presented in the report, the results for the two cases are virtually identical. Because the two cases are so similar, the U.S. power plant emission projections for the three effluents under the assumptions made in the flexible case are presented only. Tables 1.a and 1.b summarize the results.

Table 1.a U.S. CO_2, SO_2, and NO_x Power Plant Emissions - Metric Units

Year	CO_2 Mt	SO_2 Mt	NO_x Mt
1995	2025	12.5	7.6
2000	2274	8.2	6.1
2010	2920	7.6	6.6
2020	3596	6.1	6.1
2030	4358	4.4	5.4

Table 1.b U.S. CO_2, SO_2, and NO_x Power Plant Emissions - American Units

Year	CO_2 *10^6 short tons*	SO_2 *10^6 short tons*	NO_x *10^6 short tons*
1995	2233	13.8	8.4
2000	2506	9.0	6.7
2010	3219	8.4	7.3
2020	3964	6.7	6.7
2030	4804	4.8	5.9

2.2 Sulfur and Nitrogen Oxide Emissions

For each of the scenarios analyzed, emissions abated from fossil fuel-burning power plants are estimated. In analyzing the impacts of design changes to the appliances, lower sulfur emissions resulting from decreased steel production are not considered. No changes in the amount of steel used per unit are expected.

In order to capture the effects of cleaner-burning power plants in future years, emission rates (g/kWh) for power plant fuel-burning are calculated from projected emissions and electrical generation data. The electrical generation data is translated below into energy use (EJ) by assuming a 30% overall energy conversion efficiency. The source of these projected emissions and electrical generation data is the report that accompanies the 1991 NES (data for Tables 1.a and 1.b was extracted from the same Service Report). Tables 2.a and 2.b present these data and the calculated emission rates for SO_2 and NO_x.

Table 2.a Electricity Generation, Emissions Data, and Emission Rates for SO_2 and NO_x at Fossil Fuel-Burning Power Plants - Metric Units

	Electricity Generation			Energy Use	Emissions		Emissions Rates(generation)	
Year	Coal TWh	Oil TWh	Gas TWh	Total EJ	SO_2 Mt	NO_x Mt	SO_2 g/kWh	NO_x g/kWh
1995	1602.2	193.7	442.0	27	12.5	7.6	5.6	3.4
2000	1814.0	179.8	605.0	31	6.7	6.1	3.1	2.3
2010	2660.6	149.9	482.5	40	7.3	6.6	2.3	2.0
2020	3727.8	67.2	292.3	49	6.1	6.1	1.5	1.5
2030	4837.3	29.0	179.2	61	4.4	5.4	0.9	1.1

Table 2.b Electricity Generation, Emissions Data, and Emission Rates for SO_2 and NO_x at Fossil Fuel-Burning Power Plants - American Units

	Electricity Generation			Energy Use	Emissions		Emissions Rates (primary)	
Year	Coal *10^9 kWh*	Oil *10^9 kWh*	Gas *10^9 kWh*	Total *Quads*	SO_2 *10^6 short tons*	NO_x *10^6 short tons*	SO_2 *10^3 tons/ Quad*	NO_x *10^3 tons/ Quad*
1995	1602.2	193.7	442.0	25.74	13.8	8.4	552.5	336.3
2000	1814.0	179.8	605.0	29.89	9.0	6.7	310.3	231.0
2010	2660.6	149.9	482.5	37.88	8.4	7.3	228.6	198.6
2020	3727.8	67.2	292.3	47.01	6.7	6.7	146.9	146.9
2030	4837.3	29.0	179.2	58.03	4.8	5.9	85.2	104.8

The calculated emissions rate data listed in Tables 2.a and 2.b represent the average SO_2 and NO_x emissions rates for all fossil fuel-burning power plants in the United States. Emissions rates were not calculated for each fuel-burning source as the emissions data supplied by the Service Report were not disaggregated according to power plant type (i.e., coal, oil, gas). To obtain emission rate values, the amount of emissions was divided by the total energy use of fossil fuel-burning power plants. The total energy use by fossil fuel-burning power plants was calculated from the electrical generation data supplied by the report accompanying the 1991 NES. The electrical generation data was disaggregated by fuel source. To obtain the total energy use (input), the electrical generation data

from each fossil fuel source was summed and then divided by the assumed efficiency of fossil fuel-burning power plants (30%), which includes transmission and distribution losses. This fossil fuel-burning power plant efficiency is consistent with that used by the LBL Residential Energy Model (LBL-REM).

The amount of SO_2 and NO_x emissions abated for any particular year is determined by multiplying the estimates of energy saved through reduced electricity generation in that year by the emission rate for that particular year. For years not covered in the Service Report, linear interpolation was used to derive emission rates and, in turn, the corresponding abated emissions.

2.3 Carbon Dioxide Emissions

Emission rates for CO_2 were derived in the same manner as those derived for SO_2 and NO_x. As presented in Table 1.a and 1.b, the report accompanying the 1991 NES also provided emissions data with regard to CO_2.[1] Table 3.a and 3.b present the CO_2 emission rate data as derived from the electrical generation data and emissions data supplied by the 1991 NES report.

Table 3.a Electricity Generation Data, Emissions Data, and Emissions Rates for CO_2 at Fossil Fuel-Burning Power Plants - Metric Units

Year	Electricity Generation			Energy Use Total EJ	Emission CO_2 Mt	Emission Rate CO_2 g/kWh
	Coal TWh	Oil TWh	Gas TWh			
1995	1602.2	193.7	442.0	27	2025	905
2000	1814.0	179.8	605.0	31	2274	875
2010	2660.6	149.9	482.5	40	2920	887
2020	3727.8	67.2	292.3	49	3596	880
2030	4837.3	29.0	179.2	61	4358	864

[1] Upon phone conversations with David Streets at Argonne National Laboratory (February 1992), it was determined that the carbon emissions data provided in the report accompanying the 1991 NES were mistakenly reported as tons of *carbon* emitted. David Streets was one of authors at Argonne who contributed to the 1991 NES report.

Table 3.b Electricity Generation Data, Emissions Data, and Emissions Rates for CO_2 at Fossil Fuel-Burning Power Plants - American Units

Year	Electricity Generation			Energy Use Total *Quads*	Emission CO_2 *10^6 short tons*	Emission Rate CO_2 *10^6 tons/Quad*
	Coal *10^9 kWh*	Oil *10^9 kWh*	Gas *10^9 kWh*			
1995	1602.2	193.7	442.0	25.74	2232.5	89.39
2000	1814.0	179.8	605.0	29.89	2506.2	86.41
2010	2660.6	149.9	482.5	37.88	3219.3	87.60
2020	3727.8	67.2	292.3	47.01	3964.2	86.90
2030	4837.3	29.0	179.2	58.03	4804.4	85.32

As with the SO_2 and NO_x emissions, the amount of CO_2 emissions abated for any particular year is determined by multiplying the estimates of energy saved through reduced electricity generation by the emission rate for that particular year. For years not covered in the Service Report, linear interpolation was used to derive emission rates and, in turn, the corresponding abated emissions.

3. RESULTS

The following results in Table 4-7 indicate what changes can be brought about in the amounts of emitted CO_2, SO_2, and NO_x by imposing efficiency standards for appliances considered in this analysis. A table is presented for each of the 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 a trial standard level for this type of appliance. Each table shows, for a specific year between 1998 and 2030, the amount of emission abated from power plant generation. Also included are the cumulative changes of each pollutant (between the years 1998 and 2030).

3.1 Sulfur and Nitrogen Oxide Emissions

Sulfur dioxide emissions would be decreased by a cumulative total of up to 1720 kt (1896 thousand short tons) between 1998 and 2030 in the level 4 scenario. In the year 2000, decreases in SO_2 will represent about 0.19% of the SO_2 emissions estimated to come from power plants in that year. In the year 2030, decreases in SO_2 emissions will represent about 1.2% of the SO_2 emissions estimated to come from power plants in that year. As discussed earlier, the possible reductions of SO_2 emissions caused by standards will reduce the utility's need to purchase allowances or permit it to save them for future use, or sell them. To the extent saved allowances are used for future emissions, the standards' net effect on those SO_2 emissions would be only a reduction in the demand for emissions allowances.

Level 4 design changes to residential refrigeration would result in an estimated decrease in NO_x emissions of 1635 kt (1802 thousand short tons) between 1998 and 2030. NO_x decreases would represent 0.19% and 1.2% of the NO_x emissions estimated to come from power plants in the years 2000 and 2030, respectively.

3.2 Carbon Dioxide Emissions

The cumulative reduction in CO_2 emissions from level 4 design changes is 914 Mt (1007 million short tons of CO_2).

Table 4. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level One

SO_2

Year	Abated from Power Plant Generation		Total Emissions		% U.S. SO_2 Power Plant Emissions
	kt	(10^3 of short tons)	kt	(10^3 of short tons)	
1998	4.9	5.4	12362	13623	-0.04
2000	11.2	12.3	9853	10858	-0.11
2005	26.8	29.5	8867	9772	-0.30
2010	38.8	42.8	7956	8767	-0.49
2015	42.3	46.6	6546	7214	-0.65
2020	38.5	42.5	5489	6048	-0.70
2025	31.1	34.3	4412	4862	-0.70
2030	24.5	27.0	3488	3844	-0.70

Cumulative SO_2 reduction, 1998-2030 = 1017 kt (1 120 thousand short tons)

NO_x

Year	Abated from Power Plant Generation		Total Emissions		% U.S. NO_x Power Plant Emissions
	kt	(10^3 of short tons)	kt	(10^3 of short tons)	
1998	3.3	3.7	8356	9208	-0.04
2000	8.3	9.2	7335	8083	-0.11
2005	21.6	23.8	7136	7864	-0.30
2010	33.7	37.2	6914	7619	-0.49
2015	39.2	43.2	6070	6689	-0.65
2020	38.5	42.5	5489	6048	-0.70
2025	34.1	37.6	4836	5330	-0.70
2030	30.2	33.3	4289	4726	-0.70

Cumulative NO_x reduction, 1998-2030 = 966 kt (1 065 thousand short tons)

CO_2

Year	Abated from Power Plant Generation		Total Emissions		% U.S. CO_2 Power Plant Emissions
	Mt	(10^9 short tons)	kt	(10^6 short tons)	
1998	1.1	1.2	2714	2990	-0.04
2000	3.1	3.4	2744	3024	-0.11
2005	8.8	9.7	2918	3216	-0.30
2010	14.9	16.4	3049	3360	-0.49
2015	20.1	22.2	3114	3432	-0.65
2020	22.8	25.1	3248	3579	-0.70
2025	23.7	26.1	3365	3708	-0.70
2030	24.6	27.1	3491	3848	-0.70

Cumulative CO_2 reduction, 1998-2030 = 540 Mt (595 million short tons)

Table 5. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level Two

SO_2

Year	Abated from Power Plant Generation kt	Abated from Power Plant Generation (10^3 of short tons)	Total Emissions kt	Total Emissions (10^3 of short tons)	% U.S. SO_2 Power Plant Emissions
1998	6.0	6.6	12362	13623	-0.05
2000	14.5	16.0	9853	10858	-0.15
2005	34.0	37.5	8867	9772	-0.38
2010	49.3	54.3	7956	8767	-0.62
2015	53.7	59.2	6546	7214	-0.82
2020	49.0	54.0	5489	6048	-0.89
2025	39.5	43.6	4412	4862	-0.90
2030	31.2	34.3	3488	3844	-0.89

Cumulative SO_2 reduction, 1998-2030 = 1292 kt (1424 thousand short tons)

NO_x

Year	Abated from Power Plant Generation kt	Abated from Power Plant Generation (10^3 of short tons)	Total Emissions kt	Total Emissions (10^3 of short tons)	% U.S. NO_x Power Plant Emissions
1998	4.0	4.4	8356	9208	-0.05
2000	10.8	11.9	7335	8083	-0.15
2005	27.4	30.2	7136	7864	-0.38
2010	42.8	47.2	6914	7619	-0.62
2015	49.8	54.9	6070	6689	-0.82
2020	49.0	54.0	5489	6048	-0.89
2025	43.3	47.8	4836	5330	-0.90
2030	38.4	42.3	4289	4726	-0.89

Cumulative NO_x reduction, 1998-2030 = 1228 kt (1353 thousand short tons)

CO_2

Year	Abated from Power Plant Generation Mt	Abated from Power Plant Generation (10^9 short tons)	Total Emissions kt	Total Emissions (10^3 of short tons)	% U.S. CO_2 Power Plant Emissions
1998	1.3	1.40	2714	2990	-0.05
2000	4.0	4.40	2744	3024	-0.15
2005	11.2	12.30	2918	3216	-0.38
2010	18.9	20.80	3049	3360	-0.62
2015	25.6	28.20	3114	3432	-0.82
2020	29.0	32.00	3248	3579	-0.89
2025	39.5	43.60	4412	4862	-0.90
2030	31.2	34.30	3488	3844	-0.89

Cumulative CO_2 reduction, 1998-2030 = 686 Mt (756 million short tons)

Table 6. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level Three

SO_2

Year	Abated from Power Plant Generation kt	(10^3 of short tons)	Total Emissions kt	(10^3 of short tons)	% U.S. SO_2 Power Plant Emissions
1998	7.0	7.7	12362	13623	-0.06
2000	16.4	18.1	9853	10858	-0.17
2005	38.7	42.6	8867	9772	-0.44
2010	55.9	61.7	7956	8767	-0.70
2015	60.8	67.1	6546	7214	-0.93
2020	55.6	61.3	5489	6048	-1.01
2025	44.9	49.5	4412	4862	-1.02
2030	35.5	39.1	3488	3844	-1.02

Cumulative SO_2 reduction, 1998-2030 = 1465 kt (1615 thousand short ton)

NO_x

Year	Abated from Power Plant Generation kt	(10^3 of short tons)	Total Emissions kt	(10^3 of short tons)	% U.S. NO_x Power Plant Emissions
1998	4.7	5.2	8356	9208	-0.06
2000	12.2	13.5	7355	8083	-0.17
2005	31.1	34.3	7136	7864	-0.44
2010	48.6	53.6	6914	7619	-0.70
2015	56.4	62.2	6070	6689	-0.93
2020	55.6	61.3	5489	6048	-1.01
2025	49.2	54.2	4836	5330	-1.02
2030	43.6	48.1	4289	4726	-1.02

Cumulative NO_x reduction, 1998-2030 = 1393 kt (1535 thousand short tons)

CO_2

Year	Abated from Power Plant Generation Mt	(10^6 of short tons)	Total Emissions kt	(10^3 of short tons)	% U.S. CO_2 Power Plant Emissions
1998	1.5	1.7	2714	2990	-0.06
2000	4.6	5.0	2744	3024	-0.17
2005	12.7	14.0	2918	3216	-0.44
2010	21.4	23.6	3049	3360	-0.70
2015	28.9	31.9	3114	3432	-0.93
2020	32.9	36.3	3248	3579	-1.01
2025	34.2	37.7	3365	3708	-1.02
2030	35.5	39.2	3491	3848	-1.02

Cumulative CO_2 reduction, 1998-2030 = 778 Mt (858 million short tons)

Table 7. Reduction of Pollutants for Refrigerators, Refrigerator-Freezers, and Freezers, Level Four

SO_2

Year	Abated from Power Plant Generation kt	Abated from Power Plant Generation (10^3 of short tons)	Total Emissions kt	Total Emissions (10^3 of short tons)	% U.S. SO_2 Power Plant Emissions
1998	8.1	8.9	12362	13623	-0.07
2000	19.1	21.1	9853	10858	-0.19
2005	45.4	50.1	8867	9772	-0.51
2010	65.6	72.3	7956	8767	-0.82
2015	71.5	78.8	6546	7214	-1.09
2020	65.3	72.0	5489	6048	-1.19
2025	52.7	58.1	4412	4862	-1.20
2030	41.6	45.9	3488	3844	-1.19

Cumulative SO_2 reduction, 1998-2030 = 1720 kt (1896 thousand short tons)

NO_x

Year	Abated from Power Plant Generation kt	Abated from Power Plant Generation (10^3 of short tons)	Total Emissions kt	Total Emissions (10^3 of short tons)	% U.S. NO_x Power Plant Emissions
1998	5.5	6.0	8356	9208	-0.07
2000	14.2	15.7	7335	8083	-0.19
2005	36.6	40.3	7136	7864	-0.51
2010	57.0	62.8	6914	7619	-0.82
2015	66.3	73.1	6070	6689	-1.09
2020	65.3	72.0	5489	6048	-1.19
2025	57.8	63.7	4836	5330	-1.20
2030	51.2	56.4	4289	4726	-1.19

Cumulative NO_x reduction, 1998-2030 = 1635 kt (1802 thousand short tons)

CO_2

Year	Abated from Power Plant Generation kt	Abated from Power Plant Generation (10^3 of short tons)	Total Emissions kt	Total Emissions (10^3 of short tons)	% U.S. CO_2 Power Plant Emissions
1998	1.8	2.0	2714	2990	-0.07
2000	5.3	5.9	2744	3024	-0.19
2005	14.9	16.5	2918	3216	-0.51
2010	25.1	27.7	3049	3360	-0.82
2015	34.0	37.5	3114	3432	-1.09
2020	38.6	42.6	3248	3579	-1.19
2025	40.2	44.3	3365	3708	-1.20
2030	41.7	46.0	3491	3848	-1.19

Cumulative CO_2 reduction, 1998-2030 = 914 Mt (1007 million short tons)

3.3 Sensitivity Cases

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 Appliance Standards Environmental and Utility Model (ASEUM) for the base case and trial standards level 1 and then comparing results to each of 5 sensitivity cases. The sensitivity cases selected are defined as follows: 1) Lower Energy Price: Assume lower energy prices by using energy prices from the Low Economic Growth Case Scenario in the Annual Energy Outlook 1994; 2) Higher Energy Price: Assume higher energy prices by using energy prices from the High Economic Growth Case Scenario in the Annual Energy Outlook 1994; 3) 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; 4) Higher Equipment Price: The price of the baseline unit and the incremental price associated with each engineering level is increased by the estimated uncertainty level; 5) High Equipment Efficiency: Assume continuing future improvement in appliance efficiencies at a rate of 2% per year.

Tables 8.a and 8.b show the results from the 5 sensitivity cases relative to the level 1 test case. Presented are the cumulative emissions of SO_2, NO_x, and CO_2 for each case.

Table 8.a. Sensitivity Results on Cumulative Emissions - Metric Units

Sensitivity	Cumulative SO_2 kt	Cumulative NO_x kt	Cumulative CO_2 Mt
level 1	1017	966	540
low energy price	1021	971	542
high energy price	1013	963	538
low equipment price	1025	974	545
high equipment price	1026	976	546
high equipment efficiency	299	260	123

Table 8.b. Sensitivity Results on Cumulative Emissions - American Units

Sensitivity	Cumulative SO_2 (*10^3 of short tons*)	Cumulative NO_x (*10^3 of short tons*)	Cumulative CO_2 (*10^6 of short tons*)
level 1	1120	1065	595
low energy price	1125	1070	598
high energy price	1117	1061	593
low equipment price	1129	1074	601
high equipment price	1131	1075	601
high equipment efficiency	329	287	136

REFERENCES

1. National Appliance Energy Conservation Act (NAECA), Public Law 100-12, March 17, 1987.

2. U.S. DOE. Energy Information Administration. *Effects of the Clean Air Act Amendments on Reducing SO_2/NO_x Emissions.* Energy Information Administration, SR/NES/90-01, 1990.

REGULATORY IMPACT ANALYSIS

Energy Conservation Standards for Consumer Products

Covering: Refrigerators, Refrigerator-Freezers, and Freezers

U.S. DEPARTMENT OF ENERGY
Energy Efficiency and Renewable Energy, Office of Building Technologies

July 1995

REGULATORY IMPACT ANALYSIS

1. INTRODUCTION

Part B of Title III of the Energy Policy and Conservation Act (EPCA) (P.L. 94-163), as amended by the National Energy Conservation Policy Act (NECPA) (P.L. 95-619), by the National Appliance Energy Conservation Act (NAECA) (P.L. 100-12), and by the National Energy Conservation Amendments of 1988 (NECA) (P.L. 100-357), created the Energy Conservation Program for Consumer Products other than Automobiles. The consumer products covered by this program (often referred to hereafter as "covered products") are: refrigerators, refrigerator-freezers and freezers; dishwashers; clothes dryers; water heaters; central air conditioners and central air conditioning heat pumps; furnaces; direct heating equipment; television sets; kitchen ranges and ovens; clothes washers; room air conditioners; pool heaters; fluorescent light ballasts; and any other consumer product classified by the Secretary of Energy [Section 322]. To date, the Secretary has not classified any additional products.

For 12 covered products, the Act prescribes an initial Federal energy conservation standard [Section 325 (b) - (k)]. The Act establishes effective dates for the standards in 1988, 1990, 1992, or 1993, depending on the product, and specifies that the standards are to be reviewed by the Department within three to ten years, also depending on the product [Section 325(b) - (k)]. After the specified three- to ten-year period, DOE may promulgate new standards for each product; however, the Secretary may not prescribe any amended standard which increases the maximum allowable energy use, or decreases the minimum required energy efficiency, of a covered product [Section 325 (o) (1)].

The Act requires DOE to publish a final rule no later than November 17, 1994, to determine if the standards on refrigerators, refrigerator-freezers, and freezers should be amended. [Section 325(b) (3) (B)] These 3 sub-products are categorized as one overall product, and are the subject of the rulemaking for which this Regulatory Impact Analysis is being issued.

Any new or amended standard must be designed to achieve the maximum improvement in energy efficiency that is technologically feasible, and economically justified [Section 325 (o) (2) (A)].

Section 325 (o) (2) (B) (i) provides that before DOE determines whether a standard is economically justified, it must first solicit comments on a proposed standard. After reviewing comments on the proposal, DOE must then determine that the benefits of the standard exceed its burdens, based, to the greatest extent practicable, on a weighing of the following seven factors:

(1) The economic impact of the standard on the manufacturers and on the consumers of the products subject to such standard;

(2) The savings in operating costs throughout the estimated average life of the covered product in the type (or class) compared to any increase in the price of, or in the initial charges for, or maintenance expenses of, the covered products which are likely to result from the imposition of the standard;

(3) The total projected amount of energy savings likely to result directly from the imposition of the standard;

(4) Any lessening of the utility or the performance of the covered products likely to result from the imposition of the standard;

(5) The impact of any lessening of competition, determined in writing by the Attorney General, that is likely to result from the imposition of the standard;

(6) The need for national energy conservation; and

(7) Other factors the Secretary considers relevant.

In addition, the Act specifies criteria for petitions to DOE in regard to amendments to standards [Section 325 (n)]. Under the Act, any person may petition the Department to conduct a rulemaking to amend a Federal energy conservation standard for any covered product [Section 325 (n) (1)]. The Department must grant such a petition if it determines that an amended standard will result in significant conservation of energy, is technologically feasible and is cost-effective [Section 325 (n) (2)].

This Regulatory Impact Analysis describes the analyses performed by DOE to arrive at the proposed energy efficiency standards for the product types listed above.

Executive Order 12291 (46 FR 13193, February 19, 1981) directs that, in proposing a major rule, an agency perform a regulatory analysis. Such an analysis presents major alternatives to the regulation that could achieve substantially the same regulatory goal at lower cost, as well as a description of the costs and benefits (including potential net benefits) of the proposed rule.

DOE has determined that this proposed rule is a "major rule".

Since Congress mandated that DOE promulgate performance standards, the only other alternative within the boundaries of the law is a no standard alternative. However, in preparing this Regulatory Impact Analysis, the list of alternatives has been expanded to include alternatives that would require new enabling legislation or statutory amendments.

This Regulatory Impact Analysis is concerned with the projected economic impacts of the standards, and their major alternatives, on the nation as a whole.

In addition to examining possible alternatives to the proposed standards, this Regulatory Impact Analysis examines the way in which performance criteria and other factors are defined and measured for the proposed standards. The proposed alternatives are examined for reasonableness and possible biases which might affect the success of the standards in achieving the legislated goals of energy conservation and reduced demand for energy. The analysis briefly presents the results of the Technical Support Document (TSD) [1] and explains how these results were used to determine the relative impact of the proposed standards on the nation.

2. DESCRIPTION AND ANALYSIS OF MAJOR ALTERNATIVES

There are many methods to achieve energy conservation through the increased energy efficiency of consumer products. This section describes and analyzes various regulatory and non-regulatory alternatives and their effectiveness in conserving energy.

The alternatives examined in this analysis ranged from the no-action alternative or the "base case" against which the benefits of other alternatives are measured to alternatives requiring new legislation for implementation.

Each alternative has been analyzed in comparison to the other alternatives in terms of potential energy savings, net present value, and other impacts that differ among the alternatives. A summary of this comparative analysis is presented in the following section. A detailed discussion and quantitative description of each alternative is presented in the remaining sections of this chapter.

2.1 Comparative Analysis of the Alternatives

To compare each alternative quantitatively to the proposed conservation standards in terms of energy savings and the net present value (or cost savings), it is necessary to quantify the effect of each alternative on the purchase and use of energy-efficient consumer products. Each alternative to the proposed regulation was quantified so that inputs to the forecasting model (LBL-REM) could be determined. The forecasting model was used to calculate the energy use and the net present value corresponding to each alternative. The key inputs to the forecasting model are:

- energy prices and escalation factors;
- implicit market discount rates for trading off purchase price against operating expense when choosing appliance efficiency;
- consumer demand and income elasticities;

- price versus efficiency relationships for each consumer product;
- appliance stock data (purchase of new appliances or turnover rates for inventories).

An example of the input to the forecasting model is shown in Tables R.1 through R.4. Only those parameters that were needed to specify the alternatives were changed from the base case. Otherwise, all aspects of the base case remained constant throughout the analysis to permit a quantitative comparison of the alternatives without extraneous effects.

The results of the simulations are summarized in the first three columns of Table R.5 for each alternative evaluated. All results are relative to the base or no-action case so that the energy savings resulting from each alternative can be assessed readily. Most alternatives would result in some energy savings and in positive net present value compared to the base case. As the comparison shows, the proposed approach results in appreciably higher energy savings and a greater national net present value than most of the other alternatives.

Summary of Key Inputs to Simulate the Base Case:
Table R.1 Escalation Rates for Residential Electricity Prices and Household Income

	Residential Electricity	Household Income
1991-1995	-0.5%	0.9%
1996-2000	0.8%	1.1%
2001-2005	1.0%	0.8%
2006-2010	1.4%	0.9%
2011-2030	1.0%	1.0%

Table R.2 Market Discount Rates for Efficiency Choice (Percent)

Refrigerator:	
Top Mount Auto no TTDF	126
Top Mount Auto with TTDF	121
Bottom Mount Auto	113
Side-by-side Auto no TTDF	173
Side-by-side Auto with TTDF	201
Compact Manual	195
Freezer:	
Upright Manual	191
Upright Auto	122
Chest Manual	211

Table R.3 Market Share Elasticities

	Refrigerator	Freezer
Operating Expense	-0.05	-0.05
Income	0.02	0.30
Equipment price	-0.24	-0.43

Table R.4 Consumer Price vs Energy Consumption (Example: Top Mount Auto Defrost Refrigerator-Freezer)

	Design Option	Purchase Price (1992$)	kWh/a
0	Baseline	259.53	700.9
1	0 + 5.45 EER Compressor	270.59	620.1
2	1 + Reduce Cond Motor Power	275.09	594.5
3	2 + Add 1/2" Insulation to Doors	278.71	572.4
4	3 + Reduce Evap. Motor Power	285.21	543.1
5	4 + Improve Evap. Fan Eff.	286.02	539.4
6	5 + Add 1/2" Insulation to Walls	297.37	495.4
7	6 + Reduce Gasket Heat Leak	300.34	484.4
8	7 + Add 1" Insulation to Doors	303.45	473.4
9	8 + Add 1" Insulation to Walls	312.35	444.0
10	9 + Increase Condenser Area	315.61	436.7
11	10 + Adaptive Defrost	322.76	425.7
12	11 + Increase Evaporator Area	325.86	422.0
13	7 + Increase Evaporator Area	303.45	477.0
14	13 + Increase Condenser Area	306.71	470.0
15	14 + Adaptive Defrost	313.86	458.7
16	2 + Reduce Evap. Motor Power	281.59	561.4
17	16 + Improve Evap. Fan Eff	282.40	557.8
18	17 + Reduce Gasket Heat Leak	285.37	546.7
19	18 + Increase Evaporator Area	288.47	539.4
20	19 + Increase Condenser Area	291.73	532.1
21	20 + Vacuum Panels	338.48	433.0
22	21 + Adaptive Defrost	345.63	422.0

The impacts of measures of each program are:

- Residential Energy Use (EJ = 10^{18} joule): Cumulative, 1998-2030 for the appliance product. Electricity consumption is reported as primary energy (11,500 Btu = 1 kWh).

- Energy Savings. Cumulative energy use from base-case projection less alternative-policy-case projection.

- Net Present Value. Value of future savings from appliances bought in the period 1998-2030. Calculated as difference: present value of equipment and energy expenditures in base case less present value of expenditures in alternative policy case. Future fuel and equipment expenditures are discounted to 1990 using 7% real discount rate. Fuel expenses are calculated for the life of the appliance.

The additional columns presented in Table R.5 focus on other aspects of each alternative that are pertinent to the regulatory analysis, including:

- equity impacts (or effects on the well-being of the nation);

- legislative authority for implementing the alternative;

- major barriers to implementation and enforcement (other than legislative);

- impact of the alternative on competition; and

- compliance and reporting requirements of each alternative.

These factors for each program are compared alternative to the proposed standards. None of the alternatives show energy or economic savings comparable to the proposed program. The proposed approach appears to be less favorable than some of the other program alternatives in competition and reporting/compliance requirements. (See Table R.5, Expected Impacts of Program Alternatives) Those program alternatives (voluntary targets, enhanced labeling/consumer education) that involve non-mandatory methods for achieving more energy-efficient consumer products fare better in these two areas. However, the reporting/compliance requirements and the potential effects on competition of the performance standards must be weighed against the greater and more certain energy savings of the proposed approach compared to what the alternatives could achieve in this area.

2.2 No-Action Alternative

This alternative was analyzed as the "base case" and assumes that the proposed standards are not implemented. The no-action alternative does not imply that no energy savings would be realized; some energy savings will be achieved because of higher energy costs, the continuation of other Federal energy conservation activities, and a variety of state and utility company programs aimed at increased appliance efficiency. These programs include the deregulation of energy prices, consumer product labeling, the public education and information program, and the residual effects of state and federal consumer product efficiency standards already in place.

2.2.1 Energy Prices

In recent years, the prices of natural gas and oil have been deregulated. Projected energy prices to the year 2010 for the residential sector were developed by DOE in the Annual Report to Congress (1994). These prices after the year 2010 were extrapolated:

Residential electricity prices are projected to decline at 0.5% per year until 1995, then increase at 0.8% per year until 2000, and then increase at 1.0% and 1.4% per year until 2005 and 2010, respectively. After 2010, residential electricity prices are projected to rise at 1.0% per year.

Table R.5 Expected Impacts of Program Alternatives

Alterative Programs	Refrigerators and Freezers (1998-2030)			Equity Impacts*	Legislative Authority	Major Barriers to Implementation & Enforcement	Competition	Compliance & Reporting Requirements
	Energy Use EJ (Quad)	Energy Savings EJ (Quad)	NPV*** (billion 1990$)					
No Action	48.05 *(45.54)*	0	None	None	**	None	None	None
Tax Credits (Consumers)	47.98 *(45.47)*	0.07 *(0.07)*	0.19	Some costs will be borne by all taxpayers regardless of purchase of energy efficient product	No	None, other than legislative	May favor large manufacturers	Could be unwieldy
Tax Credits (Manufacturers)	48.05 *(45.54)*	0	0	"	No	Enforcement problems likely	"	"
Rebates (Consumers)	47.97 *(45.47)*	0.08 *(0.07)*	0.23	"	No	Potential difficulties in administration	"	"
Prescriptive Standards	41.43 *(39.27)*	6.62 *(6.27)*	7.26	None	No	Restricts development of innovative technology	May reduce number of models and competition	Minimal reporting but extensive testing
Voluntary Energy Efficiency Targets — 5-yr delay	41.97 *(39.78)*	6.08 *(5.76)*	6.07	None	No	No assurance that participation will be widespread	None	None
Voluntary Energy Efficiency Targets — 10-yr delay	43.49 *(41.22)*	4.56 *(4.42)*	4.33					
Enhanced Labelling & Consumer Education	48.00 *(45.50)*	0.05 *(0.05)*	0.08	None	Yes	None	None	Minimal
Performance Standards	40.53 *(38.42)*	7.52 *(7.12)*	8.19	None	Yes	None	Not anti-competitive	Reasonable

Key:
None = 0 or not significant
EJ = 10^{18} Joule
Quad = 10^{15} Btu of energy
1 kWh = 11,500 Btu

Notes:
* Economic well-being of nation as a whole.
** Yes, if no standard is justified
*** Net present value for fuel and equipment discounted to 1990 at 7% real

2.2.2 Increasing Consumer Information

Congress has mandated in the Energy Policy and Conservation Act (EPCA) (P.L. 94-163) both a labeling program and a complementary consumer education and information program. The labeling program took effect on May 21, 1980, implemented by the Federal Trade Commission (FTC); the public education and information program is being handled by DOE.

Under the labeling program, consumer awareness of the relative efficiencies of consumer products available in the marketplace is expected to increase. That is, the basic information that consumers need to make a *rational* purchase decision would be more available to them.

The consumer education and information program involves the development and expansion of existing Federal energy information programs and is designed to educate consumers about the value and use of energy labels on products. The educational activities focus on steering the consumer away from the idea of minimizing first cost and on promoting the use of life-cycle costing as the primary factor in selecting a consumer product for purchase.

- There are several drawbacks to relying wholly on the education program above, even in conjunction with the labeling program, to achieve the desired results:

- Consumer education and labeling programs are directed only at the demand for consumer products; they will not guarantee the appropriate supply-side responses by manufacturers;

- In many cases, as in new residential construction, consumer products are installed by builders, and minimum first cost is an overriding consideration;

- Energy efficiency is only one factor in consumers' purchase decisions;

- There is a long lag before the effect of such educational activities is manifest in the marketplace.

As a means of achieving the level of energy savings believed possible under the proposed standards, the labeling effort by itself, or in conjunction with a consumer education program, is expected to have only a moderate effect. According to studies performed in support of the Consumer Product Energy Efficiency Program, consumers can be expected to use the label, together with a number of other criteria, to make their purchase decisions. The studies also indicated that there will be significant variations in consumer attitudes, depending on certain product-specific factors.

2.2.3 Existing Mandatory Standards

Before the passage of the National Appliance Energy Conservation Act of 1987 (NAECA), several states established programs that set minimum efficiency levels for certain consumer products and/or set prescriptive standards through the adoption of ASHRAE Standards. These programs have changed the distribution patterns for efficient appliances which has impacts at the national level. Full compliance with the mandatory standards in NAECA is expected, on schedule.

2.2.4 Quantitative Description

The base case includes the following assumptions about factors likely to increase residential energy efficiency:

- Residential electricity prices are projected to decline at 0.5% per year until 1995, then increase at 0.8% per year until 2000, and then increase at 1.0% and 1.4% per year until 2005 and 2010, respectively. After 2010, residential electricity prices are projected to rise at 1.0% per year.
- The FTC labeling program for consumer products will continue;
- The U.S. Department of Energy's existing public information program, designed to inform consumers about the advantages of purchasing more energy-efficient products will continue;
- Manufacturers will be able to produce the more energy-efficient equipment demanded by consumers;
- NAECA will be effectively implemented, at the levels proposed;
- Thermal integrity of homes is projected to continue to improve as energy prices increase;
- Appliance purchase decisions are based on operating expenses, as well as on equipment price. Appropriate weights for these are determined empirically.

The base case as quantified by the forecasting models shows that cumulative energy demand for refrigerators, refrigerator-freezers, and freezers from 1998 to 2030 will be 48.05 EJ (45.54 Quad). There are no energy savings associated with the base case.

The present value (in 1990 dollars, discounted at 7% real) of refrigerators, refrigerator-freezers, and freezers purchased from 1998 to 2030 in the U.S. is projected to be $102 billion, of which $46 billion represents equipment prices and $55 billion represents energy expenses.

2.3 Tax Credits to Consumers

2.3.1 Discussion

The Energy Tax Act of 1978 (PL 95-618) provided a homeowner with a tax credit of up to 15% of $2,000 for the installation of energy-saving materials and equipment. This tax credit could have been used by the taxpayer in one year or over a number of years, but it could not exceed $300 for a given residence.

Tax credits for appliances would require new legislation that would include all covered products. The use of similarly structured tax credits for the purchase of energy-efficient appliances is apt to have only a marginal effect because the size of the credit would be modest in most cases.

The costs of such a program would be borne by all taxpayers because it would result in less tax revenues to the government.

Tax credits alone affect only the demand for consumer products. There is no guarantee that manufacturers will respond properly to consumer needs by producing more efficient consumer products. Thus, without a complete approach to alleviate existing market imperfections, it is doubtful that tax credits could achieve significantly larger energy savings than would occur with the no-action alternative.

2.3.2 Quantitative description

A program offering a tax credit of 15% of the increased cost of higher energy efficiency of consumer products was evaluated. This program might be more easily administered than a rebate program because it can be carried out through an existing organization, the IRS. The program as evaluated here would return to a participating consumer exactly the same amount of money as the rebate program described in Section 2.5 below. The most important difference to the consumer between rebate and tax credit programs is that a rebate can be obtained quickly whereas a tax credit is delayed until income taxes are filed or a tax refund is provided by the IRS. This difference means that middle- and low-income purchasers, who generally have little ready cash to purchase more expensive products, are not as likely to take advantage of a tax credit program as are upper income purchasers. To simulate this impact, DOE has assumed that only 60% of consumers would purchase more energy-efficient products as a result of the tax credit program. The forecast results show energy savings of 0.07 EJ (0.07 Quads) for the consumer tax credit program alternative. The net present value (in 1990 dollars), discounted at 7% real, is $0.19 billion.

2.4 Tax Credits to Manufacturers

2.4.1 Discussion

DOE examined the possibility of providing tax credits to manufacturers. This approach would allow manufacturers to recoup some of the costs of manufacturing more energy-efficient consumer products. In combination with tax incentives or rebates for consumers, manufacturer tax credits could correct some of the market imperfections resulting from focusing only on incentives to consumers. However, the timing of a dual program for manufacturers and consumers would have to be precise to ensure that maximum benefits are achieved.

In any event, the potential would exist that many manufacturers would not respond to tax incentives. The cost of a manufacturer tax credit program could be very high. A tax credit program that would attract a high manufacturer participation rate could have very large costs. Also, the strictness of energy efficiency requirements for receiving a tax credit will affect participation. Less stringent requirements will result in greater participation but limit the energy savings achieved by the program; more stringent requirements may result in reduced participation and, thus, also limit energy savings.

Therefore, although the tax credit program has the potential for achieving energy savings, the many issues associated with optimizing the benefits need to be analyzed carefully. Some of this

analysis has been performed by DOE and indicates that the cost of achieving significant energy savings through a tax credit program would be very high.

2.4.2 Quantitative Description

Offering tax incentives to consumer product manufacturers was considered as an alternative to regulation. The tax incentive analyzed would be an investment tax credit for installation of machinery and tools required to produce more energy-efficient appliances.

Production of energy-efficient consumer product requires investment in some new tools and machinery. The manufacturer tax credit considered by DOE provided a 20% credit for investment in tools and machinery required to produce energy-efficient appliances. The credit would not apply to investments in other forms of tools and machinery, nor would it apply to other forms of investment such as acquisition of subsidiaries, financial instruments, i.e., stock, loans, or new construction of plants.

Because the tax credit only applies to the portion of investment going toward production of energy-efficient consumer products and not toward investment in replacement equipment, an enforcement mechanism would be needed to prevent abuse. Enforcement would probably be divided between DOE and the Internal Revenue Service (IRS). DOE would have to stipulate specific categories of investment subject to the credit. IRS would have principal responsibility for review of claims for the credit. Investigation of alleged violations would probably require joint action by DOE and IRS. The cost of the enforcement program was not investigated, but it is thought to be high; the program would probably not be cost effective.

The effect of the investment tax credit is to lower the cost of design options requiring new tooling and machinery. Consumer prices were lowered in the forecasting models consistent with the lower manufacturer cost. Many design options are not affected, and those that are affected are the more expensive (and more efficient) designs. The effect on consumer purchase decisions is minimal, according to the forecasting models.

Estimated energy consumption under this alternative remains at 48.05 EJ (45.54 Quads), with no energy savings, between 1998 and 2030. The net present value (in 1990 dollars), discounted at 7% real, is none.

2.5 Rebates to Consumers

2.5.1 Discussion

Providing rebates to consumers who purchase energy-efficient appliances would be difficult to implement. Although manufacturers now occasionally offer rebates as marketing tools, there is no consistent or large-scale model for a nationwide program. The concept of government-mandated rebates would entail complex interference in the market place; decisions would need to be made on which products should qualify, amount of rebate, time period covered, etc.

The rebate concept could be coupled with a tariff, much like the proposed "gas-guzzler tax" for automobiles; consumers who purchased inefficient units would be charged a federally imposed tax. It would be a costly, unwieldy, and cumbersome program to implement. However, it may be more effective than the no-action alternative.

As with tax credits, the rebate alternative will affect only the demand for energy-efficient consumer products. There will be uncertainty about the manufacturers' ability and/or desire to respond to the demand, particularly if the rebate program is not continued over a long enough time period to account for manufacturers' lead time to produce energy-efficient products. Thus, as a separate alternative, rebates will have only a small and potentially short-term effect on energy consumption.

2.5.2 Quantitative Description

A Federal program that gives consumers a rebate to encourage the purchase of energy-efficient consumer products was analyzed. This program would apply to all new consumer products whether they are replacements or for new construction. The program was assumed to provide a rebate of 15% of the increased cost of energy conservation for product efficiencies above the baseline design. The assumption of a 15% rebate has been chosen because Congress has in the past approved similar financial incentives for energy conservation retrofits of building shells and for installing renewable energy systems.

The implementation of a rebate program could be somewhat complicated because of the need to specify the exact cost of extra energy conservation in consumer products. Generally, many features are changed at one time when a new model consumer product is developed. Thus, the exact cost of increased energy efficiency may be difficult to specify. This problem could be circumvented by having the Federal government set the size of the rebate for products of differing efficiencies. However, obtaining the information to establish the level of rebate for numerous products would require considerable effort to avoid arbitrary determinations. No assumption is made regarding the means of implementing the rebate (for example, through the retail store with a refund from the Federal government or directly by the government).

The effect of the rebate program on residential energy consumption is simulated by reducing by 15% the incremental price to the consumer of products with efficiencies greater than the baseline model. The 15% reduction in incremental price is assumed to be paid by the Federal government. The LBL-REM model is run with the new price versus energy consumption curves, and results are compared with the base case.

The 15% rebate program alternative results in energy savings of 0.08 EJ (0.07 Quads) between 1998 and 2030. The net present value (in 1990 dollars), discounted at 7% real, is $0.23 billion.

2.6 Prescriptive Standards

2.6.1 Discussion

Prescriptive standards as applied to consumer products would involve specifying designs, materials, and/or manufacturing methods to achieve the desired energy use levels. For example, one requirement would be to use insulation with a specific R value in specific areas on a product. Currently, performance standards have been specified for some of the covered products. The legislative authority to set prescriptive standards for these products would have to be established.

This alternative would be fairly easy to enforce. However, it would probably result in high start-up costs and would not provide manufacturers with the necessary incentive or flexibility to increase product efficiencies or to reduce costs through innovative designs and use of new technologies. It is also highly likely that competition in the consumer product industry could be severely limited by prescriptive standards because of design constraints. This lack of competition could result in higher product prices and an increased rate of failure for firms.

2.6.2 Quantitative Description

The cost to the manufacturer of complying with prescriptive standards is greater than or equal to the cost of complying with performance standards for similar efficiencies, if manufacturers are able to find more cost-effective ways of meeting the performance standards than those assumed by DOE in developing the performance standards.

There are two major disadvantages to the prescriptive approach: (1) manufacturers are given no flexibility in meeting the standards; thus, innovation in product design is likely to be substantially reduced or stifled; and (2) the certification of compliance may be ineffective because the efficiency of most consumer products depends on how the components are integrated into the product. As a result, individual components could meet prescriptive standards while overall product performance could be lower than would be true if it had to meet energy performance standards. These two effects are simulated in the LBL-REM model by assuming that prescriptive standards will achieve smaller efficiency improvements than performance standards in the same time frame.

Cumulative energy savings from 1998 to 2030 are estimated to be 6.62 EJ (6.27 Quads). The net present value (in 1990 dollars), discounted at 7% real, is $7.26 billion.

2.7 Voluntary Energy Efficiency Targets

2.7.1 Discussion

EPCA called for industry to meet voluntary energy-efficiency targets for the covered products. If industry did not meet the voluntary targets, provisions were made for establishing Federal standards. In amending the Act, NECPA, Congress specifically changed the legislation to provide for immediate establishment of Federal standards to ensure the timely manufacture of energy-efficient consumer products. Although it is possible that voluntary targets might have been as effective as mandated performance standards in achieving the energy savings goals, there probably would have been a considerable time lag because of the many uncertainties associated with a program

requiring concurrence from so many participants as well as uncertainties about future consumer demand for energy-efficient products.

2.7.2 Quantitative Description

It is assumed for analysis purposes that the voluntary program would specify the energy-efficiency levels of the performance standards as goals. A fully voluntary program is assumed to cause a 10-year delay in achieving the energy conservation goals of the proposed standards. If these goals are achieved earlier in the base case for specific consumer products, then the voluntary program and the base case are assumed to be identical for these products. A voluntary program that is made mandatory if the goals are not met is assumed to achieve the energy efficiencies of the performance standards with a 5-year delay. Thus, the effects of a voluntary program are bounded by the assumptions of a 5- to 10-year delay.

The effect of this alternative is total energy savings between 1998 and 2030 ranges from 6.08 EJ (5.76 Quads) (5-year delay) to 4.56 EJ (4.42 Quads) (10-year delay). The net present value (in 1990 dollars), discounted at 7% real, ranges from $6.07 billion (5-year delay) to $4.33 billion (10-year delay).

2.8 Enhanced Consumer Education and Labeling Programs

2.8.1 Discussion

DOE considered expanding the current consumer education program and the FTC labeling program as an alternative to the approach mandated by Congress. The labeling program was reviewed for possible improvements or expansion beyond the current scope. An expanded enforcement program was identified as a potential improvement to the existing program. The current enforcement program relies on consumers' and other interested parties' complaints to identify noncompliance. An expanded program could more actively pursue the identification of noncomplying manufacturers and retailers.

DOE similarly reviewed the current consumer education program. The consumer product education program developed by DOE sponsored 10 regional workshops for industry, educators, utilities, and state energy officials in 1979. A national consumer awareness campaign began in May, 1980 to tell consumers about the appearance of the consumer product labels and how to use labeling information in the purchase of energy-efficient products. A consumer information booklet, public service announcements for radio and TV, educational exhibits, and a training package for retail sales persons are among the components of this nationwide effort.

The education program could be enhanced in several ways. The amount of information provided to consumers could be expanded to include product-specific information about the energy-efficient operation and maintenance of the covered products. A more active approach to reach potential consumers before they purchase products would involve increased publicity, which would require additional expenditures for media advertising and producing suitable advertisements. The advertising campaign should probably be supplemented with additional information in mailers or toll-free hot lines to answer specific consumers' questions. Finally, the education program could

be expanded to other persons involved in the purchase of the covered products, such as builders and retailers.

An enhanced education program could be expected to increase consumer demand in proportion to the amount of money spent on publicity and dissemination of information. This approach, as with the financial incentives to consumers, does not address the supply side of the marketplace equation, and, therefore, could result in less-than-optimal energy savings because of potential supply and demand inequalities.

2.8.2 Quantitative Description

Evaluating the expansion of the Consumer Education and Labeling Program requires that assumptions be made about the number of persons reached by the expanded program and to what extent the information received will influence their purchase of more energy-efficient consumer products. The program is defined, for purposes of analysis, as being able to reach an average of 10% of the purchasers of consumer products per year. These purchasers will be encouraged to use life-cycle cost techniques for selecting consumer products. Sources of information that will enable consumers to make life-cycle cost decisions will be identified.

The average purchaser reached by the program will reduce his or her discount rate by 50% (reducing the discount rate by 50% means that the purchaser will double the length of time normally considered acceptable to recover the initial higher cost of the product) for those products purchased by the user directly. For purposes of analysis, the reduction in discount rate (increase in acceptable payback period) is distributed equally among all consumers.

In general, any reasonable expansion of a government consumer information program is likely to reach a relatively small percentage of the purchasing public. It will not influence those who either have insufficient funds or would not benefit enough to purchase more efficient equipment.

The variables in determining whether a purchaser of consumer products will respond positively to information presented by the programs cannot be assessed with any degree of confidence. Response is highly dependent on the purchaser's ability to comprehend the information, agree with the concepts that are presented, gather needed information, and want and afford to make the purchase. The quantitative description does not attempt to estimate this response. It merely assumes that those reached will respond positively by purchasing the most energy-efficient products (in terms of life-cycle costs) for their particular needs. Thus, the energy savings identified by the LBL-REM will often be overestimates of the response to the program because not all purchasers reached can be expected to respond positively.

Analyzing the effects of the expanded consumer product information program involved changing the implicit discount rates in the LBL-REM to simulate the program impacts stated above. For this alternative, total energy savings from 1998 to 2030 are 0.05 EJ (0.05 Quads) and these savings have a net present value (in 1990 dollars, discounted at 7% real) of $0.08 billion.

2.9 Performance Standards

2.9.1 Discussion

The only alternative that fully complies with the Act is the setting of energy-efficiency or performance standards. This alternative is being used in the proposed regulation.

The standards will establish the maximum energy consumption or minimum efficiency level permitted for each product class but will not prescribe the means by which that level is to be achieved. The efficiencies are specified in ratios relating the output of a product to its energy use. The standards levels vary among product classes, depending on the design limitations of each class. The standards levels are based on test procedures developed by DOE, which it intends, on a continuing basis, to modify to accommodate new product designs.

Performance standards will allow manufacturers the flexibility that prescriptive standards do not. Also, performance standards must be viewed in conjunction with labeling and consumer education/information programs because of the requirements in the Act. Labeling and consumer education will ensure that purchasers are aware of the benefits accruing from the purchase and use of the more energy-efficient products; in the long term they encourage the manufacture and purchase of even more energy-efficient products than required by the proposed standards. In this context, the proposed standards provide a balanced approach to regulating the manufacture and purchase of efficient consumer products that cannot be achieved by any other alternative or group of alternatives. This balanced approach will ensure that the regulation corrects both the demand and supply-side market imperfections, and that energy savings will be realized.

2.9.2 Quantitative Description

Performance standards were quantified by assuming that all products would comply with the standards as proposed. That is, all manufacturers would meet the deadlines for the 1998 efficiency or energy consumption levels, and, after existing stocks of nonregulated products are depleted, only products meeting the proposed standards would be distributed in commerce. Maximum benefits do not accrue immediately, however, because the standards do not require retrofitting of existing consumer products, so it will take some time to replace all nonregulated products with regulated products.

The implementation of performance standards results in a total estimated energy savings of 7.52 EJ (7.12 Quads) beyond the standards set forth in NAECA. These additional savings have a net present value (in 1990 dollars, discounted at 7% real) of $8.19 billion.

3. COSTS AND BENEFITS OF ALTERNATIVE STANDARDS LEVELS

During the development of the proposed standards, DOE considered several alternative standards levels for each product. This chapter briefly describes how the alternative levels were selected, then presents a quantitative discussion of the costs and benefits of each of these levels to consumers, manufacturers, electric utilities, and the nation.

3.1 Choice of Standards Levels to Analyze

The analysis began with engineering estimates of the energy efficiencies associated with various design options that could meet/be specified by standards. Then, estimates were made of the added manufacturing costs that would be associated with each of the design options. After markups were applied, a consumer price associated with each of the design options was estimated.

Using the engineering estimates of the energy savings that would accrue from each design option, as well as current DOE forecasts of future energy prices, the department estimated the value of the energy savings associated with each design option.

One measure of the effect of proposed standards on consumers is change in operating expense as compared to the change in purchase price, both resulting from standards. This measure is quantified by the difference in life-cycle cost (LCC) between the base and standards cases for the appliance class analyzed. The LCC is the sum of the purchase price and the operating expense, including maintenance costs, discounted over the lifetime of the appliance.

The LCC for each design option in each class is calculated in the year standards are imposed using consumer discount rates of 2, 6, and 15%. The consumer price is calculated by applying a factory markup plus a distributor and retailer markup to the factory costs in the Engineering Analysis. Energy price forecasts are inputs taken from the most recent (1994) *Annual Energy Outlook* of the Energy Information Administration. Appliance usage forecasts are taken from the results of the LBL-REM.

The differences in life-cycle costs between the base case and various levels of standards for the product are presented in Tables 4.1 - 4.9 of the TSD [1]. These LCCs are calculated at a 6% discount rate; a higher rate, e.g., 15%, gives a smaller difference; a lower rate, e.g., 2%, produces a greater difference.

When the LCC numbers are plotted (on the Y axis) against unit energy consumption (on the X axis), the data generally produce a curve that is U-shaped. This means that at first the curve will decline as efficiency improvements are made, will reach a minimum (which may or may not be discrete), and then rise. This indicates that the first efficiency improvements will produce energy savings, the value of which will more than pay for the design change. Eventually, as additional efficiency improvements are made, it becomes increasingly costly to save more energy, and the value of the energy savings will not cover the cost of the design improvement (See the TSD, Chapter 4). The standards levels that were analyzed were taken directly from the LCC estimates. One standards level that had to be examined by law was the "maximum technologically feasible" (max-tech) level.

The minimum of the LCC curve was of particular interest in the analysis. The minimum of the curve represents the level of efficiency improvements that maximizes the difference between the value of energy saved (relative to the baseline design) and the additional consumer expenditures resulting from the efficiency improvements. Therefore, design options that corresponded to the minimum point were of special consideration in establishing standards levels. The LCC minima for each product represent the levels of energy efficiency at which the average consumer's economic benefits are maximized and the burdens minimized. Efficiency levels exceeding the LCC minima were generally rejected as not being economically justified. At efficiency levels beyond the LCC minima,

the first cost of an increment in the efficiency of the product exceeds the value of the energy saved, so a majority of consumers do not realize a benefit from the additional investment.

In addition to the max-tech and minimum LCC levels of efficiency for each class, DOE examined additional trial standards levels that were slightly lower in efficiency and price and correspondingly higher in consumer life-cycle cost than the minimum. In each case it is assumed that the standard level would be just stringent enough to induce manufactures to use all engineering design options up through the one listed. For a more complete description of these design options see Chapter 3 of the TSD. Table R.6 shows the correspondence between the trial standards levels, the engineering design levels, and the associated unit energy consumption.

Table R.6 Trial Standards Levels for Refrigerators

	Trial Standard Level			
	1	2	3	4
Engineering design option:				
Top-Mount Auto no TTDF*	7	13	15	22
Top-Mount Auto with TTDF	14	15	17	22
Bottom Mount Auto	11	14	17	23
Side-by-Side Auto no TTDF	3	13	15	22
Side-by-Side Auto with TTDF	5	16	18	28
Compact Manual	2	2	3	3
Annual energy consumption (kWh)				
Top-Mount Auto no TTDF	484	477	459	422
Top-Mount Auto with TTDF	624	569	553	517
Bottom Mount Auto	588	518	485	444
Side-by-Side Auto no TTDF	641	536	519	502
Side-by-Side Auto with TTDF	670	583	556	516
Compact Manual	301	301	295	295

* TTDF: through-the-door features

3.2 Impacts on Consumers

The major cost to consumers of stricter energy-efficiency standards is an increase in the purchase price of new products, as shown in Table R.7 and Table R.8.

The higher purchase prices of more efficient products are offset by reduced expenditures on electricity. The net benefit to consumers is summarized in Table R.9, which shows the present values of the life-cycle costs for appliances purchased between 1998 and 2030 discounted to 1992 at a 6% real rate. The difference between no action and the proposed standard is shown; positive values represent savings, i.e., reduced life-cycle cost.

Table R.7 Average Purchase Price for New Refrigerators (1990 Dollars per Unit)

Year	Base	Trial Standard Level 1	2	3	4
1990	626.8				
1993	619.1				
1998	623.3	673.4	692.0	710.3	751.0
2000	623.5	673.5	692.2	710.4	751.1
2015	624.2	674.0	692.8	711.0	751.6
2030	624.9	674.6	693.4	711.6	752.2

Source: LBL-REM.

Table R.8 Average Purchase Price for New Freezers (1990 Dollars per Unit)

Year	Base	Trial Standard Level 1	2	3	4
1990	353.4				
1993	377.5				
1998	378.5	391.9	417.0	457.8	481.9
2000	378.5	391.9	417.0	457.8	481.9
2015	379.7	392.5	417.1	457.8	481.9
2030	379.7	392.5	417.1	457.9	481.9

Source: LBL-REM.

Table R.9 Life-Cycle Cost Differences at 6% Discount Rate (1992 Dollars)

Refrigerator-Freezers	Level 1	Level 2	Level 3	Level 4
Top Mount Auto Defrost	127.87	129.97	129.75	112.32
Top Mount with TTD	26.36	-143.89	-282.72	-53.43
Side-by-Side Auto Defrost	66.61	85.31	79.11	57.93
Side-by-Side Auto Defrost with TTD	80.56	114.78	125.58	122.89
Bottom Mount Auto Defrost	67.15	74.45	54.47	84.25
Freezers				
Upright Auto Defrost	52.22	52.97	42.27	110.32
Upright Manual Defrost	54.80	116.07	108.84	109.87
Chest Manual Defrost	57.08	103.33	81.16	71.17
Compacts				
Manual Defrost Refrigerator-Freezer	8.59	8.59	11.37	11.37

More details on the impacts of the proposed standards on consumers can be found in Chapter 5 of the TSD.

3.3. Impacts on Manufacturers

The costs and benefits of standards at various levels of stringency are summarized in terms of long-run changes in shipments, prices, revenues, net income, and return on equity (ROE). These quantities are shown in Tables R.10 and R.11 for refrigerators, refrigerator-freezers, and freezers. The first column in the tables gives the value of each variable in the base case. This case represents the state of the industry in the mid-1990s if the current NAECA standards remain unchanged. Each of the next columns shows the estimated state of the industry in 1998 if one of the trial standards levels is implemented.

Each column of the tables gives the estimated values of the five most important output variables. Under each of these five values can be found two percentages. The upper tells how much the variable has changed from the base case, and the lower gives the standard error of the variable's estimated value. For all variables, the change is given as a percentage change.

Except for the most stringent standards levels, manufacturers show small changes in profitability at all levels of standards. These changes in ROE are estimated to be less than one percentage point. Although shipments decline at the highest standards levels considered, the higher selling price of efficient units more than compensates for this decline. Thus, there are increases in revenues and net income at these levels. Chapter 6 of the TSD contains a detailed description of the impacts of standards on manufacturers.

Table R.10 Refrigerator: Primary Scenario – Long-Run

	Base	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	1.34	1.32	1.32	1.31	1.29
% change		-1.41%	-2.01%	-2.62%	-3.98%
S.E.		2.83%	3.11%	3.45%	5.22%
Price	$447.05	$485.42	$499.24	$513.09	$545.12
% change		8.58%	11.68%	14.77%	21.94%
S.E.		2.70%	3.34%	4.24%	7.32%
Revenue (in $M)	600.21	642.55	656.83	670.86	702.75
% change		7.05%	9.43%	11.77%	17.08%
S.E.		3.17%	3.81%	4.71%	7.29%
Net Income (in $M)	38.42	40.32	40.50	41.03	44.16
Difference		1.90	2.08	2.61	5.74
S.E.		2.91	4.42	6.21	8.65
ROE	7.31%	7.36%	7.18%	7.15%	7.72%
Difference		0.04%	-0.13%	-0.16%	0.41%
S.E.		0.45%	0.75%	1.00%	1.57%

Table R.11 Freezer: Primary Scenario – Long-Run

	BASE	Level 1	Level 2	Level 3	Level 4
Shipments (in Mil)	0.25	0.24	0.24	0.23	0.22
% change		-0.91%	-2.91%	-6.83%	-8.93%
S.E.		2.73%	6.71%	8.82%	10.61%
Price	$225.30	$233.77	$249.31	$274.58	$290.22
% change		3.76%	10.66%	21.87%	28.82%
S.E.		1.51%	3.50%	7.93%	8.45%
Revenue (in $M)	55.25	56.81	59.36	62.74	64.82
% change		2.81%	7.44%	13.55%	17.32%
S.E.		2.56%	6.74%	11.40%	13.75%
Net Income ($M)	3.54	3.59	3.61	3.60	3.90
Difference		0.05	0.07	0.06	0.36
S.E.		0.24	0.50	1.59	1.23
ROE	7.30%	7.33%	7.08%	6.74%	7.51%
Difference		0.03%	-0.22%	-0.56%	0.20%
S.E.		0.40%	0.78%	2.86%	2.28%

3.4 Impacts on Electric Utilities

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. This section summarizes these effects for the eight Regulatory Impact Analysis alternative policy cases. A complete discussion of utility impacts is presented in Chapter 7 of the TSD and in Appendix D.

Calculating lost revenues accurately depends on assumptions about economic fluctuations, regulatory behavior, voluntary consumer conservation, and existing tiered rate structures. Rate

structures differ widely among utilities, and they are frequently changed by regulatory agencies, which makes calculating lost revenues difficult. In general, rate structures are adjusted so that utilities recover operating costs and receive some rate of return on investments. Furthermore, these lost revenues represent a transfer payment between the utility and its customers, so they are a cost to the utility and a benefit to the ratepayers, but they are not a true social cost. Because of the difficulty of calculating them accurately, gross utility revenue losses are estimated by the reduction in consumer electricity expenditures. This is estimated by multiplying the average residential price of electricity by the electricity consumption calculated by the LBL-REM model.

Gross revenue losses are largely offset by avoided costs. Avoided costs can be split into two parts, avoided energy costs and avoided capacity costs. Avoided energy costs result from the reduction in fuel purchases by utilities. Avoided capacity costs result from reduced capital investment both in the form of generation capacity and transmission and distribution capacity. Avoided costs are calculated separately for standards on heating, cooling, and baseload appliances because of the differential seasonal and time-of-day effects of these appliance groups on energy and peak. Residential refrigeration is assumed to be a baseload demand for the purposes of the results presented here.

Table R.12 summarizes utility impacts for the eight Regulatory Impact Analysis cases, including the gross change in revenue, the net change in revenue, peak demand savings, and capacity savings. Changes in revenues are simple, undiscounted sums over the 1998 to 2030 period. Peak demand savings and capacity savings are shown for 2000, 2015, and 2030.

Table R.12 Impacts of Different RIA Cases on U.S. Electric Utilities

	Enhanced Labeling, Consumer Ed.	Tax Credits, Consumer	Tax Credits, Manufacturer	Rebates, Consumer	Prescriptive Standards	Volunt. (5-yr.)	Volunt. (10-yr)	Performance Standards
Cumulative gross change in revenues 1996-2030 (M 1990$)	-35	-71	0	-74	-3960	-2999	-1858	-4515
Cumulative net change in revenues 1996-2030 (M 1990$)	-2	-15	0	-15	-343	0	0	-397
Peak demand savings (GW) 2000	0	0.01	0	0.01	0.43	0	0	0.49
2015	0.02	0.04	0	0.04	2.76	2.42	1.51	3.14
2030	0	0	0	0	3.48	3.91	3.88	3.92
Capacity Reductions (GW) 2000	0	0.01	0	0.01	0.52	0	0	0.59
2015	0.03	0.04	0	0.04	3.31	2.91	1.81	3.77
2030	0	0	0	0	4.17	4.69	4.66	4.7

3.5 National Impacts

3.5.1 Energy Savings

Standards for refrigerators, refrigerator-freezers, and freezers result in energy savings for the period 1998-2030. Cumulative energy savings are shown in Tables R.13 and R.14. All savings are expressed in primary energy units (with electricity at 11,500 Btu/kWh), and include fuel-switching and behavioral (usage) effects.

Table R.13 U.S. Energy Consumption for Refrigerators, EJ (Quads) Primary

Year	Base Case	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
1990	1.54 *(1.46)*				
1993	1.48 *(1.40)*				
1998	1.35 *(1.28)*	1.34 *(1.27)*	1.34 *(1.267)*	1.34 *(1.27)*	1.33 *(1.26)*
2000	1.31 *(1.24)*	1.26 *(1.20)*	1.26 *(1.191)*	1.25 *(1.19)*	1.24 *(1.18)*
2015	1.17 *(1.11)*	0.91 *(0.86)*	0.87 *(0.821)*	0.84 *(0.79)*	0.78 *(0.74)*
2030	1.34 *(1.27)*	1.02 *(0.96)*	0.96 *(0.912)*	0.92 *(0.87)*	0.85 *(0.81)*
1998-2030	40.66 *(38.53)*	33.62 *(31.86)*	32.45 *(30.76)*	31.60 *(29.95)*	30.07 *(28.50)*
Cumulative Savings:		**7.04 (6.67)**	**8.20 (7.78)**	**9.06 (8.59)**	**10.58 (10.03)**
Percent of Base:		17.3%	20.2%	22.3%	26.0%

Table R.14 U.S. Energy Consumption for Freezers, EJ (Quads) Primary

Year	Base Case	Standard Level 1	Standard Level 2	Standard Level 3	Standard Level 4
1990	0.414 *(0.392)*				
1993	0.357 *(0.338)*				
1998	0.265 *(0.251)*	0.264 *(0.250)*	0.262 *(0.248)*	0.261 *(0.247)*	0.260 *(0.246)*
2000	0.245 *(0.232)*	0.241 *(0.228)*	0.235 *(0.223)*	0.233 *(0.221)*	0.231 *(0.219)*
2015	0.211 *(0.200)*	0.193 *(0.183)*	0.160 *(0.152)*	0.145 *(0.137)*	0.131 *(0.124)*
2030	0.236 *(0.224)*	0.216 *(0.205)*	0.177 *(0.168)*	0.157 *(0.149)*	0.140 *(0.133)*
1998-2030	7.394 *(7.008)*	6.915 *(6.554)*	6.054 *(5.738)*	5.629 *(5.335)*	5.265 *(4.990)*
Cumulative Savings:		**0.479 *(0.454)***	**1.340 *(1.270)***	**1.765 *(1.673)***	**2.129 *(2.018)***
Percent of Base:		6.5%	18.1%	23.9%	28.8%

3.5.2 Net Present Value of Standards

The net present value 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. That difference is then multiplied by the standards case shipments between 1998 and 2030. The net present value to consumers is calculated using a discount rate of 7% and average electricity prices for these products. Table R.15 displays the net present value of standards to consumers.

Table R.15 Net Present Value to Society of Standards for Refrigerators and Freezers Purchased from 1998-2030 (1990 Billions Dollars, Discounted to 1990 at 7% Real)

	Trial Standard Level			
	1	2	3	4
Refrigerator				
Benefit (Energy)	10.89	12.61	13.84	15.91
Cost (Equipment)	3.23	4.42	5.58	8.12
Net Present Value = Benefit - Cost	7.66	8.19	8.26	7.78
Ratio: Benefit/Cost	3.37	2.85	2.48	1.96
Freezer				
Benefit (Energy)	0.73	1.99	2.33	2.72
Cost (Equipment)	0.20	0.57	1.13	1.44
Net Present Value = Benefit - Cost	0.53	1.42	1.20	1.29
Ratio: Benefit/Cost	3.66	3.50	2.06	1.89
Total: Refrigerators and Freezers				
Benefit (Energy)	11.62	14.6	16.17	18.63
Cost (Equipment)	3.43	4.99	6.71	9.56
Net Present Value = Benefit - Cost	8.19	9.61	9.46	9.07
Ratio: Benefit/Cost	3.39	2.93	2.41	1.95

Source: LBL-REM.

3.5.3 Environmental Impacts

The main environmental concern addressed here is emissions from fossil fuel-fired electricity generation. All of the standards levels for residential refrigeration decrease electricity use and, therefore, reduce power plant emissions. The Environmental Assessment Document, which is included in the TSD, contains a detailed discussion of the environmental impacts of proposed standards for this residential appliance type.

Power plant emissions include oxides of nitrogen and sulfur as well as carbon dioxide (NO_x, SO_2, and CO_2, respectively). The first two are major causes of acid precipitation, which can affect humans by reducing the productivity of farms, forests and fisheries, decreasing recreational opportunities, and degrading susceptible buildings and monuments. NO_x is also a precursor gas to urban smog and is particularly detrimental to air quality during hot, still weather. CO_2 emissions contribute to raising the global temperature via the "greenhouse effect." The long-term consequences of higher temperatures may include perturbed air and ocean currents, perturbed precipitation patterns, changes in the gaseous equilibrium between the atmosphere and the biosphere, and the melting of some of the ice now covering polar lands and oceans, causing a rise in sea level.

Efficiency standards on refrigerators, refrigerator-freezers, and freezers which reduce power plant emissions contribute to people's increased health and well-being. Since these impacts are difficult if not impossible to quantify in monetary terms, they are discussed in terms of reductions in gross pollutant emissions.

The proposed efficiency standards will decrease air pollution by decreasing future energy demand. Under the most efficient scenario, the maximum decrease of SO_2 emissions is 3.7% of U.S. power plant emissions for the year 2020. That represents a total of 1017 kt (or 1120 thousand short tons) of SO_2 abated for that year. The new amendments to the Clean Air Act of 1990 (P.L. 101-549, November 15, 1990) dramatically change SO_2 emissions regulation. SO_2 emitters, mostly electric utilities, must obtain emission allowances to match their emissions, while the total amount of allowances issued is capped. Under such a regime, emissions will always hover near the cap. If a utility emits less pollutant than the allowances it holds, the law allows it to sell them to others or to "bank" them for future use. Therefore, appliance standards will not physically reduce the level of SO_2 emissions, rather, the lowered SO_2 emissions reported represent a decreased demand on the part of electric utilities to emit.

Under the most efficient scenarios of each product, the maximum decrease in NO_x emissions is equal to 3.7% of the U.S. power plant emissions for the year 2020. This represents 966 kt (or 1065 thousand short tons) of NO_x abated for that year. NO_x emissions are handled differently under the Clean Air Act Amendments and these are real physical reductions in pollution.

Another consequence of the candidate standards would be a reduction of CO_2 emissions. CO_2 from fossil fuel burning is considered an environmental hazard because it contributes to the "greenhouse effect" by trapping heat from the sun that has been absorbed by the earth and emitted as infrared radiation. This "greenhouse effect" is expected to gradually raise the mean global temperature. Under the most energy-efficient scenario, the estimated total reduction of CO_2 in 2020 is 540 Mt (or 595 million short tons), which represents 3.7% of the projected total U.S. emissions for that year.

Other environmental effects, such as effects on particulate or heavy metal emissions, related to a standards-induced decrease in electricity generation would be minor compared to effects on decreases in SO_2, NO_x, and CO_2, and, therefore, are not covered here.

4. ECONOMIC IMPACTS OF THE PROPOSED AND ALTERNATIVE STANDARDS

4.1 Introduction

The proposed consumer product efficiency standards will affect both consumers and manufacturers of the covered products. In addition, there will be national economic effects. Potential economic impacts to consumers are higher purchase prices for covered products and lower expenditures on energy. Manufacturers will probably experience retooling and equipment costs, changes in sales volume, and changes in sales revenue. Potential national

effects include changes in gross national product (GNP), energy consumption, income distribution, and employment.

The economic analyses that were performed in support of the proposed standards studied the above effects for each class of covered products. DOE evaluated from these up to eight levels of standards for each product. Based on the economic analysis, the most stringent energy-efficiency level that could be justified economically was chosen for each product class. The complete economic analysis is presented in the TSD. A brief overview and summary of the methods and results of the economic analysis are presented in the following section.

4.2 Methodology

The economic analysis of the proposed standards focused on likely effects on consumers, manufacturers, and the nation. Tests to measure these impacts were developed and applied to each class for varying levels of regulation. The tests examined the potential of each level to cause:

- Greater consumer expenses;
- An inequitable distribution of costs and benefits among consumer groups;
- An inequitable distribution of costs and benefits among regions of the United States;
- No reasonable energy savings to the nation;
- Reduced profit margins among manufacturers of the products under consideration;
- An inequitable distribution of financial impacts among these manufacturers, especially small manufacturers;
- Exposure of the manufacturers to a greater risk of financial failure; and
- Reduced competition.

The LBL-REM provides the information needed to calculate consumer life-cycle costs as well as energy savings and net present benefit to the nation. The LBL-MAM calculates impacts on profitability of firms of various sizes. The results of these models were used to compare the effects of alternative regulatory scenarios and are detailed in Chapters 3 and 6 of the TSD. The remaining sections of this chapter summarize those results and discuss the national economic impacts of the proposed standards and other regulatory approaches. Equity issues are addressed in terms of differences in effects on regions and income classes and in the variation in profitability for various size firms, which could lead to a lessening in competition.

4.3 Effects of Proposed Standards on Consumers

The major effect of the proposed standards on consumers will be changes in the purchase price and energy use of products. An analysis of life-cycle costs incorporates these two impacts. The gross benefit to the consumer from appliance efficiency standards is the reduction in life-cycle cost (LCC). LCC discounts future operating expense savings and

weighs them against the increased prices of more efficient equipment. DOE performed this analysis for each product class without regulation and at each trial standard level.

No standard was proposed that had a higher LCC than the baseline unit. The time over which the consumer recovers the higher initial price of the more efficient appliance ranges from 0.5 years for manual defrost upright freezers, to 9.2 years for top mount auto defrost refrigerator with through-the-door features. Previous studies indicate that energy comprises a larger fraction of the expenditures of low-income households than of average households. To the extent that the proposed performance standards decrease energy costs, low-income households would enjoy greater benefit than average. On the other hand, the increased purchase price represents a disadvantage over the short term although that increase is recovered over time. To the extent that low-income households purchase used, rather than new, appliances, this disadvantage may be small. In fact, since many low-income households are made up of renters rather than homeowners, the landlord will bear the additional equipment price, and the tenant will benefit from reduced energy expenditures if the increase in equipment price is not passed through as higher rent.

4.4 Effects of Proposed Standards on Manufacturers

The effects of the proposed standards on manufacturers are analyzed extensively in the TSD. Although these results are subject to uncertainty, that uncertainty has been estimated by using Monte Carlo techniques. The analysis presented here uses results for runs done at standards levels 1 through 4 for refrigerator-freezers. Both the estimates of change in ROE and the uncertainty of these estimates expressed in standard errors are presented in Table R.16 for refrigerator-freezers, and Table R.17 for freezers.

Table R.16 Change in Profitability Due to Proposed Standards: Refrigerator-Freezers

	Level 1	Level 2	Level 3	Level 4
ROE Before	7.33%	7.33%	7.33%	7.33%
ROE After	7.52%	7.41%	7.43%	8.09%
Change	0.19%	0.08%	0.11%	0.77%
SE of Chng	0.62%	0.76%	0.82%	1.82%

Table R.17 Change in Profitability Due to Proposed Standards: Freezers

	Level 1	Level 2	Level 3	Level 4
ROE Before	7.30%	7.30%	7.30%	7.30%
ROE After	7.33%	7.08%	6.74%	7.51%
Change	0.03%	-0.22%	-0.56%	0.20%
SE of Chng	0.40%	0.78%	2.86%	2.28%

The most obvious and important trend in the structure of these industries is the continuing consolidation that has been taking place for the past 30 years. This process tends to decrease the competitiveness of the industry, and is generally stimulated by the development of low profitability in certain firms (most often in smaller firms), which then become candidates for takeovers by larger, more profitable firms. Since the analysis predicts little change in profitability in these manufacturing industries, the proposed standards would probably have no effect on the consolidation trend in the industry.

Because one cannot reliably analyze the effects on individual firms that are due to difficulties that they would encounter in attempting to implement the proposed standards, the shifts in market share among firms as a result of standards is unpredictable. The shifts would be reflected in changes in profits. However, the demand for these products are not likely to diminish by a significant amount, and the industry as a whole will find a way to meet that demand profitably under proposed standards. What one firm may lose through poor strategy, another will gain. This is not different from the continuous, normal process of competition for market share.

4.5 Effects of Proposed Standards on GNP and Employment

4.5.1 Overview

Standards will cause a shift in demand for final goods because consumers will be induced to spend more on appliances and less on energy. This in turn will cause the suppliers of these goods to spend more or less on capital, labor, and intermediate inputs. These demand changes will not cancel each other out because they will occur at different times and because the decreases in demand will eventually outweigh the increases. As a result, aggregate demand (that is demand for goods and services by the economy as a whole) will be affected. Aggregate demand can in turn affect the level of GNP and/or the level of employment. But the translation of changes in demand to changes in output is a complex one and its analysis is subject to considerable debate among economists. The relevant theoretical considerations are discussed below.

4.5.2 Crowding Out

An increase in demand by one sector of the economy will tend to reduce demand by other sectors in two ways. The first way is through the classic crowding-out mechanism. A demand for capital goods is normally realized by means of reliance on financing from the debt and equity markets. This demand for funds causes an increase in the interest rate which inhibits borrowing by others seeking to make capital investments. Thus, investment by one sector crowds out some investment by other sectors. Modern theory of debt markets suggests that rationing may take place, in which case some crowding out could happen directly, rather than as a result of interest rate changes.

A second type of displacement can happen in the consumer sector. If consumers are forced to spend more for one commodity, they will spend less on others. If the life-cycle cost of appliances is reduced, and consumers are completely rational and have adequate access to credit, then one would not expect any short-run decrease in consumer spending because they would fully anticipate future savings. However, the fully rational view and unlimited credit seem unlikely, and, thus, some crowding out of other types of consumption is expected in the short run. Other types of consumption are expected to increase in the long run because of lower energy expenditures. The net effect is discussed later when efficiency is considered.

4.5.3 The Multiplier

The multiplier effect is a counteracting effect to the crowding-out effect. Manufacturing firms are expected to employ additional labor after standards, and the firms that supply capital goods will need additional labor to produce the required equipment, leading to an increase in employment. The newly employed workers will increase their demand for goods; this is the standard Keynesian multiplier effect. Another, more abstract view of this process, is that all realized demand becomes income, and all income is divided between savings and further demand. Generally, the far larger part of income becomes demand.

4.5.4 The Rational Expectations View

Standard macroeconomic analysis has been modified by the development of rational expectations theory, which points out that fully anticipated changes tend to be completely compensated for by the various economic actors. Thus, consumers who anticipate the price of a new appliance well in advance will save the same fraction of their income regardless of the actual price. Conversely, if the consumer is surprised by a price increase, he may spend more and save less in the year of purchase than was planned. The result of this analysis is to predict that once the implications of standards are thoroughly understood, and all parties have had time to adjust fully, the standards will have virtually no effect on the level of aggregate demand.

4.5.5 Efficiency

One effect on real GNP (but not employment) that is long lived and not subject to the rational expectations argument is that of greater efficiency. Since standards make appliances more efficient, post-standards appliances produce a given stream of utility for a lower present value. As a result, the long-run impact of standards is to increase real GNP. This effect can be measured only if the GNP price deflator correctly reflects the efficiency gain in appliances. But whether or not it is correctly measured, this will be the only long-run effect on GNP. In other words, if the country can buy water heating services or room air conditioning services, etc. for less, it will spend its money on something else, resulting in the same real consumption of those services along with greater consumption of other goods.

This completes the theoretical discussion. The following sections trace the effects of changes in demand through the appliance retail sector, the appliance manufacturing sector, and the power industry.

4.5.6 Demand Effects and the Retail Sector

On appliances the typical retail markup over the wholesale price is about 1.66. This means that for an increase of $1.00 in cost to the retailer the consumer will be charged $1.66. In other words, 0.66/1.66 or 40% of the increase in consumer price resulting from the proposed standards will go to retailers. This increase will occur very rapidly after the implementation date, after which demand will remain fairly constant.

4.5.7 Demand Effects and the Manufacturer Sector

Preparing for standards will require large capital expenditure, mostly before the implementation date. After implementation there will still be some increased demand for intermediate inputs and labor.

4.5.8 Demand Effects and the Energy Industry

After standards are implemented, energy demand will be reduced slowly (below the base-case level). This reduction will have a direct effect on income for the energy industry, and a multiplier effect as that reduced income is spent. As more efficient appliances are put in place, and the reduction in energy demand accumulates, the demand for energy generation facilities will eventually be affected. Changes in the construction of these facilities will occur at different times in different locations, and, consequently, the effect will be spread over many years. Also, because the effect is gradual and will not reach significant proportions for several years after implementation, it should be well anticipated. Thus, rational expectations theory assures us that changes in energy demand should not affect aggregate demand.

4.5.9 Summary and Conclusions

In the short run, crowding out will be incomplete, so that aggregate demand will first increase and then return to normal. This increase will begin about three years before implementation. The value of the short-run Keynesian multiplier depends on prevailing macroeconomic conditions, estimates of which vary widely, but values between one and three are typical, including crowding-out effects. The peak rate of investment should occur one to two years before, when the demand for capital for retooling to meet the standards by water heater, mobile home furnace, direct heating equipment, television, kitchen range and oven, room air conditioner, pool heater, and fluorescent light ballast manufacturers would rise by several hundred million dollars per year above normal.

Another large increase will occur when standards are implemented because revenues in these industries are estimated to increase by approximately $211 million per year. Again this increase can be translated directly into a short-run increase in GNP. Demand will probably return to its original level within two or three years of the implementation of standards. This estimate is based on the view that the multiplier is a relatively short-run phenomenon, and that, in the long run, crowding out is nearly complete.

4.5.10 Trade

Standards will have virtually no effect on appliance imports. However, oil imports are essentially determined by the gap between domestic production (which is independent of demand) and the demand for oil. Thus, to the extent that standards reduce the demand for oil, the trade balance will be improved.

4.6 The Impact of Alternative Regulations

This section analyzes the macroeconomic impacts of alternatives to performance standards. As with the above analysis of performance standards, the impacts are given relative to the base case of "no action". For a list of the alternatives and their non-macroeconomic impacts, see Table R.5.

4.6.1 Tax Credits

Tax credits for consumers and for manufacturers were analyzed in sections 2.3 and 2.4 respectively. The impact will be small in proportion to the reduction in net present value (NPV) for fuel and equipment, as shown in Table R.5. Thus, after implementation, the impacts should be 2.3% as large as those predicted for performance standards.

The impact of the manufacturer tax credit is small because the investment tax credit is applicable only to the manufacturers' tooling and equipment costs, and most of the cost of the design options considered involve purchased parts. This analysis found that the resulting price reductions would be small and would apply to only a limited number of design options. Furthermore, because of the increase in appliance efficiencies under the 1990 NAECA standards, tax credits would induce only a small change in consumer purchases. Since very few high-efficiency appliances would be purchased, manufacturers would not choose to

manufacture them. Thus, they would not invest in the necessary equipment, and, if the law were correctly enforced, would not receive large tax credits. As can be seen from Table R.5, the magnitude of these effects is immeasurably small.

4.6.2 Consumer Rebates

A program of consumer rebates is an incentive for consumers to purchase more efficient appliances, similar to the program of consumer tax credits. The macroeconomic impact will be smaller in proportion to the reduction in NPV for fuel and equipment, as shown in Table R.5. Thus, after implementation, the impacts should be 2.8% as large as those predicted for performance standards.

One small distinction between the macroeconomic effect of a consumer rebate and a mandated standard can be noted. The rebate partially supplements the consumer's income, and, thus, reduces the consumer's tendency to reduce other spending because of the increased expenditures on efficient appliances. In order to analyze this program on its own terms, and not as part of a deficit spending program, one should assume the rebate is paid for with taxes. These taxes will have nearly the same crowding-out effect that the extra appliance expense would have had. So, in the end, no correction needs to be made to the original analysis.

4.6.3 Prescriptive Standards

Prescriptive standards are assumed to be implemented as standards at one level below the performance standards. For example, if refrigerators, refrigerator-freezers, and freezers performance standards were at standard level 3, prescriptive standards were analyzed at level 2. The lower standards level entails slightly smaller expenditures for tooling and purchased parts. Consequently, the macroeconomic impacts before the implementation date should be slightly smaller for prescriptive standards.

After implementation, the impact of prescriptive standards will be smaller in proportion to the reduction in NPV for fuel and equipment, as shown in Table R.5. Thus, after implementation the impacts should be 87% as large as those predicted for performance standards.

4.6.4 Voluntary Efficiency Targets

The macroeconomic impacts of voluntary targets will be smaller than would be indicated from the size of the NPV for fuel and equipment in the targets case. Although the NPV of the savings is between 53% and 74%, the macroeconomic impacts will be much less than these figures suggest because the multiplier is a short-run effect, but the various forms of crowding out are long-run effects. Although the estimates must be quite rough, if the multiplier has a half-life of two years (it is unlikely to be more), the macroeconomic impact with a five-year delay would be, at the very most, half of 74% (or 37%) of the performance standards impact. With a 10-year delay, the impact would be at most one-fourth of 53% (or 13%) of the performance standards impact.

4.6.5 Enhanced Labeling and Consumer Education

Enhanced labeling and consumer education is not likely to be a good incentive for consumers to purchase more efficient appliances. If consumers respond as expected, the macroeconomic impact of this alternative will be much smaller in proportion to the reduction in NPV for fuel and equipment, as shown in Table R.5. After implementation, the impact is only 1.0% as large as that predicted for performance standards.

REFERENCE

1. U.S. Department of Energy, *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, and Television Sets.* 1993. DOE/EE-0009, in 3 vols. DE94006 575-577.