Energy Research and Development Division
FINAL PROJECT REPORT

CONSUMER ELECTRONICS AND MOTORIZED APPLIANCES

Prepared for: California Energy Commission
Prepared by: Electric Power Research Institute

JANUARY 2015
CEC-500-2016-034

PREPARED BY:

Primary Authors:
Brian Fortenbery
Frank Sharp
Jeff Dols
Micah Sweeney
Ben Ealey
Clancy Donnelley
Roger Lawrence

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304
www.epri.com

Contract Number: 500-010-022

Prepared for:

California Energy Commission

Bradley Meister, Ph.D., P.E.
Project Manager

Virginia Lew
Office Manager
Energy Efficiency Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

EPRI would like to acknowledge the sponsors of this project—the California Energy Commission and its Public Interest Energy Research Program—and in particular, Bradley Meister for his management and support throughout the course of this project.

EPRI would also like to extend its gratitude to its subcontractors for their support in the many efforts undertaken during the course of this project:

- Clancy Donnelly, Suzanne Foster Porter, Eric Wanless, Laura Moorefield, Philip Walters, Erica Lighthiser, and Dave Denkenberger of Ecova for their outstanding work in multimedia computers, adjustable-speed drives, home audio devices, power factor, and Title 20 recommendations.
- Jonathan Koomey, Ph.D, for his guidance and support for several of the reports in the power factor task.
- Jon Vencil of KEMA for overseeing the installation of meters in homes throughout the regions of California to monitor important plug loads. The data collected in this field study helped to further understand the potential energy savings of power factor correction.
- Barbara Toole O'Neil and Brian Boothe of Redhorse for managing the technicians that went to each home of the field study to install, uninstall, and download the data from the meters.
- Mort Blatt for the development of the Tech Transfer Plan and driving the effort to create a white paper for each task of this project.
- Roger Lawrence of RGL Solutions for all of his excellent work in the adjustable-speed drives task.
- Jason Lai, Ph.D of Virginia Tech

EPRI would also like to thank the members of the PAC:

- Henry Wong, Intel
- Steve Blanc, Pacific Gas & Electric (PG&E)
- Rich Fassler, Power Integrations
- Scott Durfee, NIDEC Motor
- Elton Sherwin, Ridgewood Capital
- Chuck Mullet, ON Semi
- Juan Menendez, Southern California Edison (SCE)
- Sanjiv Lakhanpal, AMD
- Craig Keefner, Kiosk.com

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

California Energy Commission Consumer Electronics and Motorized Appliances is the final report for the Consumer Electronics and Motorized Appliances project (contract number 500-010-022) conducted by the Electric Power Research Institute. The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Annually, the California Energy Commission (Energy Commission) funds Public Interest Energy Research (PIER) projects which benefit California rate payers. In 2010, Energy Commission funded PIER project 500-10-022 to advance electronics and save energy in consumer electronics and motorized appliances. This project involved research in five (5) areas: kiosk and multimedia computers, home audio equipment, induction cooking, power factor corrections and adjustable speed drives that could provide energy savings in California through Title 20 codes and standards development. Through careful market research, laboratory testing, and field studies, the research team concluded that it is possible to save more than 2,300 billion kilowatt-hours each year.

The research found that using adjustable-speed drives offered the most energy benefit. The power factor research showed significant potential efficiency gains can be made in many electrical devices that use switching power supplies including computers, home audio devices, televisions, and appliances. Computer research showed efficiency gains could be found in number of components with power supplies and video cards having the largest potential. Research also showed that high-efficiency computers could deliver more computing power while using less energy. The home audio research revealed that there are numerous potential efficiency gains, including using sleep modes in home audio devices that offer noticeable energy savings. Induction cooking demonstrated efficient cooking technology that offered savings, however there are still some hurdles which currently prevent it from being a universal residential retrofit solution.

Keywords: California Energy Commission, Kiosk Computers, Multimedia Computers, Home Audio Devices, Induction Cooking, Power Factor Correction, Adjustable-Speed Drives, Energy Efficiency

Please use the following citation for this report:

Brian Fortenbery, Frank Sharp, Jeff Dols, Micah Sweeney, Ben Ealey, Clancy Donnelley, Roger Lawrence. (Electric Power Research Institute (EPRI)). 2014. ***Consumer Electronics and Motorized Appliances***. California Energy Commission. Publication number: CEC-500-10-034.

TABLE OF CONTENTS

Acknowledgements i

PREFACE ii

ABSTRACT iii

TABLE OF CONTENTS iv

LIST OF FIGURES ix

LIST OF TABLES ix

EXECUTIVE SUMMARY 1

Introduction 1

Project Purpose and Results 1

Benefits to California 4

CHAPTER 1: Introduction 6

CHAPTER 2: PCs in the Workplace 7

2.1 Multimedia Computers 7

2.1.1 Background 7

2.1.2 Research Goal 8

2.1.3 Technical Overview 9

2.1.4 Multimedia PC Efficiency Today 9

2.1.5 Opportunity: Components Targeted for Efficiency Improvements 12

2.1.6 Results 13

2.1.7 System Level Interim Results 22

2.1.8 2013 Update: PSU Investigation and Component Updates 25

2.1.9 Title 20 Implications – Multimedia Computers 34

2.2 Kiosk Computers 34

2.2.1 Background and Issue 34

2.2.2 Technical Overview 40

2.2.3 Opportunity 42

2.2.4 Testing Overview 44

2.2.5 Testing Setup and Results 54
2.2.6 Market Impact 63
2.2.7 Title 20 Impacts 64
CHAPTER 3: Survey of Potential Energy Efficient Design Techniques for Home Audio Devices 66
3.1 Background and Purpose 66
3.2 Technical Overview 67
3.2.1 Amplification 67
3.2.2 Technology Description 68
3.3 Opportunity 69
3.3.1 Benefits of Using Class D Amplifiers over Linear Amplifiers 69
3.3.2 Drawbacks of Class D Amplifiers 72
3.3.3 Power Scaling 73
3.3.4 Sleep Mode Power 74
3.4 Market Impact and Sales Trends 74
3.5 Testing Approach 80
3.5.1 Overview of ENERGY STAR Test Method 80
3.5.2 Modifications to Energy Star Test Method 81
3.5.3 Equipment 84
3.5.4 Products Procured for Testing with Modified Test Method 86
3.6 Test Results 86
3.6.1 Results for Passive Mode (Idle and Sleep) Power Tests 86
3.6.2 Results for Active Mode Power Tests 89
3.7 Energy Consumption and Savins Potential Estimates 91
3.7.1 Current California Standards for Home Audio Equipment 91
3.7.2 Potential Savings Estimates Based on Test Results 91
CHAPTER 4: Induction Cooking 101
4.1 Executive Summary 101
4.2 Background 103

4.2.1 Codes and Standards 103
4.3 Technical Overview 103
4.4 Compatibility with Nonferrous Cookware 107
4.5 Next-Generation Induction Cooker Prototype 107
4.6 Testing Protocols for Measuring Cooking Efficiency 107
4.6.1 U.S. Department of Energy Test Procedure 107
4.6.2 U.S. ASTM Test Procedure 108
4.6.3 IEC Test Procedure 109
4.7 Development of an Induction-Compatible Testing Method 110
4.7.1 Details of EPRI Cooking Efficiency Test Procedure 110
4.8 Evaluation of Residential Cooking Technologies 113
4.8.1 Induction Cooker A 113
4.8.2 Induction Cooker B 115
4.8.3 Conventional Cooking Appliances 118
4.9 Results of Efficiency Testing 121
4.9.1 Simple Water Heating Test Procedure 121
4.9.2 Water Heating with Small Cooking Vessel 122
4.9.3 Water Heating with Extended Simmer 123
4.9.4 Comparison with DOE Results 123
4.9.5 Summary of Cooking Efficiency Results 125
4.10 Qualitative Evaluation 126
4.11 Market Impacts 127
4.11.1 Non-Energy Impacts 128
4.11.2 Market Barriers 129
4.12 Recommendations 131
CHAPTER 5: Power Factor Requirements for Electronic Loads in California 134
5.1 Background and Purpose 134
5.1.1 Objective 134

5.1.2 Power Factor 134
5.2 Technical Overview 137
5.2.1 Interaction of Harmonic Currents and Electrical Distribution 138
5.3 Opportunity 142
5.4 Testing Approach 144
5.4.1 Laboratory Testing 144
5.4.2 Field Testing 148
5.4.3 Simulations 150
5.5 Testing Results 150
5.5.1 Laboratory Testing 150
5.5.2 Simulations 153
5.5.3 Best-Case-Scenario 153
5.5.4 Field Testing 156
5.5.5 Branch-Circuit #1 158
5.5.6 Branch-Circuit #2 160
5.5.7 Branch-Circuit #3 162
5.5.8 Branch-Circuit #4 164
5.5.9 Branch-Circuit #5 165
5.5.10 Whole-House Savings 167
5.6 Market Impacts 167
5.7 Energy Consumption and Savings Potential Estimates 169
5.7.1 Initial Calculations 169
5.7.2 Applying Field Measurements to the Calculations 170
5.8 Conclusion 171
5.8.1 Key Findings 172
5.8.2 Significance 172
5.8.3 Future Opportunities 174
CHAPTER 6: Efficient Motor-Driven Appliances Using Embedded Adjustable-Speed Drives 175

6.1 Background 175
6.2 Technical Overview 176
6.2.1 Motor and ASD Technology 176
6.2.2 The Fundamentals of Electric Power Delivery 176
6.2.3 The Fundamentals of Electric Motor Operation 176
6.2.4 The Fundamentals of an Adjustable Speed Drive 176
6.2.5 Performance and Efficiency 190
6.3 Opportunity 196
6.3.1 Test Results Refrigerator/Freezer 196
6.3.2 Clothes Dryers 199
6.3.3 Ductless Single-Room HVAC System 209
6.3.4 Summary of Testing Results 212
6.4 Market Impact 213
6.5 Title 20 Impacts 213
CHAPTER 7: Technology Transfer Plan and Execution 216
7.1 Program Objectives/Introductions 216
7.1.1 Project 1: Kiosks and Multimedia Computers 216
7.1.2 Project 2: Home Audio Equipment Efficiency Assessment 218
7.1.3 Project 3: Residential Induction Cooktop 221
7.1.4 Project 4: Power Factor Correted Electronics Technology 222
7.1.5 Project 5: Adjustable-Speed Drives 225
7.2 Preface 226
7.3 Market Barriers 226
7.3.1 Overcoming Market Barriers 228
7.4 Market Influences/Actions Needed 229
7.5 Information Resource Channels 238
7.6 Codes and Standards 255
7.6.1 Interactions with Codes and Standards Organizations 256

7.6.2 Codes and Standards Deliverables 267
7.6.3 Codes and Standards White Papers 267
7.6.4 Change Proposals 268
7.7 Technology Transfer Products 268
7.7.1 Fact Sheets 268
7.7.2 White Papers 269
7.7.3 Journal Articles/Technical Papers 269
7.7.4 Presentations 270
7.7.5 "Word of Mouth" Contacts 270
7.8 Summary/Conclusions and Plan Execution 272
Glossary 273
REFERENCES 274
APPENDIX A: Power Levels of Desktop Computers 1
APPENDIX B: 3D Mark 11 Score 2
APPENDIX C: Modified ENERGY STAR Test Method 1
APPENDIX D: Estimated Energy Consumption for Class AB Versus Class D Amplifiers 1
APPENDIX E: Cooking Efficiency Test Data 1
APPENDIX F: Single-Line Residential Drawings 1

LIST OF FIGURES

Figure 1: Residential Sector Energy Consumption in the United States 8
Figure 2: Capabilities of Various Multimedia Devices 9
Figure 3: A Typical Power Supply Marketing Add 10
Figure 4: Annual Energy Conumption of Various Electronic Devices 10
Figure 5: Baseline Multimedia PC Energy Consumption 12
Figure 6: Computing Efficiency through Time 14
Figure 7: Asus Mini-ATX Motherboard 15
Figure 8: Comparison of Various Storage Drives 17
Figure 9: A Discrete Graphics Card 18

Figure 10: Efficient PC Case Designed with Cooling In Mind (Left) and Traditional OEM Case (Right) 21

Figure 11: Energy Consumption Reductions Due to Various Modifications 22

Figure 12: Comparing Power Demand by Mode 24

Figure 13: Quantitative Benchmark Score (Bigger is Better) 24

Figure 14: ENERGY STAR Duty Cycles 28

Figure 15: Energy Savings Potential of Optimizing Power Supply Size 31

Figure 16: Net Losses in Original and Replacement External Power Supplies 32

Figure 17: Custom Desktop, Gaming Notebook, and Integrated Desktop Comparison 33

Figure 18: Kiosk Computer, System Interaction, and Cmmon Peripherals 35

Figure 19: Typical Kiosk Components and Design; (1) Kiosk Cabinet, (2) CPU, (3) Display Device, (4) Peripheral, (5) Signage and External Functionality 36

Figure 20: ENERGY STAR Computer Definitions 37

Figure 21: ENERGY STAR Computer Exceptions 38

Figure 22: Internal Power Supply Efficiency Ratings 39

Figure 23: Power Supply Efficiency Allowances 39

Figure 24: ENERGY STAR Calculation 40

Figure 25: Baseline Computer Specifications 46

Figure 26: 80 PLUS Summary 48

Figure 27: Baseline Computer Specifications 49

Figure 28: Small Form Factor Computer Specifications 50

Figure 29: Slim Line Computer Specifications 51

Figure 30: Industrial Computer Specifications 52

Figure 31: Efficiency Computers #1 Through #3 - Specifications 53

Figure 32: Efficiency Computers #4 Through #6 - Specifications 53

Figure 33: Efficiency Computers #7 Through #9 - Specifications 54

Figure 34: Power and Performance Test Setup 55

Figure 35: System Power Consuption in Watts 56

Figure 36: Kiosk PassMark Results 58

Figure 37: Power Factor of Evaluated Systems 62

Figure 38: ENERGY STAR Calculation 64

Figure 39: Large Heat Sink Attached to the Traditional Linear Amplifier 67

Figure 40: Power Loss for a Linear Power Supply/Linear Amplifier (Wasted Power = 60 W) 70

Figure 41: Schematics of a Class D Switched Amplifier 70

Figure 42: Power Loss for a Switching Power Supply/ Class D Audio Amplifier (Waste Power = 11.25 W) 71

Figure 43: Signal Distortion in Class D Amplifiers 72

Figure 44: Observed Behavior of Amplified Audio Systems 73

Figure 45: Expected Behavior of Amplified Audio Systems 73

Figure 46: Unit Shipments of Amplifiers, Speakers, and Audio Separates from 2005 to 2017 75

Figure 47: Unit Shipments of Amplifiers, Speakers, and Audio Separates from 2005 to 2017 76

Figure 48: Unit Shipments of HTiB from 2005 to 2017 77

Figure 49: Unit Shipments of iPod/MP3Docks and Mini Systems from 2005 to 2017 78

Figure 50: Unit Shipments of DVD and Blu-ray Players from 2009 to 2017 79

Figure 51: ENERGY STAR 2012 Unit Shipment Data Including Estimated Market Penetration of ENERGY STAR Products 80

Figure 52: Input Power at Different Levels of Sound Pressure Using Full Spectrum (Pink Noise) Signal Versus Narrow Spectrum (Using Band Pass Filter) Signal 82

Figure 53: Home Audio Testing Example Spreadsheet 84

Figure 54: The Sound Pressure Meter Used in the Testing 85

Figure 55: Range in Sleep Mode Power Draw Across All Devices Tested Within Each Category 87

Figure 56: Range in Idle Mode Power Draw Across All Devices Tested Within Each Category . 87

Figure 57: Power Draw in Idle and Sleep Modes, Time to Sleep (Or Standby) From Idle Mode Across All Devices 88

Figure 58: Range of Average Power Draw In Active Mode, Across All Devices Within Each Category 89

Figure 59: Active Mode Power Draw at Different Sound Pressure Test Points for Recievers 90

Figure 60: Active Mode Power Draw at Different Sound Pressure Test Points for Soundbars 91

Figure 61: Unit Energy Consumption by Mode for Various Home Audio Devices 92

Figure 62: Total Annual Energy Consumption by ode in California of Home Audio Equipment 95

Figure 63: EPRI Cooking Efficiency Testing Results 101

Figure 64: Basic Principle of Induction Cooking 104

Figure 65: Induction Cooker Driver Circuit with Single-Ended Inverter Topology 106

Figure 66: Driver Circuit with Half-Bridge Inverter Powering Two Cooking Units 106

Figure 67: Counter-Top Induction Cooker A 113

Figure 68: Induction Cooker A Power Settings 114

Figure 69: Induction Cooker A Power Cycling at Lowest Power Setting 115

Figure 70: Counter-Top Induction Cooker B 116

Figure 71: Induction Cooker B Power Settings 117

Figure 72: Induction Cooker B Cycling at Lowest Power Setting 117

Figure 73: Induction Cooker B Cycling at Power Level 2 118

Figure 74: Conventional Electric Resistive Range Chosen for Evaluation 119

Figure 75: Natural Gas Range Chose for Evaluation 120

Figure 76: EPRI Cooking Efficiency Testing Results 125

Figure 77: Switch-Mode Power Supply with Passive Power Factor Correction Provided by Line-Frequency Inductor 136

Figure 78: Displacement of Current by a Linear Inductive Load 137

Figure 79: Distortion of Current Waveform by a Nonlinear Load 138

Figure 80: Single-Line Drawing of Multi-Load (Top) and Home Run (Bottom) Circuits 139

Figure 81: The Structure of a Residential Split Phase System 140

Figure 82: Distortion in a Split Phase System 140

Figure 83: Three-Phase Distribution Common in Commercial Buildings 141

Figure 84: Distortion in a Three-Phase System 141

Figure 85: Measured Savings in Power Supply Testing Based on Cable Length 143

Figure 86: Test Setup for Laboratory Testing 146

Figure 87: PM 1000+ Power Analyzer 147

Figure 88: MX45 AC Power Supply 147
Figure 89: Watts Up? Pro Power Meter Used in the Field Study 149
Figure 90: Power Factor of Some Common Household Appliances 151
Figure 91: Current Harmonics of the Laptop Tested in the Laboratory 152
Figure 92: Current Harmonics of a PFC Television 153
Figure 93: Usage Pattern of a Game Console 155
Figure 94: Residential Devices Identified in the Field during the Survey 156
Figure 95: Branch Circuit #1 Device Contributions to Total Load 159
Figure 96: Usage Profile of One Day for Branch Circuit #1 159
Figure 97: Branch Circuit #2 Device Contributions to Total Load 161
Figure 98: Usage Profile of One Day for Branch Circuit #2 161
Figure 99: Branch Circuit #3 Device Contributions to Total Load 163
Figure 100: Usage Profile of One Day for Branch Circuit #3 163
Figure 101: Branch Circuit #4 Device Contributions to Total Load 164
Figure 102: Usage Profile of One Day for Branch Circuit #4 165
Figure 103: Branch Circuit #5 Device Contributions to Total Load 166
Figure 104: Usage Profile of One Day for Branch Circuit #5 166
Figure 105: USB Sockets in a Receptacle Sample 1 168
Figure 106: USB Sockets in a Receptacle Sample 2 169
Figure 107: Voltage-Fed ASD System with Input Diode Rectifier, DC Link, Inverter, and Motor 177
Figure 108: Diagrammatic Representation of Sinusoidally Modulated DC Pulses (One Cycle) 177
Figure 109: Diagrammatic Representation of Sinusoidally Modulated DC Pulses (Two Cycles) 178
Figure 110: Pulse Width Modulated Current Waveform 178
Figure 111: Pul ASD 50-Hz to 150-Hz Refrigerator Motor Controller 179
Figure 112: Compact, Three-Phase Salient Pole Synchronous Induction Motor 179
Figure 113: Split Phase Stator Winding 180
Figure 114: Squirrel Cage Rotor 180

Figure 115: Electronically Commutated Motor 181

Figure 116: Basic Refrigerant Path Common to Refrigerator/Freezer Systems 183

Figure 117: Practical Layout of the Refrigerator/Freezer Heat Exchanger Components 183

Figure 118: Energy Reduction Achieved by Using Adjustable Speed Control of the Compressor Motor 184

Figure 119: Opportunities to Optimize Compressor Capacity Once Speed Control Has Been Implemented 184

Figure 120: Panasonic Reports a Significant Noise Reduction Over a Wide Frequency Range . 185

Figure 121: Panasonic Reports a Significant Reduction in Noise Transients 185

Figure 122: GE GTDP400EMWS: Typical Resistive Clothes Dryer 186

Figure 123: Electric Dryer Performance 187

Figure 124: Cut-Away View of a Ductless Heat Pump Clothes Dryer 187

Figure 125: Cut-Away View of a Ductless Heat Pump Clothes Dryer Showing Main Components 188

Figure 126: Typical Heat Pump Cooling Mode 189

Figure 127: Typical Heat Pump Heating Mode 189

Figure 128: Range of Heating and Cooling 190

Figure 129: ASD Controlled Heat Pump Performance Improvement 191

Figure 130: ASD Controlled Heat Pump Performance Improvement as Documented by Emerson 192

Figure 131: Typical Window Air Conditioning Unit Partially Obscuring the Window Area 193

Figure 132: Contrasting Single-Room HVAC Systems 194

Figure 133: Contrasting Single-Room Ductless HVAC Systems in Operation in the Same Space 195

Figure 134: Split Ductless Single-Room HVAC Components 195

Figure 135: Comparison of Energy Used by ASD and Non-ASD Refrigerators/Freezers 197

Figure 136: Power Draw Over Time for Slow Mode 200

Figure 137: Power Draw Over Time for Fast Mode 201

Figure 138: Cumulative Energy Consumption over Drying Time for ASD Dryer vs. Heat Pump and Electric Resistance Dryers 202

Figure 139: Dryer Efficiency vs. Drying Time for ASD Dryer vs. Heat Pump and Electric Resistance Dryers 203

Figure 140: ASD Dryer Power Draw at Five Different RPMs 204

Figure 141: ASD Dryer Energy Consumption 206

Figure 142: Comparison of Cooling Capacity Between ASD and Non-ASD Ducted Central HVAC System 208

Figure 143: Comparison of Energy Efficiency Ratio Between ASD and Non-ASD Ducted Central HVAC System 209

Figure 144: Comparison of Energy Efficiency Ratio Between ASD and Non-ASD Ducted Central HVAC System 210

Figure 145: Comparison of the Average Power Used by a Window AC Unit and a Ductless Heat Pump 211

Figure 146: Opportunity Grading Scale 214

Figure 147: Opportunity Evaluation of Residential Refrigerators/Freezers 214

LIST OF TABLES

Table 1: Baseline Multimedia PC Characteristics 11

Table 2: Component Function and Bearing on System Performance and Energy Consumption 13

Table 3: Summary of Baseline and Efficient Multimedia PC Components 23

Table 4: System Configurations 27

Table 5: Alternate Desktop Computer Components Tested 29

Table 6: Common Kiosk Applications 35

Table 7: Power and Annual Cost Savings 60

Table 8: General Sales Forecasts for Home Audio Categories 74

Table 9: Specifications for the Speakers Used in the Receiver Portion of Active Mode Testing .. 85

Table 10: Characteristics of Products Selected for Testing 86

Table 11: Power, Duty Cycle and California Stock of Home Audio Equipment 94

Table 12: Assumed Product Lifetimes Used for Energy Savings Estimates 96

Table 13: Assumed Market Penetration of Existing Devices that can Meet the Proposed Tier 1 and Tier 2 Standards 97

Table 14: Tier 1 Estimated Unit and California Annual Energy Savings Potential by Device Type After Stock Turnover, Assuming Level Sales of All Devices 98

Table 15: Tier 2 Estimated Unit and California Annual Energy Saving Potential by Device Type After Stock Turnover, Assuming Level Sales of All Devices 99

Table 16: Comparison of Cooking Efficiency Measured by EPRI and DOE 102

Table 17: Skin Depth and Surface Resistivity of Common Cookware Materials at Different Frequencies 105

Table 18: Comparison of ASTM and ANSI Cooking Efficiency Testing Loads 109

Table 19: Input Power Characteristics of Induction Cooker A 114

Table 20: Input Power Characteristics of Induction Cooker B 116

Table 21: Equivalent Induction Power for Typical Gas Burner Heat Rate 120

Table 22: Cooking Efficiency Results Measured According to EPRI Test Procedure 121

Table 23: Cooking Efficiency Test Results Measured with Small Cooking Load 122

Table 24: Cooking Efficiency Measured With Extended "Simmer" 123

Table 25: Comparison of Cooking Efficiency Measured by EPRI and DOE 124

Table 26: Summary of Cooking Efficiency Results from EPRI and DOE 126

Table 27: Savings Potential of Induction Cooking in California 128

Table 28: Field Strength Limits Permitted by FCC Part 18 for Induction Cooking Ranges 129

Table 29: Annual Energy Consumption of Cooktop Technologies Using Small Cookware Only 131

Table 30: Proposed Standards for Standby Power Use of Major Cooking Appliances 132

Table 31: Estimated Annual Energy Savings per Unit and Across California 132

Table 32: Devices Tested in the Laboratory 148

Table 33: Sample of Power Savings for Sample Appliances with PFC 150

Table 34: Load Profile of the Devices in Worst Case Scenario 154

Table 35: Size of Sample Homes Compared to the Homes in the CLASS 157

Table 36: Devices on Branch Circuit #1 158

Table 37: Devices on Branch Circuit #2 160

Table 38: Devices on Branch Circuit #3 162

Table 39: Devices on Branch Circuit #4 164

Table 40: Devices on Branch Circuit #5 165

Table 41: Simulated Whole-House Savings for a More Realistic Home 167

Table 42: PFC Savings Estimates and Assumptions 170

Table 43 Power Factor Summary 173

Table 44: Bench Rest Results of Refrigerator Condenser Fan 198

Table 45: Bench Test Results of a Typical Refrigerator Evaporator Fan 198

Table 46: Data Summary for Six Valid Runs 200

Table 47: Summary of Market Projections 212

Table 48: Summary of Test Results 212

Table 49: Range Results for Appliances Utilizing ASD Control 215

Table 49: Approximate Efficiency of Home Audio Amplifier Types (%) 220

Table 50: Residential Cooktop Efficiency 221

Table 51: Market Barriersto Adopting Improved Technologies (Improved Consumer Electronics and Motorized Appliances) and Possible Approaches to Reducing These Barriers 227

Table 52: Market Influences in Improved Consumer Electronics and Motorized Appliance Technologies in California 231

Table 53: Information Resources for Dissemination of Information on Improved Consumer Electronics and Motorized Appliances 239

Table 54: Connections for Types of Key Market Participants for Each Project and Equipment Type 250

Table 55: Organizations Providing General Information Dissemination for Improved Consumer Electronics and Motorized Appliances 254

Table 56: Codes and Standards Organizations and Issues Relating to Consumer Electronics and Motorized Appliance Technologies in California 258

Table 57: Timing and Delivery of Expected Technology Transfer Materials 271

EXECUTIVE SUMMARY

Introduction

The Electric Power Research Institute (EPRI) tested various advanced electronics to determine the potential for energy savings in consumer electronics and motorized appliances. This project examined five areas including kiosk and multimedia computers, home audio equipment, induction cooking and adjustable speed drives that could provide energy savings in California through Title 20 codes and standards development. These five areas consume over 5 percent of the State's energy. Through careful market research, laboratory testing, and field studies, the EPRI research team concluded that it is possible to save almost 1 percent of the State's electrical energy or about 2,321 billion kWh per year through implementation of the efficiency improvements identified for these projects.

Project Purpose and Results

Kiosk and Multimedia Computers

Research looked beyond mainstream office-productivity desktop PCs to high-performance multimedia PCs. Focusing on this relatively small portion of the computer market provided the highest potential for absolute energy savings per machine, while also investigating the technologies that will eventually be incorporated into more mainstream computers at lower price points. These high performance multimedia computers have continued to fall behind game consoles and mobile devices in efficiency improvements, suggesting large potential energy savings—a first step in developing efficiency programs and standards.

The main focus of the multimedia research was replacing typical /common system components with higher efficiency components including the system CPU, the motherboard and chipset, the system/case fans, separate/add on graphic cards, hard drives, memory, and the system power supply. Some of these components have very small system impacts, others were large; however it should be noted that even small improvements when implemented numerous times can have a noticeable impact on energy savings.

The first phase of the multimedia computer research demonstrated a 24 percent reduction in energy use. More testing was done with newly available components, resulting in an additional 11 percent reduction in energy use.

Kiosks are a stand-alone device using a computer screen to deliver content, information or services. Recently, the number of public kiosks has increased as have their duties and the amount of energy they consume annually. Researchers focused on evaluating the potential of using improved or high efficiency computer components or systems in these kiosks. Only the computing device of three different categories were studied - baseline, market ready and high efficiency.

The results of the market ready kiosk computing devices tests showed that depending on configuration, systems delivered between 45 to 73 percent energy savings or five times the efficiency of the baseline system. The high efficiency computers, again depending on configuration, delivered 83 to 97 percent energy savings, equivalent to nine times the

computing performance of the highest energy consumption baseline system. These changes could potentially save 130 GWh/yr in California or a fraction of a percent of total State energy.

Home Audio Equipment

Researchers surveyed existing technologies and products in the home audio marketplace with special emphasis on highly efficient products. Findings were then used to direct product testing and possible future energy-efficiency policy.

Home audio products tested used the ENERGY STAR definition and focused on audio separate components, blu-ray player, compact audio, DVD player, docks (integrated amplifiers that include attached or separable speakers) and home theater in a box. Laboratory testing was performed to determine the load profile of thirty-five devices in stand-by, idle, and active modes. Based on the analysis, three main opportunities were identified to reduce the energy used by home audio products:

- Reduce sleep mode power to 1 watt.
- Reduce time in idle mode (increase time in sleep mode) by requiring auto power down (APD) after 30 minutes.
- Reduce idle mode power by 30 percent for devices that amplify sound (applies to powered speakers, receivers, and Home Theater in a Box HTiB categories only).

For California energy savings estimates in California, two tiers were considered. Tier 1 reducing sleep mode power and time in idle mode. Tier 2 applies to all three opportunities

These changes combined represent a potential savings of 350 GWh/yr.

Induction Cooking

This study evaluated the efficiency of residential induction cooking products to guide new potential codes and standards for cooking appliances. Two induction cooking devices, one electric coil range and one natural gas range, were chosen to represent the different cooking technologies, and each was tested according to the procedure developed. The results of this testing found that induction cooking is 77 percent efficient, electric coil 83 percent, and natural gas 35 percent efficient at full power.

Researchers were surprised at these results and testing was repeated under two amended procedures, including using a smaller cooking vessel and water load, and a simmer test. These results show that the efficiencies of conventional cooking technologies dramatically decrease with a small cooking vessel, but the efficiency of induction remains unchanged.

As expected the potential energy savings for induction cooking relies on the size of cookware. Using induction to replace conventional electric technology in California is between 134 GWh increased consumption and 974 GWh saved. There is, however, at least a $300 incremental cost for induction cooktops over similar conventional products, excluding the cost of new cookware that would be required for users whose cookware is not compatible with induction technology. The simple payback of this minimum incremental cost from the 57 kWh maximum annual

energy savings per device was calculated to be 33 years, roughly double the typical expected lifetime of consumer appliances.

Unfortunately, induction cooking is not considered an economically feasible opportunity for energy savings and is not recommended for consideration in any potential cooking efficiency standards under California Title 20.

Power Factor Correction

This project estimated the energy that could be saved if consumer electronics used in the residential and commercial sectors were corrected to a power factor of 0.9 (adjusted to the most efficient flow of electricity (1 most efficient, 0 least) allowing the device to do more work). Implementing power factor correction in electronic devices such as desktop computers, computer monitors, laptops, etc., decreases the electricity distortion in the building wiring and reduces energy waste. The research team identified the energy savings each year if 100 percent of the electronic devices in California used power factor correction.

The researchers concluded that savings in the residential sector are much smaller than previously estimated and power factor correction in residential appliances is not likely to be a cost-effective option, except for larger devices like televisions. Commercial savings, however, are more easily and cost effectively realized, and should be considered as a viable option for future codes and standards enhancements, such as Title 20.

Since the savings potential of implementing power factor correction increases with higher currents, and kitchens typically house the appliances with some of the highest currents (coffee makers, toasters, microwaves, etc.), it was expected that the kitchen could provide a reduction in energy losses with PFC. This was not the case, however, since almost every appliance in a kitchen is either power factor corrected, a resistive load, or a motor load (such as a refrigerator).

With the exception of state level regulations on television power factor, no other state or federal power factor standards apply to plug loads. In California, televisions must be power factor corrected to 0.9 when 100 watts are exceeded during operation. Some voluntary specifications, such as the 80 Plus program and Energy Star for desktop power supplies, require specific power factor performance levels for plug loads. Many products that would benefit from improved power factor are also already subject to regulation related to other aspects of device performance.

The relative level of effort required to implement power factor correction policy was rated as high due to the diversity of products covered under potential regulations. Manufacturers from dissimilar product classes would have to be engaged and the technical implementation of power factor correction equipment evaluated. Energy savings were seen as low, but cost effective due to low per product upgrade costs. Existing state and federal device regulations may cause preemption issues and should be further studied.

Considering these factors, the research team developed a recommended specification that could inform Title 20 regulations that would require all plug-loads larger than 50 watts to have power

factors of at least 0.9 when operating at 50 and 100 percent load. With this policy, an estimated energy savings of 241 GWh per year after full stock turnover could be achieved.

The research contained in this report can be used to inform the Title 20 rulemaking process, and increase the overall energy efficiency of California's electronic devices. Currently, improving power factor in electronic devices is a largely untapped avenue for significant energy savings. California is the only state to regulate PF at all, and that presently only affects televisions of 100 watts or higher. This work shows that there is a much greater opportunity than televisions alone.

Adjustable-Speed Drives

Using adjustable-speed drives saves energy. Adjustable speed drives typically control the speed or torque of motors by varying their frequency and are typically 92 to 95 percent efficient. This research demonstrated that adding adjustable speed drives to common domestic appliances, such as clothes dryers and refrigerators/freezers will save energy and that other associated benefits will accrue. Adjustable speed drives were also applied to air conditioning applications where they have been used but have not become widespread. These benefits translate to lower energy bills, better controllability, and overall smoother operation and greater equipment reliability.

Research has shown there are benefits to be gained in energy efficiency from using variable control in domestic products. The research team explored building on the federal regulations under the Energy Star program by developing California Title 20 regulations for appliances that incorporate adjustable-speed drives. Refrigerator/freezers were good candidates as were both ducted and ductless domestic heating, ventilation air conditioning (HVAC) systems, with the latter appearing to offer higher returns per unit. Refrigerator/freezers are used in almost all households in California. HVAC units are used in 50 percent of households. Potential savings for adjustable-speed drives in refrigerators/freezers is 1,400 GWh annually

The federal Department of Energy (DOE) standard for central air-conditioning, effective January 1, 2015, differentiates energy efficiency levels according to different climate conditions within the country. Unfortunately, since the DOE test procedure measures address peak temperature conditions rather than varying conditions indicates that an adjustable-speed drive would provide no benefits and this technology was not considered. The researchers believe that there is potential for effective Title 20 regulations and suggest that energy efficiency benefits could accrue from further adjustable-speed drive control of refrigerator/freezers. Additionally, adjustable-speed drive control of HVAC household applications offers potential for energy savings and significant comfort/life quality benefits.

Benefits to California

EPRI tested advanced electronics in five areas to save energy in consumer electronics and motorized appliances. This project examined kiosk and multimedia computers, home audio equipment, induction cooking, power factor corrections and adjustable speed drives that could provide energy savings in California through Title 20 codes and standards development.

The research found that the using adjustable-speed drives for residential appliances offered the most energy benefit. The power factor research showed significant potential efficiency gains can be made in many electrical devices that use switching power supplies including computers, home audio devices, televisions, and appliances. Computer research showed efficiency gains could be found in number of components with power supplies and video cards with the largest potential. Research also showed that high-efficiency computers could deliver more computing power while using less energy. The home audio research revealed that there are numerous potential efficiency gains including using sleep modes in home audio devices that offer noticeable energy savings. Induction cooking demonstrated efficient cooking technology that offered savings, however there are still some hurdles which currently prevent it from being a universal residential retrofit solution.

Through careful market research, laboratory testing, and field studies, the research team concluded that it is possible for California consumers to save an estimated 2,300 billion kilowatt-hours each year through implementation of the projects recommended in this report.

CHAPTER 1: Introduction

In 2012, the California Energy Commission (Energy Commission) contracted with the Electric Power Research Institute (EPRI) to perform testing in a range of areas related to the use of advanced electronics to save energy in consumer electronics and motorized appliances. This work was funded by the Energy Commission's Public Interest Energy Research (PIER) Program.

This Energy Commission PIER project covered research in the following areas:

- Kiosk and multimedia computers
- Induction cooking
- Home audio equipment
- Power factor
- Adjustable-speed drives (ASDs)

This project also included a technical transfer portion where the results and findings of the work were shared publically and utilized by interested parties.

This work was performed by the EPRI research team, which was comprised of EPRI and its subcontractors. This report was divided into six primary segments, with each discussing the relevant research within each area of the project.

CHAPTER 2:
PCs in the Workplace

2.1 Multimedia Computers

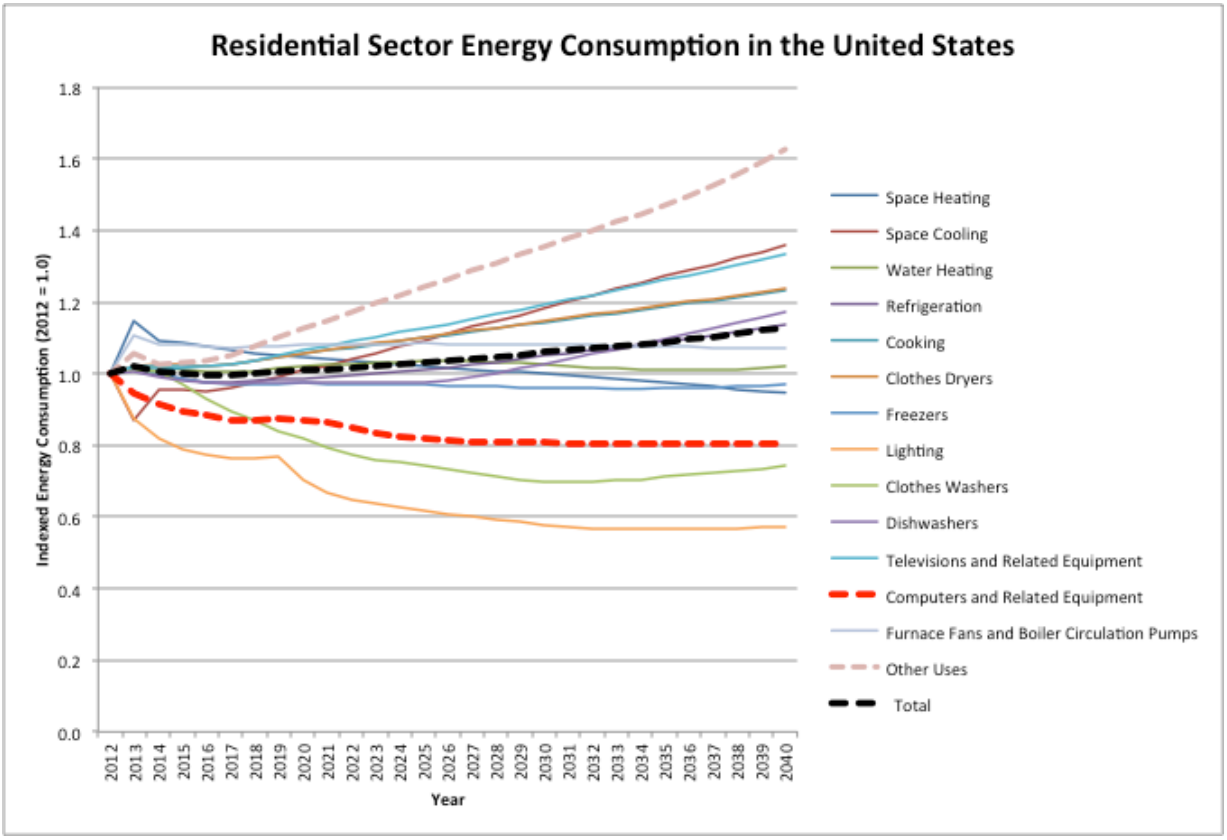
2.1.1 Background

Personal computers (PCs) enable professional services and the retail economy to perform a variety of tasks. Electronic mail, scheduling events, e-commerce, and browsing social media sites are fundamentally tied to the use of a PC or other computing device (laptop, smart phone, etc.). The number of PCs in the workplace has jumped from 1.2 million units in 1981 to nearly 13 million in 1986. In 2003, more than 77 million people (55.5 percent of the U.S. workforce) used a computer at work. The use of PCs in the home is more striking. More than three-quarters of households had one or more computers in 2010.

In 2008, Ecova (formerly Ecos Consulting) and the Electric Power Research Institute (EPRI), funded by PIER, investigated the potential to save energy in conventional, medium-performance commercial desktop computers. This research demonstrated that energy consumption could be reduced by as much as 38% relative to ENERGY STAR Version 4 requirements using existing 2008 technology. In the intervening time, the performance and efficiency of desktop computer technology have continued to improve markedly. While the prototype computers built in the 2008 work offered significant savings relative to ENERGY STAR Version 4, they would not qualify for the currently pending ENERGY STAR Version 6 levels.

As efficiency opportunities in some computers are captured, the total computer energy consumption is forecast to drop by 20% by 2040 relative to 2012 consumption (see Figure 1). However, it is likely that part of this reduction is due to increased use of mobile devices and non-traditional computers (such as the iPad or Chromebooks) that are captured in the "Other Uses" category (the dashed pink line). Achieving the forecasted absolute reductions in total U.S. computer energy use during the next few decades will be challenging, even with steady improvements in efficiency, because of the steadily expanding reliance on information technology (IT) for home entertainment, automation, and productivity.

Figure 1: Residential Sector Energy Consumption in the United States



2.1.2 Research Goal

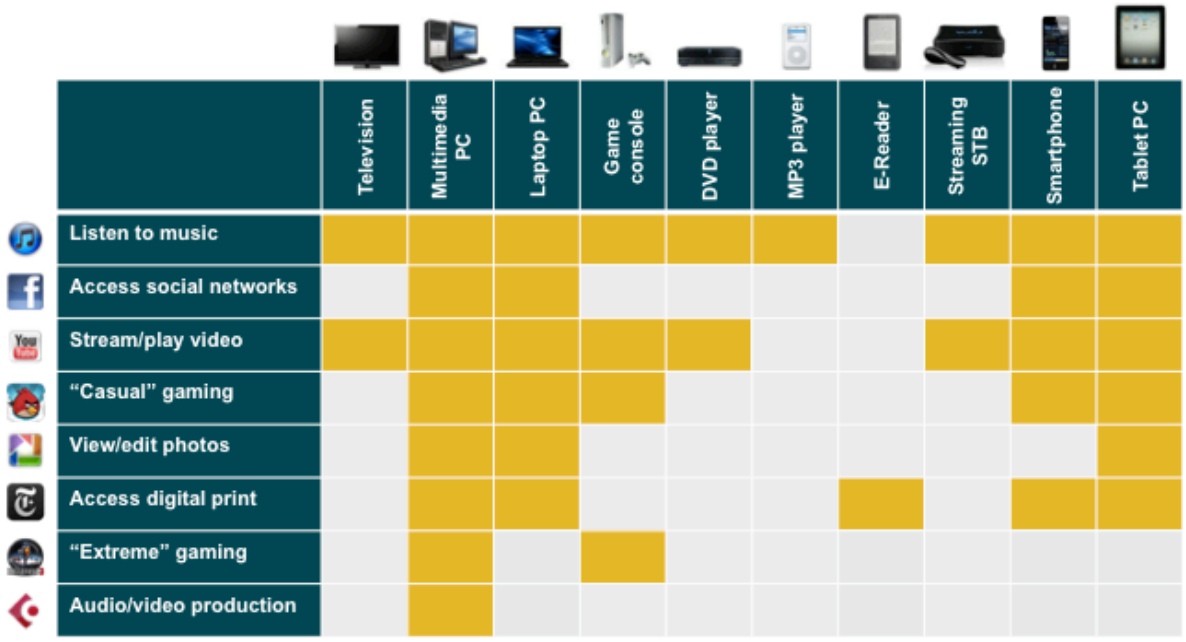
The goal of this research was to look beyond mainstream office-productivity desktop PCs, which was the focus of PIER's previous computer efficiency research, to high-performance multimedia PCs. The rationale for looking at this relatively small portion of the computer market was to demonstrate the highest potential for absolute energy savings per machine, while also investigating the technologies that will eventually be incorporated into more mainstream computers at lower price points. These multimedia computers have also increasingly fallen behind game consoles and mobile devices with regard to efficiency improvements, suggesting a large remaining potential to save energy. In constructing an efficient multimedia PC, cost was explicitly ignored as a constraint (as articulated in the original PIER scope of work). This work demonstrates what is possible with computer efficiency in a high-performance machine—a first step in developing efficiency programs and standards.

Ecova completed the first phase of this work in 2012, demonstrating a 24% reduction in unit energy use. The research then paused while the California utilities and energy efficiency organizations began to investigate opportunities for Title 20 computer standards with help from Ecova's laboratory and research team. In late 2013, EPRI and Ecova conducted a new set of tests to compliment, and update, 2012 testing with newly available components, resulting in an additional 11% reduction in energy use.

2.1.3 Technical Overview

In the early stages of the PIER work, a multimedia PC was defined as a computer that can perform a very wide range of tasks (from listening to music to audio/video production to gaming) and that contains a discrete graphics card.Figure 2 illustrates this concept.

Figure 2: Capabilities of Various Multimedia Devices



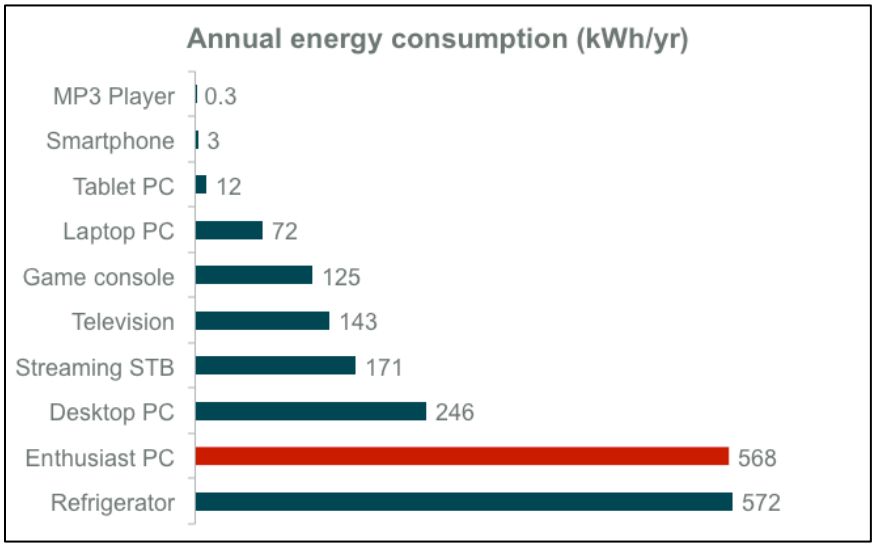
2.1.4 Multimedia PC Efficiency Today

Not all computers are created equal; there is a wide range of performance. The ENERGY STAR Version 5 categorization scheme was used initially to further constrain the multimedia PC definition to a high-performance Category D desktop. The ENERGY STAR specification has since been revised to Version 6 (effective June 2014), in which ENERGY STAR has put forth six different categories of desktop computers using various hardware and performance metrics. The desktop computer that was ultimately used as a baseline also falls into the ENERGY STAR Version 6 high-performance DT D2 category.

PCs in the DT D2 category are often marketed to "enthusiast" users who prioritize performance over cost and energy efficiency. There is a misconception among these users that more power is synonymous with increased performance. Indeed, marketing materials that target multimedia PC users emphasize the size of computer power supplies and often accent the enormous power requirements of a given system (see Figure 3). As such, some extreme systems can consume as much energy as a refrigerator, almost 50 times as much energy as a tablet computer and more than twice as much energy as a conventional desktop computer, as the results indicate in Figure 4.

Figure 3: A Typical Power Supply Marketing Add

Figure 4: Annual Energy Conumption of Various Electronic Devices



While it is possible to purchase an extreme PC that consumes an outsized amount of energy, the research team focused on a more common multimedia machine. The research team used Steam, a gaming community consisting of over 65 million players, to identify the most common components present in user machines and then chose an original equipment manufacturer

(OEM) system to match these components.[1] The machine was also marketed as being appropriate for 3D gaming and high-definition photo and video editing.Table 1 summarizes the baseline machine.

Table 1: Baseline Multimedia PC Characteristics

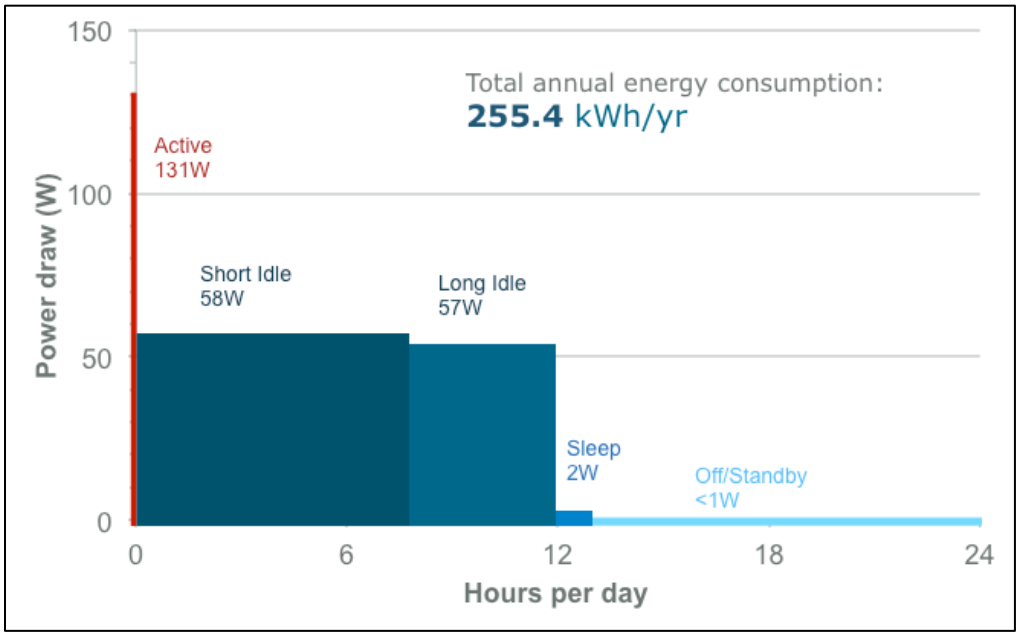
Parameter	Value
System	HP Pavilion HPE h9-1110t Phoenix CTO Desktop PC
Cost	$1,500
Central Processing Unit	Intel Core i7 2600, 3.4 GHz
Graphics Processing Unit	AMD Radeon HD 6870
Memory	8 GB
Storage Drive	Hitachi, 2TB 7,200 RPM
Power Supply	600 Watt ATX
Optical Drive	DVD/Blu-ray
Operating System	Windows 7

The baseline system's typical energy consumption (TEC) was calculated using the ENERGY STAR Version 5.2 methodology. The system consumes 255 kilowatt-hours (kWh) of electricity each year under the assumed duty cycle (See Figure 5). The proposed ENERGY STAR qualification level for this type of machine is 250 kWh. The baseline system nearly qualifies under ENERGY STAR despite being a fairly common system.[2] (Figure 5 below) details the power consumption of the baseline system in various operational modes. Note that the active mode power was measured (and shown in the figure) but was not used in calculating the TEC for the machine (in accordance with the ENERGY STAR methodology).

1 http://steamcommunity.com/

2 Extensive comments suggesting more stringent specification levels have been submitted to the ENERGY STAR program based on these and other research findings.

Figure 5: Baseline Multimedia PC Energy Consumption



2.1.5 Opportunity: Components Targeted for Efficiency Improvements

There are many components that must be combined to create a high-performance multimedia PC. In order to evaluate the impact of various components on computer efficiency, one component was changed at a time and power demand was measured in the various computer operational states (active, short idle, long idle, sleep, and off/standby) using the proposed (at the time of testing) ENERGY STAR Version 6, Draft 3 methodology. This step-wise approach allowed for isolating the impact of each specific change. All measurements were made using a Yokagawa WT1600 power analyzer and a Chroma 61602 programmable ac power source in Ecova's ISO 17025 accredited lab.

In order to evaluate changes in non-energy performance, two benchmarking software programs that provide a semi-quantitative gauge of computer performance were run. 3DMark11 was used to test graphics and central processing unit (CPU)-intensive tasks.[3] PassMark7 was used to gauge overall computer performance using more common, low-intensity computing tasks.[4]

The focus was on changes to major components that are keys to computer function. Through industry interviews, product research, and spot power measurements, the relative impact of components on computer performance and energy consumption was identified. These interim results were then used to prioritize changes to the baseline system. Table 2 summarizes these initial findings.

3 http://www.3dmark.com/3dmark11/

4 http://www.PassMark.com/

Table 2: Component Function and Bearing on System Performance and Energy Consumption

Component	Primary Function	Performance Impacts	Energy Impacts
Central Processing Unit	Central processing of digital data	High	Medium
Motherboard and chipset	Electrical and data connection between other components	Medium	Medium
Fans	Ventilation to keep components cool	Low	Medium
Discrete graphics card	Primary graphics processing unit; may also assist CPU	High	High
Hard drive	Long-term storage	High	Medium
Memory	Short-term storage	Medium	Low
Power supply unit	AC-to-DC converter with several DC bus outputs	Low	High

2.1.6 Results

2.1.6.1 CPU Efficiency

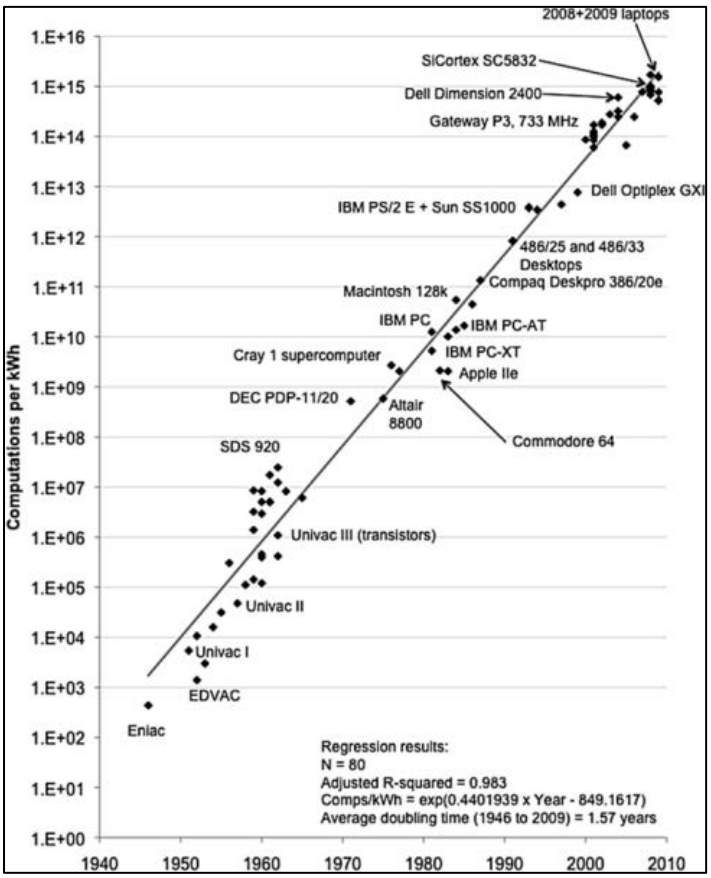
Intel and Advanced Micro Devices (AMD) are currently the major manufacturers of CPUs used in traditional desktop computers. While previous Ecova/EPRI work evaluated both Intel and AMD CPUs, the work presented here focuses exclusively on Intel CPUs. At the time of this research, AMD was shifting its emphasis away from the very high-performance CPU market, choosing instead to focus on lower-power, medium- and entry-level performance systems.[5] Indeed, the previously mentioned Steam community survey revealed that the majority of PCs use Intel-based systems.

CPUs are continually becoming more efficient in their processing performance per energy consumed (see Figure 6). Much of this efficiency is gained through increased performance

[5] This has since changed, with AMD recently releasing several high-performance "Richland"-based CPUs to compete with Intel's Core i7 products.

rather than decreased power demand. At the time of this research, Intel was in the process of releasing its next-generation Ivy Bridge CPUs. Previous generations of CPUs utilized 32-nm planar transistors, whereas Ivy Bridge utilized smaller 22-nm Tri-Gate transistors that allow 37% more operations per second at a much lower voltage. The first 14-nm and 11-nm processors are expected in 2015 and 2016, respectively.

Figure 6: Computing Efficiency through Time



This improved performance is largely due to higher transistor densities compared to previous generations. This design shift inherently demands more efficient operation, as thermal management of more switching in the same area without efficiency improvements would be difficult. Replacing an older generation CPU with a similar performance Ivy Bridge CPU reduced system energy consumption by 8.8 kWh, a 3.4% decrease relative to the OEM baseline.

2.1.6.2 Potential Next Steps in CPU Efficiency Research

Much time has passed since the original testing of Intel's Ivy Bridge CPUs. Intel is close to releasing its next-generation 22-nm-based microarchitecture, Haswell. To ensure that this research remains relevant, possible next steps could include testing a Haswell CPU in the efficient multimedia PC. Also, AMD's most recent offerings could be evaluated given their

continued push to more fully integrate CPUs and GPUs on one die. Note that changing the CPU will likely also require changing the motherboard used in the efficient machine.

Chips designed for mobile applications such as smart phones and tablet PCs could also be investigated. ARM designs such chips, and ARM-based CPUs have historically consumed less power than either AMD or Intel chips. However, an ARM-based system would require a significant redesign.

2.1.6.3 Motherboard Efficiency Improvements

Previous Ecova/EPRI research suggests that motherboard design choices—including trace width, voltage regulation modules, copper layer thickness, and board layout—can impact computer energy consumption. Recent research for Pacific Gas and Electric (PG&E) confirmed that motherboard choice does indeed impact system energy consumption. Changing motherboards in systems tested for PG&E changed overall energy consumption by as much as 140 kWh.

The desire to test the latest generation CPUs somewhat constrained the choices of motherboards choice in the multimedia computer efficiency research by the desire to test the then latest generation CPUs. Motherboard selection is dictated by both the socket type (the CPU's physical connection to the board) and supporting chipsets associated with a specific CPU. At the time of the original research, relatively few motherboards were available that accommodated the latest version Ivy Bridge CPUs. While the motherboard selected was a small-form-factor mini-ITX motherboard marketed as being highly efficient (see Figure 7), it actually increased the annual energy consumption of the baseline system by 18.5 kWh, a 7% increase.

Figure 7: Asus Mini-ATX Motherboard

This increase was due to an increase in short- and long-idle power demand. However, this motherboard did reduce active mode power demand by nearly 27 watts, more than any other component change. This could have a meaningful impact on the energy consumption of high-performance workstations or gaming PCs that may spend a significant portion of time in active mode. Unfortunately, typical computers are assumed to spend relatively little time in active mode, and the ENERGY STAR methodology does not account for active-mode power consumption. As a result, it is difficult to quantify the exact annual energy savings impacts associated with active-mode power reductions.

2.1.6.4 Potential Next Steps in Motherboard Efficiency Research

Several motherboards that accommodate the Ivy Bridge CPU socket have become available since the time of the original testing. The hypothesis (confirmed by industry contacts) is that the first motherboards that are designed to work with the latest iteration of CPU are not necessarily designed with efficiency in mind. They are designed for rapid production to accommodate new CPUs. Now that multiple motherboards that support the latest generation Intel CPUs are available, a next step could be additional testing of additional motherboards. It is likely that a much more efficient motherboard is now available. Research conducted for PG&E regarding motherboard impacts could also be leveraged in updating the results.

Additional thought could also be given to the TEC calculation methodology. Multimedia computers spend a larger percentage of their time in active mode relative to other types of computers. The results presented here utilize the ENERGY STAR methodology that does not account for active-mode power demand. Subsequent research could develop and evaluate alternative mode time-weightings.

2.1.6.5 Storage Drive Efficiency

The baseline OEM machine used a conventional 3.5-inch spinning hard disk drive (HDD). Ecova/EPRI's previous research suggests that a 40% idle power reduction can be achieved by switching from a conventional HDD to a 2.5-inch mobile HDD (Beck, May-Ostendorp, and Calwell 2008). Solid-state hard drives (SSDs) offer significant savings relative to both conventional and mobile HDDs. The majority of these savings can be attributed to the lack of a motor in SSDs; they contain no moving parts and therefore require less power.Figure 8 compares a traditional 3.5-inch HDD, a 2.5-inch mobile HDD, and an SSD (from left to right).

Figure 8: Comparison of Various Storage Drives

Replacing the traditional HDD with an SSD generated large savings: 32.6 kWh per year, a 13% reduction relative to the baseline machine. While cost-effective savings are not the focus of this research, market data suggests that the cost per gigabyte of storage for SSDs is rapidly approaching parity with traditional HDDs (Wanless, Trimboli and May-Ostendorp 2013). Further, SSDs dramatically increase system performance because of their increased read/write speeds.

It is important to note that a 256-gigabyte (GB) SSD was used to replace a 2-terabyte (TB) HDD. This is a significant storage size difference; however, individual SSDs were not available in such large sizes at the time of the initial research (512-GB SSDs are now available). This might still be a reasonable choice for many users that do not require large local storage for, say, editing audio or visual content. It is assumed that cloud storage will address many users' bulk data storage needs in the near future. Indeed, Gartner predicts that one third of digital content will be stored in the cloud by 2016.

2.1.6.6 Key Next Steps in Storage Drive Efficiency

"Do-it-yourself" (DIY) hybrid SSD/HDD kits have recently become available. These DIY kits allow for combining the massive storage associated with conventional HDDs with the rapid read/write speed associated with SSDs.[6] Purpose-built hybrid drives have long been available but have yet to support users with large storage needs. A next step could be to build and test a DIY hybrid drive with 2 TB of storage to compliment the savings estimates associated with using a smaller local SSD and cloud storage.

Multiple storage drives were also tested in the recent PG&E computer work and were shown to reduce annual energy consumption in desktops by more than 15%. Results presented here could be compared with PG&E results to ensure that the most efficient drive possible is being

6 http://www.tomshardware.com/news/Storage-HDD-SDD-Cache-Drive,9591.html

used in the final efficient multimedia PC. The PG&E research also found that the price per GB of storage for SSDs will become comparable with traditional HDDs by mid to late decade. As the price of SSDs continues to fall, and their maximum available size increases, they will likely become a cost-effective savings opportunity in most computer systems.

2.1.6.7 Graphics Processing Unit Efficiency

The presence of a high-power discrete GPU is the defining characteristic of a high-performance multimedia desktop computer. Figure 9 displays a typical discrete graphics card. The mere presence of a discrete GPU can more than double the annual energy consumption of a desktop computer.

Figure 9: A Discrete Graphics Card

Recent advances in GPU technology allow GPUs to automatically scale their power demand with workload. However, at the time of the initial PIER research, only one power-scaling GPU was available. Market research, funded by PG&E, revealed that two-thirds of NVIDIA's and one-quarter of AMDs current discrete desktop GPU product lineup utilizes the Kepler or Graphics Core Next (GCN) architectures, which deliver significant energy savings relative to GPUs that use older architectures. In general terms, the Kepler architecture allows the GPU to scale the power it demands to match the task that it is completing, generating significant savings during the idle state.[7] The GCN architecture with its ZeroCore feature also enables power scaling and allows the GPU to power down some components when the computer screen is off or not displaying content.[8] More than 80% of the GPUs released in 2012 use these more efficient technologies, and the remaining 20% are simply older GPUs that have been relabeled and re-released. In other words, market research suggests that Kepler and GCN represent a new

7 http://www.nvidia.com/content/PDF/kepler/NVIDIA-Kepler-GK110-Architecture-Whitepaper.pdf

8 http://www.amd.com/la/Documents/amd_powertune_whitepaper.pdf

standard for GPU efficiency and a compelling opportunity that will enable computers who utilize discrete graphics cards to be more efficient without sacrificing graphics processing performance. Test results indicate that these latest architectures can save anywhere from 20% to 75% of discrete GPU energy consumption, depending on the performance class of the card.

In the PIER work, switching from an older, medium-performance GPU to a newer, high-performance GPU that utilizes GCN architecture reduced the overall system energy consumption by 13.4 kWh, a 5% reduction relative to the baseline system.

2.1.6.8 Potential Next Steps in Graphics Processing Unit Efficiency Research

At the time of the initial PIER research, only one power-scaling GPU was available. Since then, the market has been transformed, and most new GPUs sold today utilize some form of power scaling. A possible next step would be to leverage the results of recent GPU testing work completed for PG&E to select the most efficient discrete GPU currently available for use in the high-efficiency multimedia computer.

The power-scaling GPU that was used in the efficient build was also the highest performance card available on the market, significantly higher than the baseline GPU. Now that the market has been transformed, a more efficient GPU with performance parity could be tested in the efficient build.

Finally, both Intel and AMD offer CPUs with integrated graphics processing. If this technology evolves to the point where CPU-based graphics can perform as well as discrete GPUs, then significant savings could be captured through eliminating the discrete GPU entirely.

2.1.6.9 Memory Efficiency

Previous Ecova research found that a single 2-GB module consumed 1 to 2 W less power than multiple smaller modules with no significant performance impacts (Beck, May-Ostendorp and Calwell 2008). The baseline OEM PC shipped with two 4-GB modules of memory. Rather than confirming that a single, larger module would consume less energy, the impact of memory that is marketed as being more efficient was evaluated.

This more efficient memory typically utilizes a lower voltage (such as 1.35 V instead of 1.5 V). By replacing the OEM modules with equivalent 1.35 V modules, minimal savings (0.9 kWh) was achieved. While the savings seen in the experimental setup were small, third-party reviews claim more significant savings, albeit in active mode.

2.1.6.10 Key Next Steps in Memory Efficiency Research

In constructing the final efficient multimedia PC, the two low-voltage 4-GB memory modules may be replaced with a single 8-GB low voltage memory module. This is likely to generate some additional amount of energy savings relative to the OEM baseline machine.

2.1.6.11 Power Supply Efficiency

Ecova and EPRI's past research on computer power supply efficiency demonstrated significant energy savings opportunities by upgrading to greater than 80% efficient power supplies. Since the initial research into computer power supply efficiency, a large variety of 80 PLUS-compliant power supplies have become available on the market such that several mainstream computer

OEMs now integrate them into common models. For the interested reader, the 80 PLUS program and its associated testing levels and rating system are discussed in great detail within the Kiosk portion of this report.

However, a highly efficient power supply will only reduce a desktop's power consumption so much. Ultimately, it is the net power consumption of a computer's power supply, the amount of electrical energy dissipated as heat by the power supply during typical operation, that governs real-world energy savings. If a computer's power supply is grossly oversized for the application, it might operate at a particularly inefficient part of its load curve, resulting in higher net consumption. A right-sized power supply, on the other hand, will operate at a higher percent of rated load, thus operating more efficiently, dissipating less power as heat and generating more energy savings.

The OEM baseline machine shipped with an oversized, inefficient 600-W power supply. Marketing literature suggests that the power supply is oversized to allow for upgrading the system with more powerful components. However, active-mode testing (running 3dMark11) of the baseline system revealed that power demand rarely exceeded 130 W in active mode, suggesting that the OEM power supply is significantly oversized, even when expansion capability is considered.

For the efficient build, a more reasonable 460-W, 80 PLUS Gold power supply was installed. This efficient power supply eliminated the need for a power supply fan and reduced the net power consumption of the system. The annual energy savings associated with this change is 11.26 kWh, a 4.4% reduction relative to the baseline machine. It has become difficult to locate even smaller capacity power supplies at the highest efficiency levels, but these could be expected to save additional energy.

2.1.6.12 Potential Next Steps in Power Supply Efficiency Research

In developing the final efficient multimedia PC, additional, smaller, and more efficient PSUs could be tested. Also, the role that CPU and GPU firmware plays in allowing for the use of smaller PSUs could be investigated. The efficient system would not boot with a 300-W PSU, even though the maximum power demand observed was less than 131 W This finding suggests that the CPU or GPU may not allow the system to boot with a PSU that is smaller than a given size even if the system does not require such a PSU.

In addition, building a dynamic PSU that uses multiple smaller PSUs to provide just enough power could be pursued to meet what the system demands at a given time. As the power demand of the system increases, so too would the size of the PSU, a system demanding 80 W in active mode may use the 100-W step of a dynamic PSU, and a system demanding 120 W might use the 150-W step. Such a dynamic PSU would significantly reduce losses associated with the gross oversizing of PSUs.

2.1.6.13 BIOS Optimization

The Basic Input/Output System (BIOS) is software that is built into the computer hardware—sometimes called firmware—and is the initial program that boots hardware components and

loads the operating system from hard drive storage. The BIOS often manages power settings for the motherboard and can sometimes be used to adjust CPU clock speed.

While there was little ability to adjust such power-management settings with the baseline motherboard, the more efficient motherboard had multiple options for power management. By adjusting these settings to enable more frequent use of low-power states, annual energy consumption was decreased by 6.9 kWh, a 3% reduction relative to the baseline system.

2.1.6.14 Potential Next Steps in BIOS Optimization Research

Additional BIOS optimization research is not planned at this time; however, if new motherboards are used in subsequent testing, BIOS changes may be evaluated to generate energy savings.

2.1.6.15 Case and Fan Efficiency Improvements

Multimedia PCs often contain multiple case fans to dissipate heat generated by the various components. The need for these fans is highly dependent on case design and component layout. The suspicion was that a high-efficiency multimedia PC should not need case fans to complement CPU and graphics processing unit (GPU) fans if an appropriately ventilated case were used. To evaluate the potential savings associated with this design choice, a Thermaltake case designed for cooling efficiency was substituted for the OEM case and the case fans were disabled (see Figure 10). This change reduced energy consumption by 4.3 kWh each year, a 2% reduction relative to the baseline system.

Figure 10: Efficient PC Case Designed with Cooling In Mind (Left) and Traditional OEM Case (Right)

2.1.6.16 Potential Next Steps in Case and Fan Efficiency Research

Potential additional research could confirm that the thermal performance of the system remains constant (or is improved) due to the case and fan changes. Next steps could include installing thermocouples in both the original OEM case and in the Thermaltake case and measuring case temperature while the system is under similar load for sustained periods of time. If this additional research is pursued, the systems would likely be loaded by running 3DMark11 in "loop mode" until the case temperature stabilizes.

Also, several alternative CPU cooling systems were procured that utilize heat pipes and liquid cooling, but these have not yet been tested. While CPU fan changes are not expected to yield significant savings, we may test the impact of using these alternative CPU cooling systems if time and budget allow.

2.1.7 System Level Interim Results

The efficiency opportunities explored in 2012 reduced the energy consumption of the baseline OEM multimedia PC by more than 60 kWh per year, a 24% reduction. If the anomalous motherboard result is removed, the reduction is closer to 70 kWh per year, a 30% reduction. Figure 11 summarizes the various component-level reductions. Table 3 summarizes the components used in the baseline and efficient multimedia PC.

Figure 11: Energy Consumption Reductions Due to Various Modifications

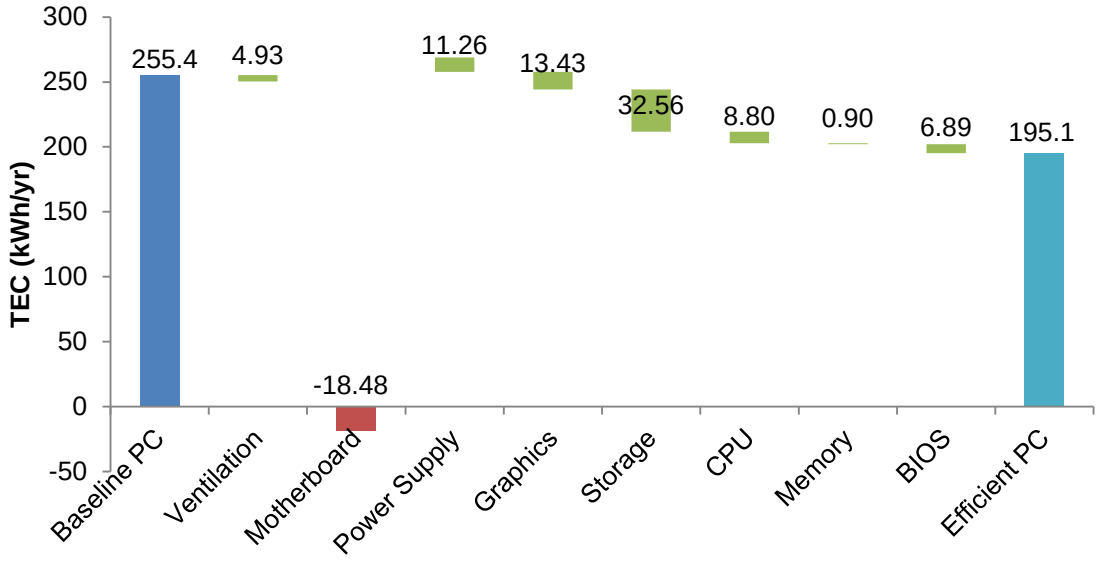


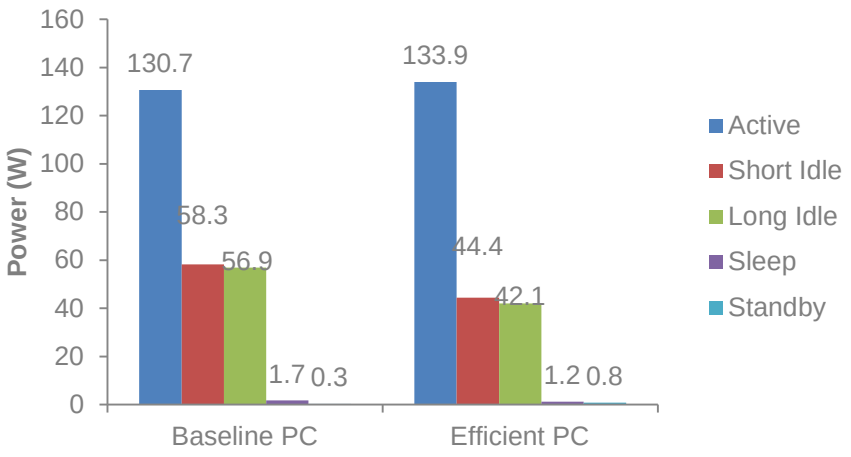
Table 3: Summary of Baseline and Efficient Multimedia PC Components

	Baseline Multimedia PC	Efficient Multimedia PC	Savings (kWh)
Case	HP case (OEM)	Thermaltake VM7000 with no fans	4.9
Motherboard	Pegatron 2AB5 (OEM)	ASUS P8Z77-I Mini-ITX	-18.5
Power Supply	600W ATX (OEM)	Seasonic X-460	11.3
CPU	Intel Core i7 2600 3.4GHz	Intel Core i7 3770 3.4GHz	8.8
GPU	AMD Radeon HD 6870	AMD Radeon HD 7970	13.4
Memory	8GB PC3-10600 DDR3	8GB G.SKILL Sniper F3-12800CL9D Low-Voltage	0.9
Hard Drive	Hitachi HDD 7200rpm 2TB	OCZ Vertex 3 256GB	32.6
Optical Drive	LITEON iHBS212 Blu-ray Writer	LITEON iHBS212 Blu-ray Writer	0.0
BIOS	Default OEM Settings	Energy Saving Settings	6.9
Operating System	Windows 7 Professional	Windows 7 Professional	0.0

Figure 12 compares the power consumption of the baseline and efficient PCs in various operational modes. Note that most of the system energy savings come from reducing the power demand of the system in both short and long idle mode.

Pacific Gas and Electric Company's (PG&E)'s Emerging Program funded Ecova to examine the cost effectiveness of incorporating efficient computer components into typical desktop computer builds.

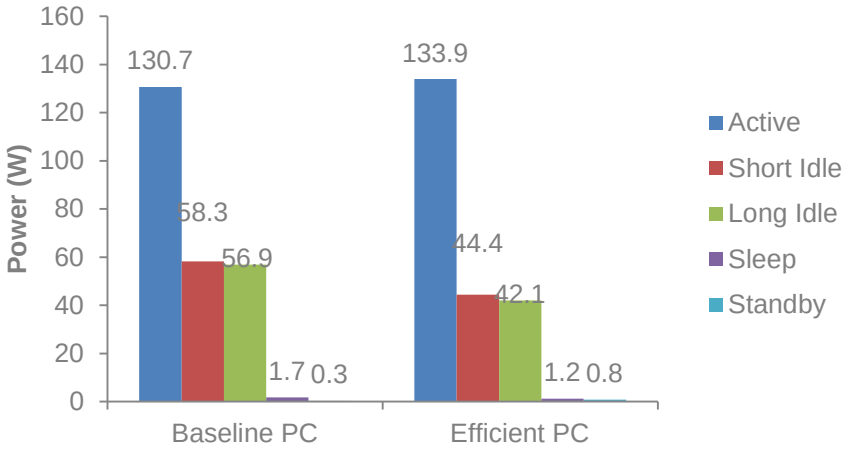
Figure 12: Comparing Power Demand by Mode



The largest savings were due to the use of an SSD instead of a traditional HDD followed by the use of a latest generation power-scaling discrete GPU instead of a conventional discrete GPU.

While there was initially some concern that the choice of more efficient components would reduce system performance, the opposite was found to be true. The efficient PC has nearly doubled the performance score using both 3DMark11 and PassMark7 benchmarking software, and the system boot time was cut in half (see Figure 13). Interestingly, the most significant improvement in benchmark scores was also due to the use of a more efficient SSD and the power-scaling GPU.

Figure 13: Quantitative Benchmark Score (Bigger is Better)



2.1.8 2013 Update: PSU Investigation and Component Updates

In the research described above, Ecova showed that the greatest energy savings opportunities included incorporating more efficient processors (CPUs), graphics (GPUs), and power supplies (PSUs). Also, computer power supplies were found to often be oversized and optimized for maximum expansion capability, not operational efficiency. The 2012 research did not fully explore this opportunity because the most efficient power supplies on the market at the time were still greatly oversized, even for the computing needs of most high-performance multimedia computers.

Desktop computer manufacturers size their power supplies for possible user upgrades and expansion of the system and to confer marketing advantages when competing against other computer models. As a result, a desktop power supply may be able to provide several times more dc power than the system requires under out-of-the-box operation. This has direct efficiency consequences, because power supply efficiency varies depending on the fractional loading of the unit. Supplies are typically most efficient between 50% and 75% of rated load, with efficiency decreasing significantly below 20% load. Because of partial loading, it is quite possible for a "low-efficiency" supply to operate more efficiently than a "high-efficiency" supply if the more efficient unit is oversized.

Since the previous research into the impact of incorporating efficient desktop components into high-performance multimedia computers, smaller-capacity, highly efficient PSUs have become more readily available.

This follow-on research project explored whether further savings can be obtained by using more appropriately sized power supplies. In addition, upgrades were conducted on a few other components most significant to energy use. Due to time and budget constraints, the potential next steps put forth in the 2012 research (previous section) were not able to be fully explored.

2.1.8.1 Research Methodology

The team employed a five-step process to determine whether more savings could be obtained by optimizing power supply size.

Key steps included:

1. Selecting three high-performance multimedia computers: a custom desktop computer, a notebook, and an integrated desktop. The custom-built desktop was used for most power optimizations, whereas the notebook and integrated desktops were purchased because the form factors of these systems require more power-optimized designs.
2. Modifying the baseline system configuration of the custom desktop with non-PSU components to determine the most efficient system configuration prior to PSU optimization.
3. Measuring the energy consumption of the notebook, integrated desktop, and efficient configuration of the custom desktop computer.

4. Comparing the performance of each computer configuration using PassMark V8 and 3DMark 11 computer benchmarking software to ensure that component changes did not degrade performance and to allow comparisons between both the performance and energy use of three disparate computer types.
5. Determining the energy impact of optimizing power supply size of the computers by swapping original power supplies with power supplies of different sizes and efficiencies. PSU optimization was only possible for the custom desktop and notebook, because a viable alternative for the integrated desktop's PSU could not be found. Performance was then checked again using PassMark and 3DMark software.

All measurements were made using a Yokagawa WT1600 power analyzer and a Chroma 61602 programmable ac power source in Ecova's ISO 17025-accredited lab.

2.1.8.2 Results and Discussion

Manufacturer websites and online reviews were researched to select:

- An expandable, high-performance gaming desktop, built from the most efficient parts available, but containing a typically oversized power supply.
- A moderately configured integrated desktop that was likely to have an energy-efficient, correctly sized power supply.
- A high-performance gaming notebook computer that was likely to have an energy-efficient, correctly sized power supply.

The selected systems are described in Table 4 included below are the 2012 efficient build configurations from previous research as a point of reference.

Table 4: System Configurations

Component Type	2012 Efficient Desktop	2013 Efficient Desktop	Razer Blade Notebook	iMac Integrated Desktop
CPU	Intel Core i7 3770 3.4GHz	Intel Core i7-4770K	Intel Core i7-4702HQ Quad Core 2.2 GHz-3.2GHz turbo	2.9GHz Intel Core i5, Turbo Boost up to 3.6GHz
Number of Cores	4	4	4	4
Motherboard	ASUS P8Z77-I Mini-ITX	MSI- Intel Z87-G41	Intel HM65 Express chipset	Custom, Proprietary information
Memory	8GB G.SKILL Sniper F3-12800CL9D Low-Voltage	2133 MHz DDR3 DIMMs. 2 x 8 GB for total of 16 GB	8 GB DDR3L SDRAM	8 GB of 166 MHz DDR3
Storage	240 GB Solid State Drive OCZ VTX3-25SAT3-240G	240 GB Solid State Drive OCZ VTX3-25SAT3-240G	256 GB Solid-State Drive	1 TB Hybrid Drive Serial ATA Drive @ 5400 rpm
GPU	AMD Radeon HD 7970	NVIDIA GTX 780	NVIDIA GeForce GTX 765M	NVIDIA GeForce GT 750M 1GB GDDR5
PSU including Size (W)	Seasonic X-460 (Gold 460 W)	Seasonic SS-400 FL Active PFC (Platinum 400 W)	Level V 150 W (switched to level V 90 W)	ACBEL Polytech Inc 0T8043 185 W
Purchase Price[9]	$2,100	$1,500	$2,400	$1,700

2.1.8.3 Energy Savings Potential of Optimizing Power Supply Size

Each system was measured with the ENERGY STAR Version 5.2 test procedure, which measures power draw in the off/standby, sleep, short idle, and long idle modes of operation (the ENERGY STAR v5.2 test method does not require power measurements when the computer is actively processing tasks for the user). The ENERGY STAR Version 5.2

[9] Retail prices are approximate and are not intended to be used to determine a precise incremental cost of efficiency.

conventional duty cycle (see Figure 14) was then used to calculate each computer's typical energy consumption (TEC) in kWh per year.

Figure 14: ENERGY STAR Duty Cycles

Table 3: Mode Weightings for Desktop, Thin Clients, and Integrated Desktop Computers

Mode Weighting	Conventional	Full Network Connectivity			
		Base Capability	Remote Wake	Service Discovery/ Name Services	Full Capability
T_{OFF}	45%	40%	30%	25%	20%
T_{SLEEP}	5%	15%	28%	36%	45%
T_{LONG_IDLE}	15%	12%	10%	8%	5%
T_{SHORT_IDLE}	35%	33%	32%	31%	30%

Table 4: Mode Weightings for Notebook Computers

Mode Weighting	Conventional	Full Network Connectivity			
		Base Capability	Remote Wake	Service Discovery / Name Services	Full Capability
T_{OFF}	25%	25%	25%	25%	25%
T_{SLEEP}	35%	39%	41%	43%	45%
T_{LONG_IDLE}	10%	8%	7%	6%	5%
T_{SHORT_IDLE}	30%	28%	27%	26%	25%

A variety of energy-efficient components were researched and obtained for the custom desktop computer. A summary of all components tested is provided inTable 5. Major component modifications were not possible with the gaming notebook and integrated desktop due to their small form factors and highly integrated designs. However, the external power supply (EPS) for the gaming notebook was able to be optimized somewhat, as described below.

Table 5: Alternate Desktop Computer Components Tested

Component type	Description
Motherboard	
Gigabyte	Motherboard with lower losses, higher efficiency and excellent thermal management, according to manufacturer claims.
Graphics	
Nvidia GTX 660	Previous high-efficiency Nvidia card from NRDC/CLASP and California IOU-funded testing.
Nvidia GTX 780	Latest generation, high-performance Nvidia card using similar Kepler architecture.
Processors	
Intel Core i7-4770K	"Unlocked" Haswell part with ability to adjust clock speed up and down from base frequency of 3.4 GHz per core.
Intel Core i7-4770T	Low thermal design power (TDP) part with base clock speed of 2.5 GHz per core.
Power Supplies	
Corsair ATX 860i Platinum 860 W	Oversized Platinum power supply with Corsair "iLink" feature, allowing dc power measurements.
Seasonic SS-380GB Active PFC F3 / S12II-330 Bronze 380 W	Slightly improved efficiency, appropriately sized power supply.
Seasonic SS-400FL Active PFC F3 / X-400 FANLESS Platinum 400 W	High efficiency, appropriately sized power supply.
Seasonic SS-300 TGW Gold 300 W	Efficient, appropriately sized power supply
MEAN WELL G390 A19-P1M (for notebook)	Level V EPS with 19.0 V @ 4.74 A voltage output and 90 W dc output.

To create a high-performance, high-efficiency desktop baseline, a "most efficient" system configuration was first established by installing each efficient component in the system (excluding power supplies) and measuring its energy impacts independently of other components. Next, PassMark V8 computer benchmarking software was used to compare the

performance of the new build to the performance of the baseline build. In this way, the performance impacts were quantified which confirmed that individual component changes did not degrade system performance. The resulting baseline system formed the foundation for further PSU optimizations and represented an updated version of the efficient media computer developed during the 2011–2012 portion of this project. Optimizing all components in the build saved 36 kWh per year.

The energy impact of optimizing power supply size of the custom desktop computer was determined by swapping the baseline power supply with power supplies of different sizes and efficiencies. Optimizing the power supply size saved 15 kWh per year. The final build used 173 kWh per year, 23% less than the baseline build and 11% less than the efficient build from the previous research. Detailed power draw and energy consumption results are provided in Appendix A.

More specifically, the following power supplies were measured:

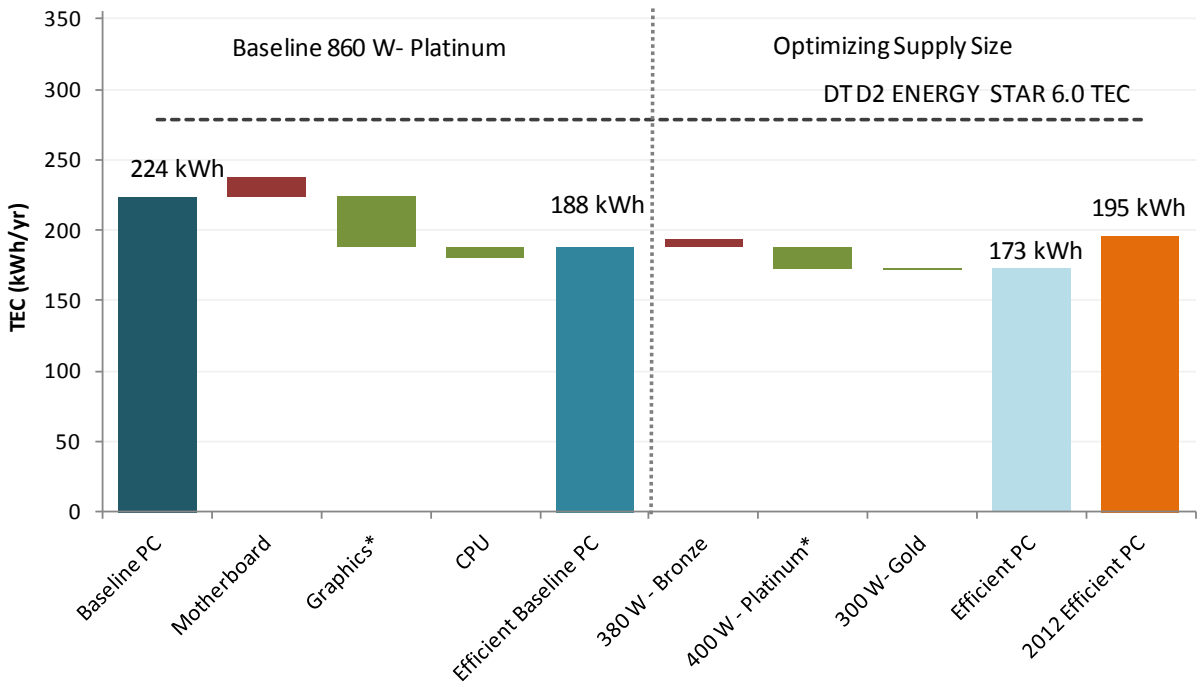
- An oversized (860-W) Platinum power supply with Corsair "ilink" feature, allowing us to measure dc power consumption.
- A slightly improved efficiency (Bronze), more correctly sized power supply (380 W).
- A highly efficient (Platinum), more correctly sized power supply (400 W).
- An efficient (Gold) more correctly sized power supply (300 W).

The 380-W Bronze supply used about the same energy as the oversized 860-W Platinum supply and was significantly cheaper, showing that optimizing power supply size can save on first cost because smaller supplies are also cheaper. The 300-W Gold supply generated roughly the same savings (17 kWh/yr) as the 400-W Platinum supply (15 kWh/yr) in the baseline efficient build. However, to allow for future user upgrades and expansion of the system, the 400 W-Platinum supplies were selected.

Figure 15 provides a summary of individual component measurements and final efficient build measurements. The components marked with an asterisk were the most efficient components that maintained the system's performance and thus were included in the final efficient build. The red bars represent components that increased energy consumption. The green bars represent the energy savings associated with components.

Note that in certain cases, a component may have saved energy but reduced performance. These components were not included in the final efficient build. For example, an underclocked Intel Haswell CPU was looked at to see whether reasonable performance could be maintained and save significant energy. Instead, a marginal amount of energy was saved and performance was significantly reduced. This component was not included in the final efficient build.

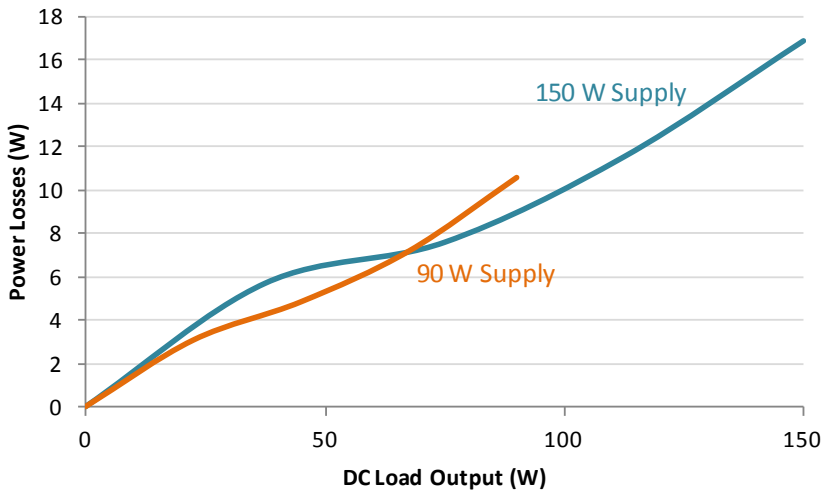
Figure 15: Energy Savings Potential of Optimizing Power Supply Size



*Included in final build.

The EPS for the gaming notebook was also optimized, which was initially expected to be efficient and correctly sized. The original EPS was highly efficient (89.6%) but slightly oversized (150 W), likely to accommodate possible computing upgrades The original supply was replaced with a level V 90-W supply and reduced annual energy consumption by 6%. The average efficiency of the replacement 90-W EPS (89.55%) was slightly lower that the average efficiency of the original 150 W EPS (89.6%); however, the replacement EPS was operating at a more optimal point, resulting in higher efficiency and lower net losses (Figure 16).

Figure 16: Net Losses in Original and Replacement External Power Supplies



These results suggest that optimizing power supply size can present another strategy for improving operational efficiency of power supplies, without incurring significant incremental cost. In fact, optimizing power supply size improves both energy savings and cost effectiveness, allowing lower efficiency power supplies to operate at higher efficiencies and reducing the bill of materials associated with oversized power electronics.

These results are by no means comprehensive, but they indicate that policymakers and utility program designers may want to consider the impact that power supply oversizing can have on the expected energy savings from high-efficiency power supplies. A power supply must be both highly efficient and right-sized to yield significant energy savings. Policies and programs might discourage oversizing by requiring minimum PSU efficiency levels (or maximum allowable PSU losses) for a given PSU-computer combination during idle modes.

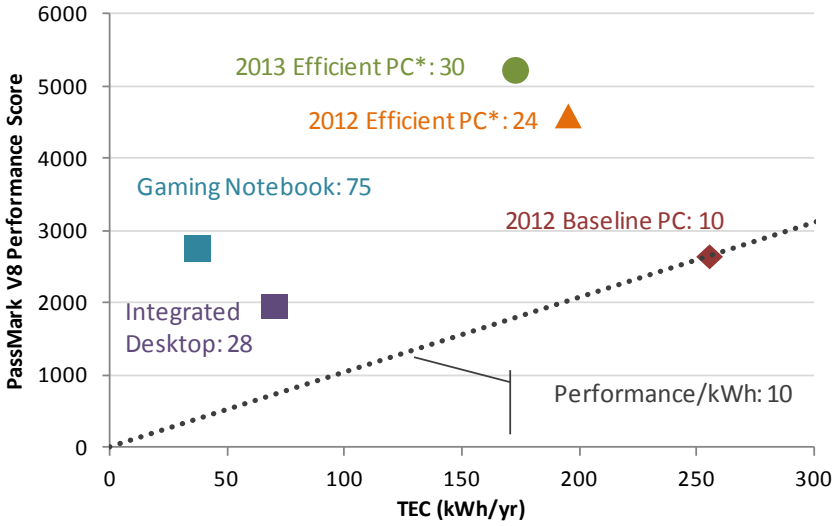
2.1.8.4 Expandable Desktop Computer, Gaming Notebook, and Integrated Desktop Comparison

The study results showed that there is ample room for the expandable desktop computers to realize significant energy savings. However, the energy consumption of the efficient desktop computer was significantly higher than the energy consumption of the gaming notebook and integrated desktop that was tested. Therefore, broader savings opportunities must be explored. Who buys the majority of high-performance computers? Do those users really need expandable desktop computers or can notebooks or integrated desktops provide a sufficient level of performance for most users, even many who want to play games?

Figure 17 shows the performance and annual energy use of the three computer types tested. Also, the 2012 baseline and efficient PCs were included as reference points. The x-axis represents the energy use of the different systems. The y-axis represents the performance level of the different systems. The 2013 efficient custom desktop uses 173 kWh per year, about three times more energy than the gaming notebook (37 kWh per year) and integrated desktop (70

kWh per year). Thus by replacing a custom desktop computer with a gaming notebook or integrated desktop , 118 kWh per year per computer could be saved for the notebook as well as 115 kWh per year for the integrated desktop. The custom desktop computer achieved the highest performance level (5210 PassMark v8 score); however, the gaming notebook (2759 PassMark v8 score) and the integrated desktop (1945 PassMark v8 score) computer achieved performance levels that would still meet the performance needs of most gamers.[10] The gaming notebook used 47% less energy than the integrated desktop, and its performance level was 42% higher.

Figure 17: Custom Desktop, Gaming Notebook, and Integrated Desktop Comparison



To help put the results in perspective, a dotted line is included in Figure 17, which represents a performance/kWh ratio of 10 or the performance/kWh ratio of the 2012 baseline computer. The further left of and above the dotted line the better. The gaming notebook provided the best performance/kWh ratio, about 2.5 times the ratio of the integrated desktop and 2013 efficient desktop computer.

There are of course tradeoffs among flexibility, cost, performance, and efficiency, and this strategy would not be suitable for all users, who have different priorities. The custom desktop computer offers expandability, maximum performance, and lowest first cost. This could be the best option for enthusiast gamers who want to build their own system and do not emphasize energy efficiency. However, if the emphasis is placed on having a system with a good performance that is highly efficient, a better option would be the integrated desktop. Notebooks are more expensive than the expandable desktop and integrated desktop but are appealing to users for a variety a reasons, including good performance, portability, and convenience.

[10] Detailed 3DMark11 scores are also provided in Appendix B.

2.1.9 Title 20 Implications – Multimedia Computers

The results of this study show that there is ample room for high-performance multimedia computers to realize significant energy savings. Although the PIER-funded multimedia PC study did not address the cost effectiveness of those savings, research has since demonstrated that many of the energy-savings mechanisms discussed in this report should be cost-effective. While the voluntary ENERGY STAR program has proven to be helpful in leading the top 25% of products, there are still significant cost-effective opportunities for the broader market. The California Investor-Owned Utilities (IOUs) and Natural Resources Defense Council (NRDC) submitted a Codes and Standards Enhancement (CASE) report to the California Energy Commission (Energy Commission) proposing Title 20 mandatory efficiency standards for computers. The CASE team recommended that California adopt a two-tier standard—2015 (Tier 1) and 2017 (Tier 2)—based largely on the ENERGY STAR v6.0 computer specification framework, performance categories, and test method, with some minor adjustments. High-performance computers were split into two separate categories due to the wide range of performance capabilities in this category. This allowed setting differentiated levels for computers with significantly different performance levels. The results from the current study helped provide support for the levels proposed by the IOU and NRDC team.

There may be room for improvement in voluntary specifications as well. ENERGY STAR 5.2, the current national voluntary standard specification for desktops and notebooks, will be replaced by ENERGY STAR 6.0, which was finalized in June 2013, and thus will bring more stringent efficiency targets to the market starting June 2, 2014. This new program establishes more stringent energy consumption allowances (or "adders") for graphics cards. However, the current research showed that there is still room for improvement, even among high-performance multimedia computers such as the ones investigated in this research. Setting graphics card adders at appropriate levels will ensure that standards and labeling programs support the market for energy-efficient computers while excluding inefficient models.

2.2 Kiosk Computers

2.2.1 Background and Issue

Merriam Webster defines an automated kiosk[11] as "a small stand-alone device providing information and services on a computer screen." In 2010, when this project was proposed, there were over 1.2 million self-service, non-financial product vending kiosks in use throughout the United States. [12] Some predicted that by 2013, the number of ATMs alone would be 2.4 million worldwide. [13] These devices are utilized within a range of applications within society, the primary of which are listed in the table below:

---

11 http://www.merriam-webster.com/dictionary/kiosk

12 http://specialtyretail.com/issue/2010/01/retail-products/retail-product-features/success_with_self_serve_kiosks/

13 http://www.kioskmarketplace.com/whitepapers/5151/Executive-Summary-ATM-Future-Trends-Report-2012

Table 6: Common Kiosk Applications

Make Up / Paint Color Matching	Internet Access	Recycling
Financial Services / ATMs	Gaming	Bill Payment / Order Entry
Healthcare / Eye Examinations	Travel / Rental Car Check In	Government Services
HR / Application Systems	Concert / Travel / Movie Ticketing	DVD Vending
Digital Signage	Laptop / Tablet / Phone Charging	Visitor Management / Security
Photo Processing	Bicycle Vending	Building Directory / Wayfinding
Giving / Donation Acceptance	Point of Sale / Self Service Retail	Food Vending
Make Up / Paint Color Matching	Internet Access	Product Vending

As the reader can see from the list above, many of these applications require the use of specialized peripherals and unique sub-systems. This can lead to a range of kiosk designs, form-factors, and installation circumstances, which must be considered and addressed when installing a kiosk. Some kiosks are complex devices with their own heating and cooling systems capable of outdoor operation in a range of environments, while others are less rugged and are designed to operate only in conditioned spaces.

Figure 18 below shows the common peripherals found within a kiosk. As noted above, kiosks can feature a range of add-on components and dependent systems.

Figure 18: Kiosk Computer, System Interaction, and Cmmon Peripherals

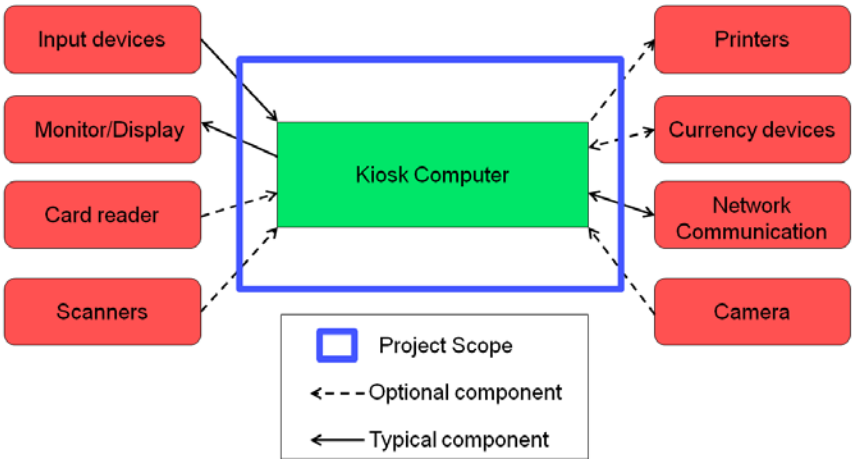
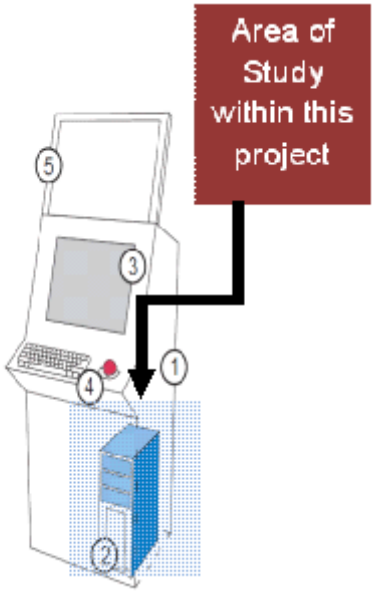


Figure 19[14] shows a typical physical kiosk design, as well as graphically demonstrating the focus of this project, which is the computer or computing device within the unit.

Figure 19: Typical Kiosk Components and Design; (1) Kiosk Cabinet, (2) CPU, (3) Display Device, (4) Peripheral, (5) Signage and External Functionality



Regardless of their task, their physical design or configuration, and the peripherals and sub-systems utilized within their operation, all automated kiosks share one thing—a core processing device/computer. Because of this commonality, this project focused solely on the computing devices used within kiosks and did not attempt to address system peripherals, such as input devices, external displays, dispensing systems, security devices, and thermal components. For the purpose of this work, the core computing device was called the *Kiosk computer* and was defined as "the central unit within a kiosk that provides peripheral connectivity and core functionality."

Because of the nature of their usage and functional charter, in view and ready to be used but out of the thoughts of most, kiosks have typically been selected without consideration for energy use. This results in sub-components like kiosk computers receiving little attention. Commonly, kiosks are designed to be deployed and forgotten about from an energy consumption and usage prospective. Kiosk tending typically only involves refreshing their content or wares and does not focus on system or physical maintenance upgrades. The operational portions of the kiosk are typically only addressed at times when they fail or are rendered unusable. This can lead to kiosks becoming invisible or vampire loads within buildings and on the grid.

Additionally, due to their operational nature—always on, no sleep mode, limited to no power down functionality, no proscribed idling, wake up via LAN rarely utilized—kiosk computers

cannot be effectively rated using either the current ENERGY STAR standard (version 5.0[14]) or the soon-to-be-implemented standard (version 6.0[15]), for desktop computers.

Version 6.0 of ENERGY STAR is scheduled to become effective June 2nd, 2014. Due to its finalized nature, the fact it will implemented soon after the completion of this project, and the direct impact it will have on future deployed computers, all discussions and comparisons regarding ENERGY STAR within this report are related to the Version 6.0 standard.

For the purpose of consistency and understanding within the testing and evaluation process, the ENERGY STAR standard specially defines what a desktop computer and an integrated desktop computer are. The graphic below is from the ENERGY STAR standard and provides details on these definitions.

Figure 20: ENERGY STAR Computer Definitions

2) Desktop Computer: A computer whose main unit is designed to be located in a permanent location, often on a desk or on the floor. Desktop computers are not designed for portability and are designed for use with an external display, keyboard, and mouse. Desktop computers are intended for a broad range of home and office applications, including point of sale applications.

   a) Integrated Desktop Computer: A Desktop Computer in which the computing hardware and display are integrated into a single housing, and which is connected to ac mains power through a single cable. Integrated Desktop Computers come in one of two possible forms: (1) a system where the display and computer are physically combined into a single unit; or (2) a system packaged as a single system where the display is separate but is connected to the main chassis by a dc power cord and both the computer and display are powered from a single power supply. As a subset of Desktop Computers, Integrated Desktop Computers are typically designed to provide similar functionality as Desktop systems.

Within the ENERGY STAR Version 6.0 standard, a desktop computer that has a discreet graphics system is delineated as a D# system. Systems with integrated or switchable graphics are delineate as I# within the standard. So, although rarely considered based on ENERGY STAR ratings, the kiosk computers that use *standard* hardware and software typically would fall within the hardware definition of desktop computers with integrated graphics. These results in kiosk computers are based on standard hardware being compared to the I1 through I3 systems categorized within the ENERGY STAR profile.

It should be noted that ENERGY STAR 6.0 specifically excludes point of sale systems, ultra thin clients, and systems t do not utilize common computing components. The details of this exclusion are described in the graphic below, with the point of sale and ultra thin client exceptions highlighted.

14http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/Version5.0_Computer_Spec.pdf

15 http://www.energystar.gov/products/specs/sites/products/files/Final%20Version%206.0%20Computers%20Program%20Requirements.pdf

Figure 21: ENERGY STAR Computer Exceptions

2.2.2 The following products are not eligible for qualification under this specification:

i. Docking Stations;

ii. Game Consoles;

iii. Handheld Computers (including eReaders);

iv. Handheld gaming devices, typically battery powered and intended for use with an integral display as the primary display;

v. Mobile Thin Clients not meeting the definition of Notebook Computer;

vi. Personal Digital Assistant devices (PDAs);

vii. Point of Sale (POS) products that do not use internal components common to Desktop Computers or Integrated Desktop Computers, including a processor, motherboard, and memory, or that do not run a standard Desktop Computer operating system;

viii. Slate/Tablets;

ix. Small-scale Servers that are marketed and sold for use in data centers;

x. Smart Phones; and

xi. Ultra-thin Clients.

This exclusion prevents many systems similar to the high-efficiency systems that are evaluated under this project from being considered for ENERGY STAR. So, in cases where highly specialized and unique computers are utilized, an ENERGY STAR rating may not be achievable under any circumstances.

ENERGY STAR certification also speaks to the performance and efficiency of internal power supplies (IPSs). These are typically found within desktop computers and are one area where noticeable energy and efficiency gains can be realized quickly. These power supply efficiency standards follow closely the values associated with basic 80 PLUS certification, which will be discussed in greater detail later in this report, but it should be noted that an ENERGY STAR rated computer will deliver a relatively high power factor and good efficiency, regardless of its loading. The graphic below provides specific details on the requirements for an IPS found within an ENERGY STAR-rated computer.

Figure 22: Internal Power Supply Efficiency Ratings

i. IPS with maximum rated output power less than 75 watts shall meet minimum efficiency requirements as specified in Table 1.

ii. IPS with maximum rated output power greater than or equal to 75 watts shall meet both minimum efficiency requirements and minimum power factor requirements, as specified in Table 1.

Table 1: Requirements for Internal Power Supplies

Loading Condition (Percentage of Nameplate Output Current)	Minimum Efficiency	Minimum Power Factor
20%	0.82	-
50%	0.85	-
100%	0.82	0.90

These efficiencies are further refined within specific ENERGY STAR computing categories. The specific values required for power supplies found in desktop and integrated desktops can be seen in the figure below.

Figure 23: Power Supply Efficiency Allowances

Table 5: Power Supply Efficiency Allowance

Power Supply Type	Computer Type	Minimum Efficiency at Specified Proportion of Rated Output Current[ii]				Minimum Average Efficiency[iii]	$Allowance_{PSU}$
		10%	20%	50%	100%		
IPS	Desktop	0.81	0.85	0.88	0.85	-	0.015
		0.84	0.87	0.90	0.87	-	0.03
	Integrated Desktop	0.81	0.85	0.88	0.85	-	0.015
		0.84	0.87	0.90	0.87	-	0.04
EPS	Notebook or Desktop	0.83	-	-	-	0.88	0.015
		0.84	-	-	-	0.89	0.03
	Integrated Desktop	0.83	-	-	-	0.88	0.015
		0.84	-	-	-	0.89	0.04

It should be noted that the ENERGY STAR computer program is a volunteer program that focuses largely on consumer (both residential and commercial office) computers, not on specialized commercial devices with unique operational requirements. Because of the unique operational nature of kiosks, the traditional testing model used for ENERGY STAR certification —which includes the measurement of idle, sleep, and other states—is not wholly applicable to kiosks.

With the above points related to the operational nature of kiosks and ENERGY STAR testing understood, there are definitely things that can be done to improve the energy profile of kiosk computers and still deliver the performance and capacities needed to meet the requirements of kiosk operation. Careful selection and integration of systems and components with improved energy efficiency can substantially reduce system energy use, while retaining or improving performance.

2.2.2 Technical Overview

As noted above, an automated kiosk is a small standalone device providing information and services via a computer screen. The focus of this project was solely on evaluating the computing device found within kiosks, not the various peripherals and associated components potentially utilized within these systems.

The computing devices that were studied were divided into two categories, which are defined below:

- Market Ready (MR) Kiosk Computers are ones built using off-the-shelf components.
- High Efficiency (HE) Kiosk Computers are ones that are designed and built to maximize energy savings using specialized, all-inclusive, or proprietary designs. Within this project, tablets fall within this category.

Each of these device categories have unique features and benefits that make them suited for particular applications and uses. Regardless of the application, the energy consumption and usage patterns of kiosks must be fully understood to properly determine the correct system to deploy.

As noted in the previous section of this report, one of the criteria that some may use to help understand the energy performance and annual cost of computer operations is ENERGY STAR. Unfortunately, ENERGY STAR certification may not be an ideal tool for this task. The following issues must be understood when utilizing ENERGY STAR to evaluate kiosk computers:

ENERGY STAR does not accurately access the energy profile and cost of operation for kiosk computers due to the nature of kiosk operation (no sleep mode / fully active / and so on).

Figure 24 below shows the equation utilized within ENERGY STAR V6.0 to determine the energy consumption of the system under test.

Figure 24: ENERGY STAR Calculation

Equation 1: TEC Calculation (E_{TEC}) for Desktop, Integrated Desktop, Thin Client and Notebook Computers

$$E_{TEC} = \frac{8760}{1000} \times (P_{OFF} \times T_{OFF} + P_{SLEEP} \times T_{SLEEP} + P_{LONG_IDLE} \times T_{LONG_IDLE} + P_{SHORT_IDLE} \times T_{SHORT_IDLE})$$

Within the ENERGY STAR 6.0 Framework, kiosk computers based on *standard* computing components would typically fall within definition of desktop computers with integrated graphics and be categorized as I1 through I3 systems.

Based on the research team's calculations, there is a potential energy savings of 130 GWh that could result from improved kiosk computer efficiency. For this project, it was important to develop a set of specific project objectives, and to also understand potential issues and challenges which may arise from this work. The following sections are provided to the reader with a high level guide to the objectives and challenges within this project.

To achieve the objectives of this project, the following goals/tasks were defined:

- Research and evaluate current kiosk components, systems, and operating strategies.
- Ensure that replacement systems must deliver improved energy efficiency without degrading performance.
- Locate traditional computers equivalent to current baseline systems.
- Establish baseline kiosk energy consumption and performance using traditional computers.
- Configure current standard and improved efficiency kiosk computers:
    - Construct representative current-generation computers with common components /characteristics.
    - Construct systems using system components that offer potential energy savings and evaluate alternative systems.
- Indentify replacement high-efficiency computing devices that offer the potential for energy savings and still deliver sufficient performance.
- Conduct energy-use testing on Typical Current, Improved Efficiency, and High Efficiency Systems.
- Conduct performance testing on Typical Current, Improved Efficiency, and High Efficiency Systems.
- Document and analyze test results.

As noted above, it is important to understand the objectives of this work. It is also important to understand the issues that can and will arise from this work.

A list of the primary issues or challenges that faced this work follows:

- Although "green" or energy-efficient kiosks are available[16], energy efficiency is of minor importance to most kiosk purchases, although some companies are beginning to deploy improved-efficiency kiosks[17].
- Improved energy efficiency cannot be permitted to degrade kiosk performance.
- Upgrading/replacement cost can be a major issue to users.
- Proper performance includes understanding several important functionality/performance issues:
    - Clarity of display, simplicity.
    - Computing power/time, response time.
    - Reliability, durability, and ease and extent of maintenance.
    - Easy integration of peripherals.
    - Effective cooling:
- Any improvements must address both Energy Efficiency and Performance.
- ENERGY STAR is aimed at evaluating mainstream computers, not specialized applications like kiosks:
    - ENERGY STAR calculations include evaluating sleep mode, display sleep, idle, wake-up via LAN, and other modes in addition to full on operation.
    - Evaluation of kiosk systems using the current ENERGY STAR method is not effective due to the nature of kiosk use.
    - Kiosk computers are typical not ENERGY STAR rated due to their installation nature and their operational mode.
    - Many kiosks operate 8760 hours annually in "full on" mode to deliver operational performance and instant response, so typical energy-saving modes are not applicable.

2.2.3 Opportunity

The work undertaken by the Energy Commission within this project regarding kiosks has the potential of having a noticeable impact on the energy consumed by California-based kiosks. Currently kiosks appear to offer substantial potential for energy savings, and their energy use has largely been unaddressed or overlooked. As noted above, this energy-usage profile results from the fact that kiosks typically operate almost exclusively in full on, no sleep, active mode. This fully functional state—in operation 24 hours a day, 7 days a week—can lead to a large

16 http://www.kiosk.com/market/green-kiosk-experience.php

17 http://www.triplepundit.com/2013/08/company-brings-redbox-long/

invisible, or vampire, load within a commercial establishment. If an establishment has multiple kiosks performing a range of tasks—such as an ATM, an informational kiosk, a product dispensing kiosk, or a ticketing kiosk—the combined energy consumption of onsite kiosks could be sufficient.

Although regularly overlooked, or unaddressed, improvement in the energy consumption profile of kiosk computers is an attainable and reasonable goal. This statement is based on the fact that new improved efficiency computers—specially designed high-efficiency systems and reduced-consumption computing components like lower-power CPUs, reduced power consumption memory, solids-state drives (SSDs), memory chip-based storage (SD, micro SD, and so on), and improved-efficiency power supplies—are readily available within the marketplace, but few kiosk designs specifically use them, and many kiosks purchases are not driven by their use. So for these efficient devices and systems to gain wider adoptions within kiosk applications, both consumers and manufacturers must be further educated on the energy gains and performance levels that they can deliver.

Some may ask, "Why does this work?" They may argue that the kiosks currently in use are performing as designed and desired. Or they may say that the majority of the market is satisfied. Consumers and operators are satisfied, and there is not a large call for reform or update. The reality is that these "facts" may not be true as many kiosk consumers (commercial enterprises) may not be aware of availability of efficient alternatives to traditional kiosks.

The next question may be, "So, why is it is important to begin this work now?" Simply put, the energy consumption of kiosks is a commonly overlooked, or ignored, area within a growing market segment. The sooner this market segment is addressed, the sooner the positive effects of reduced energy consumption per device can be realized. If left unaddressed, kiosk power consumption has the potential of being a substantial future load, which may be difficult to reduce. This difficulty arises from the long life span and usage profiles of existing or deployed kiosks.

As mentioned earlier, there were 1.2 million self-service kiosks within the U.S. in 2010. Within the timeframe of this project, the number of deployed self-service kiosks has expanded substantially each year. It should be noted, that these numbers do not include ATM's, which also qualify as kiosks.

Current market data shows that self-service kiosk sales have the potential of being a market worth $5.8 billion, and kiosks enabled $1.3 trillion dollars in transactions, by the end of 2013.[18] The fact that this increase in deployment does seem to be declining in the short term makes the work within this project even more impactful for the future. It should be noted that reducing the energy profile of a kiosk installed today has the potential of long-term benefits because kiosks typically remain in service for many years. It is also worth considering that previously deployed kiosks are currently being replaced, and helping to educate and affect the marketplace

18 http://specialtyretail.com/issue/2010/01/retail-products/retail-product-features/success_with_self_serve_kiosks/

today regarding devices currently needing replacement can noticeably reduce future energy consumption as well.

2.2.4 Testing Overview

As part of this project, EPRI evaluated a range of systems to determine their performance. The evaluated systems included mature computers, systems using currently common computer hardware, systems using improved efficiency common computer components, and high-efficiency computing systems capable of delivering sufficient performance for kiosk applications. The performances of the mature systems were utilized as the baseline values associated with kiosk computers.

The evaluated systems were divided into three categories: baseline, market-ready (both commonly available and improved efficiency), and high-efficiency systems. The market-ready systems were placed in three different chassis configurations to represent different field deployments, but the hardware found within these systems could be interchanged between the different chassis configurations without issue. Below are the definitions utilized and the testing goals within this project for both market-ready and high-efficiency systems.

2.2.4.1 Project Definition of Market Ready Kiosk Computers

- Kiosk computers that provide connectivity to the widest array of peripherals and utilize standard computing components, devices, and operating systems.

2.2.4.2 Project Scope for Market Ready Kiosk Computers

- Build computers using commonly available computing devices.
- Build similar systems that replace inefficient computer components with improved efficiency components and that demonstrate different modification paths.
- Test all constructed systems, with specific focus on the performance of improved-efficiency kiosk computers that could be integrated into new kiosk builds or that could be retrofitted into existing systems.

2.2.4.3 Project Definition of High Efficiency Kiosk Computers

- Computers designed to provide the highest efficiency and lowest power consumption and still deliver sufficient computing power for many kiosk applications. Note that these systems can maintain an interactive customer experience with a limited number of peripherals.

2.2.4.4 Project Scope for Ultimate Efficiency Kiosk Computers

- Acquire systems utilizing various configurations with the most efficient computers and/or computer components currently available.
- Some of these computers (such as tablets) will include integrated displays and provide full computing solutions.

- Evaluate all systems for both energy consumption and computing performance to fully understand the capacity and scope of their ability to replace the computing devices currently utilized and deployed in kiosk applications.

The same testing regiment was utilized on all systems. All systems were evaluated for power consumption and power factor utilizing laboratory-grade power meters. The reported values are based on systems that had reached a stable "full on" operation state because kiosks are typically operated in full on mode (no sleep, no power down, no reduced idle) 24 hours a day, 7 days a week. Tablet-based systems were evaluated in full charged mode connected to ac power because most tablet-based systems are configured to work with direct ac power and do not operate on battery power alone, or regularly go into their charge state.

For computing performance, two versions of PassMark software (mobile and PC) were utilized. A portion of the PassMark score is based on the graphics performance of the system and utilizes the 3DMark evaluation tool. This tool is commonly used to compare the performance of video cards and graphics chipsets. It should be noted that PassMark, and 3D Mark, performance scores are values that can only be compared to other PassMark and 3D Mark scores because there is no established unit for comparison between various system performance tools. Two systems included within the testing were based on chipsets/hardware platforms in which PassMark does not offer a product. These systems were noted in the findings, but their processing power is not considered in the project conclusions.

2.2.4.5 Baseline Systems

Two Intel Pentium D-based computers that utilized mechanical hard drives were selected to represent the baseline values of field-deployed kiosks. Systems like this were commonly available between 2005 and 2008 and can still be found in use today in some applications. This level of system was selected as a kiosk baseline because kiosks are rarely upgraded once deployed, and many systems remain in the field for years. It should also be noted that some kiosk manufacturers utilize after-market computers sold by other commercial or industrial agents at end of life within their systems because these systems are inexpensive and may provide sufficient computing power for less intense kiosk applications. In these situations, a newly deployed kiosk may be utilizing a computer that is several years old, so the energy profile would not be optimized in comparison to current computers. As one can see from the graphic below, these representative systems would consume approximately 1250 or 850 kWh/yr if deployed in the field.

Figure 25: Baseline Computer Specifications

	CPU	Memory	Integrated Storage
Baseline 1	Intel Pentium D 2.8 GHz	2GB	80 GB Mechanical
Baseline 2	Intel Pentium D 2.8 GHz	1.5GB	80 GB Mechanical

Baseline Computer 1 Energy Use
142.85 watts
8760 hours/year operation
1251.4 kWh/yr

Baseline Computer 2 Energy Use
97.29 watts
8760 hours/year operation
852.26 kWh/yr

2.2.4.6 Market-Ready Systems

As noted above the market-ready systems considered within this project were configured with three different chassis configurations: small form factor, slim line, and industrial. These three chassis configurations are all utilized within various kiosk systems and allow for interchangeability of components between them because they are all based on industry standard physical dimensions and specifications. Standard or off-the-shelf components available from a range of sources can be installed into these chassis and operate properly. Because of this interoperability, the testing and modifications seen within the market-ready systems should be viewed as usable in a variety of applications and conditions.

Additionally, it should be noted that EPRI decided to demonstrate a different path of modification within each defined chassis design to provide data on multiple paths to improved efficiency. Before providing component details on each of the evaluated systems, each of the market-ready segments is introduced below, and the upgrade path evaluated within that configuration is discussed.

The results of the testing performed on these systems can be found in the testing results portion of this report.

2.2.4.7 80 PLUS Power Supplies

Before discussing the specific details of each chassis configuration, and the modification pathway demonstrated within it, it is important to understand one of the primary areas of modification within the market-ready systems in greater detail. That area is efficient power supplies, because all efficient market-ready systems evaluated within this project included the substitution of 80 PLUS certified power supplies for non certified power supplies.

EPRI and ECOVA (ECOS at the time of project initiation) performed testing in the early 2000s, which showed that the internal power supplies found within most computers were not highly efficient. It was also found that the efficiency of the individual rails, or power circuits, within the power supplies varied based on loading. Simply put, a computer power supply loaded at say 50% of its capacity did not effectively utilize the power it was provided, and even if the power supply was heavily loaded as a whole, the individual +5V or -5V or -12V or +12V lines within the power supply may not be efficient because they themselves were not loaded near capacity. To address this issue, EPRI and ECOVA developed the 80 PLUS certification program, which is a voluntary program that assures the efficiency of internal computer power supplies across their loading profile. The importance of this work can be seen in the fact that the performance metrics associated with minimum 80 PLUS certification are the same as the power supply performance values required of an ENERGY STAR certified computer.

The snippet below from the 80 PLUS website[19] provides a brief summary of the goals of 80 PLUS testing and certification:

19 http://www.plugloadsolutions.com/80pluspowersupplies.aspx

Figure 26: 80 PLUS Summary

What is the 80 PLUS specification?

The 80 PLUS performance specification requires multi-output power supplies in computers and servers to be 80% or greater energy efficient at 20%, 50% and 100% of rated load with a true power factor of 0.9 or greater. This makes an 80 PLUS certified power supply substantially more efficient than typical power supplies and creates a unique market differentiation opportunity for power supply and computer manufacturers.

If you are interested in more details on the benefits of the 80 PLUS program, or want to understand the power quality impact of this program, please download the following brochures: 80 PLUS Benefits[20] and Power quality Impact of 80 PLUS.[21]

Once 80 PLUS certification was established, it became necessary to create strata within the certification standard to denote levels of performance due to the gains made by various manufacturers. The current strata delineated within 80 PLUS certifications are bronze, silver, gold, platinum, and titanium level performance. The graphic below, Figure 27, provides detail on the level of performance found within each 80 PLUS designation. It should be noted that all 80 PLUS power supplies utilized within this project were designed for certification under the 115 V portion of the 80 PLUS program, and that 80 PLUS is only relevant for internal computer and server power supplies and is not applicable to external power supplies.

20 http://www.plugloadsolutions.com/docs/collatrl/print/80plus_benefits.pdf

21 http://www.plugloadsolutions.com/docs/collatrl/print/80plus_power_quality.pdf

Figure 27: Baseline Computer Specifications

What is 80 PLUS certified?

80 PLUS Certification	115V Internal Non-Redundant			
% of Rated Load	10%	20%	50%	100%
80 PLUS	---	80%	80%	80% / PFC .90
80 PLUS Bronze	---	82%	85% / PFC .90	82%
80 PLUS Silver	---	85%	88% / PFC .90	85%
80 PLUS Gold	---	87%	90% / PFC .90	87%
80 PLUS Platinum	---	90%	92% / PFC .95	89%
80 PLUS Titanium	90%	92% / PFC .95	94%	90%

As one can see from the figure above, the majority of 80 PLUS certified power supplies are designed to deliver improved efficiency once they exceed 20% loading. [22] This means that even a 300-W 80 PLUS power supply must have a 60-W load to deliver improved efficiency. Historically, the higher the computer wattage, which typically means higher power supply loading, the easier and more cost effective it has been to deliver improved efficiency. Research in the power factor portion of this Energy Commission PIER project will show that the cost of power factor corrected circuits, even in low-wattage devices, is now minimal. These efficiency advances have not reached all levels of computer supplies due to lack of consumer demand. So, currently large-wattage computer systems are the primary target for the 80 PLUS power supply market. The combination of these facts has led to most 80 PLUS power supplies being 400 W or larger units, though there are a few 300-W 80 PLUS Bronze power supplies currently in the marketplace. All current 80 PLUS Titanium certified power supplies, which have high efficiency even as low as 10% loading, are larger than 400 W.

Both the standard and improved efficiency market-ready computers evaluated as part of this project are relatively low wattage due to their minimal configurations. All of these systems utilized integrated video and had only one storage device. Many desktop computers have external video cards and multiple storage devices, which lead to the expanded loading of the power supply.

Because of their minimal hardware, and augmented in some cases by their improved-efficiency components, only one of the evaluated MR systems was capable of loading its power supply above 20%. This sub 20% loading lead even the improved-efficiency market-ready systems to

22 http://www.plugloadsolutions.com/80pluspowersupplies.aspx#

deliver sub 80% power factors, although the use of even an under-loaded 80 PLUS power supply resulted in over a 50% gain in power factor efficiency over the OEM units, which came with the systems. These results are discussed in great detail later in the report, but it important to note these things for a full understanding of the project results.

2.2.4.8 Small Form Factor (SFF)

The small form factor (SFF) systems evaluated within this project were built to demonstrate the potential of using the same class processor within a system but moving from a desktop CPU to a mobile CPU. This upgrade path required the replacement of the motherboard as well as the CPU because mobile CPUs typically use a different chip footprint than desktop CPUs. In the addition to the motherboard, the efficient system utilized an 80 PLUS rated power supply, lower voltage memory, and a solid-state disk (SSD) hard drive. It should be noted that the 80 PLUS power supply was actually larger in capacity (300 W verses 200 W) because 80 PLUS power supplies are typically not available smaller than 300 W. The specifications of the SFF systems in this project, and the details of the modifications made to the efficient unit, can be seen in Figure 28 below. The systems were outwardly identical, but the components contained within differ.

Figure 28: Small Form Factor Computer Specifications

	Small Form Factor Standard	Small Form Factor Efficient
Case	IN WIN BP655.200BL	IN WIN BP655.200BL
Motherboard	Gigabyte GA-H61N-USB3	Jetway JNC9BU-HM67 for Mobile CPU
Power Supply	200W OEM Non 80+	300W 80+ Bronze
CPU	Intel i5-3570K 3.4GHz Quad Core	Intel i5-3320M 2.6 GHz Dual-Core
Memory	4GB Mushkin DDR3 1066MHz Standard Voltage	4GB Crucial Ballistix Tactical (Low Voltage)
Disk Drive	WD Blue 250GB	Sandisk 64GB SSD
Changes	N/A	**Motherboard, CPU, P/S, Memory, Storage Disk**

2.2.4.9 Slim Line Systems

The slim line systems evaluated within this project were built to demonstrate the potential of using the same processor family in each system but moving from an average/standard desktop CPU to a lower -power desktop CPU within that family. This change results in decrease in processor speed, 3.4 GHz to 2.8 GHz in this case, but this may not be something that greatly impacts the overall system performance due to high processor idle states in many applications. This upgrade path included the replacement of the CPU, the replacement of a standard power supply with an 80 PLUS certified power supply, the use of lower voltage memory, and an SSD hard drive. The specifications of the small form factor systems in this project, and the details of the modifications made to the efficient unit, can be seen in figure 29 below.

Figure 29: Slim Line Computer Specifications

	Slimline Standard	Slimline Efficient
Case	Cooler Master Elite 361	Cooler Master Elite 361
Motherboard	Gigabyte B75M-D3H	Gigabyte B75M-D3H
Power Supply	350W OEM Non 80+	400W 80+ Bronze
CPU	Intel i5-3570K 3.4GHz Quad Core	Intel i5-3340S 2.8 GHz Quad-Core
Memory	4GB Mushkin DDR3 1066Mhz Standard Voltage	4GB Crucial Ballistix Tactical (Low Voltage)
Disk Drive	WD Blue 250GB	Sandisk 64GB SSD
Changes	N/A	**CPU, P/S, Memory, Storage Disk**

2.2.4.10 Industrial Computer (IC)

The industrial computer systems evaluated within this project were built to demonstrate the potential benefits, or impact, of moving from one processor family to another where both processor families shared the same pin configuration. This allowed the same motherboard to be used in both systems. It should be noted as well that this upgrade path also demonstrates the use of two older processor families. These processors are of a generation between the baseline CPUs and the CPUs utilized within the small form factor and slim line systems. This upgrade path included the replacement of the CPU, the replacement of a standard power supply with an 80 PLUS certified power supply, the use of lower-voltage memory, and an SSD hard drive. The

specifications of the industrial computer factor systems in this project, and the details of the modifications made to the efficient unit, can be seen in Figure 30 below.

Figure 30: Industrial Computer Specifications

	Industrial Computer Standard	Industrial Computer Efficient
Case	Rosewill RSV-L4000 4U	Rosewill RSV-L4000 4U
Motherboard	ASRock N68C-GS FX	ASRock N68C-GS FX
Power Supply	Installed Non-PFC, Non-80+	400W 80+ Gold
CPU	AMD Phenom II X2 550 Black Edition 3.1 GHz Dual Core	AMD Athlon II X2 270 3.4 GHz Dual Core
Memory	4GB Mushkin DDR3 1066Mhz Standard Voltage	4GB Crucial Ballistix Tactical (Low Voltage)
Disk Drive	WD Blue 250GB	Sandisk 64GB SSD
Changes	N/A	**CPU, P/S, Memory, Storage Disk**

2.2.4.11 Efficient Computers

For the purposes of this project, efficient computers are defined as high-efficiency computers that can take a variety of form factors. Included within this category are tablets, which actually are entire systems because they include input devices and displays. Some kiosk applications that do not require large amounts of local storage and only require limited local computing power are beginning to utilize tablets in kiosk mode. Other common configurations for efficient kiosk computers are single-board computers and ultra-small format systems. Devices like solid-state storage utilized, which can be used within traditional computers, are utilized within some of these designs. Some of these high-efficiency designs also use SD or micro SD memory cards for storage. This method of storage can allow for field changes in capacity by simply substituting compatible memory cards.

The high-efficiency systems evaluated within this project were number #HE1 through #HE9. A brief description of each can be found in the graphics below. Due to the variety of these designs, there is no single means of comparing these devices, but the graphics should provide sufficient information for the analysis of each individual system and to demonstrate the range of systems included within this project.

Figure 31: Efficiency Computers #1 Through #3 - Specifications

	Habey BIS6564A	CompuLab FitPC 3	Samsung Galaxy Note 10.1
Motherboard	OEM	OEM	OEM
CPU	Intel Atom D525 Dual Core 1.8GHz	AMD G-T56N Dual Core 1.65GHz	ARM cortex A9 Quad Core 1.4 GHz
GPU	Nvidia ION2 Geforce GT218	Radeon HD 6320	Not Specified in specification sheet
Memory	4GB	4GB	2GB
Disk Drive	Sandisk Ultra Pro 64GB SSD	Sandisk Ultra Pro 64GB SSD	16GB NAND Flash
System Wattage	<30W	9 -24W*	Specification sheet does not specify
Notes	Installed SanDisk SSD	*Depends on system load Installed SanDisk SSD	None

Figure 32: Efficiency Computers #4 Through #6 - Specifications

	Apple iPAD	PQ Labs iStick	Kaser Net'sPC 2
Motherboard	OEM	OEM	OEM
CPU	Apple A6X Dual Core	ARM V9 / Dual Core 1.6GHz	ARM Dual Core 900MHz - 1.3GHz
GPU	Quad Core	Quad Core Mali 400	Listed as Specialty Malibu w/ 128MB of memory
Memory	1 GB (Not taken from specification sheet)	2GB DRAM	1GB 633MHz
Disk Drive	16GB Flash	4GB NAND Flash	SATA no capacity given
System Wattage	Specification sheet does not specify	1.6 - ~3.5W	Not stated in specifications
Notes	None	None	NONE

Figure 33: Efficiency Computers #7 Through #9 - Specifications

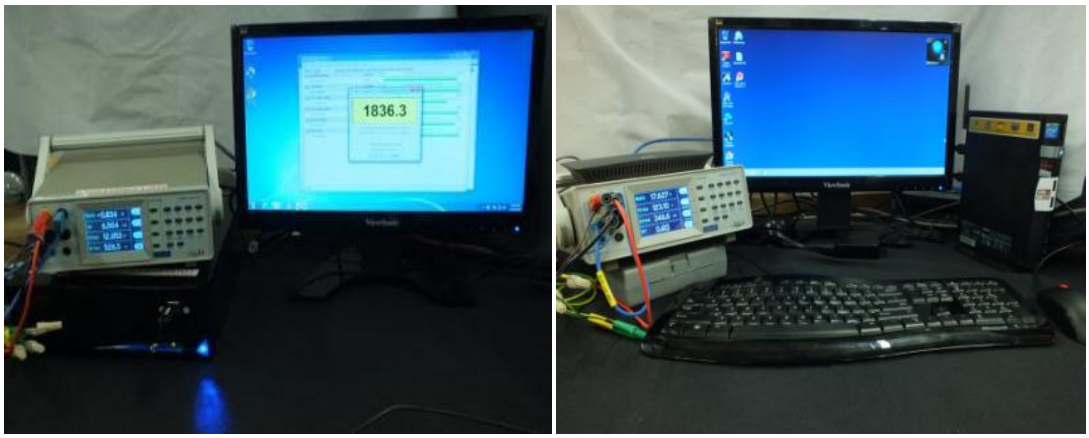
	Raspberry Pi	Asus EeBox PC EB1035	CompuLab Trim-Slice Pro
Motherboard	OEM	OEM	OEM
CPU	Broadcom BCM2835 ARM 700MHz	Intel Celeron 847 Processor	NVIDIA Tegra 2 @ 1GHz
GPU	Integrated Videocore GPU	Intel Integrated Graphics	N/A
Memory	512MB	2GB DDR3 1333MHz	1GB DDR2 - 667Mhz
Disk Drive	Removable SD Card	320GB mechanical HDD	32GB Genesys Logic GL830 1.8" USB to SATA
System Wattage	2-6W Max w/ external peripherals	65W Power Supply	2 - 6W
Notes	NONE	None	NONE

As one can see from the system specifications shown above, efficient computers typically consume very low amounts of power and can deliver a range of processor, operating, and storage solutions. Specific details on the actual performance of each system can be found later within the testing results portion of this report.

2.2.5 Testing Setup and Results

As noted above, all performance and energy testing associated with the evaluated kiosk computers was performed by EPRI and utilized laboratory-grade power meters. Photos of the performance and energy testing setup within EPRI's lab are shown below.

Figure 34: Power and Performance Test Setup



The power meter utilized was a calibrated and certified Voltech PM1000. All testing occurred at ambient temperature within a condition space. Reported energy consumption measurements are average consumption of stable systems operated at nominal 120-V wall power without any injected power quality events, sags, swells, or surges.

PassMark V8.0 64bit benchmarking software[23] or PassMark Mobile benchmarking software[24] was utilized to deliver the computing performance values reported below. These software packages utilize 3DMark, a common graphic power-analysis tool, as part of their calculation. PassMark software delivers an overall single performance value, shown later in the report, as well as values for the performance of specific sub-systems. Some of these sub-systems include CPU performance, memory performance, storage performance, and graphic performance. All systems were evaluated after any available system, and operating systems updates were installed to provide accurate scores. PassMark was not able to deliver test results on two systems selected for evaluation because the systems were based on CPU platforms and/or operating systems, which were not supported by PassMark. These systems are HE7 and HE9.

The following graphics show the results of all testing. A brief graphics guide follows:

- Figure 35 – System Power Consumption in Watts
- Figure 36 – Computing Performance of Evaluated Systems
- Table 7 – Potential Power and Operational Cost Savings for Evaluated Systems
- Figure 37 – Power Factor of Evaluated Systems

23 http://www.PassMark.com/products/pt.htm - PassMark Performance Test V8.0 64bit

24 http://www.PassMark.com/products/pt_mobile.htm - PassMark Performance Test Mobile

Figure 35: System Power Consuption in Watts

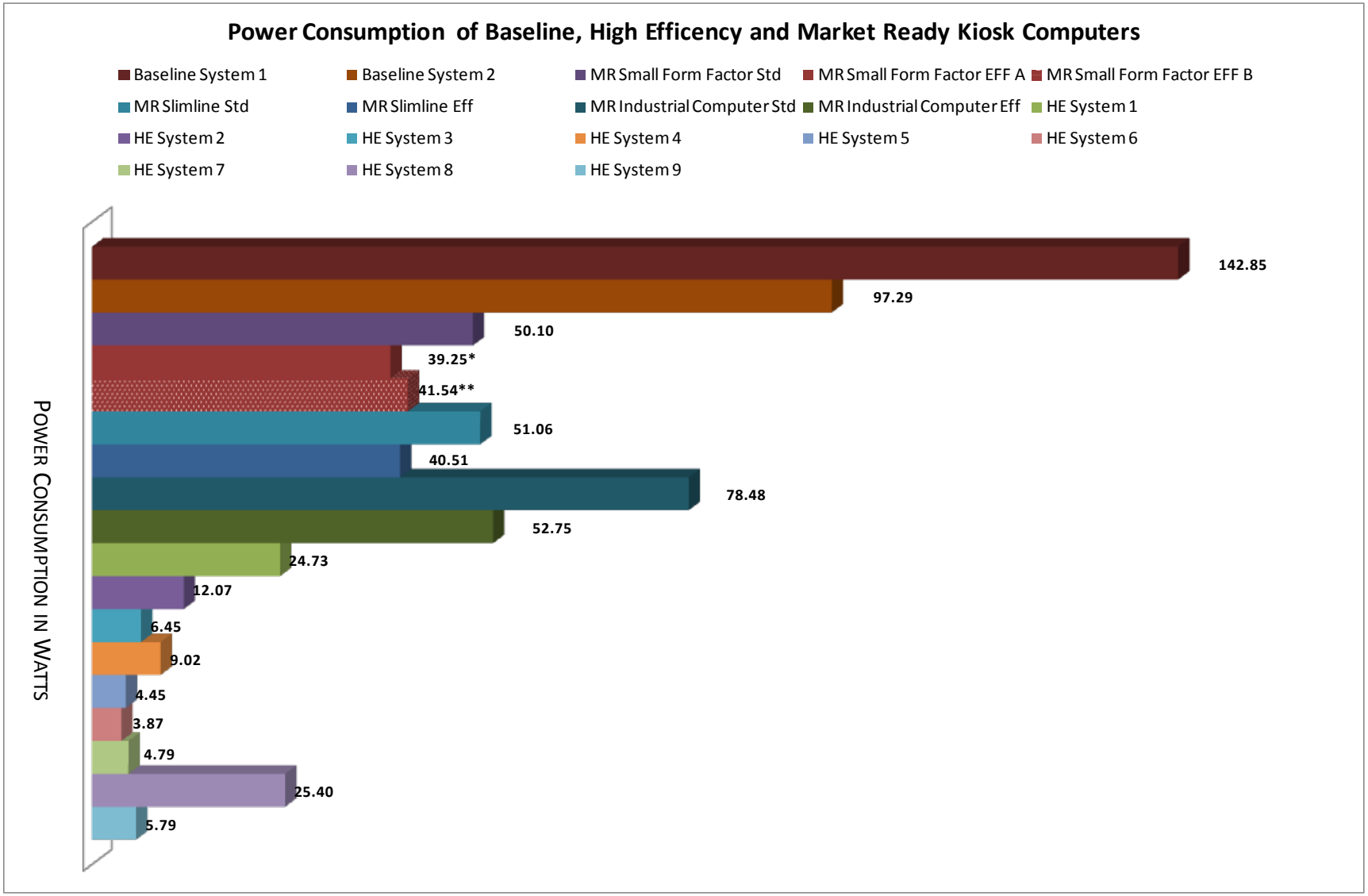


Figure 35 shows the power consumption in watts of each of the evaluated systems. It clearly shows that there is noticeable potential for power savings when even new, typical-efficiency devices are utilized to replace computing devices of just a few years ago. When high-efficiency devices are utilized, much larger power savings are easily achievable.

Note that with the exception of the industrial computer (IC) with standard components, all market-ready systems consumed approximately 50%, or less, of the power consumption by both baseline systems. Even the IC with standard components offered noticeable power savings over both the baseline systems and only consumed about half the power of the Baseline1 system. It should be noted that the use of the 128-MB Memory setting in the BIOS on the SFF market-ready system resulted in about a 2.25-W increase in power consumption. This may be useful in garnering a deeper understanding of the impact of on-board video settings.

The high-efficiency computers, HE1 through HE9, all offered substantial power savings over both the baseline and market-ready systems evaluated within this project. These systems offered approximately 75%, or more, power savings over even the lowest-consumption baseline system. Energy savings like this make a solid argument for the deeper consideration of high-efficiency systems in certain applications, and, in fact, based on the performance values shown in Figure 36 below, even support the potential use of high-efficiency computers in a variety of applications, which may require strong computing performance and only limited storage.

Six of the evaluated high-efficiency systems consumed less than 10 W of power. These six systems offered 94% or greater energy savings on average over the baseline system #1. Of these six, two were the tablets evaluated as part of this project (HE3 and HE4), which consumed 6.45 W and 9.02 W, respectively. It is important to remember when considering the power consumption of tablets that they are entire computing systems including display and screen-based input components.

Figure 36: Kiosk PassMark Results

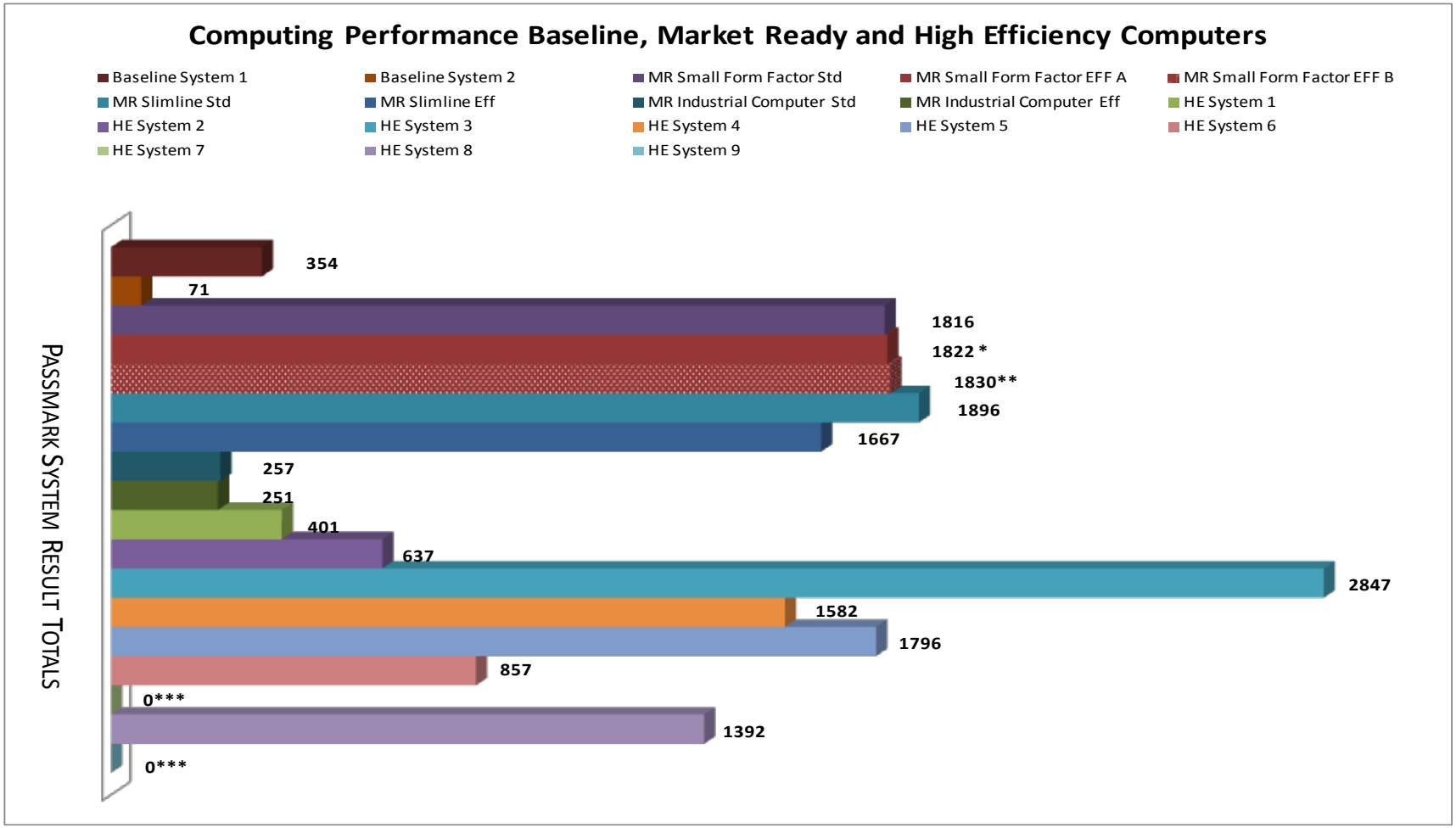


Figure 36 shows the PassMark computing values of each of the systems that are compatible with the program. As noted previously, the PassMark scores of two systems, HE 7 and HE 9, cannot be reported due to the fact they operate on processor and/or operating system platforms unsupported by PassMark.

The majority of the evaluated market-ready and high-efficiency systems far exceeded the performance of the highest performance baseline systems (a 354 PassMark score), and all market-ready and high-efficiency systems exceeded the performance of the lower performing baseline system (a 71 PassMark score). These values show that there are improved and high-efficiency solutions available in the marketplace that can deliver sufficient computing power for kiosk applications.

Most noticeable in the PassMark scores shown above is that all evaluated high-efficiency systems exceeded the performance of the baseline systems. This shows that high-efficiency computers do offer the ability to deliver the computing performance for the majority applications served by kiosks deployed several years ago. It should also be noted that several of the high-efficiency computers delivered PassMark scores similar to those of the highest performing market-ready systems. In fact, the highest recorded PassMark score within this project was actually the HE5 system. Note the PassMark scores of the high-efficiency computers does not mean that they can deliver the storage, expansion, peripheral compatibility, and communication capacity required for all kiosk applications, but it does mean that they offer sufficient computing power for many applications.

As a whole, the slim line and SSF market-ready systems far exceeded the performance of the baseline systems. Interestingly, the use of the expanded GPU memory setting within the efficient SSF market-ready system only resulted in an improvement of 8 within the PassMark score. The industrial computer based market-ready systems, which utilized two different generations of CPUs, manufactured between the baseline systems and the other market-ready systems, did not exceed the performance of the high-performing baseline system but outperformed the lower-performing baseline system.

Table 7 shows the overall power utilization, cost of operation, and the annual savings over the Baseline Computer #1 system for each system evaluated within this project. Based on 8760 hours of annual operation with 16.9 cents per kWh power cost, the Baseline Computer #1 would consume 1251 kWh annually and would cost about $211 annually to operate. Other evaluated systems were compared to this value, and all savings are based on how much less power the system under test consumed in comparison. For example, in comparison to Baseline Computer #1, using the same 8760 hours of annual operation and average cost of power, High Efficiency #6 computers would consume 33.9 kWh annually and cost about $5.75 to operate.

Table 7: Power and Annual Cost Savings

Annual Usage Values and Potential Savings	Average Power (W)	Annual Operational Cost of Energy*	Annual kWh	Savings Over Baseline #1*	Annual Energy Savings in kWh Over Baseline #1	Annual Energy Savings in Percentage Over Baseline #1
Baseline Computer #1	142.85	$211.48	1251.4	$0.00	0.00	0%
Baseline Computer #2	97.29	$144.03	852.3	$67.45	399.11	32%
MR Small Form Factor Standard	49.75	$73.65	435.8	$137.83	815.56	65%
MR Small Form Factor Efficient A	39.25	$58.11	343.8	$153.37	907.54	73%
MR Small Form Factor Efficient B	41.54	$61.50	363.9	$149.98	887.48	71%
MR Slimline Standard	51.06	$75.59	447.3	$135.89	804.08	64%
MR Slimline Efficient	40.51	$59.97	354.9	$151.51	896.50	72%
MR Industrial Computer Standard	78.48	$116.18	687.5	$95.30	563.88	45%
MR Industrial Computer Efficient	52.75	$78.09	462.1	$133.39	789.28	63%
High Efficiency #1	24.73	$36.61	216.6	$174.87	1034.73	83%
High Efficiency #2	12.07	$17.87	105.7	$193.61	1145.63	92%
High Efficiency #3	6.45	$9.55	56.5	$201.93	1194.86	95%
High Efficiency #4	9.02	$13.35	79.0	$198.13	1172.35	94%
High Efficiency #5	4.45	$6.59	39.0	$204.89	1212.38	97%
High Efficiency #6	3.87	$5.73	33.9	$205.75	1217.46	97%
High Efficiency #7	4.79	$7.09	42.0	$204.39	1209.41	97%
High Efficiency #8	25.40	$37.60	222.5	$173.88	1028.86	82%
High Efficiency #9	5.79	$8.57	50.7	$202.91	1200.65	96%

* Based on 16.9 cents per kWh power cost

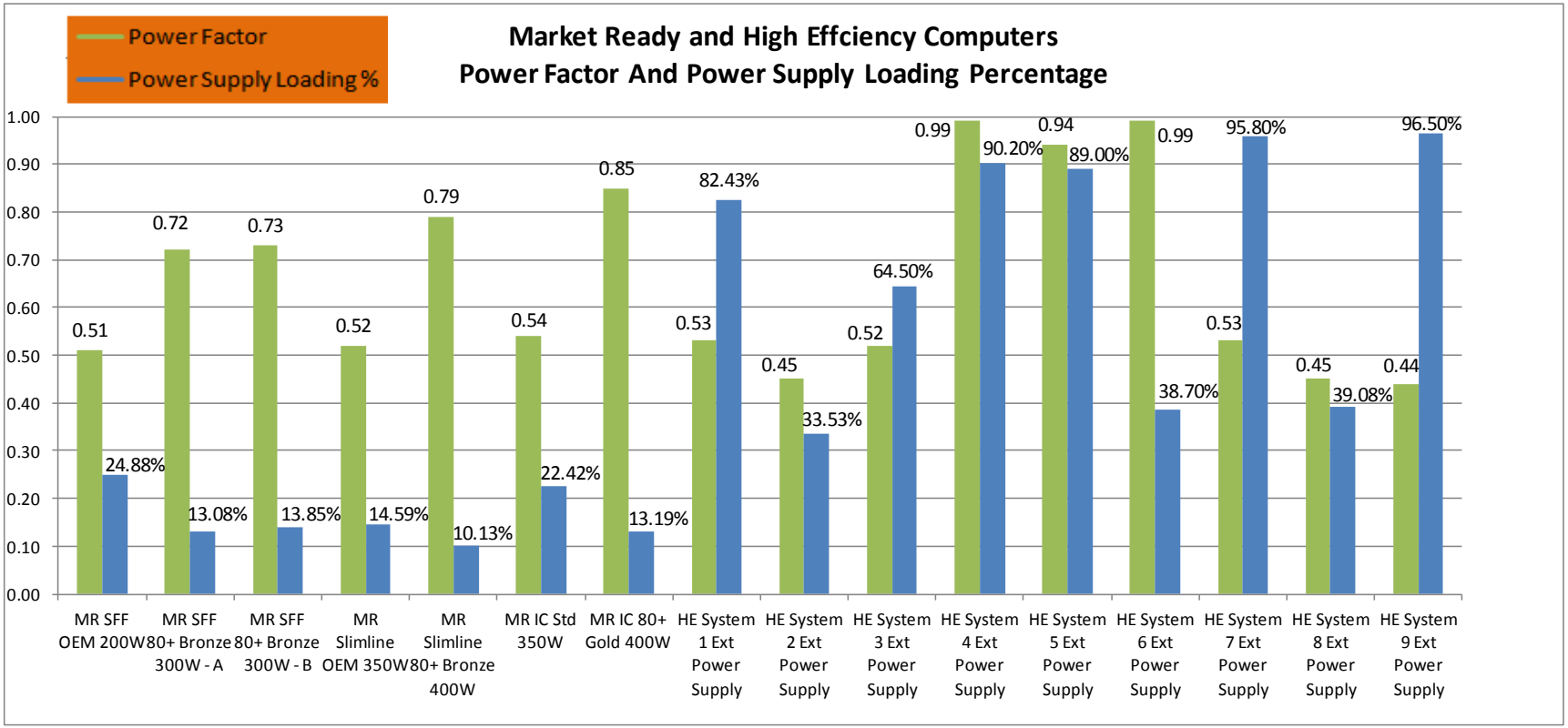
All evaluated market-ready and high-efficiency systems offered 45% or greater power savings, with several systems exceeding 95% power savings. In fact, with the exception of the market ready industrial computer system with standard components -, all evaluated MR and HE systems offered over 63% power savings. Regardless of the average cost power, these values show that there are noticeable and measureable savings potential using improved and high-efficiency systems.

As one can see in the table above, the majority of the evaluated systems offered between $150 and $205 in annual operational savings. Again, these savings are based on 16.9 cents per kWh power. The value of 16.9 cents per kWh was selected as an arbitrary future average cost of commercial power within the state of California for the purposes of evaluation. A future value was selected to allow time for legislative and policy review post publication of this report. Due to this, a calculation with actual current customer power rates would be needed to understand the true cost of operation of a kiosk today.

What is important to understand about the reported savings calculations shown above is that they demonstrate that the cost of replacement or modification of the existing kiosk computers may be offset by savings in power. As noted before, the true cost of annual kiosk operation should be measured at the system level, which includes all the other systems and components within the kiosk structure, but the testing within this project does show that some savings can be found within the computing part of the entire kiosk system.

Note: The power factor of the devices varied widely based on the system and design. Several high-efficiency devices showed a range of power supply loading values based on the computing activity of the device. Figure 37 shows the power factor (PF), as well as the percent of power supply loading, of the market-ready and high-efficiency systems evaluated within this project. The power factor of the evaluated systems varied widely, from 0.44 to 0.99. Some systems offered good power factors, and their power supplies are optimized for their loads. Others were fairly inefficient and offer the potential for improvement.

Figure 37: Power Factor of Evaluated Systems



Based on the low power consumption of some of the high-efficiency systems, the power factor may not seem important in these systems. It should be noted that inefficient power supplies/low power factor values, even in systems that consume low power can have a noticeable impact when deployed in large numbers. The high power supply loading percentage of systems like HE7 and HE9, paired with their low PF, shows that even high-efficiency computing systems have areas where they can be improved on and optimized.

It should be noted that the power factor of the market-ready systems, which utilized 80 PLUS power supplies, did not exceed the 80% minimum power factor mandated as part of 80 PLUS testing. This is because they did not meet the minimum 20% loading capacity of rated wattage for efficiency in these power supplies. Note though that these 80 PLUS power supplies, even when loaded below 20%, did deliver approximately 50% better power factor performance than the OEM power supplies they replaced. So although not optimal, the use of 80 PLUS power supplies did deliver improved power factor performance regardless of loading. As noted previously, few 80 PLUS power supplies are offered in sub-400-watt configurations. This is one area where market forces could drive product creation because there is currently minimal demand for sub-400-watt high-efficiency power supplies, and no 80 PLUS certificated power currently exist below 300 W.

In summary, just because a device is a smaller load, it does not mean that it will deliver a high power factor. As noted previously, when discussing 80 PLUS power supplies, many times manufacturers focus on creating high-efficiency power supplies designs for larger loads because their individual loads are more noticeable. The use of high-efficiency designs, even at low wattage, benefits both the grid and society due to the large number of small loads currently deployed. Research performed as part of the power factor portion of this PIER project has shown that the cost of implementing power factor corrected circuits, even in low-wattage devices, is minimal, so there appears to be few barriers to the wide deployment of high power factor devices within society. The wider use and availability of high power factor devices is definitely an area where legislation attention, selective rebates, consumer education, and public mandates may drive innovation and product improvement.

2.2.6 Market Impact

As the results from this report show, the use of improved-efficiency components and high-efficiency computers can noticeably improve energy consumption and still deliver sufficient computing performance.

When retrofitting or replacing systems that use standard computing components, industry standard designs, and *normal operating systems,* the use of higher efficiency components can allow for substantial power savings. The key components to consider when replacing or retrofitting these systems are:

- Solid state drives.
- Low power memory.
- Lower power / mobile CPUs.

- 80 PLUS (high efficiency) power supplies.

It should be noted that some of the market-ready kiosk systems did not sufficiently load even the smallest high-efficiency (80 PLUS rated) power supplies above 20%, so there are other potential gains possible if low-wattage versions of high efficiency computer power supplies are developed. This lack of loading can and did lead a reduction of power factor, even in systems using high efficiency power supplies, so this is a market area where consumer demand could noticeably impact the overall performance of deployed systems.

This report also demonstrated that high-efficiency/ultra-efficient computers can deliver sufficient computing power for most kiosk operations and offer opportunities for significant power savings. As the results above show, some of these devices offered over 95% savings in power over the baseline systems used within this project. Findings like this may result in some kiosk manufacturers and users considering the use of these lower-power devices for *some* applications. It should also be noted that *some* of these low-power systems use specialized hardware and operating system platforms, so their use may require the rewriting of operational and system software. Additional costs could also result from having to retrain employees and field staff, having to warehouse multiple parts, and the creation of additional support systems. These costs must be considered when evaluating these platforms because they may offset gains in operational saving.

With that said, the operational cost savings realized from the use of improved or high-efficiency devices may be sufficient to offset any additional cost, which may or may not exist in reality, and may drive their wider adoption within the kiosk industry if sufficient computing performance is delivered.

2.2.7 Title 20 Impacts

The results of this report show that future revisions of ENERGY STAR testing may need to consider the creation of a section within the testing devoted to the evaluation of systems that operate outside the existing evaluated operational model. The ENERGY STAR V6.0 calculation is again shown below. Note the use of sleep, off, and long idle states within this calculation.

Figure 38: ENERGY STAR Calculation

Equation 1: TEC Calculation (E_{TEC}) for Desktop, Integrated Desktop, Thin Client and Notebook Computers

$$E_{TEC} = \frac{8760}{1000} \times (P_{OFF} \times T_{OFF} + P_{SLEEP} \times T_{SLEEP} + P_{LONG_IDLE} \times T_{LONG_IDLE} + P_{SHORT_IDLE} \times T_{SHORT_IDLE})$$

Consideration of a potential ENERGY STAR category for systems that are operated exclusively in “Full on” / No sleep” mode could be useful when evaluating kiosk systems. The authors of this report will defer to others to make this decision because it is outside the scope of this work,

but as the kiosk market segment grows, and the power consumed by these devices as a whole expands, there may be sufficient consumer and market demand for such a category.

Within the state of California, it may prove beneficial to consider mandating the maximum average power consumption for kiosk computers (not including peripherals) installed within the state. This would offer at worst the ability to establish a minimum threshold of efficiency and potentially help to curtail future unfettered energy consumption of kiosks. Based on the analysis of EPRI and ECOVA, Title 20 mandates related to kiosk computers (not including kiosk peripherals) may lead to up to 130 GWh/yr of power savings. This amount of savings constitutes a medium Title 20 opportunity.

As the results of this project show, the mandating of a minimum power factor, regardless of wattage, for all computing devices sold and deployed within California may have a noticeable impact on the overall energy savings of deployed systems. Such a mandate would affect both kiosk and other computing devices. The sub-80% power factor of many of the evaluated systems, paired with the minimal market availability of sub-400-watt 80 PLUS power supplies, and the fact that there are currently no 80 PLUS certified power supplies below 300 W shows that this is a area where mandates and rebated products may directly impact many applications. It should be noted that system power factor is a topic for another part of this PIER project. For a deeper understanding of the full impact and importance of power factor, please refer to that portion of this report.

In addition to mandating maximum average power consumption and minimum power factor, there are other steps that could be taken to improve the overall efficiency of kiosk computers within California. As noted earlier in this report, any additional cost associated with improved-efficiency components and devices that consume low power may potentially be offset by power savings. Although these power savings could be substantial, the cost of 1) retraining support and field staff, 2) creating and maintaining multiple support paths, and 3) developing, or modifying, system software and peripherals that are compatible with any non standard hardware platforms and operations systems must be considered in all calculations and mandates. Due to this, the following actions may be worthy of consideration and prove impactful:

- Rebating higher-efficiency components may allow for their wider use in both retrofitted and newly deployed systems.
- Mandating the use of high efficiency/low power consumption computers in certain applications. These applications would have to be clearly defined, as would the cost of associated ancillary system changes, but applications that require only minimal to average computing performance and limited storage would probably be early candidates.

CHAPTER 3:
Survey of Potential Energy Efficient Design Techniques for Home Audio Devices

3.1 Background and Purpose

The purpose of this research was to survey existing technologies and products in the home audio marketplace with special emphasis on seeking out highly efficient products. Findings were then used to direct product testing and possible future energy-efficiency policy.

For this report, the home audio products are defined using the ENERGY STAR definition: a mains connected product that offers audio amplification and/or optical disc player functions. Throughout this document, the following product categories are referred to within the home audio marketplace:

- **Audio separate components** – Audio devices with separate enclosures sold individually that perform discrete audio functions such as amplification, radio tuning, and creating sound. Examples include amplifiers, radio tuners, receivers (amplifier and tuner combined), and speakers.
- **Blu-ray player** - A commercially-available electronic product encased in a single housing that includes an integral power supply and for which the primary purpose is the decoding of digitized video signals on a Blu-ray disc.
- **Compact audio** - Also known as a "mini," "mid," "micro," or "shelf" audio system, this term means an integrated audio system encased in a single housing that includes an amplifier, radio tuner, and attached or separable speakers and can reproduce audio from one or more of the following media: magnetic tape, CD, DVD, or flash memory (modified from the Energy Commission definition).
- **DVD player** - A commercially-available electronic product encased in a single housing that includes an integral power supply and for which the primary purpose is the decoding of digitized video signals on a DVD (modified from the ENERGY STAR definition).
- **Docks** – Similar to compact audio, these devices are integrated amplifiers that include attached or separable speakers. Their primary function is to connect to iPods and MP3 players.
- **Home theater in a box** - A multiple component system with separate enclosures that are sold as and intended for use as a single system, usually consisting of an optical disc player, amplifier, and speakers.

Recent technological innovations and changes in consumer habits and preferences have dramatically altered the home audio landscape. What was once a simple home stereo system plugged into a single outlet has proliferated into a large array of devices, mobile and hard-

wired, able to communicate with each other and across networks with content providers. Audio is increasingly just another form of digital data that can be broadcast, stored, modified, and copied from one device to another throughout the home. This desire for versatility has resulted in increased sales of portable devices such as iPods and MP3 players and the docks to which they connect for listening in the home. At the same time, sales of component audio devices are projected to remain level, indicating more rooms in homes with sound and therefore a potential increase in overall home audio energy consumption. This makes it all the more important to evaluate possible methods for reducing home audio energy consumption.

3.2 Technical Overview

3.2.1 Amplification

For home audio appliances, the amplification of audio signals is the primary energy-consuming function. The majority of audio amplifiers continue to rely on analog techniques to amplify power. These amplifiers are structured and designed to accurately reproduce audio programming with little regard to power consumption. Efficiencies of analog audio power amplifiers are around 50 percent, due to the nature of linear amplifiers and their low-efficiency linear power supplies. Linear power supplies are still preferred due to their inherent low-noise capabilities and simple design. Linear amplifiers dissipate most of their power in the form of heat and thus have large heat sinks attached to transfer heat from the device.Figure 39 shows the large heat sink attached to the conventional linear power amplifier to remove the excess heat from inside.

Figure 39: Large Heat Sink Attached to the Traditional Linear Amplifier

The home audio segment has only partially transitioned to high-efficiency designs, mostly because of the market factors such as price pressure, the complexity of alternative higher-efficiency technologies, and lack of motivation to address efficiency.

Although a small market exists for audiophile equipment in which audio quality is the paramount factor, the actual technology used to produce sound is not important to the broader consumer market. Over the past few years, two technologies have matured that set the stage to allow the design of very efficient home audio products. The first innovation, which has been around for more than a decade, is the switching power supply. Switch-mode power supplies have now achieved wide market penetration in most other consumer product areas, allowing for designs that can achieve efficiencies in the 90 percent to 95 percent range. The second technology, which was first found in automotive audio amplifier design, is the Class D amplifier. Class D audio amplifiers are to analog amplifiers what a switch-mode power supply is to a linear power supply. The following sections describe the power amplifier fundamentals and discuss the potential to save energy by moving to higher-efficiency designs.

3.2.2 Technology Description

In order to fully understand the benefits of switch-mode amplifiers, a short review of various amplifier types is helpful. Audio amplifiers fall under the category of *large signal amplifiers* or *power amplifiers,* which are typically designed to amplify large input signals or switch high current loads. There are four basic categories of amplifiers, namely Class A, Class B, Class AB, and Class D amplifiers based on the output signal that they generate.

- Class A – In a Class A amplifier, the output devices are continuously conducting for the entire power cycle. In other words, there is always bias current flowing in the output devices. This topology has the least distortion and is the most linear, but at the same time is the least efficient at about 20%. Class A amplifiers can typically be found in higher-end two-channel amplifiers.
- Class B – This type of amplifier operates in the opposite way to Class A amplifiers. The output devices only conduct for half the sinusoidal cycle (one conducts in the positive region, and one conducts in the negative region) so that if there is no input signal, then there is no current flow in the output devices. This class of amplifier is more efficient than Class A, about 80%, but has some issues with linearity at the crossover point due to the time it takes to turn one device off and turn the other device on. Class B amplifiers are rare in today's market due to their high signal distortion. However, they are sometimes used for radio frequency signal amplification.
- Class AB – This type of amplifier is a combination of the above two types and is currently one of the most common types of power amplifier in existence. Here both devices are allowed to conduct at the same time, but just a small amount near the crossover point. Hence each device is conducting for more than half a cycle but less than the whole cycle, so the inherent nonlinearity of Class B designs is overcome without the inefficiencies of a Class A design. Class AB amplifiers are approximately 50% efficient.

- Class D – This class of amplifier is also known as a "switching" or "pulse width modulation" (PWM) amplifier. This class of amplifier represents one of the most promising means of saving energy in audio equipment. In this type of amplifier, the switches are either fully on or fully off, significantly reducing the power losses in the output devices. Efficiencies of 90 to 95% are possible. The audio signal is used to modulate a PWM carrier signal, which drives the output devices, with the last stage being a low-pass filter to remove the high-frequency PWM carrier frequency.

In the past, implementation of a Class D audio amplifier required a large number of electronic components in a complex design. Recently, several integrated circuit (IC) makers have begun to offer single-chip Class D amplifier design solutions. These ICs allow implementation of Class D audio amplifiers without the large added cost burden previously incurred by these designs. An additional limiting factor has been the complexity of designing Class D amplifiers. Class D amplifiers make use of fast switching techniques to limit device losses in reproducing sound. This requires designs that must not only accurately reproduce sound but must operate as high-speed switching circuits. Class D amplifiers are becoming more common in smaller amplifiers (less than ~100 watts output) due to their cost becoming similar to AB amplifiers coupled with the benefits of less heat and lighter weight. Implementation into larger amplifiers (greater than ~100 watts output) remains limited due to higher costs and concerns over sound quality.

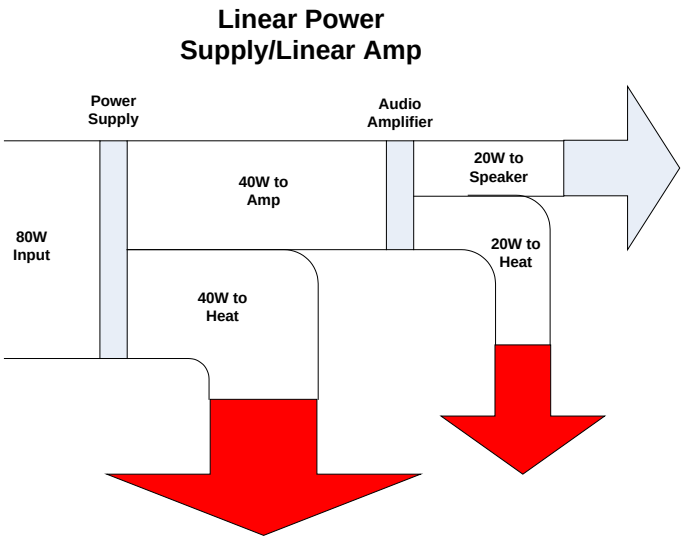
3.3 Opportunity

3.3.1 Benefits of Using Class D Amplifiers over Linear Amplifiers

3.3.1.1 Linear Power Amplifiers

In a linear amplifier, the signals always remain in the analog domain, and the output transistors act as linear regulators to modulate the output voltage. This results in a voltage drop across the output devices, which reduces efficiency. Figure 40 shows the power loss in a linear power amplifier design. The example here shows the amount of heat generated in a 20-W audio amplifier running at full power; a traditional linear amplifier design will produce about 20 W of waste heat in the amplifier (typical efficiency of 50%) and will require about 80 W input to the linear power supply, whose typical efficiency is also around 50% (which also produces another 40 W of waste heat). Thus, a 20-W amplifier generates 60 W of waste heat.

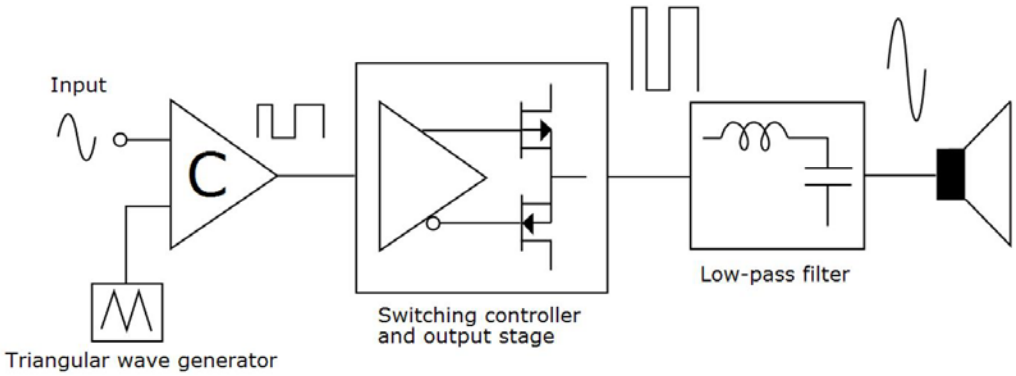
Figure 40: Power Loss for a Linear Power Supply/Linear Amplifier (Wasted Power = 60 W)



3.3.1.2 Class D or Switching Power Amplifiers

The basic block diagram for a Half Bridge Class D amplifier is illustrated in Figure 41 with the waveforms at each stage. This circuit uses feedback from the output of the half-bridge to help compensate for variations in the bus voltages. A Class D amplifier works in very much the same way as a PWM power supply. The input signal is a standard audio line-level signal. This audio line-level signal is sinusoidal with a frequency ranging from 20 Hz to 20 kHz typically. This signal is compared with a high frequency triangle or sawtooth waveform to create the PWM signal as seen in Figure 41 below[25]. This PWM signal is then used to drive the power stage, creating the amplified digital signal, and finally a low-pass filter is applied to the signal to filter out the PWM carrier frequency and retrieve the sinusoidal audio signal.

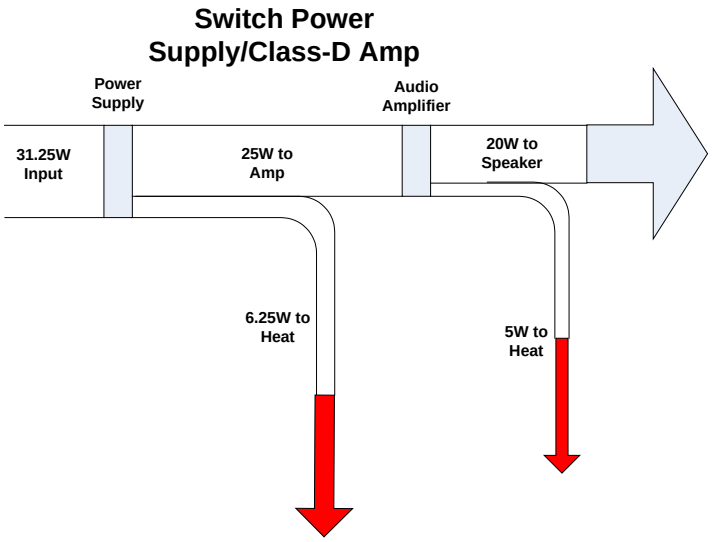
Figure 41: Schematics of a Class D Switched Amplifier



25 http://en.wikipedia.org/wiki/File:Pwm_amp.svg

In a similar example, a 20-W Class D audio amplifier running at full power produces 5 W of waste heat. Driven by a highly efficient switching power supply, the input power required is 31.25 W compared with 80 W for the linear power supply and linear amplifier, as illustrated below in Figure 42.

Figure 42: Power Loss for a Switching Power Supply/ Class D Audio Amplifier (Waste Power = 11.25 W)



The advent of Class D amplifier ICs has lowered the cost of such amplifiers. Although more complex than their analog counterparts, Class D amplifiers have an added benefit: They generate less heat. In the example cited above, a Class D amplifier powered by a switch-mode power supply can be built in a much smaller space and without costly heat control and dissipation devices due to the greater-than-5-times reduction in waste power. This allows consumer products to deliver similar specifications while operating cooler and with a smaller footprint. This has a twofold benefit: less residual heating of the consumer's home and a longer product lifetime due to the lower operating temperature.

Although these new technologies are becoming more available, it is not clear how much impact they are having on the consumer audio market. Some manufacturers of high-end audio equipment like PS Audio and Rotel began to offer Class D amplifiers years ago to enable the design of sleek, high performance equipment. Likewise, many car stereo and plasma TV manufacturers have taken advantage of the compact size of Class D amplifiers to enable high audio performance in a small space. TriPath and Bang & Olufsen introduced Class D amplification products for similar reasons. The implementation of Class D amplifiers is expected to rise in the coming years (see Sales Trends section below). This is likely due to the combination of lower cost of low-power Class D amplifiers (less than ~100 watts output) and the increase in use of smaller devices for home audio listening such as iPod and MP3 docking stations.

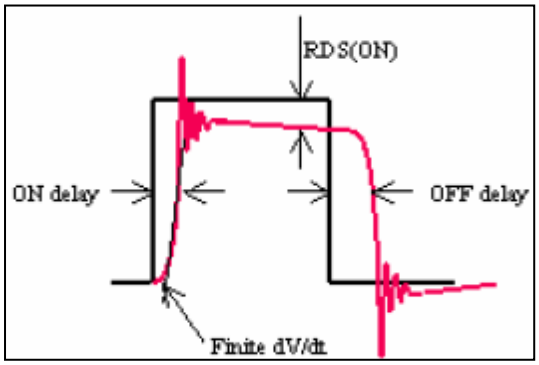
Higher-power consumer amplifiers (100 watts or more), such as those found in audio/video (AV) receivers, remain mostly powered by traditional Class AB amplifiers. Cost and sound quality issues (see Drawbacks of Class D Amplifiers) continue to be barriers to further Class D implementation. Among the manufacturers with a high AV receiver market share, only Pioneer currently offers Class D AV receivers. Although there are a handful of Class D receivers on the market, they have yet to become qualified as ENERGY STAR products, despite likely having high on-mode efficiencies, which should easily surpass the 55% qualification. Product testing is recommended to determine why this is the case.

Given that highly efficient power supply designs are now readily available and that Class D audio amplification, which previously required complex discrete designs, is now easily implemented based on integrated circuit designs, there is great potential to reduce waste power in home audio products. The reduction of waste power can be used to offset the cost increases incurred in the more complex design by reducing materials cost for circuit boards, heat sinks, and packaging. In addition, the reduction of waste power allows for more compact product designs.

3.3.2 Drawbacks of Class D Amplifiers

Even though the Class D amplifiers have several advantages over their linear counterparts, they have a few drawbacks. An ideal Class D amplifying stage has no distortion and no noise generation in the audible band, along with providing 100% efficiency. Practical Class D amplifiers, however, have imperfections that generate distortions and noise (Figure 43). The imperfections are caused by the distorted switching waveform being generated by the Class D stage.

Figure 43: Signal Distortion in Class D Amplifiers



For most consumers, it is likely that this distortion is not noticeable. For audiophiles, it remains the reason they are hesitant to transition to Class D technology. Recent reviews of Class D AV receivers indicate that manufacturers are finding ways to reduce this distortion and create products that meet very high sound quality standards.

3.3.3 Power Scaling

The ability of an amplified product to scale its power draw to its functionality may be a key element to reducing home audio energy consumption. In research conducted in 2009, Ecos Consulting finds through product testing that many devices draw a similar level of power in idle mode as they did in active mode (Figure 44).

Figure 44: Observed Behavior of Amplified Audio Systems

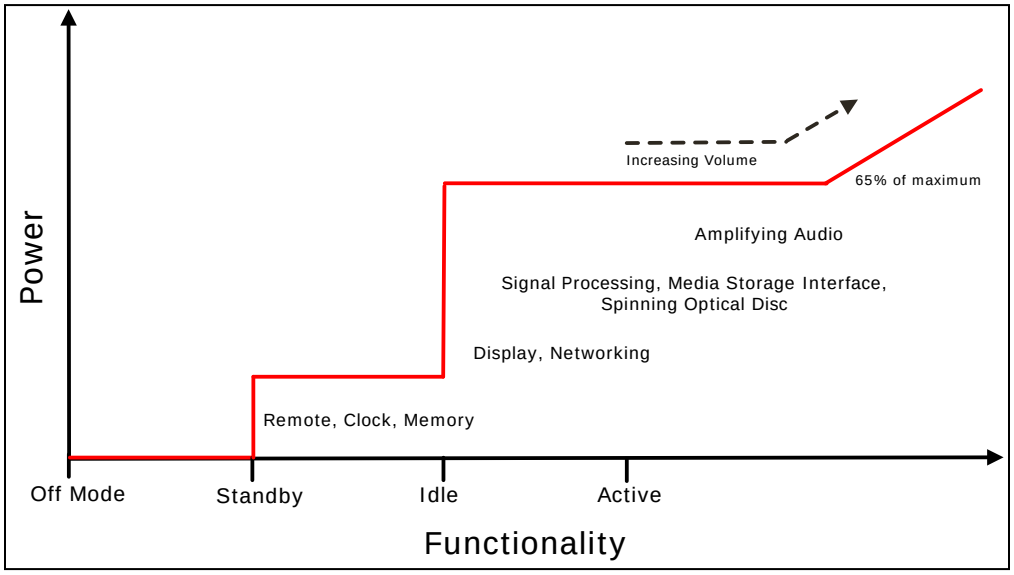
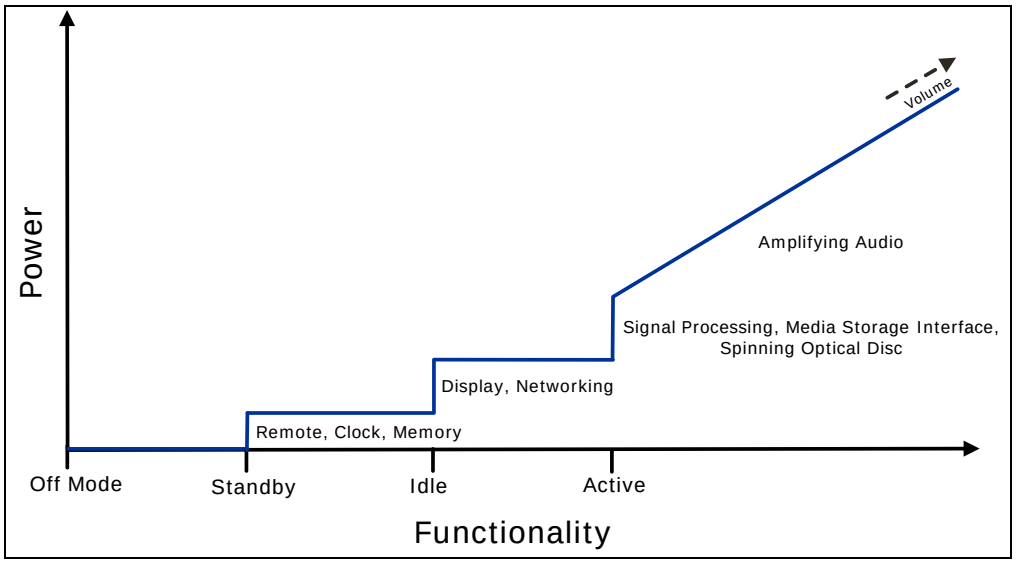


Figure 45: Expected Behavior of Amplified Audio Systems



The observed behaviors of audio systems point to a need to test audio devices at various volume levels and place limits on idle mode in addition to standby and active modes.

3.3.4 Sleep Mode Power

Another important factor of home audio energy consumption is sleep mode (also referred to as *standby mode*) power draw. This is the mode in which the device is turned off but is available to receive a signal from a remote to be turned on. There are two aspects to consider with sleep mode power: (1) how much power it draws in sleep mode and (2) the amount of time the device spends in sleep mode.

Because devices often spend anywhere from 22 to 24 hours in sleep mode, the difference between drawing 1 watt and 3 watts in this mode is significant. ENERGY STAR currently limits sleep mode power to a 1-watt baseline.

In order to maximize the time that a device spends in sleep mode, auto power down (APD) is employed by many products to meet ENERGY STAR specifications. This power-saving feature allows the device to enter sleep mode if no inputs are received for a given length of time.

These issues are discussed further in the ENERGY STAR analysis section.

3.4 Market Impact and Sales Trends

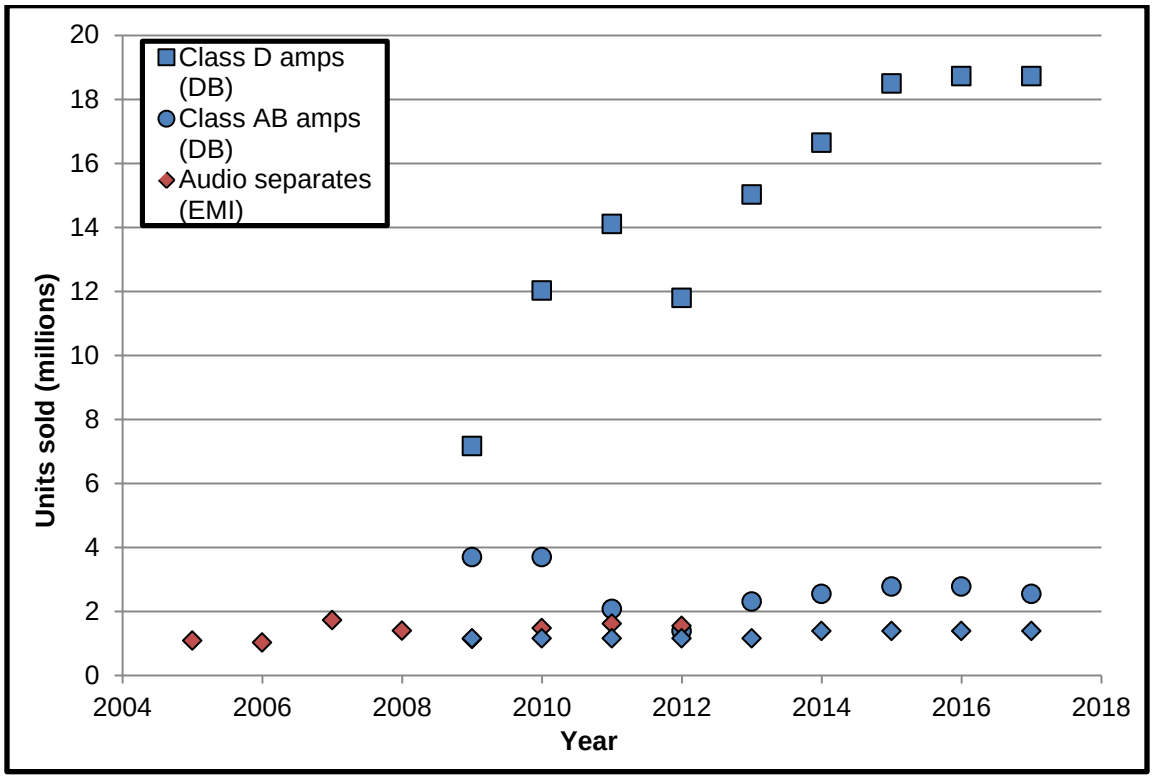
Although a generally decreasing trend of home audio product sales has occurred over the past few years, several newer home audio product categories have experienced increased sales that are forecast to continue over the next five years. These include Blu-ray players, iPod and MP3 player docks, Class D amplifiers, and speakers (Table 8). Sales of Class AB amplifiers and speakers have been level in recent years but are forecasted to increase over the next few years before leveling off. Sales of audio separate components and HTiB have been and are predicted to continue to be level. DVD player sales continue to decrease as they are replaced by Blu-ray players.

Table 8: General Sales Forecasts for Home Audio Categories

Increasing	Level	Decreasing
Blu-ray players	Audio separates	DVD players
Docks	HTiB	
Class D amplifiers	Class AB amplifiers	
Speakers	Compact audio	

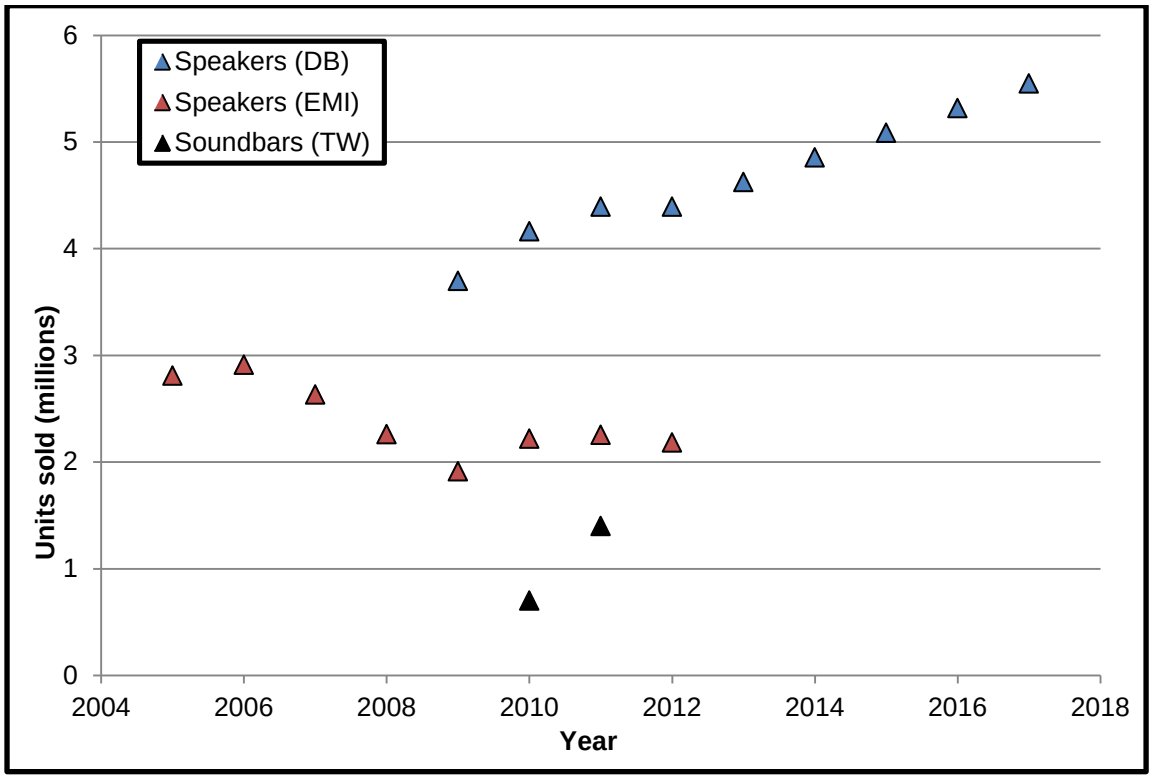
The sales trends of home audio products in the U.S. are discussed below. Figure 46 shows sales trends of Class AB and D amplifiers, audio separates and receivers from two market research reports (DB and EMI). Class AB amplifiers in home audio products showed decreasing sales through the U.S. recession and are forecasted to level off by 2016 (Figure 46). Sales of Class D amplifiers in home audio devices are predicted to continue to increase as consumers choose smaller and portable products. Sales of larger, non-portable products such as receivers and other audio separates have been and will continue to be level (Figuer 46).

Figure 46: Unit Shipments of Amplifiers, Speakers, and Audio Separates from 2005 to 2017



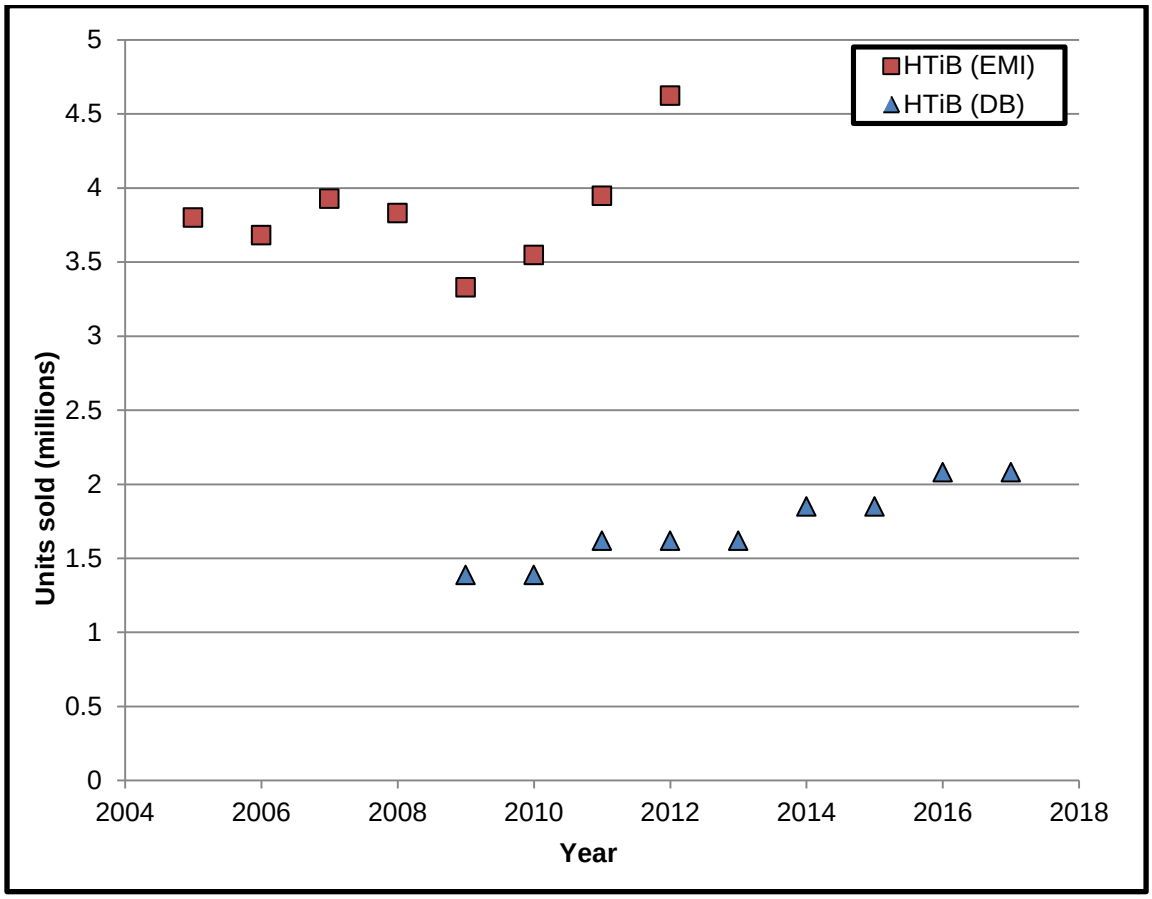
Sales of speakers and soundbars are forecasted to increase in the next four years (Figure 47) (DB, EMI, and TW). Soundbars have become a popular upgrade to the consumer TV experience; sales of soundbars doubled in 2011 over 2010.

Figure 47: Unit Shipments of Amplifiers, Speakers, and Audio Separates from 2005 to 2017



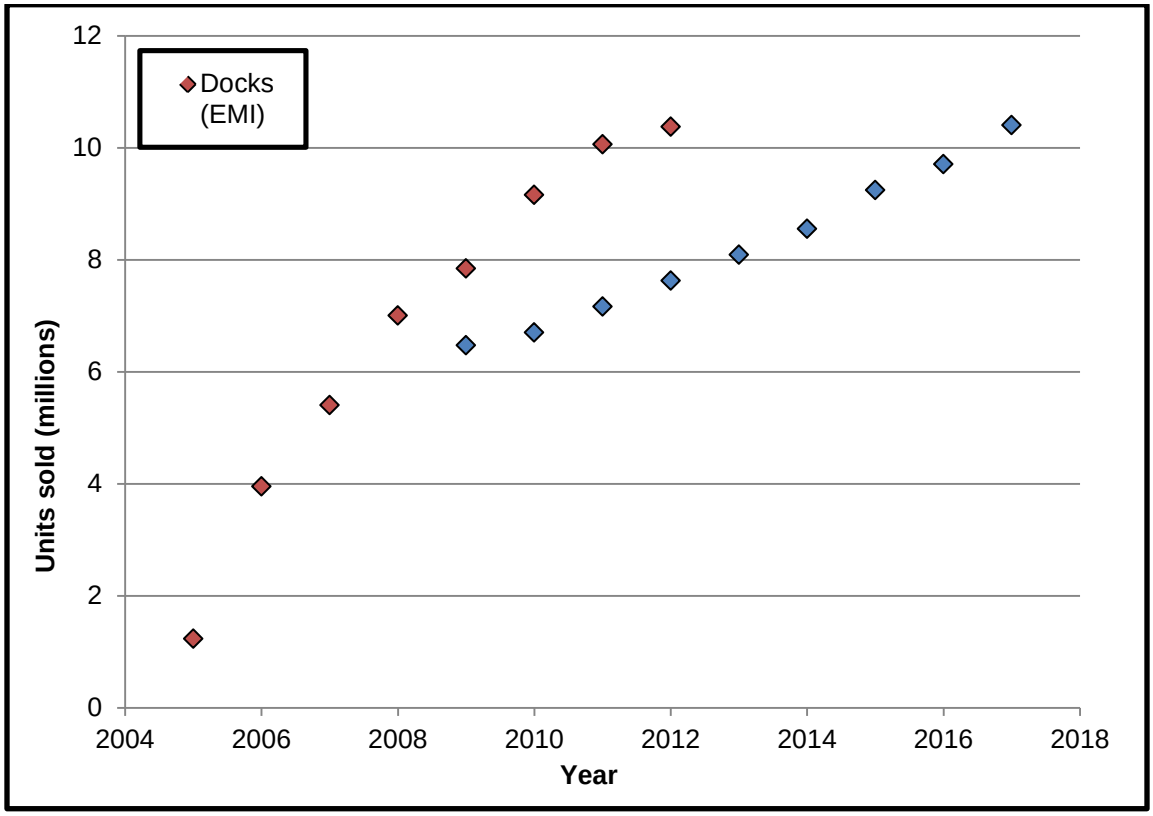
HTiB sales dropped during the U. S. recession and are expected to continue at a level or modestly increasing rate for the next four years (Figure 48) (DB and EMI). Sales totals are relatively modest compared to those of speakers and soundbars.

Figure 48: Unit Shipments of HTiB from 2005 to 2017



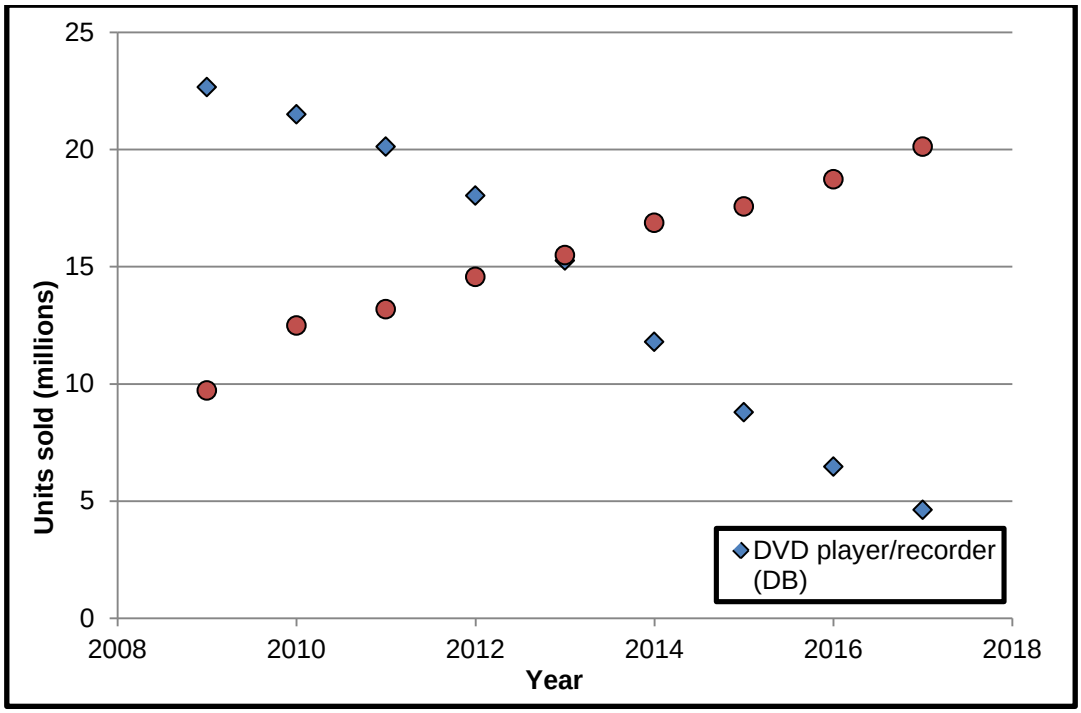
iPod and MP3 player docks continue to be a popular choice for home audio. Sales have risen steadily since their introduction in the early-2000s and will increase by an average of 2 million units per year over the next four years (Figure 49) (DB and EMI).

Figure 49: Unit Shipments of iPod/MP3Docks and Mini Systems from 2005 to 2017



Sales of DVD players will decrease as the market is replaced with Blu-ray players. Blu-ray player sales were expected to increase to levels similar to DVD players in 2013 (Figure 50) (DB).

Figure 50: Unit Shipments of DVD and Blu-ray Players from 2009 to 2017



Market penetration rates for ENERGY STAR home audio products are shown inFigure 51. Through 2012, DVD/Blu-ray players and soundbars had little trouble meeting the version 3.0 specification, while mini component and home theater systems qualified at lower rates. Included in the Home Theater category are AV receivers, of which there are none qualified as of the January 17, 2014 according to the qualified products list.

Figure 51: ENERGY STAR 2012 Unit Shipment Data Including Estimated Market Penetration of ENERGY STAR Products

Product Category[3]	2012 Units Shipped (thousands unless otherwise stated)	2012 Estimated Market Penetration	Specification Revisions Affecting Future Market Penetration (Version/Tier Effective Date)
Audio/Video Products – Consumer	12,677	50%	Version 3.0 - May 1, 2013
Audio Separates	*4*	*0%*	
Blu-ray Players	*6,742*	*61%*	
DVD Players	*5,585*	*61%*	
Home Theater	*81*	*4%*	
Mini-systems	*233*	*13%*	
Soundbars	*937*	*53%*	
Audio/Video Products – Professional/Commercial – Amplifiers	33	N/A	

3.5 Testing Approach

3.5.1 Overview of ENERGY STAR Test Method

ENERGY STAR has had a home audio specification since the end of 2002. In the first version of their specification, ENERGY STAR established a maximum allowable standby power or 2 W for consumer audio products except DVD players and recorders, which were allowed a maximum standby power of 3 W. The current version 3.0 broadens the requirements to auto power down (APD) times, sleep and idle modes, and amplifier efficiency.

The ENERGY STAR version 3.0 test procedure requires that every product's time to APD is tested. To qualify for ENERGY STAR, a product must APD from active to sleep mode in 2 hours or less. If a product's APD time is 30 minutes or less, it need not meet idle state power requirements. If APD is greater than 30 minutes but 2 hours or less, the product must meet idle state power requirements.

Sleep mode power and idle mode power tests are conducted by placing the device into the mode of interest and measuring average power for 2 minutes. The maximum allowable sleep mode power is the sum of a base allowance and an allowance for each in-use networking or

control protocol that has wake capability. The base allowance in version 3.0 is 1 W. The allowance for each networking/control protocol with wake capability is 1 W in version 3.0. The combination of APD and sleep requirements limit the time that an ENERGY STAR product is in a high-power active or idle mode without doing useful work, and they ensure low power draw when the device is functionally off.

Products capable of playback and/or recording of audio or video on optical media must pass the optical media player test. For the video playback and recording tests, average power is measured over 2 minutes of playing or recording the IEC-62087 test clip. For the audio playback and recording tests, average power is measured over 2 minutes of playing or recording a 1-kHz sine wave signal with output volume set to minimum.

Amplifying products with an input power of more than 20 W must also pass minimum efficiency requirements. Note that no efficiency requirement is placed on low-power amplifiers. The ENERGY STAR amplifier test procedure is conducted in the following steps. Each channel is monitored one at a time, and the input signal is a 1-kHz sine wave. Setting the volume of the device at maximum, the amplitude of the input signal is adjusted such that the total harmonic distortion (THD) of any channel is 1% or more. The maximum undistorted power (MUP), the maximum output power of any channel on the device, is determined, and the input power is measured. Then the input signal amplitude is reduced until the output power on this channel is reduced to 1/8MUP. The input power (P_{in}) and each channel's output power over 2 minutes are measured. The sum of the channel output powers is P_{out}. The amplifier efficiency is then calculated:

$$\eta = P_{out}/(P_{in} - P_{disc})$$

Where P_{disc} is power measured during audio playback for products that must be measured using an optical disc player rather than AV inputs for the input signal.

Version 3.0 minimum amplifier efficiencies have not changed since the previous version. For P_{in} of 20 W or greater and less than 100 W, $\eta_{min} = 0.44$; for P_{in} of 100 W or greater, $\eta_{min} = 0.55$.

After a reviewing the ENERGY STAR test method, it was determined that the ENERGY STAR test method could form as the groundwork for a test procedure modified for the goals of this investigation (seeModified ENERGY STAR Test Method). The following sections review the justification behind some of the modifications made as well as a description of some of the findings.

3.5.2 Modifications to Energy Star Test Method

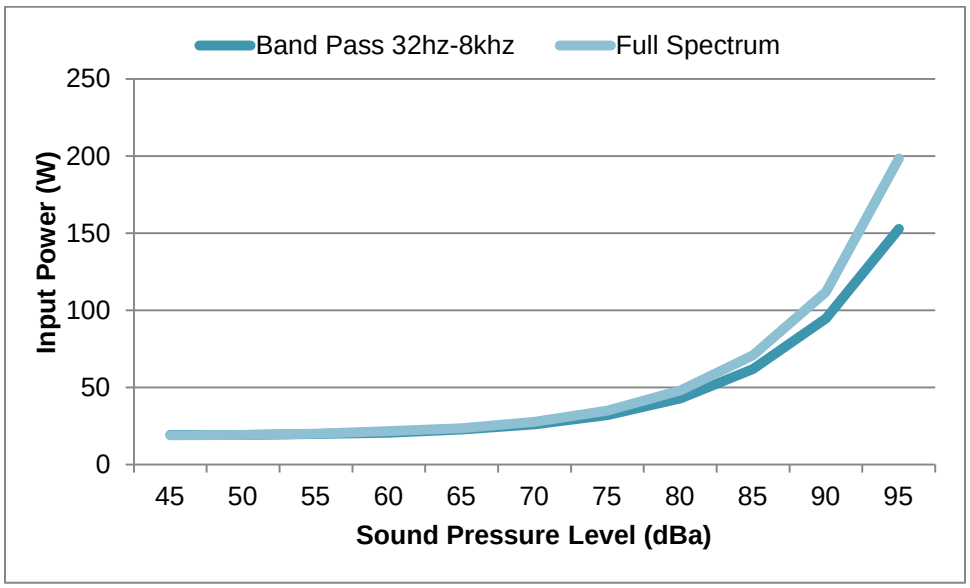
The ENERGY STAR test method provides a sturdy framework upon which the modified test procedure was built. However, revisions were made to three major aspects of the test procedure in order to provide the depth needed to make suggestions to new efficiency tiers. For the complete test method, please refer to Appendix C.

Audio Source: The ENERGY STAR test procedure requires an audio source with a 1-kHz signal. The benefit to using a 1-kHz signal is that it allows for repeatability, a necessary trait for an efficiency specification. However, 1 kHz does not span the entire spectrum of the unit under

test (UUT), and it is known that audio with lower frequencies require more power to amplify. This was a topic of much discussion in the comments to the ENERGY STAR test procedure during the revision process. In the modified test procedure, pink noise was used because it has equal energy in all octaves that the human ear perceives equally[26]. This is in contrast to white noise, which has equal energy at each frequency. This creates a fall off of 3 dB per octave where power density is lowest at the higher frequency. The human ear perceives frequencies in the range between 1 and 4 kHz loudest. Apart from its impact on humans, pink noise was also selected because it spans a much larger frequency range than 1 kHz and can be used in all audio amplification devices, including subwoofers. The type of audio played through a home audio device will change the amount of power required to amplify it because of the spectrum varieties. However, pink noise should provide an acceptable standard for this investigation.

During the development of the modified test procedure, a test was performed to determine the impact that a narrow frequency has on energy consumption. In this test, power measurements were taken at a number of different sound pressure levels. One test was performed using the full pink noise frequency spectrum and another using the same signal passed through a band-pass filter. As seen in Figure 52, the power draw measurements were lower when using the band pass filter. This result is amplified at higher listening volumes.

Figure 52: Input Power at Different Levels of Sound Pressure Using Full Spectrum (Pink Noise) Signal Versus Narrow Spectrum (Using Band Pass Filter) Signal



Resistors: The ENERGY STAR test procedure also requires that resistors be used when speaker terminals are available, such as in receivers. Power measurements are to be taken between the speaker and the resistor. In devices where speakers are built in, the measurements are to be

26 http://hyperphysics.phy-astr.gsu.edu/hbase/audio/equal.html

taken between the installed speaker and the device. This was modified for a few reasons. The goal of this investigation was to survey the existing efficiency of home audio products. The use of a resistor or speaker would allow for an efficiency measurement but may not take into account the acoustics of the device. The only way to truly compare one device to another is to measure the audible output. This way the speakers and the frequency response are included in the measurement. However, this type of measurement is not an efficiency measurement but an efficacy measurement. Efficacy is a measure of the effect a device has on its environment. However, an efficacy measurement requires that the space in which the test is conducted meet some sort of standard condition. During testing, a curtained room was used to help minimize reflection. This room allowed consistency from test to test. However, it is acknowledged that these conditions may be difficult to reproduce. If this type of test were to be used as a standard test procedure, further investigation would be required in order to standardize environmental controls for the testing room.

Another consideration when adopting an efficacy measurement is the unit of measurement. A sound pressure meter can be used to measure the total sound pressure level (SPL), where the threshold of human hearing is 0 dB. However, further complicating the measurement is that the human ear perceives sound pressure differently at different frequencies. This can be compensated for because sound-pressure meters have weighting that can be applied to the measurement. A-weighted sound-pressure measurements are weighed according to how the human ear perceives sound and are represented by the unit dBA. A non-weighted measurement is represented with the unit dBZ. The human ear more easily registers mid-range frequencies compared to very high frequencies as well as low frequencies. In an A-weighted SPL measurement, the high and low frequencies are weighted lower, or multiplied by a scaling factor of less than one, similarly to how the average human ear perceives it. dBA is the standard for measuring environmental noise and assessing for potential heating damage and noise-relayed health effects. There is no conversion between dBA and dBZ because both measurements are displayed as a single value, and all information is lost regarding the amplitude at each particular frequency. In this investigation, both dBA and dBZ measurements are taken.

Test Points: The ENERGY STAR test procedure requires one test point to be taken for on-mode testing. This test point is taken at one-eighth of maximum undistorted power (MUP). The MUP is defined as the output power of an amplifier when the total harmonic distortion of any channel of the home audio device reaches 1.0% or greater for a given output.

Figure 53: Home Audio Testing Example Spreadsheet

UUT Name						
Test Points	Measured Sound Pressure		Electrical Measurements			
SPL (dBA)	*SPL (dBA)*	*SPL (dBZ)*	*Voltage (V)*	*Current (A)*	*Power Factor*	*Power (W)*
45						
50						
55						
60						
65						
70						
75						
80						
85						
90						
95						
100						

In this investigation, more data points were needed because the power required to amplify does not increase linearly with output. The test points are a series of sound-pressure levels measured using an A-weighted SPL measurement. This allows for the analysis of how the unit performs at different sound levels. The voltage, current, power factor, and sound-pressure levels (dBA and dBZ) are measured at 5 dB increments starting at 45 and increasing until 100 dB or the unit reaches maximum volume, whichever comes first.

3.5.3 Equipment

A number of assumptions were made while conducting the modified test procedure. First, since it is difficult to fully equalize the power output of different output sources, the power delivered by the source was assumed to be negligible. It is unlikely that this assumption would have any significant impacts on the power measurements because the input power is not significant. As mentioned before, the room was not a perfectly sealed anechoic chamber, so reflections and ambient noise did have an impact on the sound-pressure level within the room. However, all devices were compared in the same room and were set up in the same location so that all environmental impacts would be similar. Ambient noise was typically around 40 dB and was mostly due to the noise created by the ac power supply fans. The power supply was located outside of the curtained area. It should be noted that 40 dB is commonly related to a quiet room. A sound-pressure level of 0 dB is very difficult to obtain in a typical setting due to traffic and other machines/devices in the area. As a reference, an average home is around 50 dB.

Similarly to room design, the speakers (electrical load) have an impact on the power consumption of an audio device, so it is expected that testing with another speaker would have shown different results on the receiver testing (the only units with interchangeable speakers). However, in this testing, the goal was to examine how efficient home audio devices performed in comparison to each other, so this assumption should not have a significant impact on the findings.

Seven speakers were used in the home audio testing, and all were positioned on or around the test stand. Each speaker position was filled by a size of speaker that may be found in a typical

home audio setup, although it is understood that setup will vary from consumer to consumer. The L and R channels used a Polk Audio Monitor 60s, the center channel was a Polk Audio CS20, and the remaining speakers were all Polk Audio Monitor 30s. For consistency, the same speakers and connectors were used in all testing where the home audio device required separate speakers. No subwoofers were used in testing unless one was included with the home audio device. Sound-pressure level was measured by a SoundPRO-DL-2-1/3-10 Class/Type 2 sound-level meter. It was positioned 2 meters from every speaker and stayed in the same location and maintained the same height throughout testing.

Table 9: Specifications for the Speakers Used in the Receiver Portion of Active Mode Testing

Manufacturer	Model	Total Frequency Response	Nominal Impedance	Efficiency
Polk Audio	Monitor 30	55 Hz–25 kHz	8 ohms	89 dB
	Monitor 60	38 Hz–25 kHz	8 ohms	90 dB
	CS20	48 – 25 kHz	8 ohms	91 dB

Power measurements were taken using a Yokogawa WT230. If the UUT has more than one plug connection, they were all plugged into a common power strip and were measured together. An external ac power supply is used to ensure that all of the devices are measured using the same ac input.

Figure 54: The Sound Pressure Meter Used in the Testing

The input is generated using a Samsung DB-D6500 that is playing pink noise from a compact disc. The Samsung DB-D6500 was selected because it has outputs to provide audio signals to all of the devices under testing.

3.5.4 Products Procured for Testing with Modified Test Method

A total of 35 unique home audio products were procured for testing, representing seven different categories of home audio devices and around 20 manufacturers. Manufacturers represented include Bose, Pioneer, Panasonic, SONOS, and others. Approximately one-third of the products tested qualified for the ENERGY STAR Version 3.0 specification; a majority of these fell in the Blu-ray/DVD player category.

Table 10: Characteristics of Products Selected for Testing

Home Audio Category	Unique Models Procured for Testing	Models Qualified for ENERGY STAR Version 3.0
Receivers	5	0
Subwoofers	3	0
Docks and Shelf Systems	9	4
Blu-ray Players	4	4
Home Theater in a Box	4	1
Computer Speakers	4	0
Soundbars	6	3
Total	35	12

3.6 Test Results

3.6.1 Results for Passive Mode (Idle and Sleep) Power Tests

Figure 55 and Figure 56 summarize test results for sleep and idle mode power draw ranges for devices tested in six categories: soundbars, HTiB, Blu-ray players, docks and shelf systems, subwoofers, and receivers. Although computer speakers were tested, they were not included in the analysis due to limited data on their duty cycle and stock in California.

Power draw during sleep mode across all tested devices in four of the six categories showed a significant range: from less than 1 W to 8 W in subwoofers, soundbars, and receivers (Figure 55).

Figure 55: Range in Sleep Mode Power Draw Across All Devices Tested Within Each Category

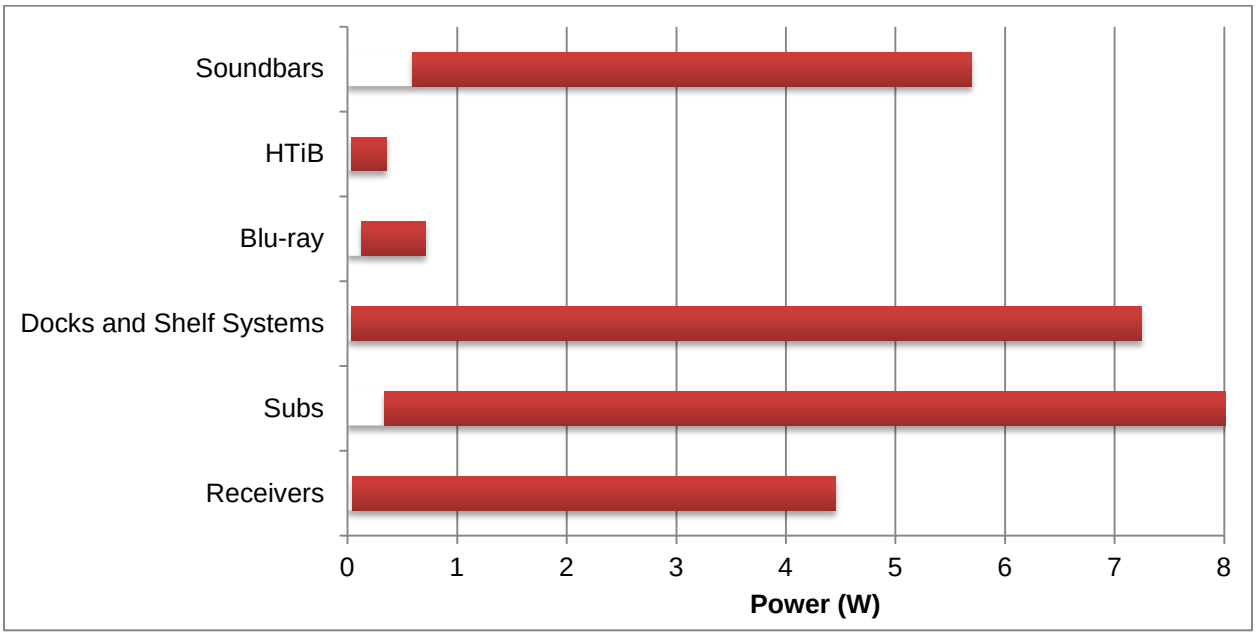
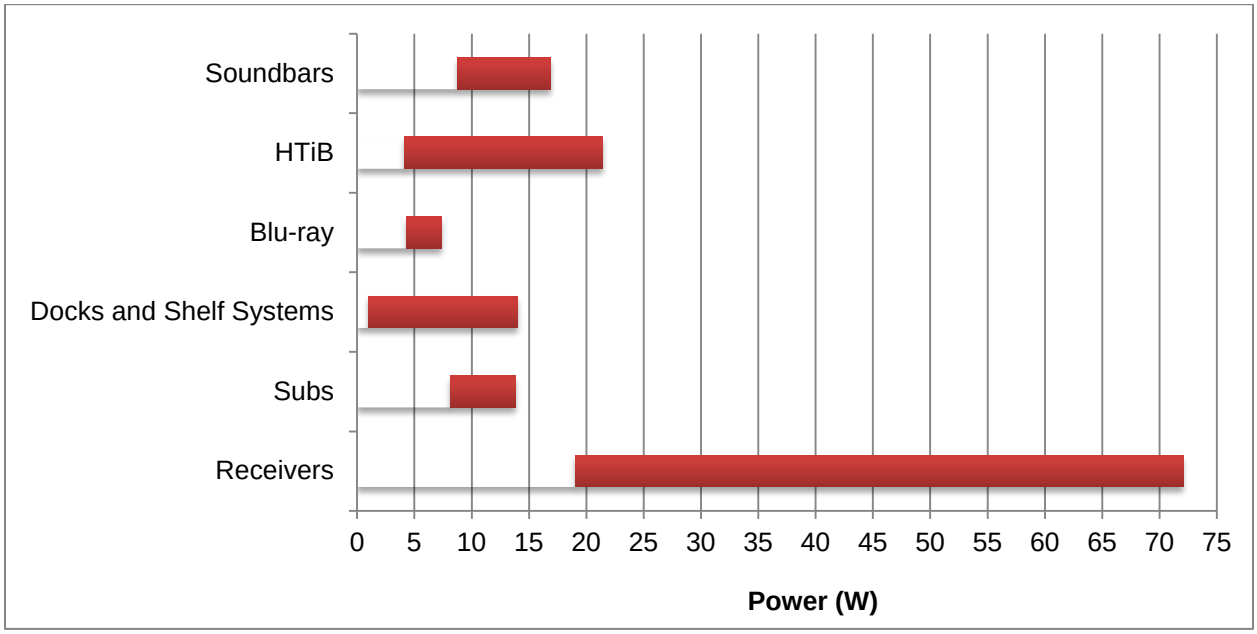
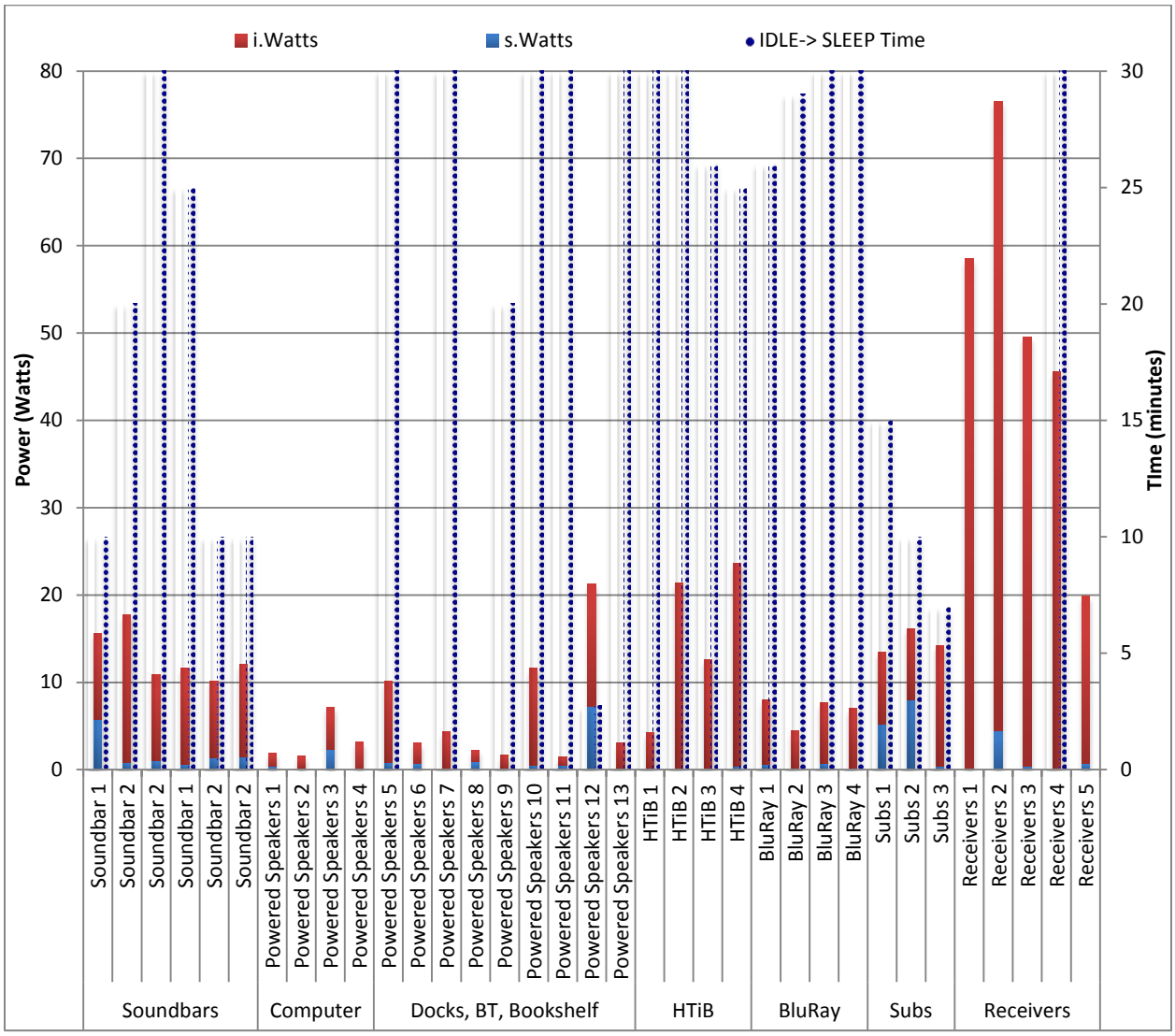


Figure 56: Range in Idle Mode Power Draw Across All Devices Tested Within Each Category



Idle mode power draw for most categories (with the exception of receivers) ranged from less than 1 W to 20 W. By comparison, idle mode power draw for receivers ranged from 20 W to over 70 W.

Figure 57: Power Draw in Idle and Sleep Modes, Time to Sleep (Or Standby) From Idle Mode Across All Devices



The figure above charts the total passive mode power draw (idle and sleep) for all devices (excluding computer speakers) and also shows the time needed for the device to auto power down (if the function was available). Note that none of the receivers (with the exception of Receiver 4) or computer speakers had auto power down functionality and therefore would have remained in idle mode indefinitely throughout the test had it not been manually switched to sleep mode. Furthermore, Receiver 4 did not fully power down to sleep mode after 30 minutes. Instead, it powered down to 50 W after 30 minutes, which was lower than its typical idle mode power consumption of 79 W but still much higher than its power draw in sleep mode (less than 1 W). This indicates that the device is utilizing some form of power scaling that enables it to reduce power draw in idle mode after a certain time, while still maintaining some idle mode functionality.

Measurements of sleep and idle mode power showed three opportunities for improvement:

- Reduction of sleep mode power consumption: A significant variation in sleep mode power draw was observed for almost all categories. However, there was at least one model in each device category that was capable of drawing less than 1 W in sleep mode.
- Reduction of idle mode power consumption: Some devices, such as receivers, used over 70 W while in idle (Figure 56).
- Enabling auto power down capability across devices: Ten out of 35 tested devices did not have auto power down and therefore remained in idle mode throughout the test.
- None of the devices tested had a power factor greater than 0.72; a majority of devices had power factors that were less than or equal to 0.5.

3.6.2 Results for Active Mode Power Tests

Figure 58 summarizes test results for active mode power consumption in six product categories. For the purposes of analysis, the average power draw was used across the range of dBa test points measured during the test. Blu-ray players and certain smaller docks/shelf systems were the least power consumptive devices tested, drawing on average less than 10 W in active mode. Larger docks/shelf systems, soundbars, and receivers drew, on average, between 10 W and 40 W while in active mode. Receivers were the most power consumptive devices tested in active mode. On average, across five receivers, these devices drew between 80 W and over 160 W while in active mode.

Figure 58: Range of Average Power Draw In Active Mode, Across All Devices Within Each Category

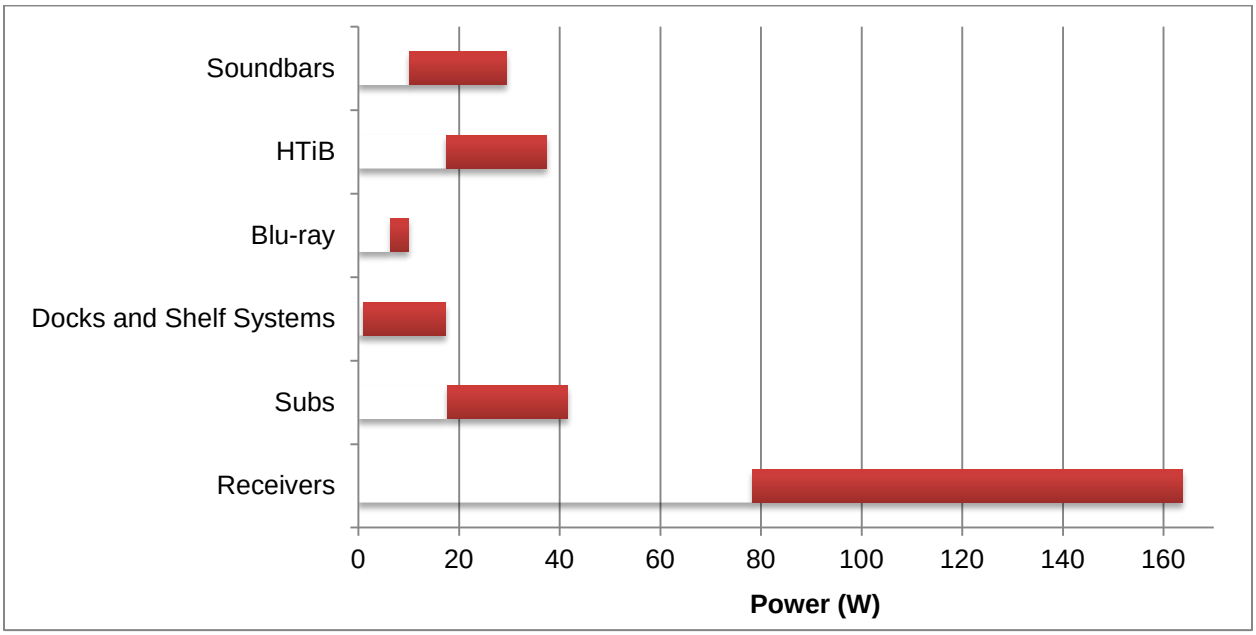


Figure 59 and Figure 60 plot active mode power consumption of receivers and soundbars at different sound-pressure test points conducted over the course of the active mode test. Note that active mode power consumption for all receivers, regardless of whether they were Class D or Class AB, remained fairly similar at test points less than 85 dBa. Likewise, active mode power consumption for all soundbars tested was similar at test points less than 75 dBa. For the purposes of the analysis, for all devices tested in active mode, the active mode power draw was assumed to be an average of active mode power draw conducted at these different sound-pressure test points.

Figure 59: Active Mode Power Draw at Different Sound Pressure Test Points for Recievers

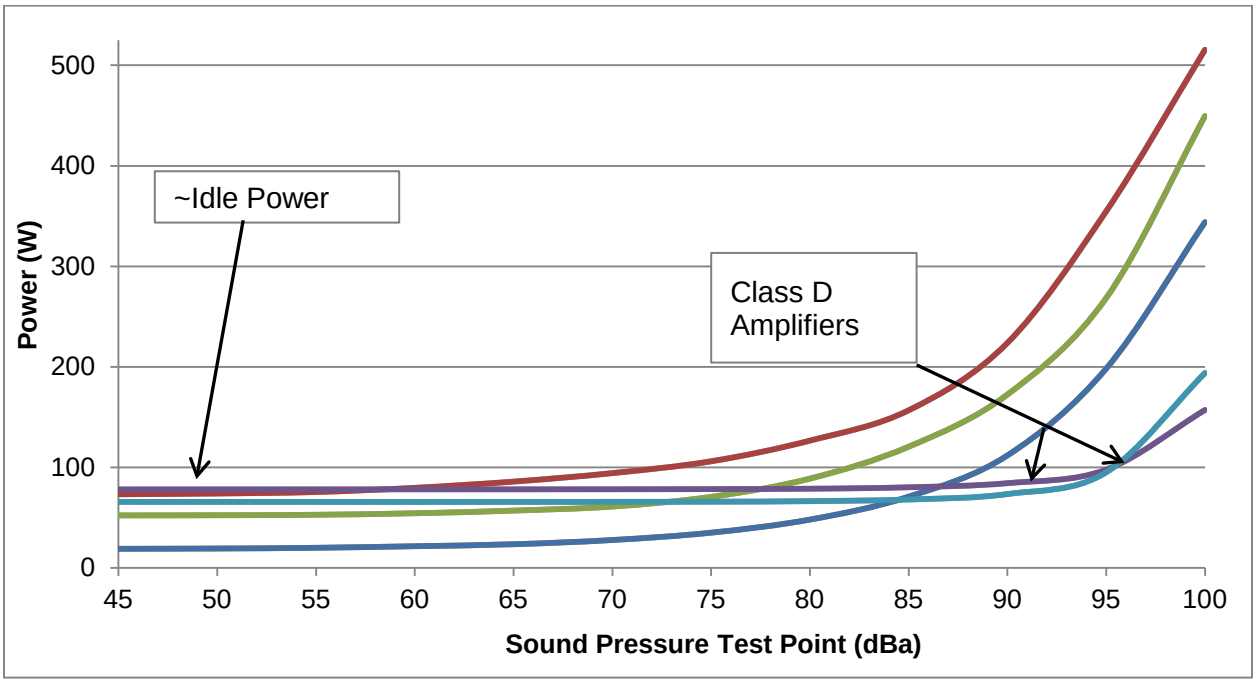
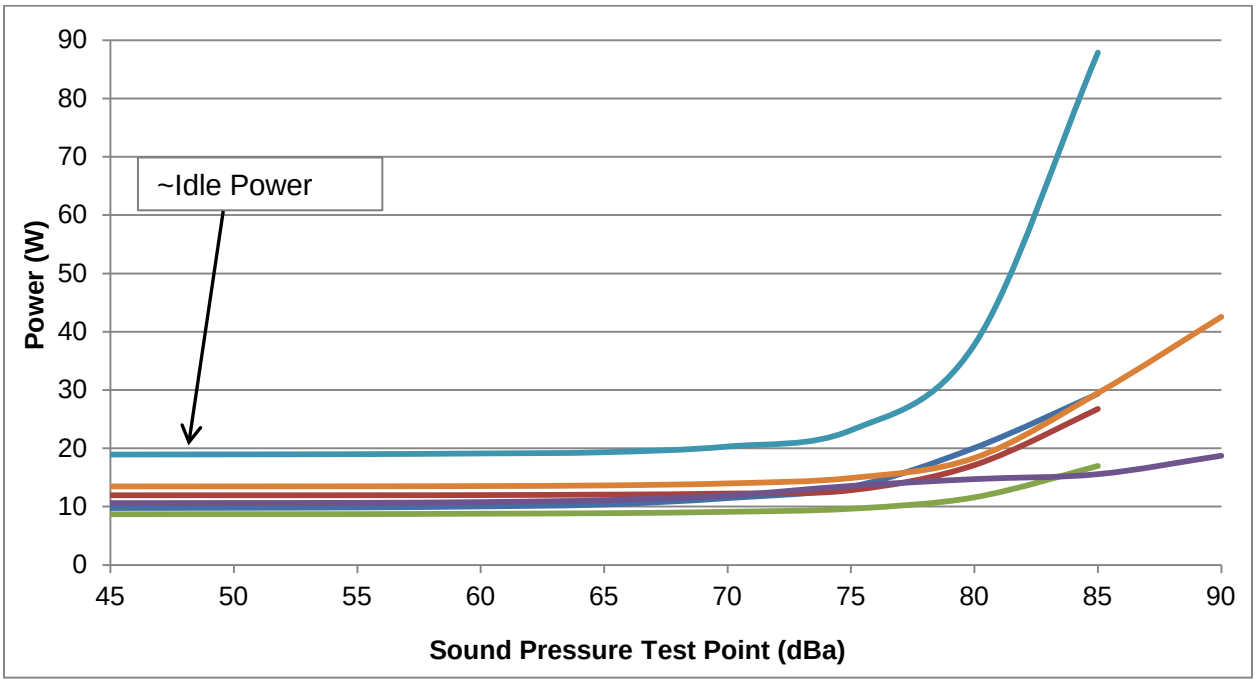


Figure 60: Active Mode Power Draw at Different Sound Pressure Test Points for Soundbars



3.7 Energy Consumption and Savins Potential Estimates

3.7.1 Current California Standards for Home Audio Equipment

California has standby power standards in place for two products, compact audio equipment and DVD players and recorders, which were adopted in 2004 and became effective in 2006 (DVD players and recorders) and 2007 (compact audio equipment). Note that Blu-ray players are included under their definition of DVD players, and compact audio may include iPod or MP3 player docks. Maximum allowed standby power for compact audio equipment is 2 W for products without an illuminated clock display and 4 W for products with an illuminated display. DVD and Blu-ray players and recorders are allowed a maximum of 3 W in standby mode. These regulations are generally less stringent than current ENERGY STAR specifications and do not cover products that consume large amounts of energy such as receivers, speakers, soundbars, and HTiB.

3.7.2 Potential Savings Estimates Based on Test Results

Below, energy consumption by individual device was estimated as well as potential energy savings from California standards. To do so, power by mode estimates from EPRI's testing of the 35 home audio devices for power by mode was used for DVD players, because EPRI did not test these devices. Urban et al. compiled field measurements and other studies to estimate power draw and energy use for a wide array of consumer electronics, including home audio devices. Duty cycle and stock estimates were used from when possible and use other sources to fill gaps.

Urban et al., ENERGY STAR, and other sources all use different names for power modes. In this report, ENERGY STAR's mode definitions were used:

Active mode: The device is performing its intended function.

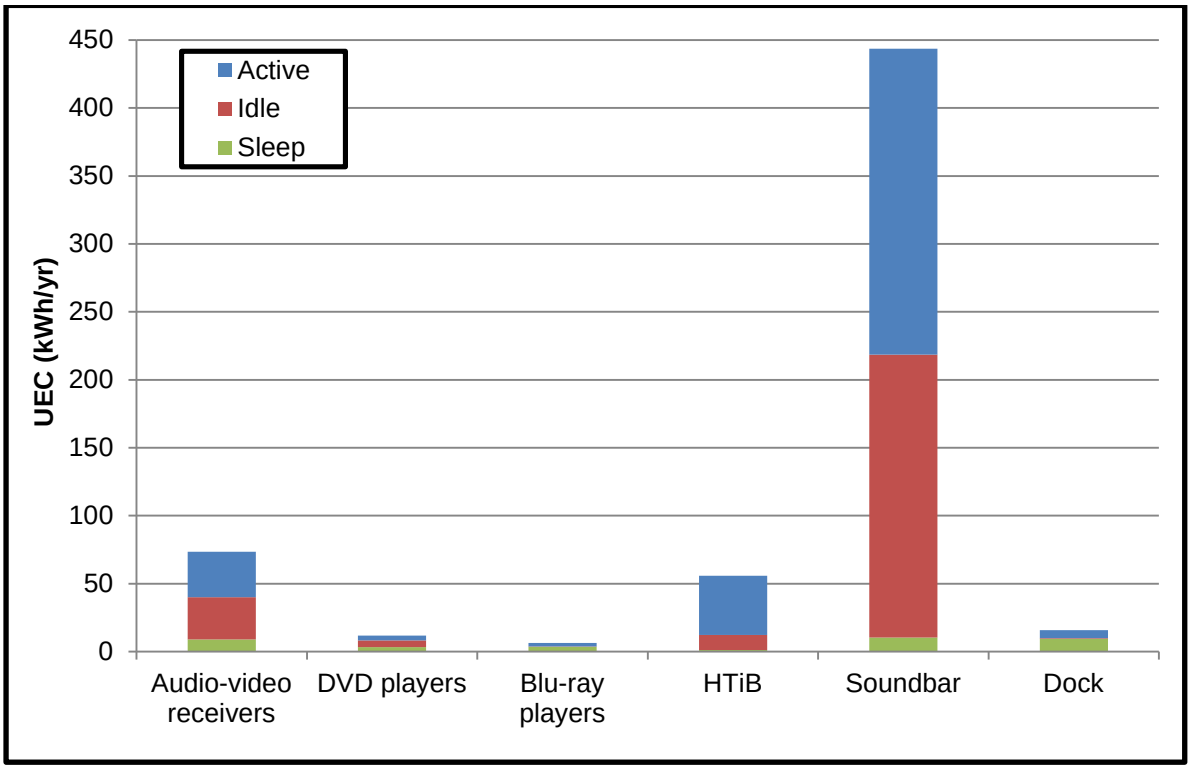
Idle mode: The device is ready to perform its intended function but not doing useful work.

Sleep mode: The device is functionally off. Urban et al. (2011)'s modes are active, sleep, and off. With the exceptions noted for receivers below, their sleep and off modes are assumed to be equivalent to ENERGY STAR's idle and sleep modes, respectively.

3.7.2.1 Unit Energy Consumption

Estimates for unit energy consumption (UEC) of home audio devices are shown in Figure 61 (see Table 11 for data sources and notes). UEC estimates for DVD players are from Urban et al. (2011); estimates for audio video receivers, Blu-ray players, HTiB, soundbars, and docks are averaged from EPRI's measurements conducted using the modified ENERGY STAR test method. Duty cycle assumptions for receivers were derived from Foster Porter et al., in which field tests demonstrate that receivers are in "on" mode 25% and in "standby/off" mode 75% of the time. Foster Porter et al. were unable to determine different levels of energy use for receivers while in "on" mode. For the purposes of the analysis, it is assumed that of the 25% of time that receivers are in use, they are only actively amplifying power one-third of the time. If this is the case, it is fair to assume that receivers are drawing "idle" mode power during the two-thirds of the time that they are "on" but not amplifying sound.

Figure 61: Unit Energy Consumption by Mode for Various Home Audio Devices



Energy consumption by mode varies by device. Audio-video receivers, HTiB, and soundbars use a large percentage of their energy in active modes. Consequently, large energy savings potential exists where both the time spent in active or idle mode and the power drawn in active or idle mode are reduced. As discussed above, Class D amplifiers draw significantly less power in active mode than linear amplifiers, and the time spent in idle mode can be reduced with APD. The application of Class D receivers that were tested is discussed further in Appendix D

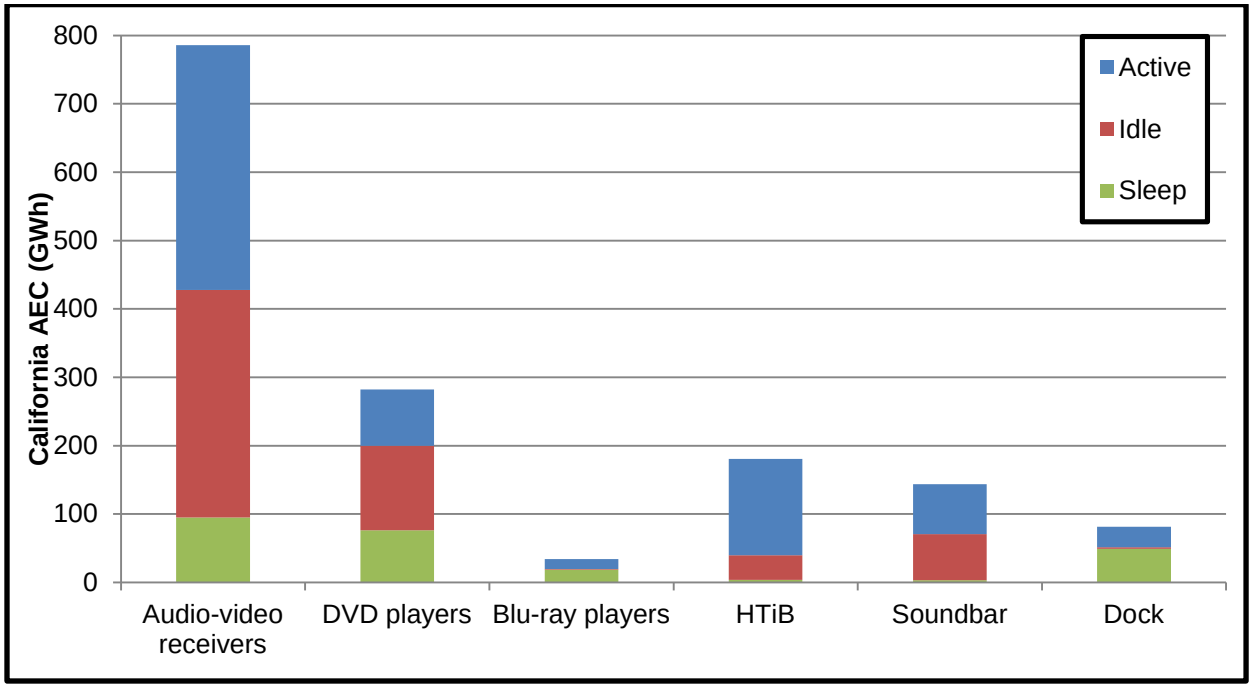
Table 11: Power, Duty Cycle and California Stock of Home Audio Equipment

	Power (W)				Duty Cycle (hr/yr)				California Stock	
	Sleep	**Idle**	**Active**	**Source**	**Sleep**	**Idle**	**Active**	**Source**	**Units (million)**	**Source**
Audio-video receivers	1.1	48.8	106.8	EPRI (2013)	7810	637	313	Modified from Foster Porter et al. (2006)	11	Urban et al. (2011)
Class AB amplifier	*0.2*	*47.3*	*144.0*	*EPRI (2013), two models tested*	*7810*	*637*	*313*	*Modified from Foster Porter et al. (2006)*	*2*	*Estimated from ENERGY STAR data*
Class D amplifier	*2.3*	*65.3*	*83.5*	*EPRI (2013), two models tested*	*7810*	*637*	*313*	*Modified from Foster Porter et al. (2006)*	*14*	*Estimated from ENERGY STAR data*
DVD players	0.4	6.4	12.0	Urban et al. (2011)	7672	804	284	Urban et al. (2011)	24	Urban et al. (2011)
Blu-ray players	0.4	6.4	8.7	EPRI (2013)	8430	30	300	Urban et al. (2011)	5	Estimated from sales data
HTiB	0.2	15.3	27.6	EPRI (2013)	6450	730	1580	Urban et al. (2011), low certainty	3	Urban et al. (2011)
Soundbars	3.0	60.0	123.4	EPRI (2013)	3467	3468	1825	ENERGY STAR duty cycle for TVs. Assume half of soundbars are left in idle when not in use, half turned off by remote (sleep).	0.3	Estimated from sales data
Docks	1.2	5.3	7.2	EPRI (2013)	7860	100	800	Urban et al. (2011), low certainty	5	Urban et al. (2011), similar to estimates from sales data

3.7.2.2 Annual Energy Consumption in California

Using stock data estimated from several sources (Table 11) and scaled to California[27], annual energy consumption (AEC) of home audio devices in California are estimated (Figure 62). Receivers and DVD players use the most energy because of high stock. AEC of Blu-ray players, soundbars, and docks is expected to rise as market penetration of these devices continues to rise. See Table 11 for data sources and notes.

Figure 62: Total Annual Energy Consumption by ode in California of Home Audio Equipment



3.7.2.3 Potential Savings Scenarios and Estimates

Based on the analysis above, three main opportunities were identified to reduce the energy used by home audio products:

- Reduce sleep mode power to 1 W.
- Reduce time in idle mode (increase time in sleep mode) by requiring APD after 30 minutes.

27 Stock was scaled using a ratio of U.S. to California households, although more complex scaling methods are possible given that household income has been shown to correlate to the number of appliances and electronics in homes (http://www.eia.gov/consumption/residential/data/2009/#undefined). Given the diverse sources and assumptions included in the UEC calculations, it is unlikely that a more complex scaling method would result in more accurate energy estimates.

- Reduce idle mode power by 30% for devices that amplify sound (applies to powered speakers, receivers, and HTiB categories only).

For energy savings estimates in California, two tiers were considered. Tier 1 involves the application of opportunities 1 and 2 above, reducing sleep mode power and reducing time in idle mode. Tier 2 involves the application of all three opportunities listed above, reducing sleep mode power and reducing both idle mode power and time in idle mode. UEC and California AEC savings potential were estimated assuming product lifetimes shown inTable 12. Energy-saving estimates for Tier 1 and Tier 2 after complete stock turnover are shown in Table 14 andTable 15 respectively. Potential savings are not stock-weighted. Annual savings after stock turnover take into account current market penetration of devices in each category that would meet the proposed Tier 1 and Tier 2 standards (Table 13). Market penetration of devices that currently meet Tier 1 is assumed to be roughly the same as market penetration for ENERGY STAR Version 3.0 qualifying devices. This study has not found any existing data for receivers, HTiB, and powered speakers that would currently meet the proposed Tier 2 standard. However, based on test results presented earlier, it is assumed that there are currently no powered speakers that are capable of reducing their idle mode power by 30% from the average idle mode power measured in the lab. Note that there are some negative values in the sleep mode columns in Tables 4 and 5. This is due to an assumed increased time spent in sleep mode and less time spent in active mode.

Table 12: Assumed Product Lifetimes Used for Energy Savings Estimates

Device	Product Lifetime (Years)
Receivers	20
DVD players	7
Blu-ray players	7
HTiB	9
Soundbars	7
Docks	7

Table 13: Assumed Market Penetration of Existing Devices that can Meet the Proposed Tier 1 and Tier 2 Standards

	Estimated Market Penetration Rates	
Device	Tier 1	Tier 2
Receivers	0%	0%
DVD players	61%	61%
Blu-ray players	61%	N/A
HTiB	75%	25%
Powered speakers	53%	0%
Dock	13%	N/A

Table 33 summarizes the estimates for the percentage of products in California that are currently compliant under the proposed Tier 1 and Tier 2 standards. The compliance assumptions are derived by using a mix of data on ENERGY STAR market penetration for these products and the test data. These are very rough estimates, and further investigation will need to confirm actual potential energy savings given current rates of compliance to the proposed Tier 1 and Tier 2 standards.

In the two tables below, sales of soundbars and docks are expected to increase, and higher savings for these devices may be realized.

Table 14: Tier 1 Estimated Unit and California Annual Energy Savings Potential by Device Type After Stock Turnover, Assuming Level Sales of All Devices

Device	Savings opportunity	Potential Annual UEC Savings			Potential California AEC Savings		
		Sleep	**Idle**	**Total**	**Sleep**	**Idle**	**Total Savings**
		kWh	kWh	kWh	GWh	GWh	GWh
Receivers	Reduce sleep and active mode power, APD after 30 min	0.6	22.2	22.8	7	237	244
HTiB	Reduce sleep and active mode power, APD after 30 min	-0.3	8.4	8.1	0	7	7
DVD and Blu-ray players	Reduce sleep mode power, APD after 30 min	0.0	4.0	3.9	-1	37	36
Powered Speakers	Reduce sleep and active mode power, APD after 30 min	3.5	197.2	200.7	1	30	31
Shelf Systems and Docks	Reduce sleep mode power, APD after 30 min	1.6	0.0	1.6	7	0	7
Total							324

Table 15: Tier 2 Estimated Unit and California Annual Energy Saving Potential by Device Type After Stock Turnover, Assuming Level Sales of All Devices

Device	Savings opportunity	Potential Annual UEC savings			Potential California AEC savings		
		Sleep	**Idle**	**Total**	**Sleep**	**Idle**	**Total Savings**
		kWh	kWh	kWh	GWh	GWh	GWh
Receivers	Reduce sleep and active mode power, APD after 30 min	0.6	24.8	25.5	7	265	272
HTiB	Reduce sleep and active mode power, APD after 30 min	-0.3	9.2	8.9	0	7	7
DVD and Blu-ray players	Reduce sleep mode power, APD after 30 min	0.0	4.0	3.9	-1	37	36
Powered Speakers	Reduce sleep and active mode power, APD after 30 min	3.5	200.5	204.0	1	65	66
Shelf Systems and Docks	Reduce sleep mode power, APD after 30 min	1.6	0.0	1.6	7	0	7
Total							389

For these estimates, constant sales levels are assumed. Note that sales of soundbars and docks are expected to increase, so the savings estimates are likely lower bounds. Receivers, HTiB, and powered speakers (soundbars, subwoofers, and so on) and docks all have modest to large savings opportunities.

Because Tier 1 involves meeting the already existing ENERGY STAR Version 3.0 specification, incremental cost to the manufacturer is expected to be minimal. Furthermore, it can be expected that with the application of power-scaling, incremental cost of reducing idle mode power draw by 30% in the proposed Tier 2 standard (for HTiB, receivers, and large powered speakers) will be only slightly more than the incremental cost is for Tier 1. In the absence of detailed cost information, the maximum incremental cost of a product that meets Tier 1 compared to the average product is estimated to range anywhere between $2 and $200 across all categories while maintaining a positive net present value. Similarly, the maximum incremental cost of a product that meets Tier 2 compared to the average product is estimated to range anywhere between $2 to $215 across all categories while maintaining a positive net present value.

CHAPTER 4:
Induction Cooking

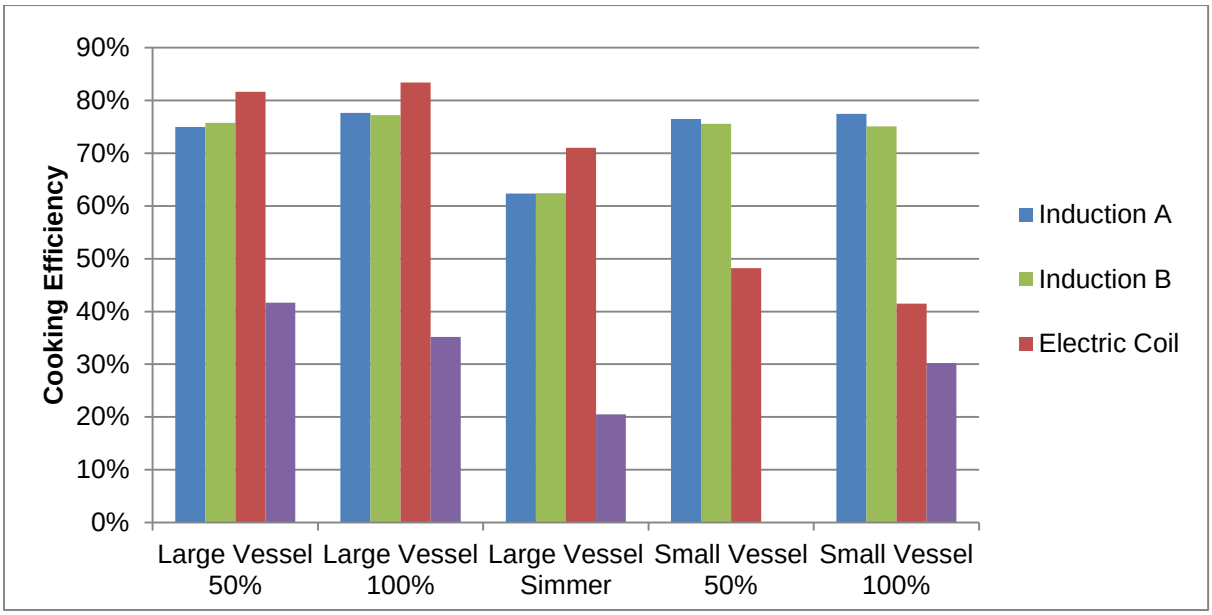
4.1 Executive Summary

Induction cooking technology is often cited as the most efficient means of cooking. This technology uses power electronics to generate a high-frequency electromagnetic field that induces eddy currents directly in the cooking vessel. With heat generated directly in the cookware, less heat is radiated to the kitchen than with conventional cooking technologies, including electric resistive—with exposed coils or a smooth surface—and natural gas devices.

This project seeks to evaluate the efficiency of residential induction cooking products to inform the development of potential codes and standards for cooking appliances. After the theory of induction cooking is described, an induction-compatible cooking efficiency test procedure is developed to fairly assess the efficiency of different residential cooking technologies. The procedure developed is based on ASTM F1521 and ANSI Z83.11, in which a specified weight of water is heated from 70 to 200°F. These commercial standards are amended to use a stainless-steel cooking vessel with water load downsized to 10 pounds for the smaller size of residential appliances.

Two induction cooking devices, one electric coil range and one natural gas range, were chosen to represent the different cooking technologies, and each was tested according to the procedure developed. The results of this testing found that induction cooking is 77% efficient, electric coil 83%, and natural gas 35% efficient at full power, as shown Figure 63 below.

Figure 63: EPRI Cooking Efficiency Testing Results



Due to the surprising nature of these results, testing was repeated under two amended procedures, including testing with a much smaller cooking vessel and water load and a simmer test similar to IEC 60350. These results show that the efficiencies of conventional cooking technologies dramatically decrease with a small cooking vessel, but the efficiency of induction remains unchanged. The results are compared with data available from the U.S. Department of Energy (DOE) published in its evaluation of alternate cooking efficiency test procedures. These results corroborate the conclusion that induction cooking is not necessarily more efficient than conventional electric coil technology, although the efficiency of electric smooth products reported by DOE is somewhat lower. These results are summarized in the table below.

Table 16: Comparison of Cooking Efficiency Measured by EPRI and DOE

	Large Vessel			Small Vessel		DOE Results	
	Half Power	Full Power	Simmer	Half Power	Full Power	Aluminum Test Block	Water Simmer
Induction	74.9%	77.6%	62.3%	76.5%	77.4%	-	81.3%
Induction	75.7%	77.2%	62.4%	75.6%	75.1%	-	79.2%
Induction	-	-	-	-	-	-	74.2%
Electric Coil	81.6%	83.4%	71.0%	48.2%	41.5%	71.0%	79.8%
Electric Smooth	-	-	-	-	-	54.2% 65.2%	61.8% 75.9%
Natural Gas	41.7%*	35.2%*	20.5%*	-	30.2%*	19%**	26%**

*Natural gas tested at 50°F.
**DOE meter error lowered measured efficiency.

These results show that the energy savings potential of induction cooking relies on the size of cookware used. Without market data showing the prevalence of cooking with cookware smaller than the heating element, the average savings cannot be accurately calculated. The impact on cooking energy consumption of using induction to replace conventional electric technology in the state of California is between 134 GWh increased consumption and 974 GWh saved.

A market survey was performed to determine the cost of induction over conventional cooking technologies. The survey showed at least a $300 incremental cost for induction cooktops over similar conventional products, without considering the cost of new cookware that would be required for users whose cookware is not compatible with induction technology. The simple payback of this minimum incremental cost from the 57 kWh maximum annual energy savings per device was calculated to be 33 years, roughly double the typical expected lifetime of consumer appliances.

Thus, induction cooking is not considered an economically feasible opportunity for energy savings. As such, it is not recommended for consideration in any potential cooking efficiency

standards set forth under California Title 20. However, it is estimated that standby power limits for major cooking appliances have the potential to save 140 GWh annually in California. It is expected that the DOE will include standards limiting the standby power of cooking appliances in 2015. With such a timeline, it is recommended that California utilities support this federal action rather than proceed with state-level action.

The low efficiency measured of the conventional technologies with the small cooking vessel highlight the dependence of their efficiency on cookware. As such, the development of educational materials intended to inform consumers of this energy loss is suggested as a cost-effective opportunity for energy savings.

4.2 Background

Induction cooking technology is an efficient means of cooking that was first commercialized in the U.S. in the early 1970s by Westinghouse Electric Corporation. The technology is based on the principle of magnetic induction, whereby current is induced directly in the cooking vessel by an oscillating magnetic field. The current generates heat for cooking through ohmic losses (the resistance of the pan) by I^2R. Because heat is created directly in the cookware, less heat is absorbed by the cooking appliance or radiated to the kitchen than with conventional cooking products. As such, the efficiency of induction cooking has been claimed as high as 90%.

4.2.1 Codes and Standards

Induction cooking is often cited as offering energy savings over conventional cooking technologies, both electric and gas-fired. Yet there are no standards for the cooking efficiency of residential cooking devices in the U.S. This project seeks to educate the applicable standards bodies of the technical performance of efficient cooking technology, so that the consideration of appropriate codes and standards for residential cooking appliances can be made with objective data on the energy used by residential cooking appliances.

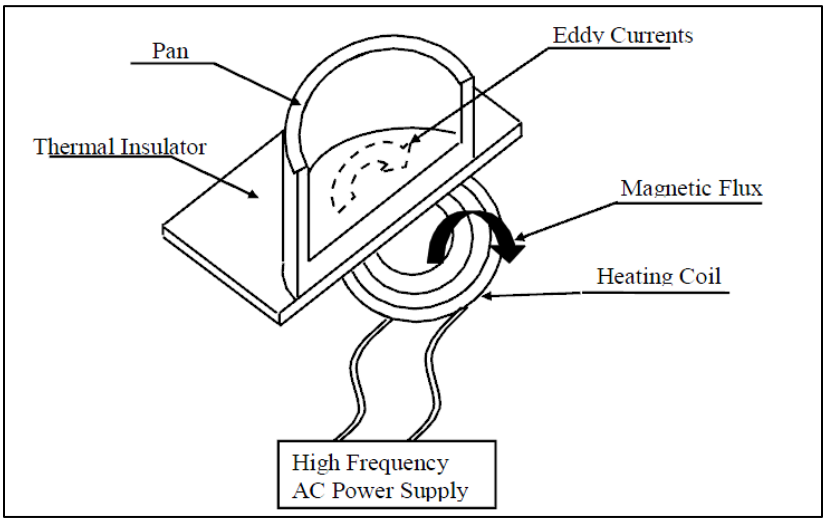
The DOE has issued regulations on the energy efficiency of residential cooking products, yet these regulations only apply to the pilot light in gas ranges and ovens. The regulations prohibit natural gas appliances made after April 9th, 2012 from being equipped with continuously burning pilot lights. No cooking efficiency standards were adopted for residential cooking appliances in the U.S. because no standards have yet been found to be technologically feasible and economically justifiable.

4.3 Technical Overview

Magnetic induction relies on Faraday's law, whereby current is induced in a ferromagnetic material in the presence of a time-varying magnetic field. This principle enables power transfer in transformers and motors and is the main reason that the electrical grid was founded on Tesla's ac distribution system rather than Edison's dc system. Current is induced directly in the cookware through a high-frequency magnetic field—around 25 to 50 kHz—generated by a planar coil of wire in the cooker (Figure 64). The eddy currents induced in the cooking vessel generate heat for cooking by the Joule effect, according to I^2R. Because heat is generated directly

in the cookware, there is no transmission of energy by thermal conduction. As such, less heat is lost to the cooker or radiated to the kitchen, and the efficiency of heat transfer is high.

Figure 64: Basic Principle of Induction Cooking



The transfer of energy in induction cooking is analogous to power flow in a transformer. The cooking vessel can be thought of as the secondary winding of a transformer that has been short-circuited. The power dissipated in the pan is dependent on the magnetic permeability and resistivity of the cookware, as well as the frequency of the oscillating magnetic field. The power can be rigorously determined using Maxwell's equations, but these calculations are quite complex. In general, the power delivered to the pan is related to the square of the induced current (or the square of the magnetic flux) times the equivalent resistance of the cooking vessel.

In order to dissipate enough power to provide satisfactory heat for cooking, the resistance of the cooking vessel must be sufficiently high. The equivalent surface resistance (R_s) of a material is related to its resistivity (ϱ) and skin depth (δ), as defined in Eq. 4-1 below.

Eq. 4-1 $$R_s \equiv \frac{\rho}{\delta}$$

The current induced in the cooking vessel is not evenly distributed in the material. Rather, current is greatest at the bottom surface of the vessel, called the "skin effect." The skin depth (δ) is defined in Eq. 4-2 below.

Eq.4-2 $$\delta = \sqrt{\frac{2\rho}{2\pi f(\mu_0 \mu_r)}}$$ Here,

ρ = the resistivity of the material in Ω·m

δ = skin depth in meters

f = the frequency of excitation in Hz0

μ_r = relative permeability of the medium

μ_0 = permeability of free space, $4\pi\times10^{-7}$ H/m

Most modern induction cookers operate between 25 and 100 kHz Table 17 lists the electromagnetic parameters of common cookware materials, with skin depth and surface resistivity calculated for each at 25 kHz, 50 kHz, and 100 kHz. As shown in the table, cast iron exhibits the greatest surface resistivity due to its high relative permeability. It should be noted that the permeability of stainless steel varies considerably, from non-magnetic (relative permeability approaching 1) to ferromagnetic (with μ_r as high as 6), depending on alloy composition, impurities, and fabrication (hardening, heat treatment, and so on).

Table 17: Skin Depth and Surface Resistivity of Common Cookware Materials at Different Frequencies

Material	ρ (μΩ-cm)	μ_r	Skin Depth δ (mm)			Surface Resistivity R_s (mΩ)		
			25 kHz	50 kHz	100 kHz	25 kHz	50 kHz	100 kHz
Cast Iron	80	100	0.3	0.2	0.1	2.8	4.0	5.6
Stainless Steel	70	1.4	2.3	1.6	1.1	0.3	0.4	0.6
Aluminum	2.6	1	0.5	0.4	0.3	0.05	0.07	0.1
Copper	1.6	1	0.4	0.3	0.2	0.04	0.06	0.08

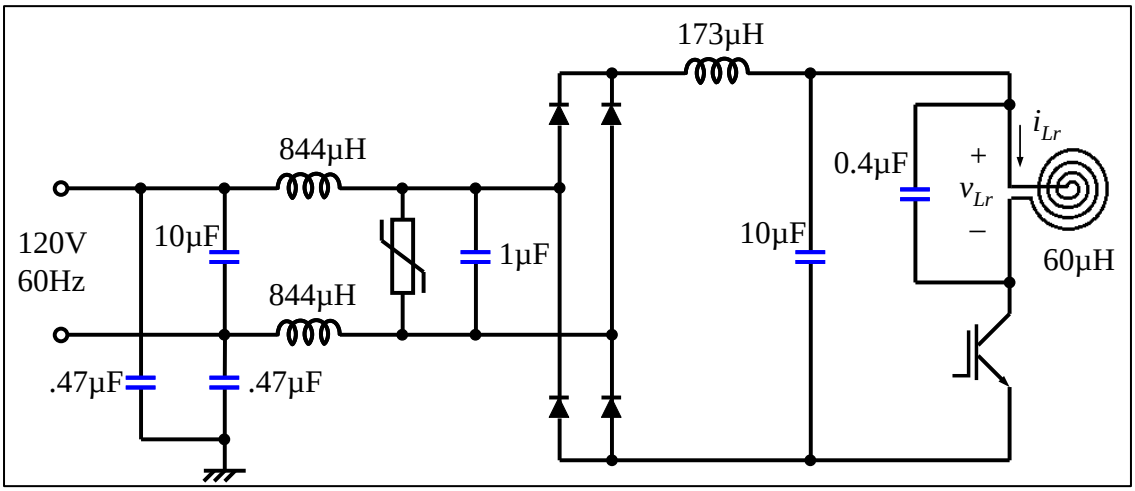
From Table 17, it is evident that cast iron is highly compatible with induction cooking. Yet it has been demonstrated that high-quality cookware made of ferromagnetic alloys of stainless steel can yield equal and sometimes superior performance to cast iron when used with induction cooking. Other materials prove more difficult to achieve sufficient cooking power. For example, the resistance of aluminum is 55 times lower than that of cast iron, requiring over seven times as much current for the same level of power dissipation.

Induction cooking devices employ power electronics to convert ac mains power to high-frequency current for coupling the cookware. The driver circuit is composed of a rectifier, which supplies dc power to an inverter that drives current through the wire coil. The inverter typically utilizes a high-frequency resonant topology that is designed around the impedance of the coil and cookware to achieve high-frequency switching of the power electronics with minimal switching losses, either zero-voltage switching or zero-current switching. Output power is controlled by varying the switching frequency of the inverter. At lower frequencies, the equivalent resistance of the cooking vessel is reduced, increasing current flow and the power dissipated in the cooking vessel.

The most common circuit topology is the single-ended inverter that uses a single 1200-V insulated gate bipolar transistor (IGBT) to switch the output coil at variable frequency Figure 65 shows the driver circuit of a single-phase, 120-V, 1.5-kW induction cooker utilizing a single-ended inverter. This circuit is very common in standalone induction cooking products manufactured in Asia. The main advantage of this design is its low cost and simplicity in design and construction. Results from laboratory evaluation of the single-ended driver depicted below

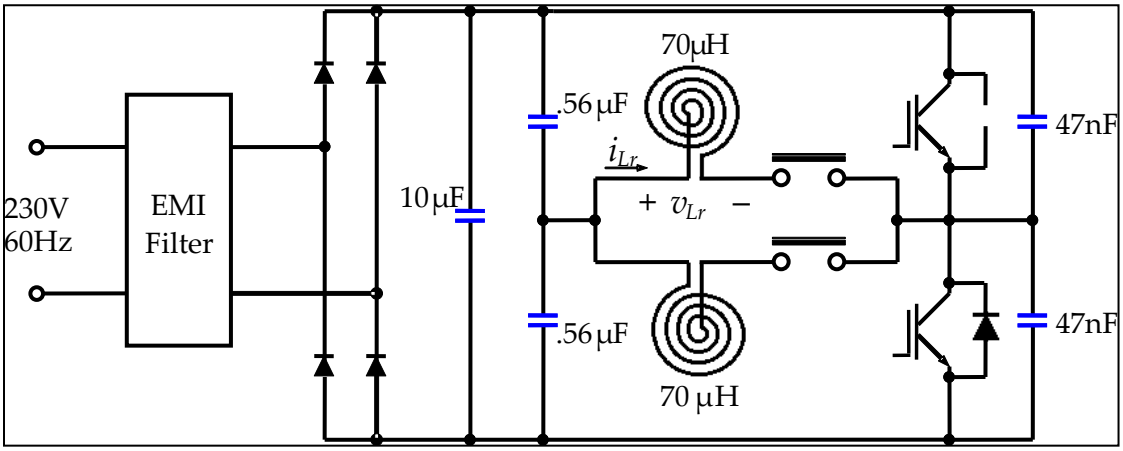
show that it operates at 23 to 29 kHz, delivering power to the coil at 75 to 80% efficiency with input power factor greater than 0.99.

Figure 65: Induction Cooker Driver Circuit with Single-Ended Inverter Topology



Other common circuit topologies include half-bridge and full-bridge inverters, which offer higher efficiency at greater cost and complexity Figure 66 shows a 2.5-kW driver circuit using a half-bridge inverter to drive two cooking units. This circuit allows one or both units to cook simultaneously. This circuit topology is often used in four-unit products, where one driver is dedicated to each pair of output coils. A product utilizing this circuit topology was evaluated in the laboratory and measured to operate at between 26 and 53 kHz. Power was delivered to the coil at between 82% and 84% efficiency.

Figure 66: Driver Circuit with Half-Bridge Inverter Powering Two Cooking Units



4.4 Compatibility with Nonferrous Cookware

Due to limitations in the power electronics, modern induction cooking devices are unable to supply enough current at sufficient frequency for compatibility with non-ferromagnetic materials. For this reason, cookware made exclusively of glass, aluminum, or copper is not compatible with induction cooking. This is a significant market barrier to the technology, as it incurs additional expense and frustration on the part of the consumer whose existing cookware is incompatible.

The development of wide bandgap semiconductors, including gallium nitride (GaN) and silicon carbide (SiC), may enable the next generation of induction cookers that enable cooking with non-ferrous cookware, especially aluminum. These materials are significant because power transistors made of wide bandgap materials exhibit significantly lower losses than silicon-based devices, allowing them to operate at higher switching frequency. As of January 2014, 600-V, GaN-based power transistors are in development for commercial release in the near future. These devices have the potential to enable aluminum-compatible induction cookers, but as yet no date has been officially announced for their commercial release.

4.5 Next-Generation Induction Cooker Prototype

As part of this project, a prototype induction cooker was developed that would be compatible with non-ferromagnetic cookware. The efficiency of this device was measured to be 84% at full load. The prototype device successfully operated with a non-magnetic alloy of steel but was not compatible with aluminum. High frequency operation was enabled by the use of GaN transistors in the inverter. However, losses in the power electronics and coil prevented high-frequency operation needed for compatibility with aluminum.

4.6 Testing Protocols for Measuring Cooking Efficiency

To accurately measure the cooking efficiency of a device for comparison with other devices, it is critical to follow a standard testing procedure. A standard testing protocol should outline a procedure and equipment requirements that allow the cooking efficiency of a device to be measured in an accurate and repeatable way. This allows the results to be compared with those reported from various sources, so long as the standard protocol was followed. Ideally, the test method should closely represent actual cooking methods, so that the results can be used to estimate the impact that different technologies have on a consumer's cooking energy consumption.

4.6.1 U.S. Department of Energy Test Procedure

DOE specifies a standard method for evaluating the efficiency of residential cooking appliances in. Cooking efficiency testing is carried out by heating a solid aluminum test block on maximum power until it reaches 144° F over its initial temperature, at which point power is reduced to 25% ±5% of maximum and held for 15 minutes. The use of an aluminum test block as the cooking load, while allowing precision and uniformity, prevents this test procedure from being performed on induction cookers.

Recognizing this limitation, DOE proposed an amendment to its procedure in 2013 that would allow compatibility with induction cooking devices. The proposed amendment would replace the aluminum test block with a hybrid test block made of two separate stacked pieces: a stainless steel base and an aluminum body. This hybrid test block would have the same heat capacity and outer dimensions of the current aluminum block. The proposed test block was chosen for its repeatability and consistency with current testing procedure. The proposed amendment would apply to all conventional cooking tops, meaning that the hybrid test block would be used for natural gas and conventional electric cooking devices as well as induction. At this time the proposed amendment to the DOE test procedure has not been ratified into law.

Included in the notice of proposed rulemaking are the results of efficiency testing carried out on a handful of residential cooking products. Testing was conducted with a variety of test loads to determine the variability of results from each method. Loads tested include test blocks made of aluminum, carbon steel, a hybrid of carbon steel and aluminum, and a hybrid stainless steel and aluminum. In addition, the use of water as a test load was investigated, in consideration of streamlining with international standards (IEC 60350, discussed below) to more accurately represent actual consumer use. These test results provide additional sources of data that can be used to evaluate the efficiency of induction cooking in relation to conventional cooking technologies.

4.6.2 U.S. ASTM Test Procedure

Due to the incompatibility of the current DOE test procedure with induction cooking, and its difference with actual consumer cooking loads, an alternative procedure was explored. One such test procedure that is widely used in the commercial food service industry is the American Society for Testing and Materials (ASTM) Standard F1521. This standard was developed in conjunction with the Food Service Test Center (FSTC) and is designed for evaluating the cooking efficiency of commercial food service equipment.

The test method is applicable to both gas and electric ranges and cooktops and consists of several components, including maximum energy input rate (maximum power), production capacity (a function of the time required to heat water), temperature uniformity, and cooking efficiency. The cooking efficiency test procedure outlined in this standard is summarized as follows:

1. Cooking vessel: a 13-inch diameter, 14-quart, heavy-duty aluminum stock pot and lid (with 0.25" diameter hole in the center to allow a thermocouple probe).
2. Testing is conducted at ambient temperature of 70° ±5° F.
3. Cooking load: 20 lb of deionized water, at 70° ±2° F.
4. Testing is performed first at 50% of rated power (±5%), followed by testing at full power.
5. A stabilization run of 30 minutes is conducted, followed by three test runs at both half power and full power, with no more than 15 minutes allowed between tests.

6. The time and energy required to heat the water to 200° F is recorded, with water temperature measured 4 inches below the bottom of the lid.

This test procedure shares many similarities with that detailed by the American National Standards Institute (ANSI) for Gas Food Service Equipment Ranges and Unit Broilers in ANSI Z83.11. Both of these cooking efficiency test methods call for the heating of a pot of water over a temperature rise of 130° F. The primary difference between these two procedures is in the size of the test load specified by the ANSI Z83.11. The ASTM procedure specifies only one test load for all burner sizes, namely 20 lb of water in a 13" pot. The ANSI method specifies three different test loads, depending on the size of the burner. In addition, the ANSI standard specifies the water in depth, rather than by weight.

Table 18 compares the differences between test loads specified by these two procedures. Although the procedures specify water load by different parameters (weight rather than depth), the equivalent quantity has been shown in parentheses for the sake of comparison. As shown in Table 18, the test load specified by the ASTM protocol roughly aligns with that specified by ANSI Z83.11 for units between 15,000 and 26,000 Btu. Although the ASTM procedure was developed for use with commercial cooking products, the ANSI standard is better suited to residential cooking units, with heat rates below 15,000 Btu. Typically, residential gas cooking appliances are not equipped with burners that are larger than 18,000 Btu.

Table 18: Comparison of ASTM and ANSI Cooking Efficiency Testing Loads

	ASTM F1521	ANSI Z83.11		
Burner Heat Rate (Btu)	(all)	<15,000	15,000 to 25,999	>26,000
Pot Diameter (inches)	13"	9.5"	13"	16"
Water Weight (lbs)	20	N/A (10)	N/A (19)	N/A (29)
Water Depth (inches)	N/A (4.2")	4"		

4.6.3 IEC Test Procedure

The International Electrotechnical Commission (IEC) is drafting its own standard for the evaluation of cooking appliances as an amendment to IEC Standard 60350-2 Edition 1.0 "Household electric cooking appliances – Part 2: Hobs – Method for measuring performance." ("Hob" is the British term for "stove" or "cooktop.") Similar to the ASTM and ANSI standards, this test procedure specifies heating a known quantity of water through a specific temperature rise without boiling. However, unlike the ASTM or ANSI methods, the IEC protocol calls for an extended simmer at reduced power. This standard specifies a variety of aluminum test pot sizes and corresponding water loads (by weight) for burners of various sizes.

The initial water-heating phase of the test is conducted at full power until the water reaches 363 K (194° F), from an initial temperature of 293 K (68° F). At this point, the energy input rate is reduced to a setting that will ensure that the water is held above 194° F, but as close to 194° as possible without adjusting the power setting. This "simmer" is held for 20 minutes, beginning when the water reaches 194° F.

4.7 Development of an Induction-Compatible Testing Method

None of the cooking efficiency test procedures identified is compatible with induction without modification, due the use of aluminum cookware specified by each. EPRI determined that the ASTM / ANSI test procedure—involving the heating of water from 70° to 200° F—most accurately represented actual consumer cooking while enabling sufficient repeatability of results.

The ASTM Standard F 1521 procedure was modified in several minor ways to better evaluate the residential induction cooking products that this study examines. First, the test load was reduced to a 9.5" stainless steel stock pot with a cooking load of 10 lb of water, closely matching the ANSI guidelines for testing smaller burners, including those sized for residential appliances. Clearly, an aluminum cooking vessel would not be suitable for evaluating induction cooking, so it is critical that the pot used for testing be made of a ferromagnetic alloy of stainless steel.

It was decided that the simmer specified by IEC 60350, while most representative of actual cooking methods, introduces a number of sources of variation that would detract from the consistency of efficiency results measured according this procedure. Specifically, during the simmer phase of the test, heat losses are dependent on the temperature of the water during the simmer. Yet the exact temperature set point is only specified as being greater than 194°. For example, different test runs that maintain a simmer temperature of 194° and 200° F would each be valid under this test procedure yet would produce different results due to the increased losses radiated by the load at 200°.

DOE has found that the use of water for the test load introduces additional sources of variability not present with the solid metal test blocks used in its procedure. These sources of variability include non-uniform temperature distribution of the water, differences in water properties among test laboratories, and the large impact that ambient conditions and cookware surface effects can have on water boiling and evaporation during the test. These additional sources of variation were acknowledged in the development of an induction-compatible procedure. It was concluded that the use of water as a test load most accurately represented actual cooking load and that the level of variability introduced was tolerable for this investigation.

4.7.1 Details of EPRI Cooking Efficiency Test Procedure

To evaluate the cooking efficiency of typical residential cooking appliances, EPRI drafted the following procedure, which closely follows ASTM F1521 while providing for compatibility with residential cooking loads.

4.7.1.1 Apparatus

Cooking vessel: 9.5-inch diameter, 8-quart, stainless steel (magnetic alloy), weighing 2.8 lb with a 1.4-lb lid. A 0.25" hole is located in the center of the lid for insertion of a thermocouple probe.

Gas meter: A high-precision meter for measuring the natural gas consumption of the range, of positive displacement type with at least 0.01 ft^3 resolution.

Thermocouple probe: Capable of immersion with a range of at least 32° to 212° F and accuracy of ±2° F.

Watt-hour meter: For measuring the electrical energy consumption of the electric range and induction cooker, with a resolution of at least 1 Wh and maximum error no greater than 1.5%.

4.7.1.2 Preparation of Apparatus

The appliances are installed according to the manufacturers' instructions, downstream from an appropriate energy-use meter. *Ideally*, the testing environment should be temperature (and humidity) controlled to maintain an ambient temperature of 70° ±5° F. For electrical installations, supplied voltage should be within ±2.5% of the manufacturer's nameplate voltage. Similarly, a gas range should be supplied by pressure within ±2.5% of manufacturer specifications.

For gas ranges, the following values should be recorded for each test run:

1. Heating value
2. Standard gas conditions for calculations
3. Measured gas temperature
4. Measured gas pressure
5. Barometric pressure

Testing of gas ranges should be performed with gas whose heating value is between 1,000 and 1,075 Btu/ft^3. Ideally, the heating value of the gas should be determined by using a calorimeter or gas chromatograph.

4.7.1.3 Cooking Efficiency Test Procedure

This procedure is performed twice: once at half-energy input rate and once at full-energy input rate. At each energy input rate, a 30-minute stabilization run is followed by three separate test runs. Energy efficiency is reported as the average of the three test runs.

1. Prepare the cooking vessel with 10 lb of 70° ±2° F water, and place the lid on the pot.
2. Center the cooking vessel on the cooking unit and set the controls of the cooking unit to 50% ±5% of the full-energy input rate. Allow the unit to operate for 30 minutes to stabilize.

3. At the end of the stabilization run, turn off the energy input to the unit. Cool the cooking vessel under running tap water. Dry the outside of the vessel, and refill with 10 lb of water. Confirm that the water is 70° ±2° F.
4. Center the pot on the cooking unit, allowing no more than 15 minutes between the removal of the previous pot and the placement of this vessel.
5. Record the time and energy required to raise the temperature of the water to 200° F, including any electrical energy consumed by the gas range.
6. Repeat steps 3 through 5 for the remaining two test runs.
7. After three test runs have been made at half-energy input rate, repeat steps 1 through 7 at full energy input rate.

4.7.1.4 Efficiency Calculations

Cooking energy efficiency is calculated for each test run using the values recorded. The efficiency of the unit is reported as the average of the efficiency of the three test runs.

Where:

Eq.1 $$\boldsymbol{\eta} = \frac{\boldsymbol{W_{H_2O} * c_p(H_2O) * (T_2 - T_1)}}{\boldsymbol{E_{input}}}$$

W_{H2O} – the weight of the water in the pot, specified to be 10 lb of water.

$c_p(H_2O)$ – specific heat of water = 1.0 Btu/lb·°F.

T_2 – the temperature of the water at the end of the test run.

T_1 – the temperature of the water before the test run.

E_{input} – the energy consumed by the cooking unit during the test (in Btu), including any electric energy consumed by a gas unit. The energy input of an electrical unit can be converted to Btu by multiplying by 3412 Btu/kWh.

The energy input to a gas unit is calculated as:

Eq. 2 $$E_{input} = V * HV$$

Where:

HV – the heating value, or the amount of heat released by the combustion of natural gas (Btu/ft^3), measured at standard conditions. If the specific heating value cannot be measured, use 1,025 Btu/ft^3.

V – the volume of gas, corrected for temperature and pressure to standard conditions (ft^3). Standard conditions are 60° F and 14.73 psi (101.5 kPa). The correction can be computed as:

Eq. 3 $$V = V_{measured} * T_{cf} * P_{cf}$$

T_{cf} – temperature correction factor = absolute standard temp (°R)/absolute gas temperature (°R)

Eq. 4 $$T_{cf} = \frac{519.67\ °\mathrm{R}}{[gas\ temp\ (°\mathrm{F}) + 459.67]°\mathrm{R}}$$

Pcf – pressure correction factor = actual gas pressure / standard pressure

Eq. 5 $$P_{cf} = \frac{[gas\ gauge\ press. + baromteric\ press.]\mathrm{psi}}{14.73\ \mathrm{psi}}$$

4.8 Evaluation of Residential Cooking Technologies

To evaluate the efficiency offered by induction cooking technology, EPRI selected two residential induction cooking products for side-by-side evaluation with conventional cooking products in the lab. These products were chosen to represent the basic technologies most commonly used in residential cooking applications. Baseline cooking technologies were identified as natural gas ranges and electric resistive ranges.

With induction cooktops and ranges currently serving a somewhat niche market in high-end appliances, two low-cost, standalone induction cookers were selected to represent induction cooking technology. These products can sufficiently serve as a representation of the technology across product form factors, while demonstrating the efficiency of affordable products that are currently reaching wider market adoption.

4.8.1 Induction Cooker A

Figure 67 shows a standalone, counter-top induction cooker, hereafter referred to as *induction cooker A* that was chosen for evaluation in the laboratory. This product is rated for 1.5 kW and 120 V and retails for around $70 at a well-known big-box store. The unit has six power levels and a warm setting, adjusted by digital controls on the front panel. In addition, the device has a built-in timer and automatically disables power when no cooking vessel is present.

Figure 67: Counter-Top Induction Cooker A

Table 19: Input Power Characteristics of Induction Cooker A

Level	Volts	Amps	Watts	pf	Athd
Standby (off)	122.7	0.5	1.39	0.024	14.7%
Standby (fan)	122.6	0.5	5.81	0.095	17.7%
Level 1*			281.8*		
Level 2	120.8	5.1	608.1	0.985	4.5%
Level 3	120.2	6.7	800	0.992	4.2%
Level 4	119.4	8.4	992	0.995	4.4%
Level 5	119.2	9.9	1180	0.997	4.8%
Level 6	118.3	12.0	1411	0.994	6.0%

*Input power cycling, average power calculated over 11-s cycle.

Table 20 shows the input power characteristics of induction cooker A measured in the laboratory. Induction cooker A exhibited high power factor—0.985 and higher—and total harmonic distortion (THD) less than 5%, except at full load, where THD reached 6%. Device power draw decreased linearly from its maximum power of 1400 W down to 600 W, as shown in Figure 68. At its lowest power and "warm" settings, the device cycled on and off at 600 W over approximately 11 seconds, as shown in Figure 69.

Figure 68: Induction Cooker A Power Settings

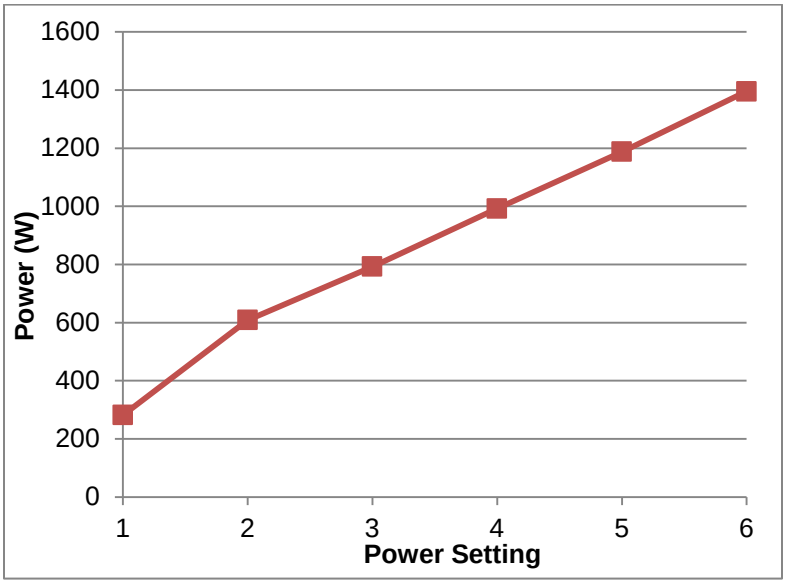
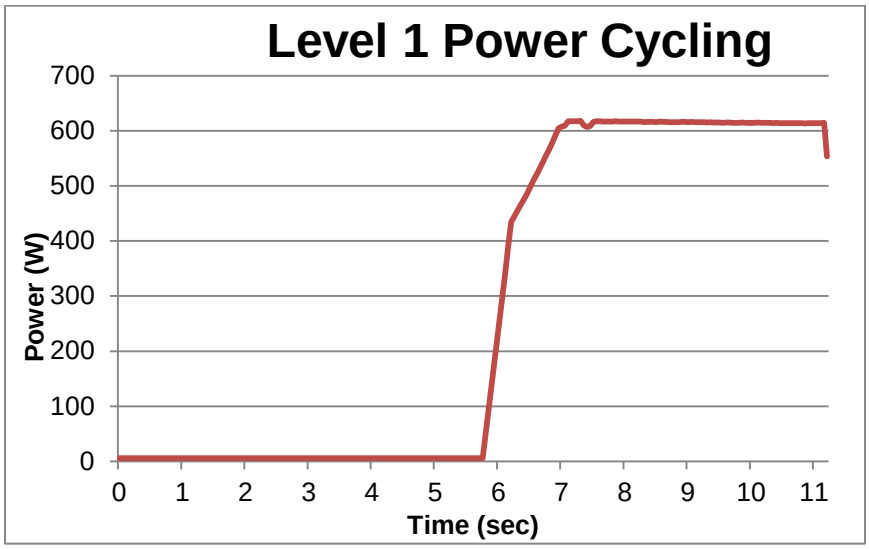


Figure 69: Induction Cooker A Power Cycling at Lowest Power Setting



This power cycling behavior is similar to that of conventional electric cooking devices, which cannot supply power continuously at any level except the maximum power rating of the device. At all power settings below maximum power, conventional cooking products cycle on and off to reduce average power. Induction cookers, on the other hand, are able to provide continuous power at levels below their maximum rating. Induction cooker A only cycled at its lowest settings, and even then it pulsed at its lowest continuous power (600 W). Average power over the 11-second cycle was 282 W, roughly half of the next lowest power setting. These power settings allow the user to adjust power levels in a relatively linear fashion, providing similar controllability as conventional cooking devices, albeit in discrete settings.

4.8.2 Induction Cooker B

Figure 70 shows another standalone, counter-top induction cooker, hereafter referred to as induction cooker B, that was chosen for laboratory evaluation. This product is rated for 1.8 kW and 120 V and retails for around $130. Although this product is only rated for 20% greater power than induction cooker A, it is marketed as a deluxe product with additional features not offered in the low-cost product. These additional features include temperature-controlled operation via a built-in temperature sensor and ten temperature settings from 140 to 450°F, as well as ten power settings. Finally, the unit incorporates a built-in timer and automatic shutdown when it senses that no cookware is present or that the surface temperature has exceeded safe operating limits.

Figure 70: Counter-Top Induction Cooker B

Table 20: Input Power Characteristics of Induction Cooker B

Level	Voltage (V)	Current (A)	Power (W)	Power Factor	Current THD
Standby	120.7	0.22	1.1	0.043	6.9%
Fan	120.7	0.25	6.4	0.211	22.9%
1*			219.0*		
2*			397.7*		
3	119.6	7.9	940.1	0.999	3.3%
4	119.4	9.3	1109.0	0.999	3.6%
5	119.3	9.9	1185.0	1.000	3.7%
6	119.2	10.5	1252.0	1.000	3.9%
7	119.1	11.2	1335.0	0.999	4.2%
8	119.0	12.2	1447.0	0.999	4.2%
9	118.9	12.6	1500.0	0.999	4.4%
10	118.8	13.4	1594.0	0.999	4.7%

Table 21 shows the input power characteristics of induction cooker B measured in the laboratory. Induction cooker B exhibited extremely high power factor—0.999 and higher—and THD below 5% at all power levels. Unlike cooker A, the power drawn by the device did not decrease linearly from its maximum power setting of 1600 W. Rather, power control was

incremental from 1600 W at power setting #10 to 940 W at setting #3, as depicted in Figure 71. At settings #1 and #2, the device cycled intermittently. At its lowest power settings, input power ramped up over approximately 9 seconds, as shown in Figure 72 and figure 73.

Figure 71: Induction Cooker B Power Settings

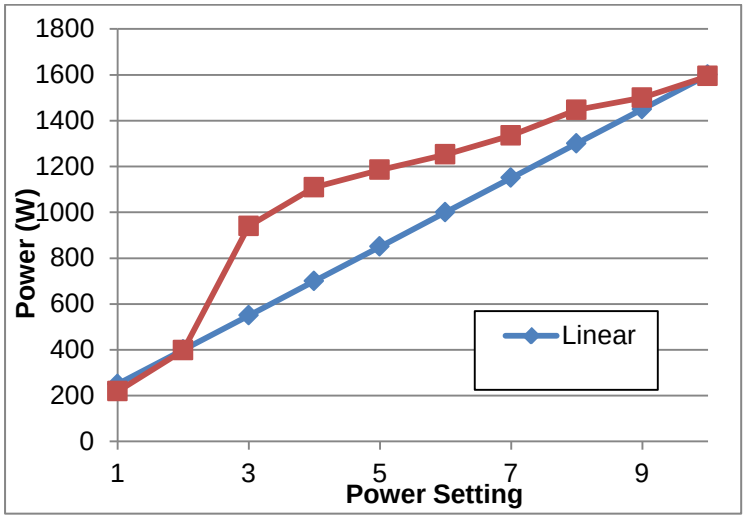


Figure 72: Induction Cooker B Cycling at Lowest Power Setting

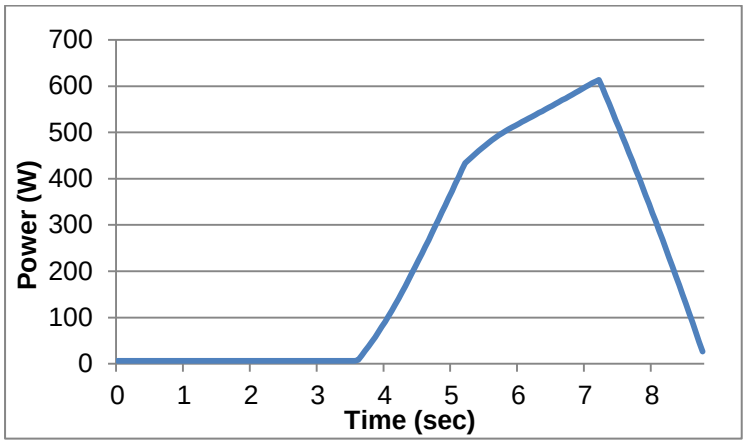
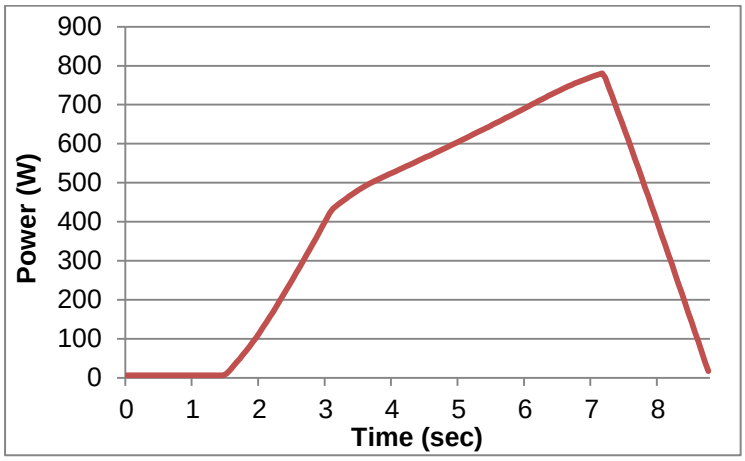


Figure 73: Induction Cooker B Cycling at Power Level 2



The ramping behavior of this device at its lowest power settings is distinct from the on-off cycling exhibited by cooker A. Yet this difference in low power cycling between the two units was not apparent in using the devices. The greatest distinction in controllability of this cooker over cooker A was the limited number of control settings below 940 W. In terms of rated power, this device offers no power settings between 25% and 60% of maximum power (settings #2 and #3) while offering relatively fine control at higher power. This makes cooking at low power very challenging, as demonstrated in the qualitative evaluation of the device. Such behavior is a flaw in the design of the control circuitry, which should be addressed in future revisions.

During qualitative evaluation of induction cooker B, it was observed that the temperature-controlled settings of the device may be better suited for low-power cooking than the lowest power levels offered. In this mode, the device adjusts its power level to maintain a temperature set point measured from the center of the cooking surface. This operating mode offers ten temperature settings: 140°, 180°, 210°, 250°, 280°, 320°, 360°, 390°, 430°, and 450° F. When checked with a thermocouple, the device's temperature setting was verified to be accurate within a few degrees Fahrenheit.

The temperature-control mode of the induction cooker offers more precision control than conventional technologies. By self-regulating to temperature set points, this mode may alleviate some of the challenges faced when using this product for cooking with low heat. However, few amateur chefs are accustomed to cooking at specific temperature. Moreover, few home cookbooks specify temperature for stovetop cooking due to the lack of this feature in conventional cooking appliances. As such, most users will need some amount of learning to fully utilize this new feature.

4.8.3 Conventional Cooking Appliances

Figure 74 shows the conventional electric range that was selected for side-by-side comparison with induction. This product uses electric (resistive) coil technology and was selected for evaluation because it is a low-cost residential product representative of what is widely used by

consumers. The range has one 8-inch element rated at 2 kW, typical for “medium-size” heating elements found on conventional electric cooking appliances. This element was chosen for comparison with the induction cookers acquired for evaluation.

Figure 74: Conventional Electric Resistive Range Chosen for Evaluation

As stated previously, conventional electric cooking appliances are typically unable to operate continuously at any power rate less than maximum power. At all power settings below maximum power, conventional cooking products cycle on and off to reduce average power. The short pulse of full power can cause scorching during a simmer, which makes cooking at low heat levels very challenging. The challenge of short power pulses is further exacerbated when cookware is used that has low thermal inertia (thin-bottomed cooking vessels). Natural gas is often the preferred cooking fuel because of its continuous heat rate, especially useful for precise cooking techniques.

Figure 75: Natural Gas Range Chose for Evaluation

It is important for a comparative evaluation of different cooking technologies to include natural gas due to its wide use, especially in commercial and high-end residential cooking. Figure 75 shows the natural gas range chosen for this evaluation. With one 5,000-Btu, two 9,500-Btu, and one 12,000-Btu burners, this range is typical for residential cooking appliances that use natural gas.

Gas cooking appliances are rated by heat rate in terms of British thermal units, or Btu. This unit is a measure of the chemical energy of the gas consumed per hour and cannot be directly converted to kW due to the efficiency of combustion of the fuel. Table 21 below gives an approximation between gas heat rate and induction element power, assuming 40% and 78%, respectively.

Table 21: Equivalent Induction Power for Typical Gas Burner Heat Rate

	Typical Gas Burner Heat Rate (Btu / hr)	Equivalent Induction Power (W)
Small	5,000	750
Medium	9,000	1,350
Large	12,000	1,800
Extra-Large	15,000	2,300
Commercial (“Pro-sumer”)	≥18,000	≥2,700

4.9 Results of Efficiency Testing

Testing of the four cooking units presented above was conducted at EPRI's laboratory in Knoxville, Tennessee, according to the test procedure outlined in this chapter. To ensure uniformity of the test results between the different technologies, only the largest cooking element or burner was tested on each of the conventional ranges. This reduces the size mismatch between the induction cookers and the smaller heating elements and burners present on the conventional ranges.

Due to infrastructure limitations, evaluation of natural gas appliances could not be conducted in a temperature-controlled environment. Under these circumstances, the ideal ambient temperature could not be maintained throughout testing, and the ambient temperature during testing was 50° F. However, all electric technologies were evaluated in a temperature-controlled testing space at 70° +/-2° F. To ensure the validity of a comparison between cooking technologies, all electric products were tested side-by-side.

With ambient temperature lower than standard test procedures, the results from the gas range should not be directly compared to results from other testing. However, these results are useful for direct comparison of the different electric technologies evaluated. It can be reasonably expected that the gas efficiency results measured at 50° are somewhat lower than those measured at 70° F.

4.9.1 Simple Water Heating Test Procedure

Table 22 shows the results of the efficiency tests performed for the four cooking devices presented earlier in the chapter, in which 10 lbs of water was heated from 70° to 200° F in a 9.5" stainless steel stock pot. According to the test procedure, three test runs were performed with each device at both half energy input rate (half power) and full energy input rate (full power). The results displayed in Table 23 are the average of the three tests for each device.

Table 22: Cooking Efficiency Results Measured According to EPRI Test Procedure

Technology	Half Power	Full Power
Induction Cooker A	74.9%	77.6%
Induction Cooker B	75.7%	77.2%
Electric Coil	81.6%	83.4%
Natural Gas	41.7%*	35.2%*

*Natural gas tested at 50°F.

The results demonstrate that the efficiency gains of induction cooking over conventional electric cooking technologies may have been overstated by vendors. With vendor claims as high as 90% efficiency, these results show that induction cooking is not inherently more efficient than conventional resistive heating elements. However, given the limited number of devices sampled, these results do not conclusively indicate the all induction cooking technologies

exhibit efficiency below 80%. Due to the somewhat unexpected nature of these results, the efficiency of these cooking products was further investigated with alternate test methods.

4.9.2 Water Heating with Small Cooking Vessel

It has been established that the cooking vessel plays a significant role in cooking efficiency due to the vessel's thermal mass and the surface area of its bottom. To examine this impact, testing was repeated with a smaller cooking vessel. A 6", 1.5-qt, stainless-steel saucepan was chosen that would provide a significant difference from the much larger, 9.5", 8-qt pot used for the primary efficiency testing. Due to the limited volume of this saucepan, only 3 lbs of water was used for the cooking load in these tests. These test runs were performed at both half- and full-energy input rates.

Table 23: Cooking Efficiency Test Results Measured with Small Cooking Load

	Large Cooking Vessel		Small Cooking Vessel	
	Half Power	Full Power	Half Power	Full Power
Induction Cooker A	74.9%	77.6%	76.5%	77.4%
Induction Cooker B	75.7%	77.2%	75.6%	75.1%
Electric Coil	81.6%	83.4%	48.2%	41.5%
Natural Gas	41.7%*	35.2%*	-	20.5%*

*Natural gas tested at 50°F.

Table 23 shows the results of efficiency testing with the smaller cooking vessel, in addition to the results measured with the large cooking vessel presented earlier. With the smaller vessel, measured cooking efficiency of both conventional cooking technologies fell dramatically. Efficiency of the electric range fell from 83.4% to 41.5%, increasing waste energy by a factor of 3.5x. Efficiency of the natural gas range fell from 35.2% to 20.5%, a 38% increase in losses. On the other hand, the efficiency results of the induction cookers from testing with smaller vessel demonstrate that the efficiency of induction cooking is much less dependent on the size of the cooking vessel used. In fact, both of the tested units exhibited roughly equivalent cooking efficiency with the smaller cooking vessel versus the large vessel.

These results further corroborate the conclusion that the size of the cooking vessel has a significant impact on the cooking efficiency of conventional cooking technologies, as shown in. With conventional cooking technologies, a smaller pot captures less of the heat dissipated by the element or burner, increasing the amount of heat radiated as losses to the kitchen. For this reason, cooking efficiency test procedures often specify the size of the cookware and/or test load used for burners or elements of different sizes. It is unclear how the small pot results translate to overall cooking energy use, as there is no data on the frequency of use of cookware and cooking units that do not match in size. It is likely that cookware is often mismatched to the size of the element or burner and may represent a large portion of the energy wasted in cooking.

4.9.3 Water Heating with Extended Simmer

Alternatively, testing was conducted in a manner similar to the procedure specified by IEC 60350, with an amount of water heated from 68° to 194° and held above 194° for 20 minutes. For large units, the test load is specified as 5.95 pounds of water in a stainless steel stock pot of 9.45" diameter with lid. To match the cooking load specified in the IEC procedure, this testing was conducted with 6 lbs of water in the large (9.5") stainless steel pot used in full loading testing above. The results of this testing are shown below in Table 24.

Table 24: Cooking Efficiency Measured With Extended "Simmer"

	10 lb Water to 200°F		6 lb Water Held >194°
	Half Power	Full Power	
Induction Cooker A	74.9%	77.6%	62.3%
Induction Cooker B	75.7%	77.2%	62.4%
Electric Coil	81.6%	83.4%	71.0%
Natural Gas	41.7%	35.2%	30.2%

The efficiency of both induction cookers was measured to be about 15% lower when tested with an extended simmer than when simply heating water. This can be explained by two possible factors. First, the efficiency of the power electronics is typically lower at partial load than full load, decreasing efficiency during the extended simmer. Second, due to the size difference between the countertop induction cookers and the conventional ranges, the induction cookers have lower thermal mass and are unable to retain thermal energy as effectively as the large ranges during the extended simmer.

With an initial full-power heating and extended "simmer," this test procedure may best represent actual cooking energy use. However, this procedure adds sources of variability in the amount of water evaporated during the simmer, and the amount of heat radiated from the pot during the simmer. Due to the added variability, DOE chose not to employ a water heating test in its future induction-compatible test procedure, as discussed earlier.

4.9.4 Comparison with DOE Results

In its recent notice of proposed rulemaking, DOE examined a variety of alternative test procedures for consideration in an upcoming amendment to its cooking efficiency test procedure that would allow compatibility with induction cooking. These alternative methods include the use of carbon steel, stainless steel, and hybrid steel-aluminum test blocks in place of the aluminum block currently specified, in addition to a water-boiling procedure similar to IEC 60350. In its consideration of these alternatives, DOE reported the cooking efficiency measured by each method for a variety of technologies, including electric coil, electric smooth, natural gas, and three induction cooking units.

Table 25 shows cooking efficiency results reported by DOE in, along with results from EPRI testing. The standard DOE test procedure calls for heating an aluminum block on maximum

power so that its temperature is raised 80°C, at which point power is decreased to 25% and held for 15 minutes. Because this procedure specifies an aluminum test block as the cooking load, the procedure is incompatible with induction cooking technology. The test block is specified to be 9 inches in diameter and 19 pounds in weight.

The final column of Table 25 shows the results of testing by DOE according to IEC 60350, which specifies the heating of water to 194° and held above this temperature for 20 minutes.

Table 25: Comparison of Cooking Efficiency Measured by EPRI and DOE

	EPRI Results			DOE Results	
	Half Power	Full Power	Simmer	Aluminum Test Block	Water Simmer
Induction	74.9%	77.6%	62.3%	-	81.3%
Induction	75.7%	77.2%	62.4%	-	79.2%
Induction	-	-	-	-	74.2%
Electric Coil	81.6%	83.4%	71.0%	71.0%	79.8%
Electric Smooth	-	-	-	54.2% 65.2%	61.8% 75.9%
Natural Gas	41.7%*	35.2%*	20.5%*	19%**	26%**

*Natural gas tested at 50°F.
**DOE meter error lowered measured efficiency.

The "electric smooth" cooktop evaluated by DOE featured large heating elements of two different sizes, each incorporating electric resistance heating beneath a ceramic surface. The efficiency of each is shown separately in the table. For natural gas testing, DOE reports that meter error caused gas consumption readings to be higher than actual consumption, resulting in low measured efficiency for the natural gas range.

The efficiencies measured from water simmer tests by DOE exceed the simmer tests measured by EPRI in all cases except for the gas range (due to DOE's errant gas measurement). The reduced simmer efficiency measured by EPRI could be due to differences in temperature, humidity, or ventilation between the two test facilities. Alternatively, the type of induction cooking appliances tested could account for the differences between DOE and EPRI results, with the cooktops evaluated by DOE potentially exhibiting greater efficiency due to their increased thermal mass.

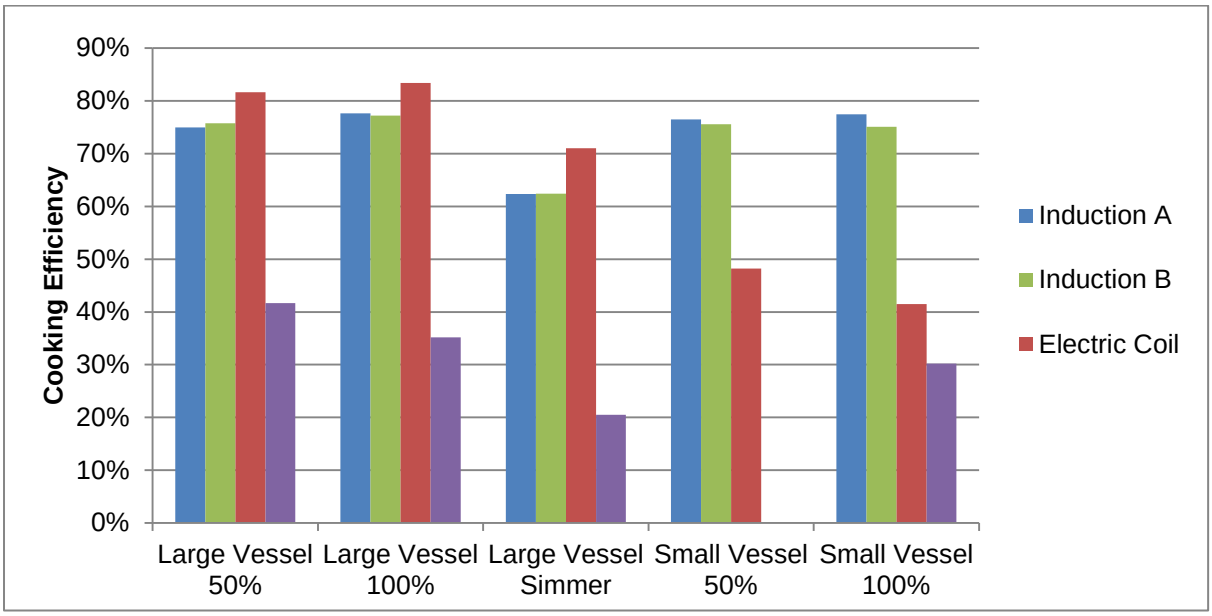
Despite differences in the absolute efficiency measured, the results from DOE testing can be used to compare the relative efficiency of different cooking technologies. In fact, DOE results corroborate EPRI findings that induction cooking is not necessarily more efficient than conventional electric resistance products. Yet the results of the smooth electric unit from DOE

further suggest that the efficiency of conventional electric cooking technologies is highly dependent on the match in size between heating element and cooking vessel.

4.9.5 Summary of Cooking Efficiency Results

Figure 76 shows the cooking efficient results measured by EPRI. Once again, it should be noted that the natural gas range was tested at 50° F due to infrastructure limitations, while the electric products were tested at 70° F. This should result in slightly lowered measured cooking efficiency for the gas technology.

Figure 76: EPRI Cooking Efficiency Testing Results



The results demonstrate that induction cooking is not necessarily more efficient than conventional cooking technologies. However, induction cooking can be significantly more efficient than conventional technologies when a cooking vessel is used that is smaller than the burner or heating element. This result is shown most clearly by the results of the small pot test, in which the efficiency of conventional cooking technologies fell dramatically. With a small cooking vessel, a significant proportion of energy is radiated from the cooking element as waste heat.

Table 26 shows the results of the cooking efficiency tests performed by EPRI, compared with the data reported by DOE in. The data from DOE corroborates the results from testing by EPRI, that induction is not necessarily more efficient than conventional electric. DOE data suggests that the efficiency of smooth electric cooktops may be somewhat less than electric coil technology. Further, the impact of cooking vessel size in relation to cooking element size can be seen in the efficiency reported by DOE for the two smooth electric elements, where the two reported efficiencies represent those measured from elements of different sizes.

Table 26: Summary of Cooking Efficiency Results from EPRI and DOE

	Large Vessel			Small Vessel		DOE Results	
	Half Power	Full Power	Simmer	Half Power	Full Power	Aluminum Test Block	Water Simmer
Induction	74.9%	77.6%	62.3%	76.5%	77.4%	-	81.3%
Induction	75.7%	77.2%	62.4%	75.6%	75.1%	-	79.2%
Induction	-	-	-	-	-	-	74.2%
Electric Coil	81.6%	83.4%	71.0%	48.2%	41.5%	71.0%	79.8%
Electric Smooth	-	-	-	-	-	54.2% 65.2%	61.8% 75.9%
Natural Gas	41.7%*	35.2%*	20.5%*	-	30.2%*	19%**	26%**

*Natural gas tested at 50°F.
**DOE meter error lowered measured efficiency.

It is unclear how often a typical consumer cooks with a cooking vessel smaller in diameter than the heating element. It can be reasonably assumed that a poorly matched resistive element and vessel could exhibit efficiency as low as 42%, as measured in the small pot test. On the other hand, conventional electric elements were measured as high as 83% efficient with a large vessel. However, the results of this testing demonstrate that induction cooking maintains high efficiency regardless of the difference in size between cooker and vessel.

Results show that energy savings potential of induction cooking is dependent on the size of the cookware used. Test results show that induction cooking offers as much as a 35% gain in efficiency over conventional electric when using small cookware. Yet when a large vessel is used, induction cooking was measured to be 6% less efficient than electric resistive technology. Without any data illustrating consumer usage patterns, the overall savings opportunity cannot be accurately computed. On average, induction cooking offers an efficiency gain somewhere between -6% (net increase in energy consumption) and 35%, likely yielding savings in many cases but potentially increasing energy consumption when only large cookware is used.

4.10 Qualitative Evaluation

In addition to the energy efficiency testing reported above, the induction cookers were subjected to a qualitative evaluation, involving the cooking of several types of food. One of the first features of the induction cooking that was observed is its ability to automatically shut down when no cooking vessel is present. This function adds a safety feature and reduces the chance of inadvertent burns or fires due to a heating element that was not properly powered off after use. Similarly, the surface of the induction cooker cooled somewhat faster than a smooth electric surface due to the lack of heating element in its surface. This also reduces the risk of burns or fires after use.

The low-power behavior of the induction cookers was generally preferred to that of conventional electric devices, due to the continuous power it provided. However, the nonlinear controls of cooker B made cooking at low power somewhat challenging. The temperature-control feature of cooker B allowed greater precision at low power levels, but this function requires some amount of experience for the user to acclimate to this unique method of cooking control.

The induction cookers proved to be similar in response to gas cooking. Conventional electric devices are typically slow to come up to heat and slow to cool off. As well as being a safety hazard pointed out above, this makes precise cooking techniques difficult. For instance, it is difficult to quickly transition from a high-heat sauté to a low-heat simmer with a conventional cooking element. This is due to the high thermal mass of the electric coil and glass cooking surface (on smooth-top devices). With heat generated directly in the cooking vessel, the surface of induction cookers does not get as hot as conventional electric, and a quick transition to low heat is possible.

4.11 Market Impacts

Although vendors' claims may overstate the efficiency gains of induction over conventional cooking technologies, this study finds that induction may offer some energy savings over conventional electric cooking technologies. The results presented above find the efficiency of induction cooking to be 78% on average, compared to 42% to 83% for conventional electric and 40% for natural gas.

From the Residential Demand Forecast in, residential cooking accounted for 4,222 GWh of electricity and 304 million Therms of natural gas consumption in California in 2006, 4.9% of the electricity and 5.7% of the gas used by California residences. Residential cooking energy consumption can be broken down into energy used by stovetops (the burners and heating elements in cooktops and ranges) and the energy used by ovens. If stovetop energy use is assumed to be half of the total cooking energy use (from DOE estimated energy use disaggregation), then 2,111 GWh and 152 million Therms can be attributed to stovetops.

Table 27 shows the potential savings offered by induction cooking, considering the replacement of all conventional stovetop cooking units with induction. The energy savings are calculated as the reduction in energy consumption at the customer's site, not the primary (source) energy use. Because the average efficiency of conventional electric products could not be accurately calculated, savings is calculated for both the highest and lowest efficiency measured. For the highest measured efficiency of conventional electric the use of induction technology is calculated to increase cooking energy use. Yet without market usage data, it is unclear where the average energy savings value lies between the boundary points shown in the table. Energy costs are computed using average residential prices in California of $0.16 per kWh and $10 per thousand cubic feet of natural gas. Emissions impact is calculated assuming 313 kg of CO_2 is saved for every MWh of electricity avoided and 53 kg per million Btu of natural gas consumption avoided.

Table 27: Savings Potential of Induction Cooking in California

	Baseline Efficiency	Site Energy Savings	Energy Cost Savings ($)	Reduction in CO2 Emissions
Conventional Electric	42% to 83%	974 GWh to -135 GWh	$156 million to -$10.8 million	135,000 tons to -42,000 tons
Natural Gas (New Induction)	40%	152 Therm (gas) -2285 GWh (electric)	-$217 million	132,000 tons

The savings shown in Table 27 demonstrate that induction cooking has the potential to save consumers energy and money when used to replace conventional electric cooking technology. Yet when replacing gas cooking, induction significantly increases electricity use and customer cost. However, in this scenario, total CO_2 emissions would be reduced.

On top of cooking efficiency, the standby energy consumption should be considered for any appliance that is connected to power at all times. As shown in Table 27.

The induction cookers evaluated in this report consumed about 1.2 W when in idle mode. If connected to a power source continuously for all 8760 hours in a year, each of these devices would consume 10.5 kWh. To put into perspective, this standby loss translates to 3.7% of the 281.5 kWh annual unit energy consumption estimated by DOE for electric ranges.

One additional factor that is not captured by these calculations is the impact of waste heat on kitchen HVAC load. Some portion of the energy losses that are not captured for useful cooking energy are radiated to the kitchen space. In warmer weather, this adds to the load on air conditioning in the system. Yet the fraction of waste energy contributing to cooling load is not well understood. Although some of the energy lost in the combustion of gas is used in the chemical reaction of oxygen and carbon (as well as a number of other elements), it is possible that this technology radiates greater losses and contributes to additional load on the HVAC than electric technologies.

4.11.1 Non-Energy Impacts

In addition to energy impacts, the adoption of induction cooking would have some impact on the power system due to power factor and current harmonics. The resistive elements used in conventional electric cooking technology exhibit power factor of unity and no harmonics. As shown in Table 26 and Table 27, the induction cookers evaluated in this testing exhibited very high power factor, indicating that they both employ some form of power factor correction. Yet both of these products contribute a small amount of current harmonics to the grid, as measured by the THD of current. Given the low THD measured for both devices, the adoption of induction cooking products in the market is not expected to have a noticeable impact.

Another difference between induction and conventional electric cooking technologies is in its current draw at low power settings. Conventional electric technology is only able to provide continuous heat at full power and must cycle on and off at lower power settings. Induction

cooking is able to provide continuous power at lower settings and is only cycled at the lowest power settings. Even at these levels, the induction cookers cycle at a power level much lower than their maximum power. In this way, induction cookers present lower peak current to the grid than conventional cooking technologies.

Because this technology relies on the generation of significant radio frequency magnetic fields, radiated and conducted electromagnetic interference are common concerns. Consumers often worry about the health impacts of EMI, as well as potential interference with other electronics and communication devices. For this reason, EMI is regulated by the FCC under Part 15 for consumer electronics, and Part 18 for industrial, scientific, and medical devices (including residential induction and microwave cooking appliances). Table 28 shows the maximum field strength permitted under FCC Part 18 for induction cooking ranges manufactured after February 1, 1980. Because induction cooking is subject to FCC regulation, these devices are not expected to cause any interference due to electromagnetic emissions.

Table 28: Field Strength Limits Permitted by FCC Part 18 for Induction Cooking Ranges

Operating Frequency	Field Strength Limit (μV/m)	Distance (m)
<90 kHz	1,500	30
≥90 kHz	300	30

4.11.2 Market Barriers

Despite impressive efficiency claims, induction cooking has not been widely adopted in the U.S. However, adoption of induction cooking has been much more widespread in Europe and Asia. This may be due to the wider availability of natural gas in the U.S., higher cost of energy in Europe, increasing acceptance of induction, and consequent reductions in equipment cost as penetration of induction has increased. According to Transparency Market Research, induction cooktops accounted for 14% of the global cooktop market in 2012. Induction cooking technology is available in a number of form factors, including standalone (countertop) units, ranges, and built-in cooktops. Yet apart from the standalone units, this technology is not offered in low-end products and carries a cost premium over conventional technologies.

To calculate the total cost of ownership, a market survey was conducted to evaluate the price and power of cooktops offered by a number of brands. Cooktops were evaluated in this study rather than ranges due to the greater number of induction products available, and because the price represents only the stovetop technology and not an oven component. Tables A-5 through A-7 in Appendix E list the cooktops identified by the market study, each one a multi-burner cooktop utilizing conventional electric coil and radiant (smooth), induction, or natural gas technology. The maximum element power is listed, indicating the power rating of the largest heating element or burner provided. Cooktops are typically available with four or five heating elements or burners and are commonly available in 30-inch or 36-inch width. Additional

features can include a low-power "warmer" element or "downdraft" ventilation built into the cooktop. Stainless-steel finish is offered as a premium feature.

From the market survey shown in Appendix E, it is clear that cooktops generally fall into three price ranges: 1) low-end, $250 to $500; (2) mid-range, $500 to $1000; (3) high-end, ≥ $1000. Low-end electric cooktops utilize conventional coils, which are not offered in high-end or mid-range products. The most popular electric cooktops are mid-range products featuring radiant (smooth) elements in the $500 to $900 price range. The smooth glass (ceramic) surface of these products is marketed as a feature due to the ease of cleaning, and some of these products are offered with touch-sensing controls. Gas products span the entire range of price points, with low-end products starting at $250 and high-end products as much as $2,000.

Apart from the standalone, counter-top units similar to those evaluated in this report, induction cooktops do not fall into the low-end price range. In fact, only one manufacturer—Summit Appliance—offers induction cooktops for under $1000. This manufacturer features compact products with unique styling at modest prices, but these product lines are not offered at major "big box" stores. Major appliance manufacturers offer induction products starting between $1,200 and $1,800 with top-of-the-line products as high as $3,000.

Calculation of the incremental cost of induction technology over conventional electric is somewhat difficult due to the nature of cooktop product pricing. Generally speaking, the high-end products offer more features and available configurations, but in many cases one make or product line is marketed as higher quality than another with no difference in features.

Because induction products are only offered in the high-end product lines, it can be expected that they offer similar features to high-end, conventional electric products. Yet the cheapest induction cooktops in this range, available from Whirlpool, Frigidaire, and Bosch for $1,200 to $1,400, are only available in 30", four-element designs with touch controls. Conventional electric products from the same manufacturers and with similar features can be had for half the cost of equivalent induction models. In addition, conventional products for $800 to $1,000 offer an extra element and/or "warming zone." Thus, induction technology adds a $300 to $600 price premium—roughly 25% to 50%—with fewer additional features.

Because induction cooking is only compatible with ferromagnetic cookware, the cost of replacement cookware must be considered in some cases with the cost of the appliance. For some users, this may entail the complete replacement of all cookware. In other cases, most of a user's existing cookware may already be induction compatible. Anecdotal evidence suggests that compatibility with induction is highly dependent on the alloy of stainless steel—so much so that different pans within a set of cookware may differ in compatibility with induction—but can be easily determined with a magnet. A quick market survey finds that induction-compatible, 10- to 12-piece cookware sets are available for $100 to $300 and more for high-end cookware lines.

With all of these factors in mind, the total cost of ownership of an induction cooktop can be estimated as follows. Considering that a consumer is considering a mid-level cooktop, either gas or electric. As identified by the market study, these models cost $900 on average. The least expensive induction models begin at $1,200, trading features such as an extra burner or warmer

element for touch controls, temperature control, and the other benefits of induction, including quick response and improved safety. Without considering the need for any additional cookware, induction adds at least $300 incremental cost—or 33%—over conventional smooth electric cooktops. If a new set of cookware is required, another $200 is added to the cost of induction. This brings the total incremental cost of induction to $500—56%—over a conventional electric (smooth) cooktop.

Yet given the energy savings potential of this technology, it is possible to calculate a payback period for the price premium that it carries. DOE estimates that the annual energy consumption of the stovetop (heating elements or burners, not including the oven) of a conventional electric range to be 128 kWh and 720 kBtu for a gas range in. The equivalent energy consumption of induction cooking can be calculated assuming an equal amount of cooking energy is delivered by each technology.

This study finds that induction cooking offers energy savings over conventional technology only if used with cookware smaller than the heating element. When used with small cookware, efficiency was measured to be 42% for conventional electric, 76% for induction, and 30% for natural gas. Table 29 shows the annual energy consumption of each cooking technology in this extreme scenario that users always use small cookware. Energy costs are calculated using average residential energy prices in California, of $0.16 / kWh and $10 per thousand cubic feet of gas.

Table 29: Annual Energy Consumption of Cooktop Technologies Using Small Cookware Only

Technology	Efficiency	Annual Energy Consumption	Cooking Energy	Energy Cost
Conventional Electric	42%	128 kWh	54 kWh	$20.48
Induction	76%	71 kWh	54 kWh	$11.32
Natural Gas	30%	720 kBtu	216 kBtu	$7.05

The energy consumption calculated in Table 29 illustrates the maximum energy savings available from induction cooking. Yet even in this scenario, natural gas provides the most cost-effective means of cooking. Induction cooking is shown to save 45% over conventional electric, for annual energy savings of 57 kWh or $9.16. To recoup the $300 minimum incremental cost of induction from energy savings requires 33 years, roughly double the expected lifetime of modern electronic appliances. Therefore, it can be concluded that induction cooking does not provide an economically viable means of saving energy at this time.

4.12 Recommendations

This study has found that the savings claims of induction over conventional cooking technologies have been overstated by its vendors. The analysis in this report identified annual energy savings of 57 kWh available from the use of induction over conventional cooking

technologies. The market study identified at least $300 incremental cost of induction over conventional products, with the potential added cost of induction-compatible cookware required in some situations. From these findings, a simple payback of at least 33 years was estimated (assuming $0.16 / kWh), not considering any added cost for compatible cookware. Therefore, it is not recommended that induction cooking be considered for inclusion in any potential cooking efficiency standards set forward under California Title 20.

It is estimated that reduction of standby power consumption of conventional cooking appliances presents a better opportunity for energy savings than use of induction cooking. In 2012, DOE implemented standards that limit the power consumption of microwave ovens to 1 W in standby mode. Similar standards are proposed for full-size cooking appliances, assuming that the primary driver of standby power draw is the digital clock, display, and timer controls, regardless of energy source (electricity or gas) used for cooking. Table 30 shows the standards proposed for the reduction of standby power use of cooktops, ranges, and ovens.

Table 30: Proposed Standards for Standby Power Use of Major Cooking Appliances

Device	Sleep Mode Power
Cooktops	<1 W
Ranges	
Ovens	

The energy savings opportunity of the proposed standard is calculated using average standby power of 2.7 W reported in. Table 31 shows the estimated savings in unit energy consumption (UEC) and aggregate energy consumption (AEC) in the state of California after complete stock turnover. The stock of cooktops, ranges, and ovens is assumed from appliance saturation numbers given in and the total number of homes in California as of the 2012 Census (3,700,000). Aggregate savings is calculated assuming level sales of all devices, a 30% penetration of devices that currently meet the proposed standard, and 15-year average product lifetime.

Table 31: Estimated Annual Energy Savings per Unit and Across California

Device	Savings Opportunity	Potential annual UEC standby savings	Potential California AEC total savings
Cooktops, Ranges, & Ovens	Reduce standby power	15.8 kWh	140 GWh

DOE has demonstrated that federal action regarding the standby power consumption of conventional cooking appliances is forthcoming. In 2012, DOE amended its test procedure for conventional cooking products to include a measurement of standby power. The Appliance Standards Awareness Project (ASAP) indicates that DOE is due to revise its standards in 2015,

an amendment which is expected to include limits on the standby power consumption of these products.

With likely federal action impending, it is not expected that any state level action could be completed before federal action comes into effect. Therefore, it is recommended that California utilities support the DOE in its development of upcoming standards to limit standby power use. Utilities can support federal action by providing comment to the DOE on its proposed rulemaking and offering additional test data to the DOE that would inform its rulemaking process. In this way, California utilities could take part in federal efforts to reduce standby power use by residential cooking appliances.

This project further corroborated the fact that cookware size plays a significant role in the efficiency of energy transfer in conventional cooking appliances. A cost-effective opportunity for energy savings could be the development of educational materials aimed at informing users of the energy saving potential of cooking with vessels and heating elements of roughly equivalent size. There may be an additional opportunity for incentivizing cooking products that incorporate heating elements of various sizes, especially those that can be reduced in size to match the cooking vessel used.

Finally, current test procedures to determine cooking efficiency do not capture the impact of cooking vessel size on the efficiency of conventional technologies. To measure this impact, it is recommended that residential cooking efficiency test procedures be amended to include testing of cooking vessels of multiple sizes with each burner or heating element. Current DOE test procure simply specifies a 6.25" block be used on burners 7" or less, and a 9" block be used on burners larger than 7". When tested according to this procedure, conventional heating elements 6" and 8" in diameter are measured with low losses, yet elements larger than 9" exhibit greater losses. The typical user employs cooking vessels of a variety of sizes that may not be well matched to the size of the burner or heating element. Furthermore, many cooking efficiency test procedures are not compatible with induction due to the specification of an aluminum cooking vessel. To allow evaluate of induction alongside conventional cooking technologies, cooking efficiency test procedures should be amended so that a ferromagnetic steel cooking vessel is used for testing. This would enable more objective evaluation of the technology, curbing some of the exaggerated claims by vendors and allowing a more detailed assessment of available energy savings.

CHAPTER 5:
Power Factor Requirements for Electronic Loads in California

5.1 Background and Purpose

5.1.1 Objective

It is well known that low power factor (PF) can cause excess heating in wiring, motors, and transformers. Low PF in electronic loads is an indication that the current drawn by the device is distorted due to harmonic content (see the Technical Overview section below for more information). Power factor correction (PFC) can remove this current distortion. Any reduction in the harmonic content of load current will result in energy savings, as well as extended equipment life. This is true in all sectors, but the proliferation of small electronic loads in the residential and commercial sectors offers an opportunity for energy savings through harmonic control. This project helps to quantify the energy savings potential of implementing a minimum requirement of 0.9 power factor in today's most common plug loads in residential and commercial buildings.

The main goal of this project is to definitively determine the energy savings potential in residential and commercial building distribution wiring from PFC in various end-use electronic products. The objectives are 1) to settle the question of whether PF is a significant factor in energy loss in the power system, through measurement and modeling, and 2) to quantify the potential energy savings benefit to rate payers for widespread adoption of high-PF products. This was accomplished first through calculations to estimate the energy savings using reputable sources like the Annual Energy Outlook (AEO) for total energy usage of end-use devices. Next, the EPRI team performed field measurements to compare against the estimated savings. The findings of both the calculations and the field measurements are presented below in the *Energy Consumption and Savings Potential Estimates* section.

5.1.2 Power Factor

Numerically, PF is represented as a dimensionless value between 0.0 and 1.0. An ideal device has a PF of 1.0, where the apparent power is equal to the real power.

$$Power\ Factor = \frac{Real\ Power}{Apparent\ Power}$$

This is true of purely resistive loads like incandescent light bulbs. PF is an aspect of the load (or loads) drawing current. When one load is on a circuit, the general relationship between current, voltage, power, and PF is as follows:

$$P = I \times V \times PF$$

Where P is the real power used by load (in watts), I is the root-mean-square (RMS) current (in amperes), and V is the RMS voltage (in volts). For an example of the importance of PF, a load with 0.4 PF will require 2.5 times the current to travel through wiring to deliver the same

amount of real power as an ideal load with a PF of 1.0. In addition to the inefficiency of drawing more apparent power than real power required by the load, the loss in the wiring is proportional to I^2R, where R is the resistance of the wiring. In the example, the building wiring losses are 6.25 times as high as a load with a PF of 1.0. Current dissipates power as heat in the resistance of the wiring. In cases of excess current, the losses are higher. In the case of multiple loads on a circuit, the losses can be significantly increased due to the larger RMS current on the circuit and the I^2 relationship to losses in the wiring. However, these larger losses also mean that the potential for savings is even higher on circuits with multiple devices.

Utilities in the U.S. supply voltage as a 60-Hz sine wave. Ideally, an energy-using product—or load—will draw alternating current (ac) in phase with the supply voltage waveform. This is how resistive loads such as incandescent lamps behave. In many cases, however, the load causes the current to flow in a manner that is out of sync with the voltage. This results in additional electron movement between the source and the load. This unsynchronized electron movement is inefficient, because the load causes more current flow than is necessary to perform a task. The ratio of real power that is useful to the load to the amount of apparent power that must travel through distribution wiring is called *displacement power factor* (DPF).

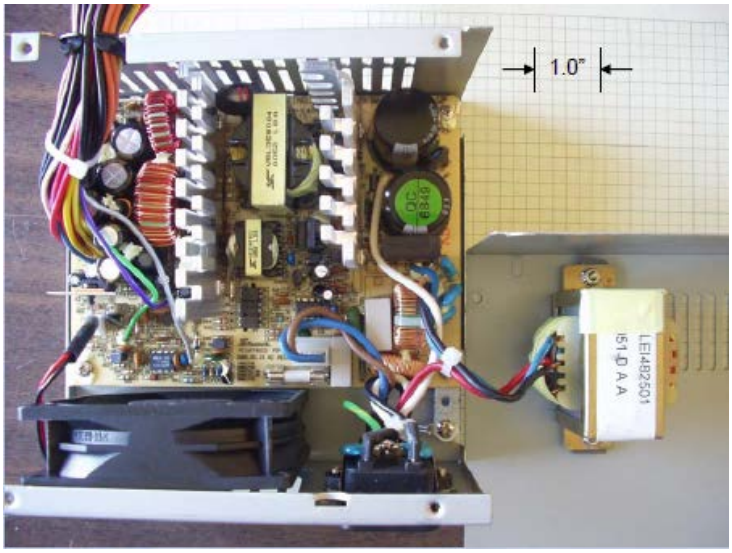
Another effect that affects power factor is harmonic distortion, which is represented by a new term known as *distortion power factor*. This type of PF is caused by the switching power supplies that are used in electronic devices. For more information on both displacement and distortion PF, please see the Technical Overview section below.

Power factor correction (PFC) to remove harmonics should be considered as an energy-saving technique that reduces energy lost from moving excess apparent power through building wiring. PFC shapes and redistributes the current waveform, making it more sinusoidal and in phase with the supplied voltage. Reshaping causes the load to behave more like a resistive load with PF near 1. PFC improves both displacement and distortion PF. There are two types of PFC, passive and active, which are described in the following sections.

Passive PFC uses inductors and/or capacitors to shift the phase of the current waveform closer to the voltage waveform. This technique corrects displacement PF; therefore, it is most effective for linear loads. Passive PFC can marginally improve PF for nonlinear loads by filtering out some of the distortion.

Figure 77 shows an example of a switch-mode power supply with passive PFC using an inductor in series with the load input. This technique is inexpensive, but it requires large and heavy parts.

Figure 77: Switch-Mode Power Supply with Passive Power Factor Correction Provided by Line-Frequency Inductor



Courtesy Chuck Mullett, P.E.,ON Semiconductor, reprinted with permission.

In contrast to the bulky but simple components used in passive PFC, active PFC typically uses small, lightweight inductors and capacitors for energy storage, as well as a switching device. An integrated circuit (IC) controls the switch so that the current moving from the mains to the energy storage emulates the shape of a sinusoid that is in phase with the voltage. The end-use device can then draw current from the energy-storage devices as it needs to, without affecting the PF. Active PFC is highly effective with nonlinear loads, and active PFC typically can improve PF to 0.95 or higher.

Active PFC is now commonplace in many electronic devices. Multiple vendors (such as On-Semi, Texas Instruments, and Power Integrations) provide inexpensive PFC controller ICs, and several different schemes for active PFC are available to suit a wide variety of electronic power supply applications and power levels.

PFC is a logical choice to reduce losses associated with poor PF; however, PF improvement should not be confused with load efficiency. Both active and passive PFC require energy to operate and, therefore, have an efficiency penalty. Active PFC circuits are approximately 90% to 95% efficient at the design load point.

Improved transistors and diodes can improve efficiency by reducing losses associated with these current-carrying parts. PF controllers that shut down PFC circuits when not needed, such as during standby, can also improve overall efficiency by reducing the added power demand of the PFC components.

Active PFC now makes it possible for electronic power supplies to have a PF better than 0.95 with good efficiency and practically no distortion at a reasonable cost with off-the-shelf components.

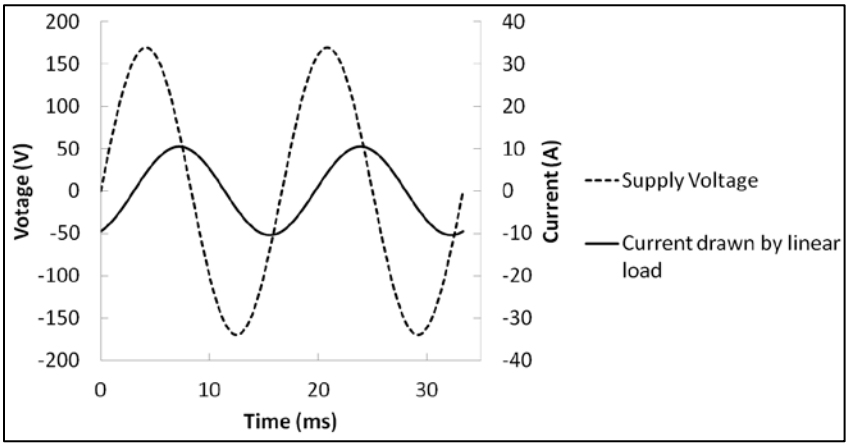
5.2 Technical Overview

Nonlinear loads, which are normally powered by ac-to-dc switching power supplies, are typical in a wide range of electronic devices, such as computers, monitors, TVs, printers, fax machines, copiers, audio equipment, and telecommunication equipment. Residential and commercial miscellaneous loads, which include consumer electronics, are the fastest growing segment of household energy use in the United States. Although the relative energy intensity of applications such as heating and cooling is declining, the U.S. Department of Energy's Annual Energy Outlook forecasts that the intensity of residential and commercial miscellaneous end uses, as defined in the 2013 Annual Outlook, will continue to increase significantly even as other loads like lighting and cooling decrease. These nonlinear electronic loads cause wiring losses that can be prevented through the use of PFC. Previous studies have shown that PFC in computers alone can result in energy savings in California of nearly 300 million kilowatt hours per year, whereas for the entire country, they could be as high as 2.4 billion kilowatt hours per year. The findings from this project indicate that savings are likely to be lower than previously estimated for the residential sector. There are several reasons for this result, such as differences in consumer usage patterns and lower overall current levels per circuit than in the commercial sector.

There are three major types of electric loads in ac systems—resistive, reactive, and nonlinear. Resistive loads, such as electric resistance heaters and incandescent lamps, draw current in time phase with the ac voltage of the grid and therefore have a PF of 1.0. Reactive and nonlinear loads have a PF of less than 1.0. When PF is less than 1.0, there are two possible reasons: displacement and distortion.

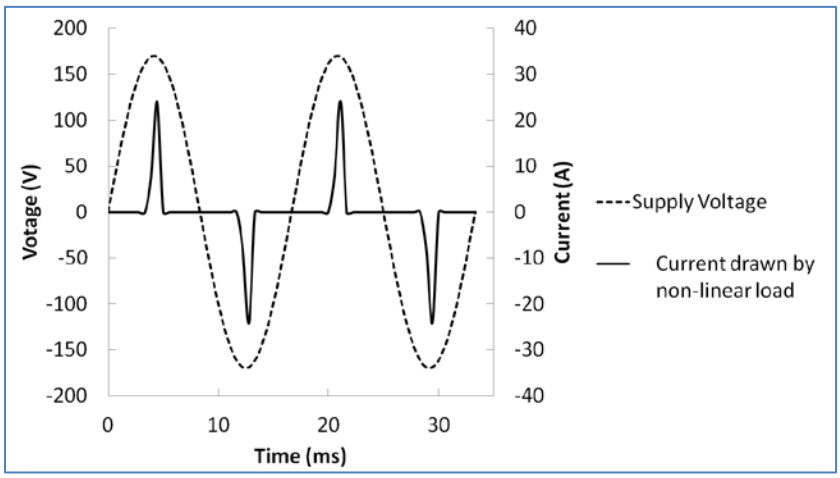
Reactive loads such as motors and ballasts are typically inductive, where the current waveform is out of phase with (lagging) the incoming ac voltage (see Figure 79). Similarly, capacitive loads draw current that lead the voltage. These characteristics of inductive and capacitive loads result in displacement PF.

Figure 78: Displacement of Current by a Linear Inductive Load



In residences and commercial office buildings with a large number of electronic loads, a significant problem is distortion PF. Distorted current is typical of nonlinear loads—primarily electronic devices that use a power supply containing a rectifier to convert ac to dc. Instead of drawing current in a sine wave, electronic power supplies typically draw current in pulses near the peak of the incoming voltage sine wave (see Figure 79).

Figure 79: Distortion of Current Waveform by a Nonlinear Load



Although the current drawn by an individual device is relatively small, when multiple loads with high energy demand and poor PF are on the same circuit, the losses are increased. This can be particularly concerning in office buildings with circuits overloaded with nonlinear loads. In the worst cases, the harmonic contributions can overheat the neutral conductor wire if it is not sized properly. More often, however, poor PF results in losses in building wiring and decreases the efficiency of building distribution systems. With the growing use of nonlinear loads, the losses associated with current distortion are on the rise. The size of the impact is difficult to quantify because it depends on not only the characteristics of the loads but also aspects of the wiring and building distribution systems.

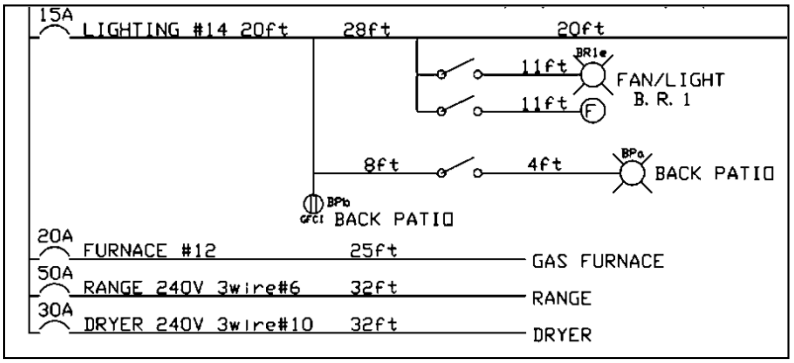
5.2.1 Interaction of Harmonic Currents and Electrical Distribution

Although PF is a characteristic of a load, to estimate the losses in a given building type, a number of characteristics of the building wiring distribution system must be understood. Because losses occur in building wiring, the effect of PF depends on the length, the resistance, and the topology or configuration of conductors in each circuit.

All buildings have electrical distribution systems that resemble a tree in structure. Larger buildings have a large-capacity trunk from the metered utility service that divides into bough-like feeders carrying power to several circuit breaker panels or simply panels, whereas smaller buildings may have a single panel connected to the utility service meter. The panels, in turn, have individual branch circuits that serve the connected loads.

There are generally two types of branch circuit configurations—multi-load and home run circuits (see Figure 80). This diagram does not illustrate an entire home, but it gives an example of what a multi-load circuit and a home run circuit might look like. Multi-load circuits are usually tree-like, with conductors branching to different loads in a manner that economizes material. In contrast, *home runs* are circuits that serve a single load. Home runs avoid the interaction between loads that can amplify the effect of poor PF.

Figure 80: Single-Line Drawing of Multi-Load (Top) and Home Run (Bottom) Circuits



The configurations of residential and commercial buildings differ. In residential construction, multi-load circuits are most common because this is the most economical use of time and material. These multi-load circuits may cover multiple rooms and have a mix of both plug loads and lighting loads. Building codes require certain loads—such as dryers; ovens; and heating, ventilation, and air conditioning (HVAC) systems—to be on home run circuits. Overall, however, residences have a relatively low number of circuits.

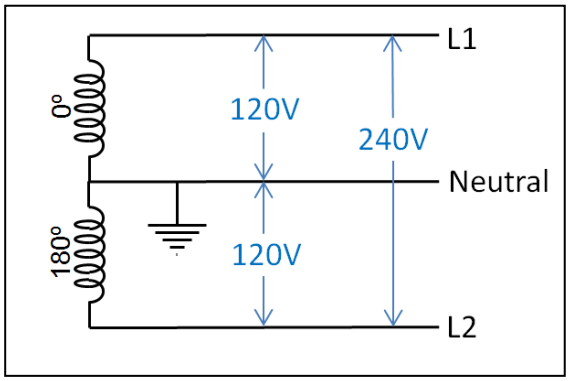
In contrast to the relatively small number of primarily multi-load circuits in a residence, commercial distribution tends to separate general lighting circuits from plug load circuits and to have a greater number of home run circuits. Commercial buildings have a larger number of home run circuits to protect reliability of certain mission-critical plug loads. For example, it is common to see appliances in company "break rooms" served by home runs, so that the coffee maker does not overload the circuit and trip the circuit breaker and interrupt power to a line of cubicles. Similarly, important servers or data processing equipment are often separate from general receptacle circuits. Another key difference is that commercial distribution separates lighting and plug load circuits. This is because large commercial buildings frequently use higher-voltage (such as 277 V) lighting. Another advantage to separating plug loads and lighting is to facilitate space rearrangements. Walls are easier to rearrange when the plug loads are separate from the lighting, which allows tenants to customize a given space.

The measurements made in this project focus on residential loads, however the effects of PFC on commercial spaces is also examined in a later section of this chapter.

Another aspect of the wiring topology of a building is whether the distribution system is single-phase or three-phase. Residential power distribution is typically a single-phase system, with

two supply conductors of opposite polarity and a neutral (Figure 81). The voltage from each supply conductor to neutral is 120 V, and the voltage between the two supply conductors is 240 V. This arrangement is referred to as *split phase*.

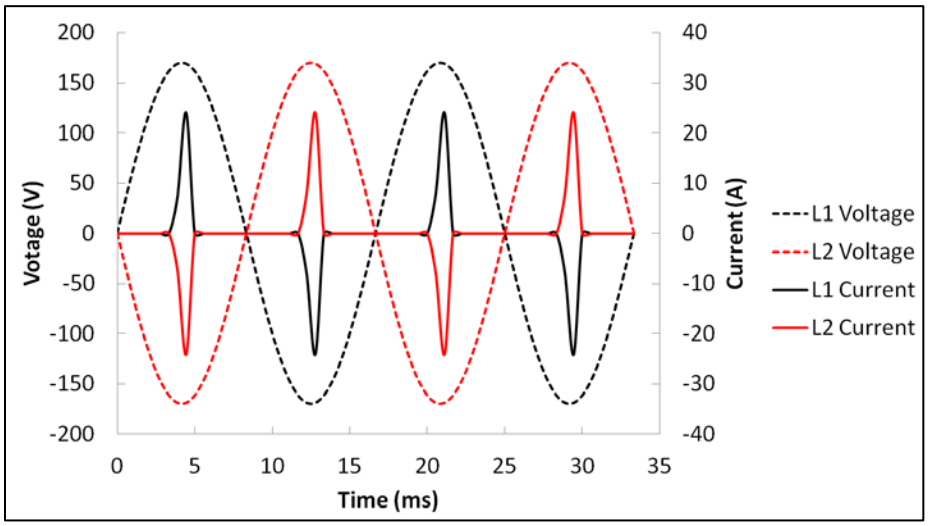
Figure 81: The Structure of a Residential Split Phase System



Branch circuits can be either two-wire, 120-V, or three-wire, 240-V circuits. A single-phase, two-wire, 120-V circuit has one supply conductor wire and a neutral plus a ground conductor. A split-phase, three-wire, 240-V circuit has two supply conductors of opposite polarity and a neutral plus a ground conductor.

Ideally, when the two supply conductors of a split-phase circuit are equally loaded, their return currents are equal and opposite, so there is little or no current flowing on the common neutral. Figure 82 illustrates how the current spikes caused by distortion on the two opposite supply conductors will be opposite in polarity at the same time and will tend to cancel each other when they combine on the neutral conductor. This may not be true unless each harmonic magnitude and phase angle is equal.

Figure 82: Distortion in a Split Phase System



In contrast with the split-phase system used in residential wiring, commercial power distribution commonly uses a three-phase system. In a three-phase system, there are four wires—three supply conductors and a common neutral. Instead of the voltage peaks occurring directly opposite each other as in split phase, the three conductors are each shifted 120° from one another, resulting in three offset voltage peaks per cycle (see Figure 83 and Figure 84).

Figure 83: Three-Phase Distribution Common in Commercial Buildings

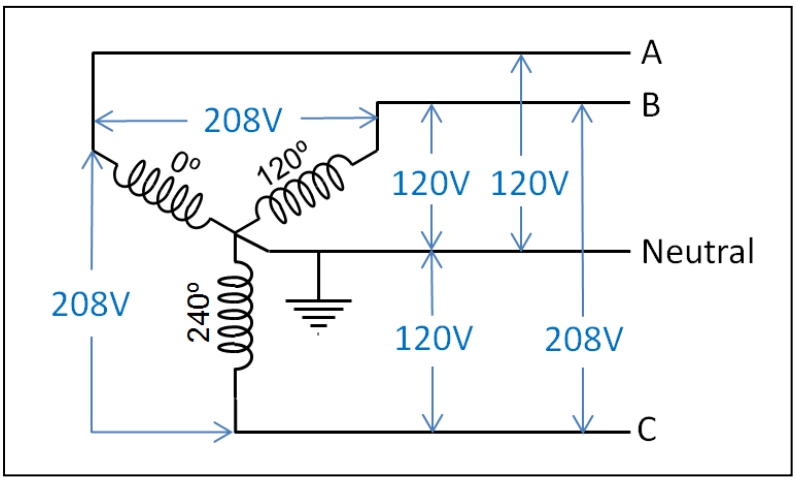
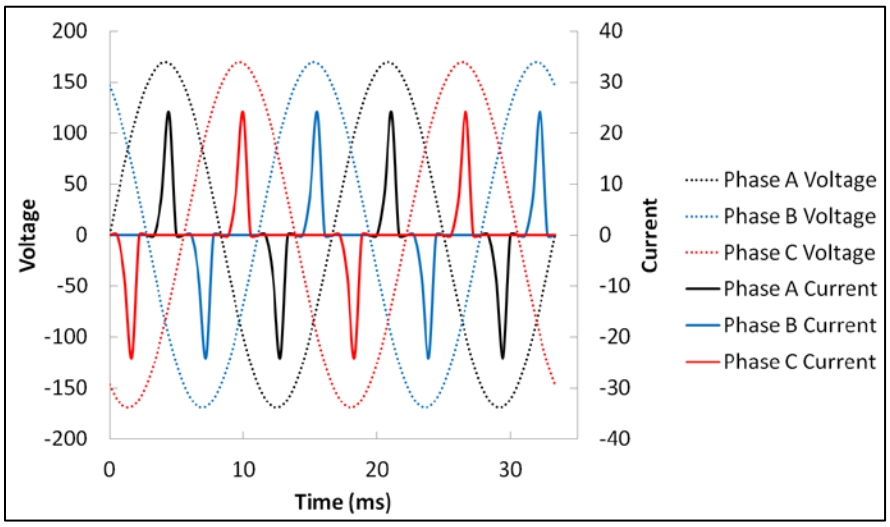


Figure 84: Distortion in a Three-Phase System



When many of the loads on a three-phase circuit are nonlinear, there is a significant current peak on the neutral conductor as each phase reaches its voltage peak. Unlike split-phase distribution systems or balanced three-phase systems, in a three-phase system, the current pulses caused by nonlinear loads do not tend to cancel each other on the neutral. This is because they are made up of multiple sinusoids at different odd frequencies (odd harmonics). The

harmonics that are the odd multiples of three, such as 3, 9, etc. (triplens), are phase shifted so that they add on the neutral. Therefore, they add up to a level of as much as 1.732 times the current that is flowing in the individual supply conductors.

Older buildings designed before the advent of plentiful electronic loads may have a neutral wire that is the same size or smaller than the phase conductors. If the triplen harmonics are present, these current levels can cause the neutral to overheat. Due to the increasing number of nonlinear loads in commercial building circuits, designers often at least double the size of neutral conductors to carry the extra current.

Another aspect of commercial building distribution systems is multiple distribution voltage levels. It is common for a building to be served with a three-phase, 480-V/277-V system in which motors and lighting are connected to panels fed by these higher voltages, and transformers are used within the building to feed 208 V/120 V to panels that serve regular plug loads and 120-V lighting.

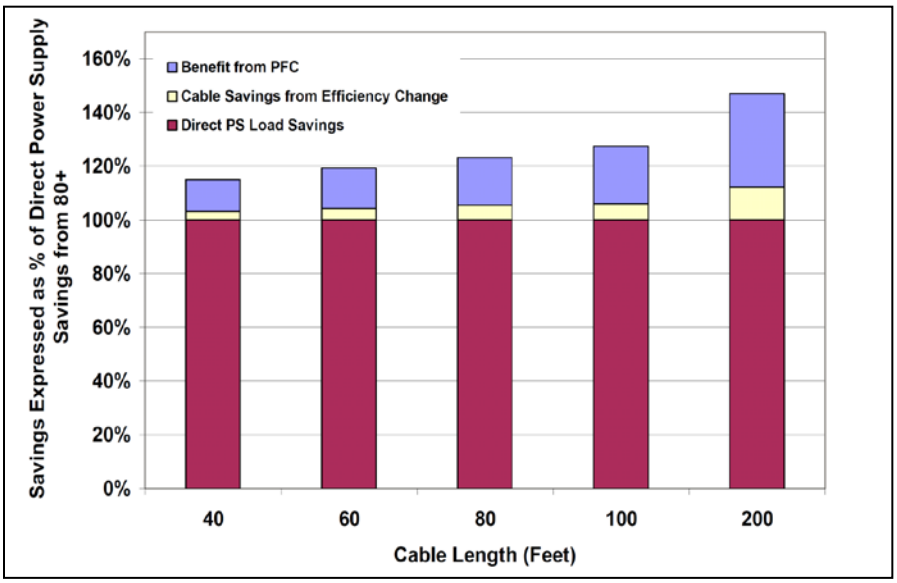
The higher voltage in the 480- V/277-V part of a building's electrical distribution allows the same power to be delivered through the wiring at lower current, reducing wiring losses. It can also allow electrical feeders (the larger branches of the tree) to be constructed more economically using smaller-gauge conductors, with the transformers located closer to the 208-V/120-V loads within the building. Similarly, the branch circuits to the 480-V/277-V loads will carry less current than would be required for an equivalent 208-V/120-V load and can be constructed with smaller conductors at lower cost.

5.3 Opportunity

A previous study on high-efficiency power supplies showed that additional energy savings could be gained by including PFC requirements along with policies that yield improvements in energy efficiency (like efficiency standards or utility rebates). The study first assessed the energy-saving benefit of improved efficiency in computer power supplies using laboratory measurements (see Figure 85) to develop and validate a detailed model of currents and associated line losses in building wiring. It then used that model to estimate any additional energy savings resulting from PFC in the computer itself and in the building wiring that distributes power to the computer. The analysis then extrapolated the findings to determine the amount of energy savings possible in California alone and in the entire United States.

The results indicated that additional savings from PFC in California could be nearly 300 million kilowatt hours per year, and for the entire country, they could be as high as 2.4 billion kWh per year. Based on these results, the EPA included PFC as a requirement in version 4.0 of the ENERGY STAR specification for desktop computers. Because of the vast numbers of miscellaneous devices that also operate with power supplies and thus represent nonlinear loads, it seems reasonable to consider PFC standards for all electronic loads. To evaluate the benefit of such a requirement, an in-depth study of the market prevalence of each device and its load profile is necessary, followed by computer modeling and computation of the impacts on building and utility power distribution systems. This study represents a basic assessment of that market prevalence and load profiles.

Figure 85: Measured Savings in Power Supply Testing Based on Cable Length



Regarding harmonics issues in buildings, different solutions can be implemented. Some of these are currently required by the NEC. There are two approaches to these solutions: 1) Adjust the circuit parameters so that the customer can tolerate the harmonic levels present and 2) make adjustments at or near the offending load to reduce the harmonics to tolerable levels. This second approach usually involves filtering the current. For cases in which filtering is applicable, the filters may be applied at various locations. The best location for filtering is at the offending load, and that is what PFC provides.

In residential spaces, many plug loads that use a USB port for charging (such as cell phones and tablets) are currently not required to be PF corrected. Rather than producing individual power supplies and chargers with low PF and low efficiency to charge these devices, they could all be plugged into a USB port that is built into the house wiring alongside standard receptacles. These ports are becoming popular.

This year, there will be a new standard called USB power delivery (PD) that will allow up to 100 W. The opportunity will be to require devices under this new standard to include PFC chips.

In addition to the energy savings created for each individual load, it is important to understand the energy savings created by reducing the total current on a branch circuit. Depending on the number and current draw of the individual loads on a circuit, the savings produced by reducing the load by only one amp can by significant. This is because of the I^2R relationship mentioned in previous sections above.

For example, if the load were 10 A and were reduced by 1 A, the difference in losses

(savings) would be:

$$10^2R - 9^2R = 19R \text{ watts}$$

But if the load were 25 A, and were reduced by 1 A, the savings would be:

$$25^2R - 24^2R = 49R \text{ watts}$$

This finding is particularly noteworthy as the share of nonlinear loads continues to grow in residential and commercial buildings.

This example shows the importance of understanding the amount of time that loads on the same circuit are used at the same time. This is also called *coincidence of use.*

5.4 Testing Approach

5.4.1 Laboratory Testing

While both residential and commercial buildings are discussed in this section, the testing and field measurements took place in the laboratory and residences. However, in many instances the same devices that are used in a residence can be found in commercial spaces (computers, monitors, etc.), and this information is used to estimate the potential for energy savings in the commercial space as well.

Lab tests were based on expected typical wiring layouts found in residential and commercial spaces. Because PF losses depend on building wiring topology, it was necessary to determine typical topologies for residential and commercial buildings. To narrow down the variety in residential and commercial buildings, buildings with high annual energy use and well-known loads were selected. Floor space was used as the criterion to narrow down residential to the following three representative sizes:

- Small, 800 to 1000 ft^2 (typically two bedrooms, one bath, with dining space in kitchen)
- Medium, 1500 to 2000 ft^2 (typically three bedrooms, two baths, with separate dining space)
- Large, 2500 to 3000 ft^2 (typically four bedrooms, three baths, with formal dining space)

These categories were chosen because the National Electrical Code (NEC) is driven by floor space, and examining these floor plans, along with estimates from a field study, helped to determine the average run length of 40 ft.

The complex distribution systems found in building blueprints are difficult to describe using traditional wiring schematics, so the research team used a simplified diagram. Instead of drawing each individual electrical conductor, single-line drawings consolidate a group of conductors into a single line that represent a feeder or a branch circuit. A similar simplification can be used in tables of circuits to avoid the need to describe each individual conductor. This single-line style of documentation was used to provide numerical descriptions of the topology and configuration of circuits in a number of building types.

Residential single-line drawings were based on the floor plans of three houses, obtained from www.houseplans.net. Residential plans do not usually provide specific details on what loads

are to be grouped on which circuits. Outlets and fixed loads were placed according to NEC 2011 and California Title 24, Part 3, requirements, when applicable, and wire run lengths were estimated using conventional installation practices. The residential single-line drawings document each branch circuit in the residence with the following information:

- The rating of the circuit breaker serving the circuit
- The gauge and number of supply conductors in each circuit
- The receptacles, fixtures, and fixed loads on the circuit
- The connection topology of the circuit
- The length of each wire segment in the circuit

Commercial single-line drawings and circuit data were based on the detailed blueprints of a 30,000 ft^2 portion of a typical large office building and a 30,000 ft^2 portion of a large retail store. Unlike residential floor plans, commercial electrical blueprints are highly detailed—each receptacle, lighting fixture, or fixed load is assigned to a specific circuit breaker on a specific panel, and the wire gauges and other circuit characteristics are also specified. However, the wire segment lengths are not specified, so again the conventional wiring practices were used to estimate the lengths of each wiring run in the representative portions chosen from each commercial building type.

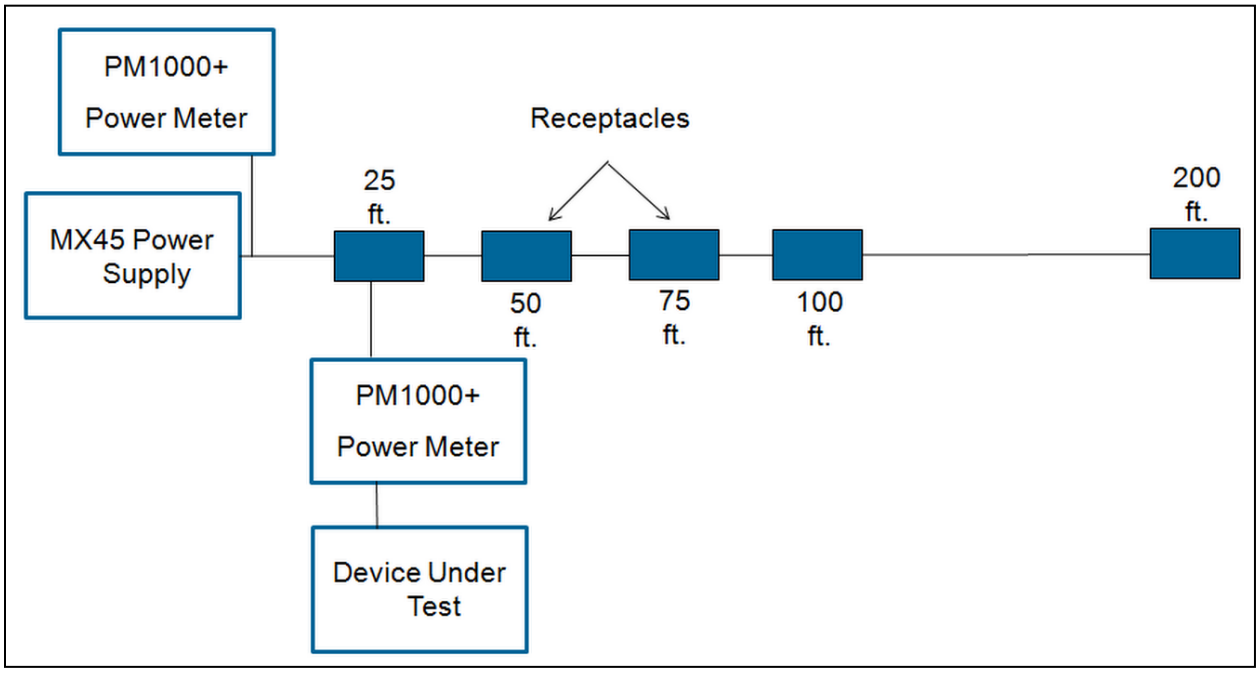
Even a single-line schematic of a 30,000 ft^2 commercial building would be too complex and too unwieldy to use. Single-line drawings that document the commercial building's power distribution from the utility service to the circuit breaker panel level were created, showing the feeders and transformers and their lengths. The final level of all branch circuits that connect the circuit breaker panels to the loads for the residential buildings are documented in Appendix F.

5.4.1.1 Test Method

Drawing from the building wiring topologies that were created to approximate typical buildings, common plug loads were tested in the laboratory to measure their power factors and other power characteristics. Because the losses in the building wiring increase with length, these devices were evaluated at 25, 50, 75, 100, and 200 feet of Romex #12 copper cabling (the same cable that would be found in most buildings). This testing showed that the losses due to wire length increase linearly so losses can be accurately calculated for any line length. Building on previous EPRI work, this testing assumes 100 foot cable length for commercial applications and 40 ft cable length for residential. The savings generated in the calculations below do not include additional savings from the transformer and cables to and from that transformer, but that could amount to about another 1/3 increase in the savings.

Figure 86 shows the test setup for each piece of equipment.

Figure 86: Test Setup for Laboratory Testing



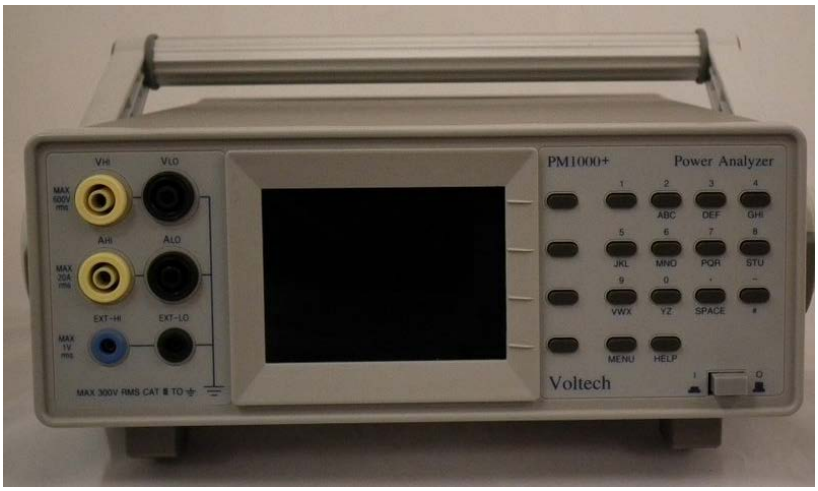
From the figure one can see that the test setup was powered using an MX45 ac power supply. This ensured that the supply power to every device was identical and eliminated the possibility of any power quality events from the grid causing errors in the measurements of each device.

Two Voltech PM1000+s were used to monitor all power characteristics at the source (MX45) and the device under test (DUT).

5.4.1.2 Equipment

To capture the power data of the devices tested, the Voltech PM1000+ power analyzer was used in all laboratory testing.

Figure 87: PM 1000+ Power Analyzer



The MX45 from California Instruments was used to power all tests.

Figure 88: MX45 AC Power Supply

5.4.1.3 Products Used in Laboratory Testing

The table below lists the devices that were selected for laboratory testing. These devices represent the typical appliances one would expect to find in the average home, and they provided measurements that could then be compared to the field measurements.

Table 32: Devices Tested in the Laboratory

Devices Tested		
Air Purifier	Alarm Clock	Coffee Maker
Desktop Computer	CRT Monitor	Desk Lamp
Dishwasher	DVD Player	LCD Monitor
Freezer	Hair Dryer	Laptop Computer
Microwave	Phone Charger	Printer
Refrigerator	Internet Router	Stereo Receiver
Toaster	Toaster Oven	Plasma Television
Vacuum Cleaner	Washing Machine	

5.4.2 Field Testing

5.4.2.1 Test Method

The purpose of the field study was to collect data on the coincidence of use in 21 typical households across the state of California. These sites were distributed across the major areas of the state including the Los Angeles are, PG&E territory, northern California, the bay area, and SD&G territory. Each home was monitored using the WattsUp Pro power meter seen below.

In each home, up to ten appliances were monitored. The selected appliances were chosen based on the likelihood that increasing their power factor would provide significant savings. Devices that are typically found on branch circuits with multiple appliances that are used at the same time were also given a higher priority. These branch circuits include primarily the kitchen and the living room, where many appliances are typically running simultaneously.

Appliances in these spaces include, but are not limited to:

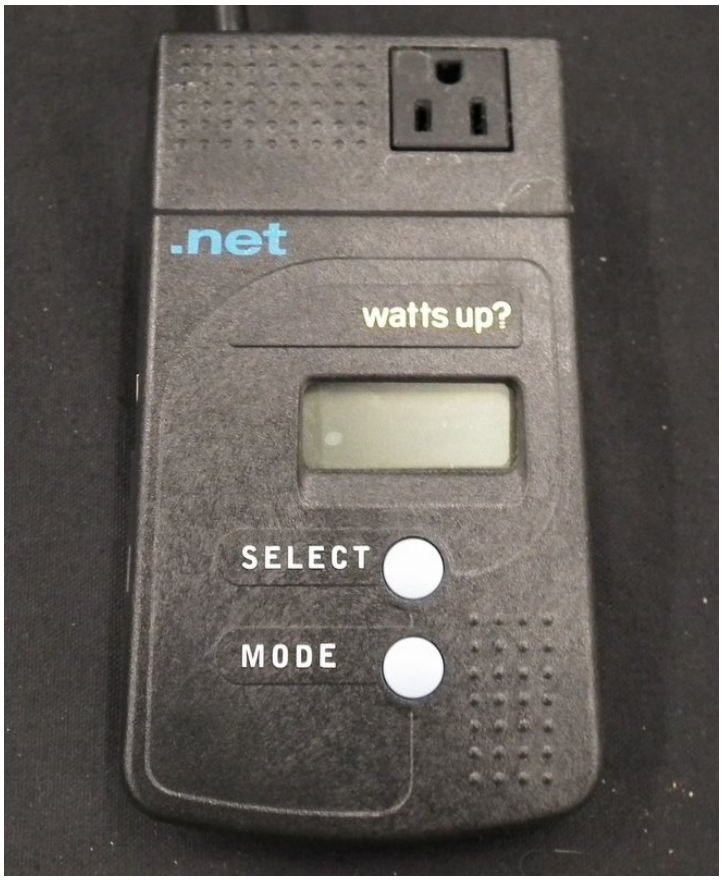
- Microwave
- Refrigerator
- Television
- Set-Top Box
- Video Game Consoles
- Home Audio Equipment

- USB Powered Mobile Devices
- Cell Phone Charger
- Tablet Chargers
- Laptop Computers
- Desktop Computers

5.4.2.2 Equipment

Each plug load in study was metered independently. The meter used in the study was a Watts Up? Pro from ThinkTank Energy Products Inc.

Figure 89: Watts Up? Pro Power Meter Used in the Field Study



Each meter is capable of measuring all of the desirable power characteristics with an accuracy of: +/- 1.5%. These characteristics include:

- Voltage
- Current
- Power

- Power Factor
- Energy

This meter measured and recorded all of the information needed to perform the calculations needed to determine the energy savings potential due to coincidence of use.

5.4.3 Simulations

In order to quantify the potential for energy savings, the research team developed a model that is capable of processing all of the data collected in the field and in the laboratory. This model is capable of creating branch circuits that could be found in both residences and commercial buildings and, based on real-world measurements, calculating the savings in energy that can be achieved if all loads involved have PFC.

5.5 Testing Results

5.5.1 Laboratory Testing

A total of 25 devices were tested in the laboratory using the test method above. In Table 33 there is a small sample of some of the common items found in residential spaces. Please note that the numbers in the table are representative of one device, and the power consumption and power factor of the many brands and models in the market are likely to have different values.

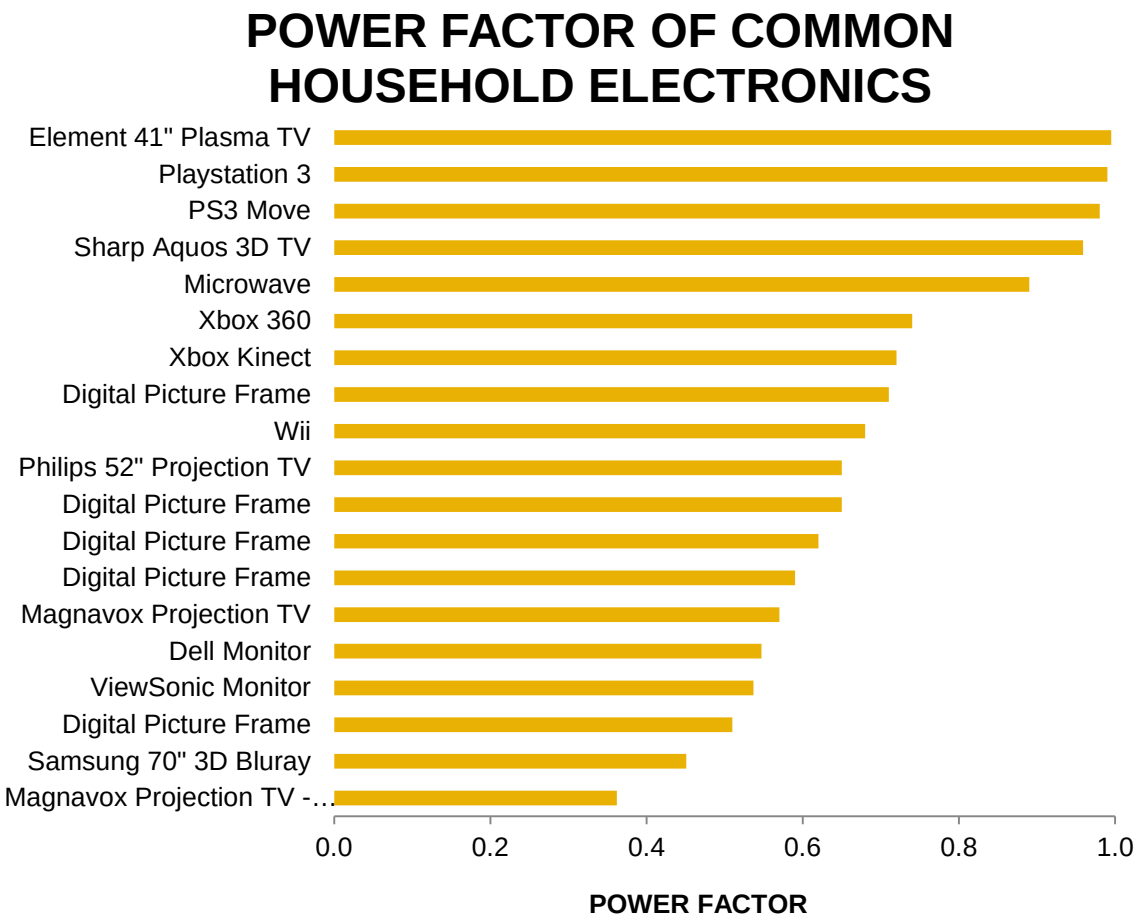
Table 33: Sample of Power Savings for Sample Appliances with PFC

Devices Tested	Power Factor	Maximum Wattage
Home Audio Receiver	0.61	16.90
Desktop Computer	0.55	43.70
CRT Monitor	0.57	66.90
Flat-Screen Monitor	0.56	22.86
DVD Player	0.42	6.09
Laptop Computer	0.51	67.70
Washing Machine	0.70	376.00
Phone Charger	0.50	3.86

These numbers represent the savings achievable considering each device individually. A closer look at how these numbers change when considering at a whole circuit can be found in the *Simulations* section below.

In addition to the 25 devices measured using the specific test method mentioned previously, EPRI has collected power factor information on thousands of devices. This information was leveraged to further populate the savings model. A small sample of additional devices and their power factors are graphed in Figure 90.

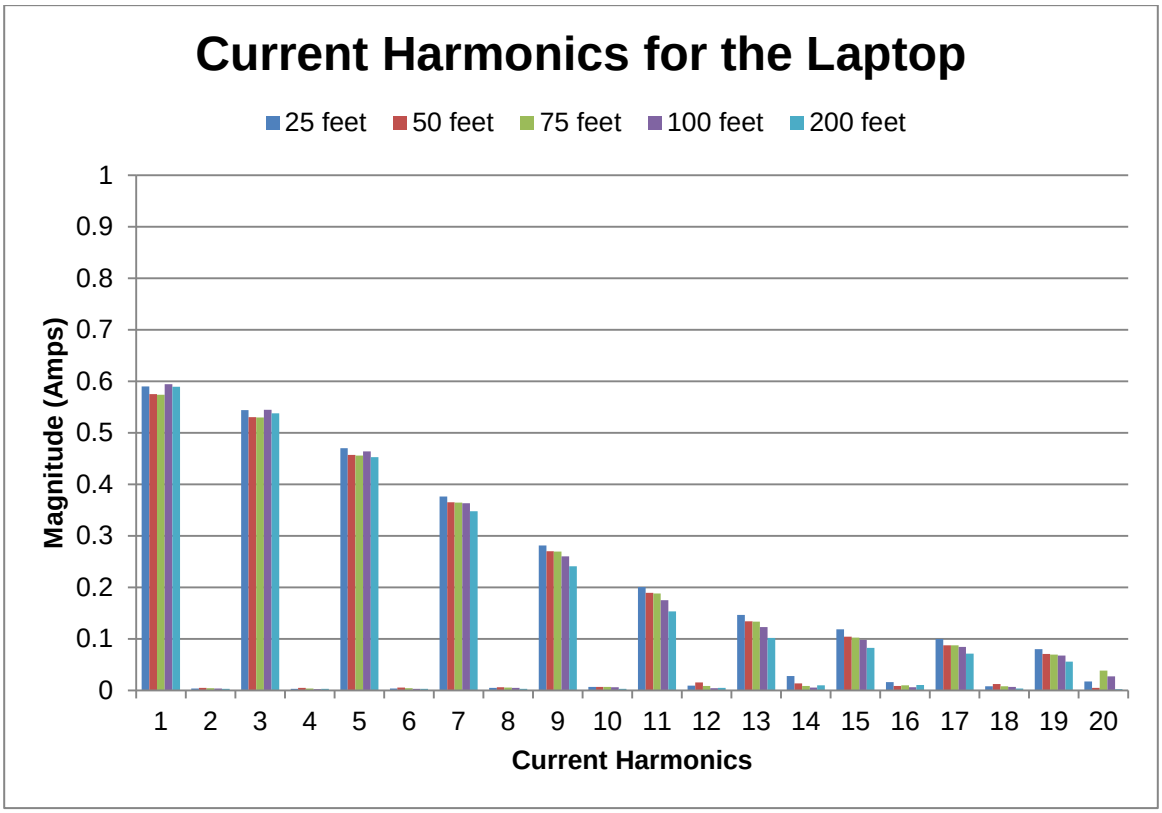
Figure 90: Power Factor of Some Common Household Appliances



In addition to examining just the power factor of these devices, the harmonic content of their current was also recorded. As stated previously, when harmonics are present in the current of a device, the device will waste more energy in the form of heat dissipated in the wiring of the building. The figures below show some examples of devices that had a high harmonic content, and, therefore, have a potential for energy savings.

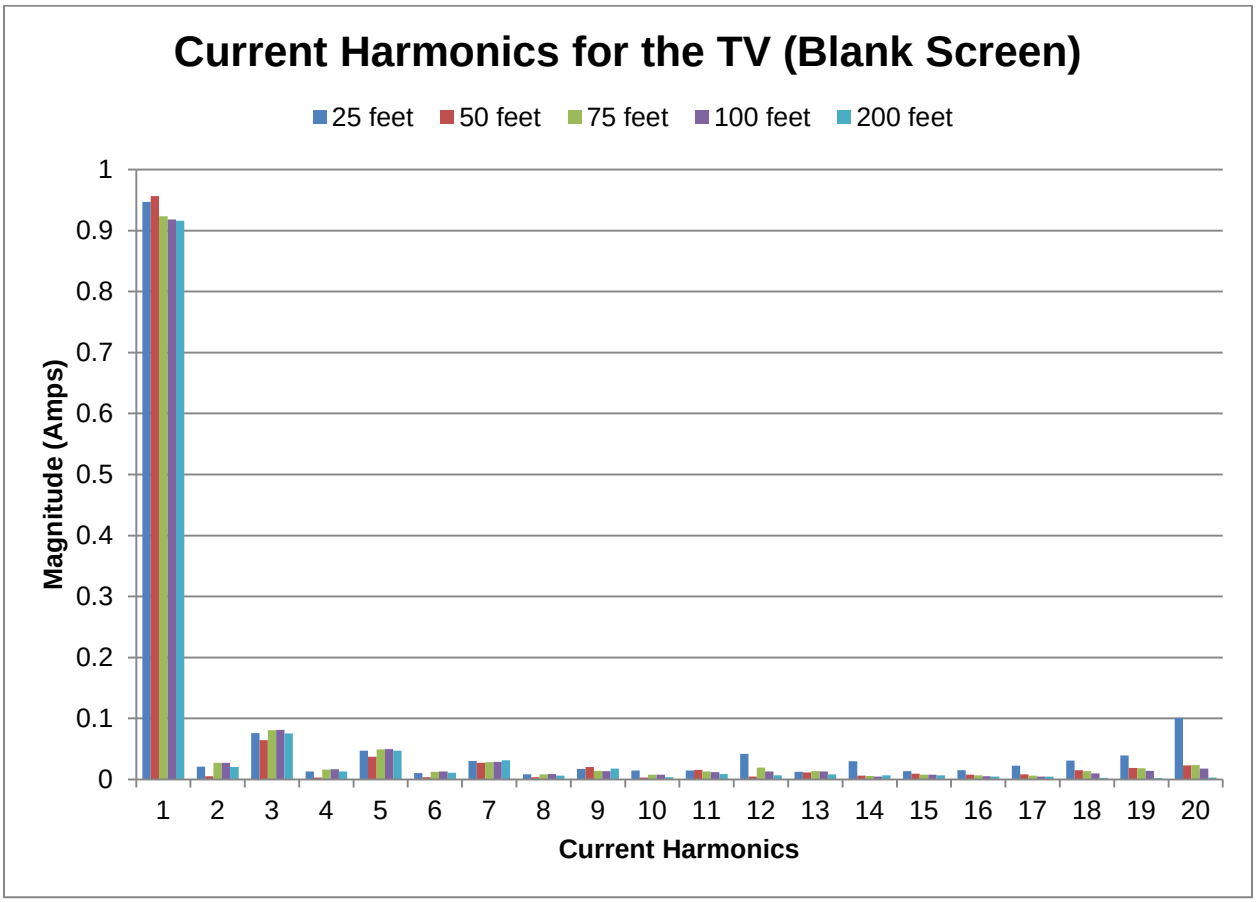
Figure 91 shows the current harmonics that were measured while monitoring a laptop computer. The first harmonic is typically known as the fundamental harmonic. The fundamental represents the amount of current that a device actually needs to operate. In the case of this laptop, the fundamental current is around 0.58 amps, but the RMS current was 1.1 amps. One can see from the figure that the odd harmonics have relatively high amplitude, and these large harmonic values lead to the device drawing more current than is actually needed. This excess current causes additional losses in the wiring of the building. For reference, this device has a power factor or 0.5, meaning that is requires twice the current that the same device with a PF of 1 would consume.

Figure 91: Current Harmonics of the Laptop Tested in the Laboratory



Now, Figure 92 below shows the harmonic content of a device that is power factor corrected. This is a flat-screen television. Like the laptop, it is powered by a switching power supply that produces current harmonics. However, this device has significantly smaller current harmonics due to PFC. This reduces the energy losses in the building wires and provides savings.

Figure 92: Current Harmonics of a PFC Television



5.5.2 Simulations

Using the information from the laboratory testing and the field measurements, the EPRI research team developed a model to estimate the energy losses due to poor power factor using measured values, and then calculate the losses present if power factor were improved to 0.9. Energy savings is calculated as the difference between them. These calculations were made for individual devices and for circuits with multiple devices. As stated previously, it is important to understand the energy savings created by reducing the total current on a branch circuit.

Below is a circuit that was constructed using actual measurements from the field to demonstrate the kind of savings possible in a "best case" scenario.

5.5.3 Best-Case-Scenario

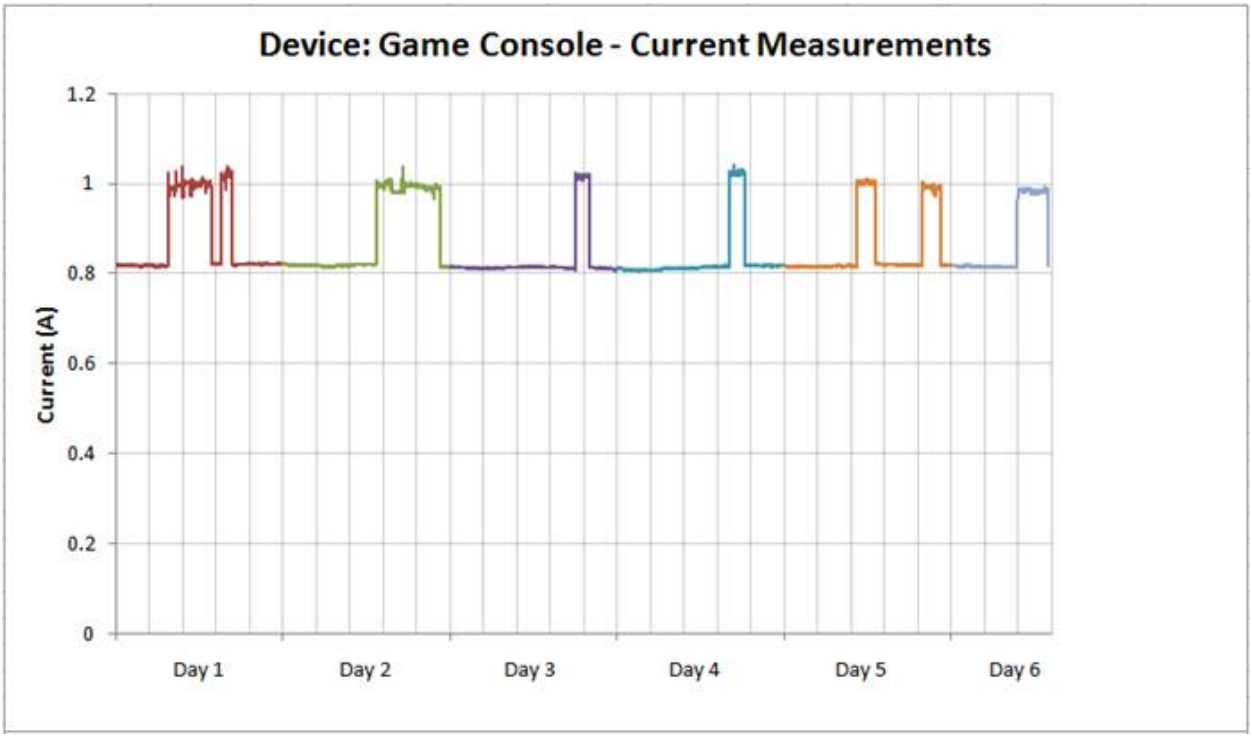
This is an example of a circuit that was created using data from several homes in the field. This is not an actual circuit, but it illustrates the best case for savings with PFC. In a living room, there is a television, a video-game console, a set-top box with DVR, a home audio receiver, and a stereo. None of these devices are equipped with PFC, and therefore represent an opportunity for energy savings. Table 43 below lists the devices.

Table 34: Load Profile of the Devices in Worst Case Scenario

Device	Average Power (W)	Power Factor
Television	48.8	0.59
Game Console	61.2	0.51
DVR	32.7	0.61
Receiver	42.6	0.68
Home Stereo	37.2	0.67

In this scenario, the homeowner never turned off the game console. This also provides an opportunity for additional standards discussion revolving around both the idle-mode power consumption of game consoles and the lack of an auto power down function, or the likelihood that consumers may disable this feature. Figure 93 shows the usage pattern of this game console and shows that even while idle the device required a current of 0.8 A. This generated a daily wiring loss of 1482.94 mWh, which over a year adds up to 0.541 kWh assuming it remains idle and is never turned off.

Figure 93: Usage Pattern of a Game Console

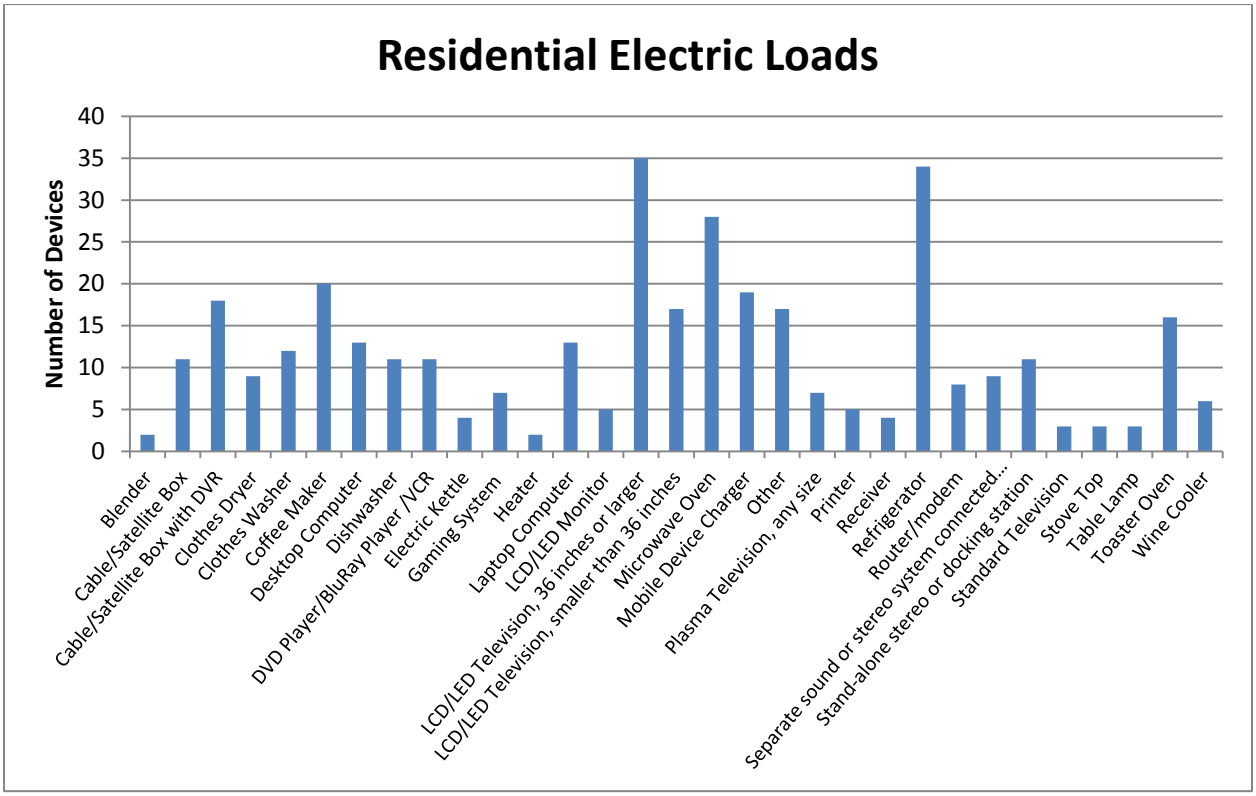


Using the field data to determine how often each of these devices is used, and when they are used simultaneously, the savings over the course of a year is estimated to be 1.46 kWh. Again, this is only a simulation to show the possibilities in a household with several devices that require PFC and are in use for long periods of time every day.

5.5.4 Field Testing

The field survey included data from 21 homes in California. Various devices in these homes were monitored as the occupants went about their normal activities. In total, 349 residential devices were identified Figure 94 shows all of these devices in a bar chart to show the most common devices. Please note, that it was not possible to monitor every device in every home.

Figure 94: Residential Devices Identified in the Field during the Survey



As can be seen from this chart, the majority of homes surveyed had televisions, microwaves, refrigerators, and a set-top box of some kind. This chart provides the kind of weighting that could be used to estimate the number of electronic devices in the homes across California. The table below shows the distribution of the square footage of the sites compares to the most recent California Lighting and Appliance Efficiency Saturation Study (CLASS).

Table 35: Size of Sample Homes Compared to the Homes in the CLASS

Dwelling Size (square feet)	EPRI Sample Set	CLASS Single Family Detached Homes	CLASS All Residence Types
Completed Sites	21	1,491	1,987
Less than 600	0.0%	0.20%	2.9%
600 to 999	0.0%	5.10%	15.8%
1,000 to 1,599	25.0%	31.7%	30.9%
1,600 to 1,999	40.0%	19.6%	14.7%
2,000 to 2,399	15.0%	14.3%	9.9%
2,400 to 2,999	5.0%	12.7%	8.3%
3,000+	15.0%	9.9%	6.4%

The table shows that the homes in the EPRI field study were reflective of the typical size homes in California, but with a slightly larger sample of medium-sized homes.

In addition to collecting information on the number of devices in the field, a number of devices were monitored with power meters to determine their power characteristics. Where possible, a group of devices on the same circuit were monitored to better understand the amount of time the devices were used at the same time, or their coincidence of use. This is important because it allows for more accurate estimates of energy savings.

In the section below, a total of five branch circuits are evaluated using the data captured from real devices in real homes in California. The devices of each branch circuit are identified in tables, and the usage pattern of the branch circuit is charted. This provides some insight into how often these devices are used in a home, which allows for more informed estimations of energy savings that can be achieved through the implementation of PFC.

Branch circuits one through three were chosen to demonstrate the effects of multiple loads on the same circuit and how the coincidence of use can affect the overall savings potential. Despite having zero savings, the fifth branch circuit was chosen as a representative sample for a typical kitchen circuit.

One important conclusion was that kitchens do not present much of a savings opportunity in most cases. It was expected that with the large number of resistive loads (toasters, toaster over, coffee pot, etc.) and refrigerators that are always running, that the opportunity for savings would be higher than it was. However, there were several important points that were learned:

1. Microwaves have a relatively high PF of 0.9.

2. The duration of the high-power resistive loads like coffee pots and toasters are short, and do not often coincide with the use of electronic loads.
3. If a refrigerator has a low power factor, it is due to displacement and not distortion. Refrigerators are primarily motor loads with the fan motors and a compressor motor, and motors do not distort the current, but rather shift it out of phase with the voltage causing displacement. This type of low power factor cannot be corrected with the removal of distortion, which is the subject of this report.

For these three main reasons, there were very little to no savings possible in the kitchen circuits that were monitored, although there could always be exceptions.

5.5.5 Branch-Circuit #1

This circuit was found in a home office. Five devices were monitored and they are listed in the table below. In this circuit, the two monitors used with the desktop computers are already corrected to over 0.9 PF.

Table 36: Devices on Branch Circuit #1

Device	Average Power (W)	Power Factor
Desktop Computer	201.1	0.64
Desktop Computer 2	17.9	0.49
Laptop	44.1	0.51
LCD Monitor	60.1	0.96
LCD Monitor 2	71.9	0.99

The figures below show the usage pattern for the devices on the office circuit over the course of a twenty-four hour period. In this room, the loading is dominated by the Monitor (indicated by the purple bar) in the first two hours of monitoring. Examining Figure 95 reveals that the total load in hour 1 and 2 is around 75 W, and this means that the monitor is using around 70 W while idle. When the desktop is actually in use, it accounts for anywhere from 40 to 95% of the total load depending on if the monitors are on or off.

Figure 95: Branch Circuit #1 Device Contributions to Total Load

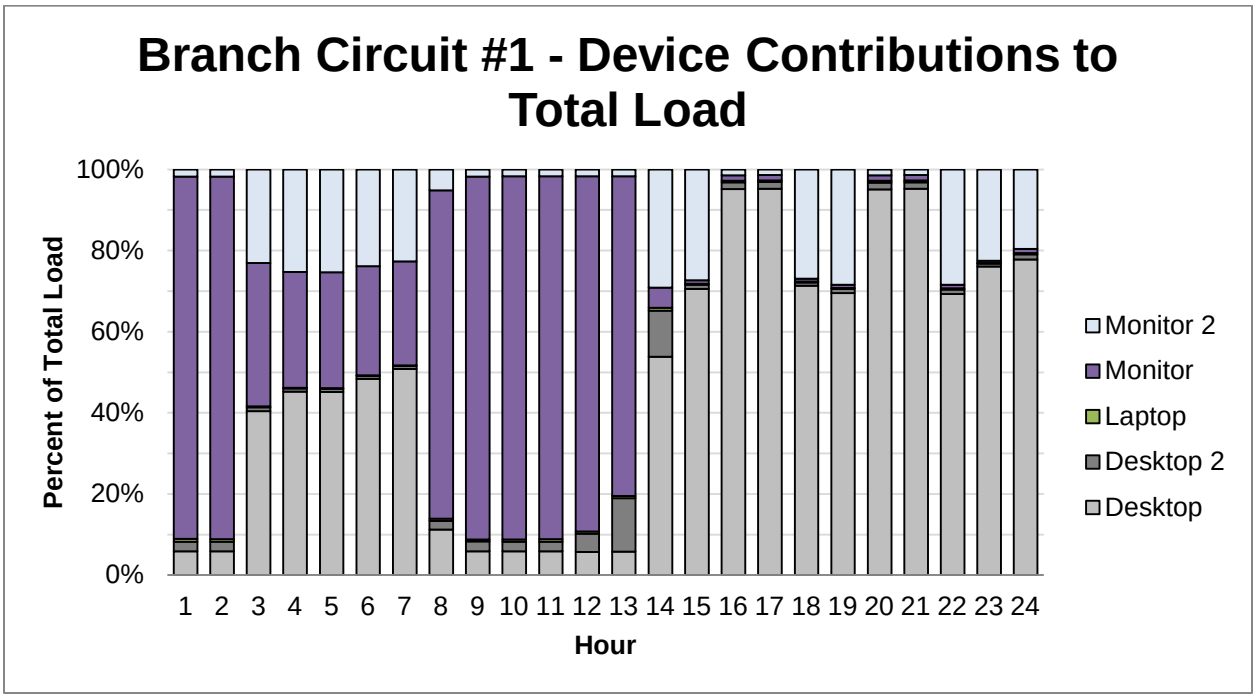
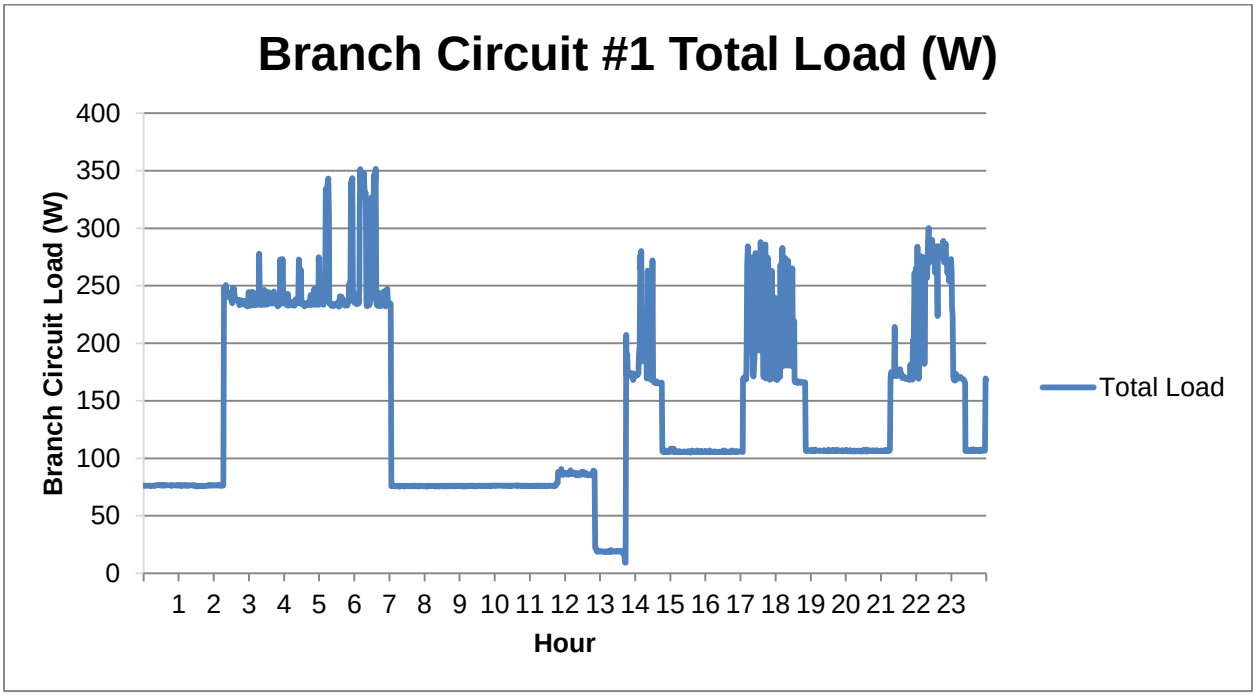


Figure 96: Usage Profile of One Day for Branch Circuit #1



With PFC, this circuit could yield 0.682 kWh savings per year.

5.5.6 Branch-Circuit #2

This circuit was found in a kitchen. Six devices were monitored and they are listed in the table below. This kitchen was atypical in this study because of the washer, dryer, television, and DVR all on the same circuit. This setup created a circuit that could produce a larger savings than the other kitchen circuits encountered in the field.

Table 37: Devices on Branch Circuit #2

Device	Average Power (W)	Power Factor
Desktop Computer	201.1	0.64
Desktop Computer 2	17.9	0.49
Laptop	44.1	0.51
LCD Monitor	60.1	0.96
LCD Monitor 2	71.9	0.99

The figures below show the usage pattern for the devices on the office circuit over the course of a twenty-four hour period. In this room, the loading is dominated by the Monitor (indicated by the purple bar) in the first two hours of monitoring. Examining figure 97 reveals that the total load in hour 1 and 2 is around 75 W, and this means that the monitor is using around 70 W while idle. When the desktop is actually in use, it accounts for anywhere from 40 to 95% of the total load depending on if the monitors are on or off.

Figure 97: Branch Circuit #2 Device Contributions to Total Load

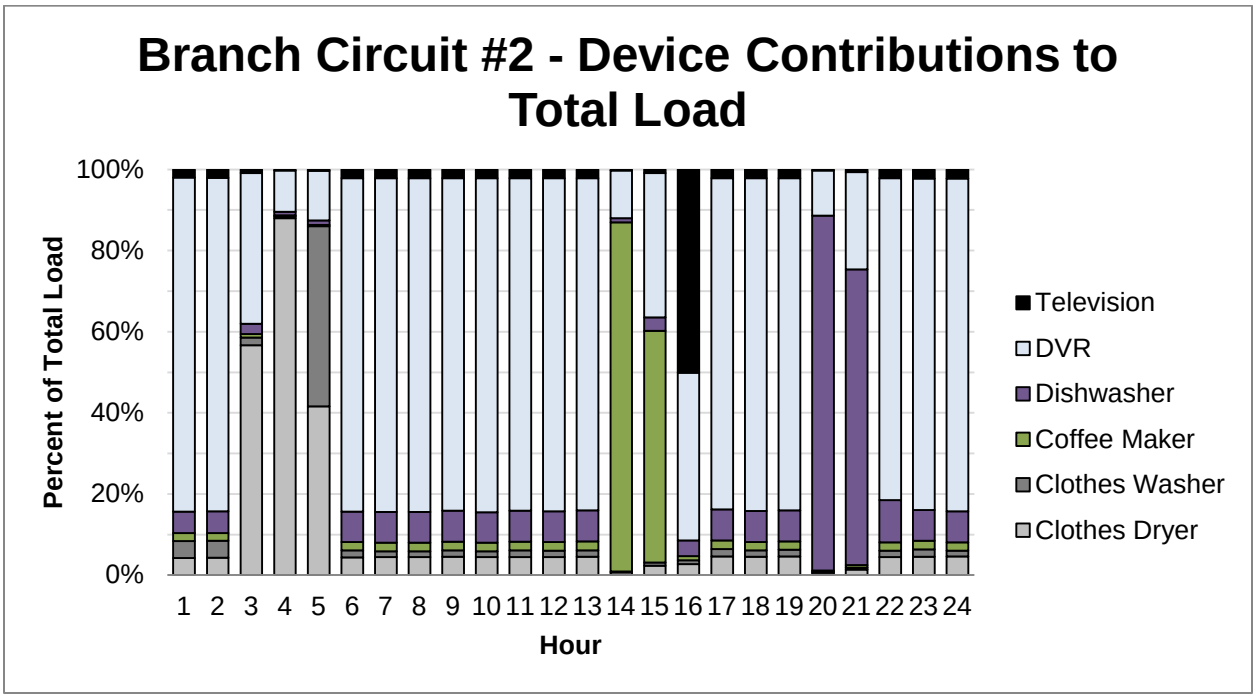
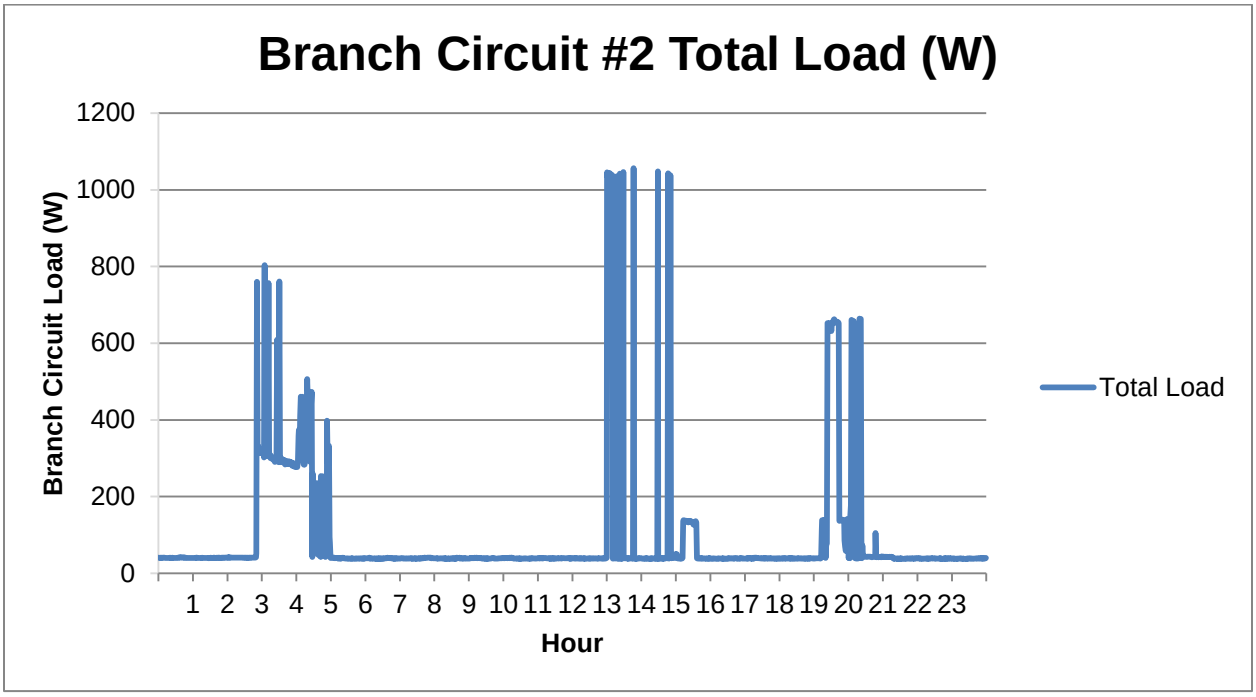


Figure 98: Usage Profile of One Day for Branch Circuit #2



With PFC this circuit could yield 0.219 kWh in energy savings per year.

5.5.7 Branch-Circuit #3

This circuit was found in a living room. Six devices were monitored and they are listed in the table below. In this circuit, the set-top box and one of the televisions was already equipped with PFC.

Table 38: Devices on Branch Circuit #3

Device	Average Power (W)	Power Factor
Home Theater	89.5	0.97
Cable Box	26.3	0.72
Receiver	7.5	0.78
TV 1	19.1	0.72
TV 2	85.8	0.98
Satellite Amplifier	9.1	0.68

The figures below show the usage pattern for the devices on the living room circuit over the course of a twenty-four hour period. This circuit's load is driven largely by the home theater system, the DVR set-top box (STB), and the satellite amplifier. The STB and amplifier are left on at all times and account for about 35 W. One interesting finding in this circuit is that the audio system used more energy than the television, on average.

Figure 99: Branch Circuit #3 Device Contributions to Total Load

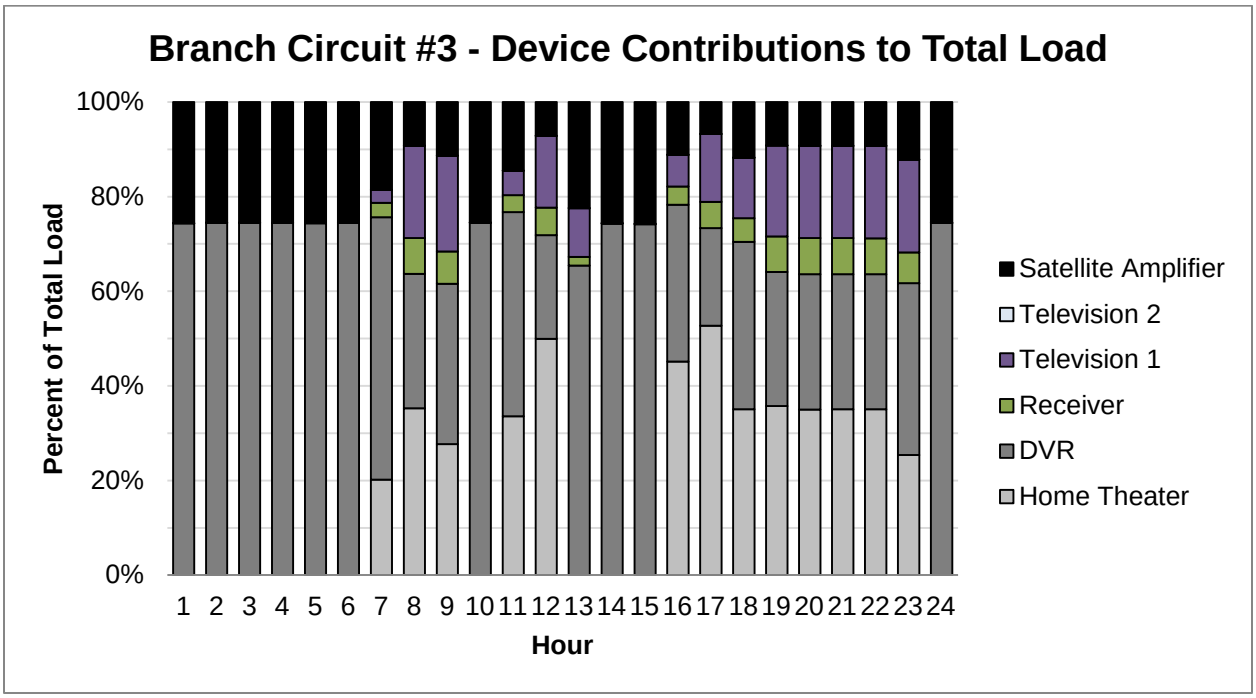
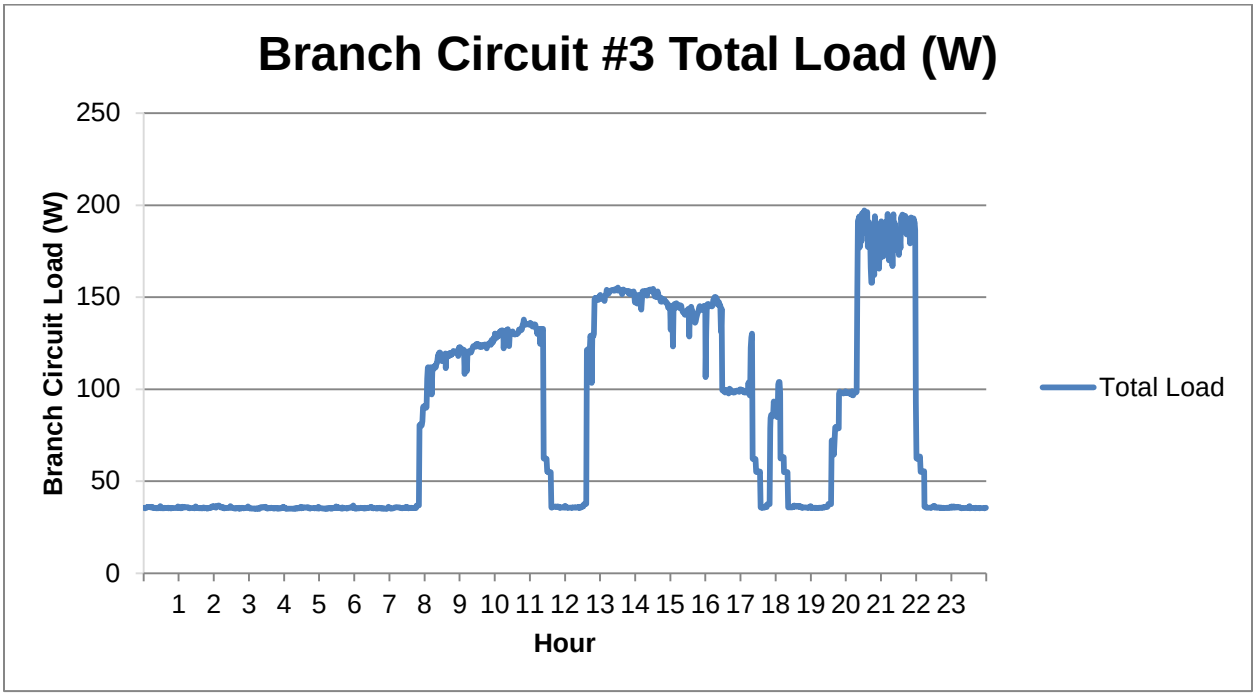


Figure 100: Usage Profile of One Day for Branch Circuit #3



With PFC this circuit could yield 0.117 kWh in energy savings per year.

5.5.8 Branch-Circuit #4

This circuit was found in a bedroom. Three devices were monitored and they are listed in the table below.

Table 39: Devices on Branch Circuit #4

Device	Average Power (W)	Power Factor
Phone Charger	11.7	0.66
Desktop Computer	203.3	0.69
Computer Monitor	12.5	0.62

The figures below show the usage pattern for the devices on the bedroom circuit over the course of a twenty-four hour period. The contributions of the phone charger have been plotted, but they are negligible compared to the desktop computer and its monitor.

Figure 101: Branch Circuit #4 Device Contributions to Total Load

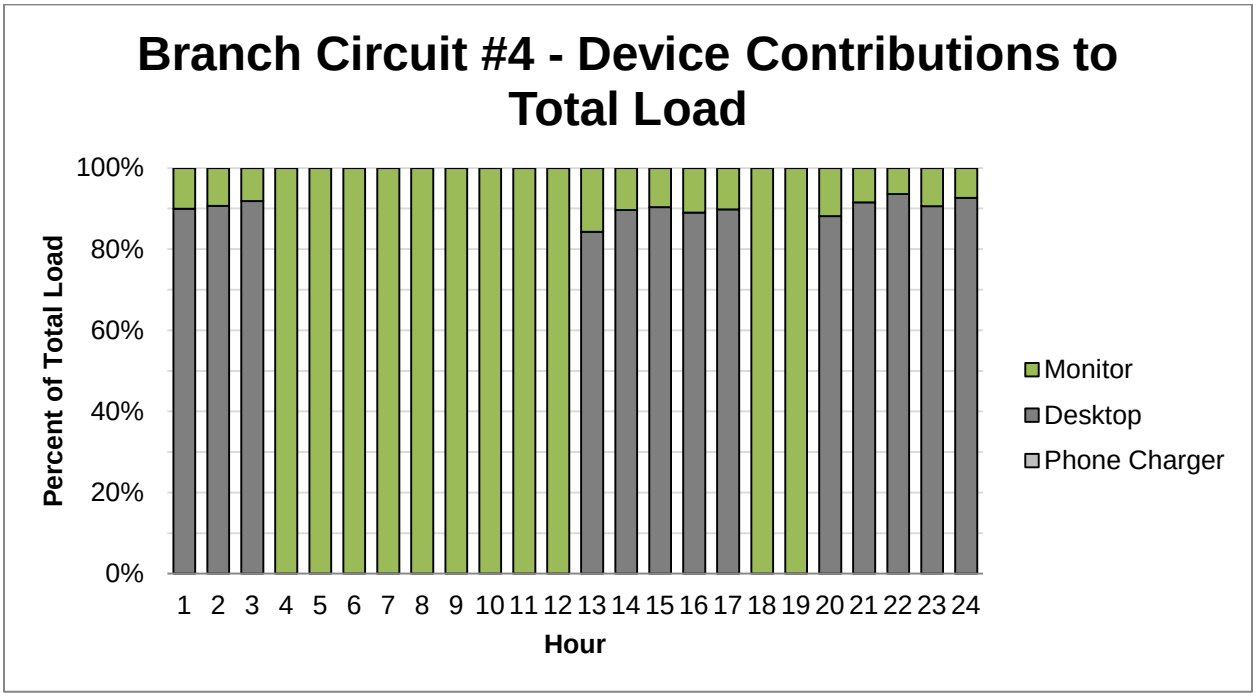
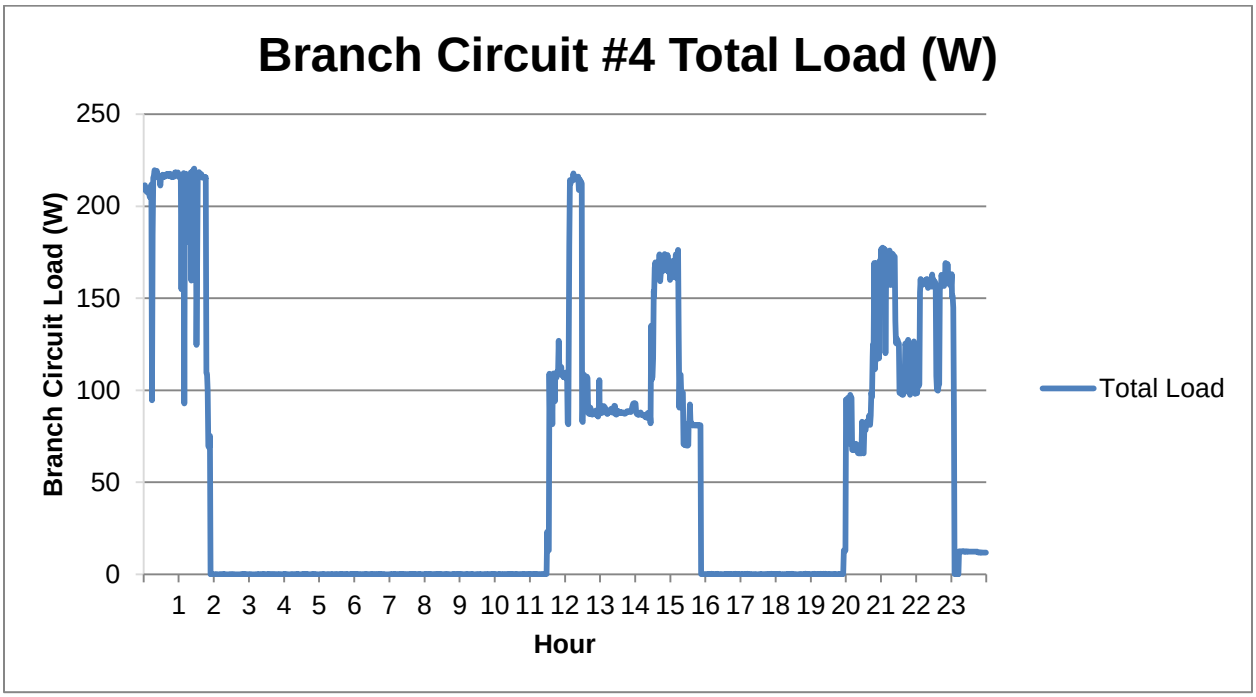


Figure 102: Usage Profile of One Day for Branch Circuit #4



With PFC this circuit could yield 0.444 kWh in energy savings per year.

5.5.9 Branch-Circuit #5

This circuit was found in a kitchen. Four devices were monitored and they are listed in the table below.

Table 40: Devices on Branch Circuit #5

Device	Average Power (W)	Power Factor
Electric Kettle	1347.3	0.99
Phone Charger	5.7	0.87
Refrigerator	109.4	0.93
Toaster	903.7	1

The figures below show the usage pattern for the devices on the kitchen circuit over the course of one day. As is typical in most kitchen circuits, the refrigerator runs nearly constantly.

Figure 103: Branch Circuit #5 Device Contributions to Total Load

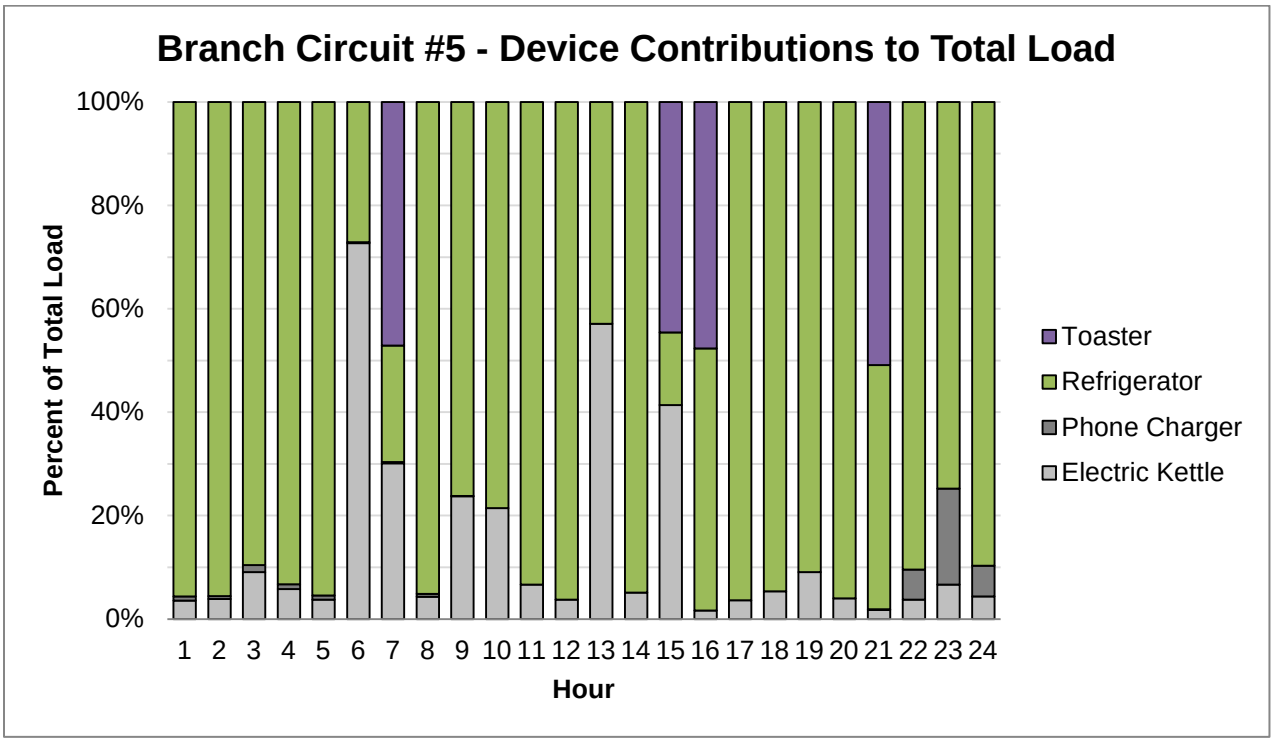
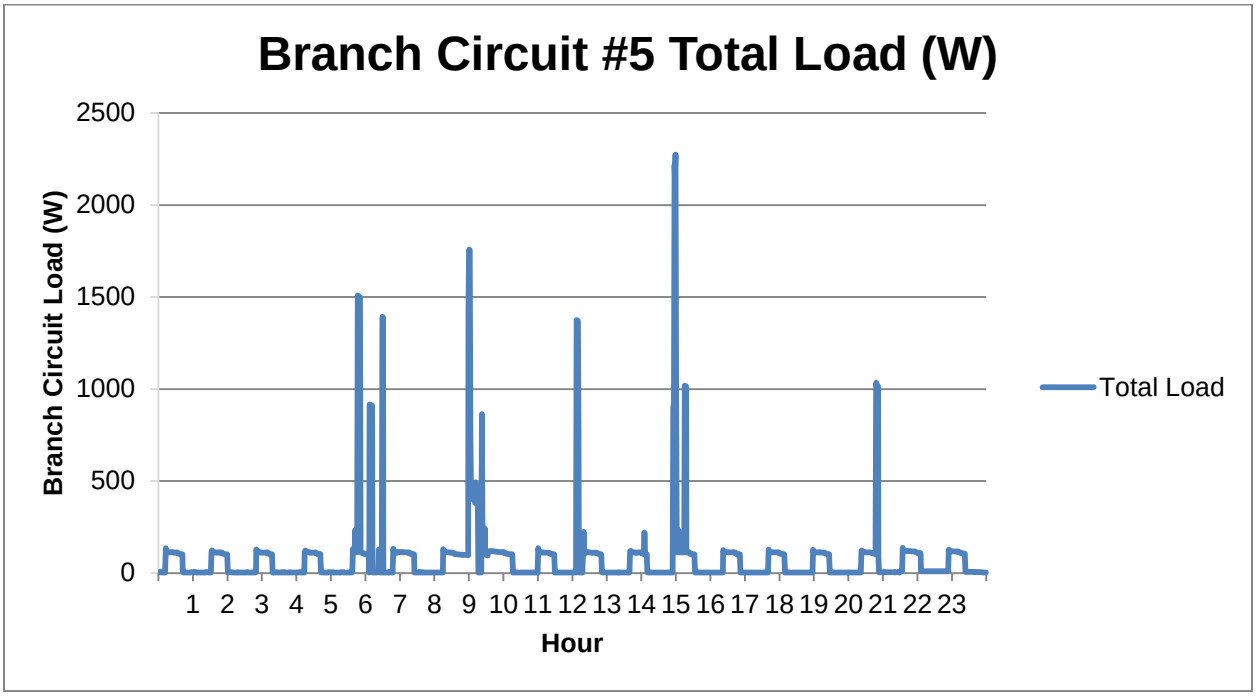


Figure 104: Usage Profile of One Day for Branch Circuit #5



With PFC this circuit could yield 0 kWh in energy savings per year. This is because the loads in this kitchen are resistive, and therefore do not need power factor correction. There are still losses in the wiring of the building, but they cannot be reduced through PFC.

There were very little savings possible in the kitchen. This result was typical of nearly all of the kitchen circuits that were monitored in the field.

5.5.10 Whole-House Savings

Using the branch circuits measured in the field, it is possible to calculate the savings that could be generated in a single home. It is important to note that this calculation may not include every single device in a house, but this calculation serves as a reasonable lower boundary for energy savings. The actual numbers that could be realized could only go up from here once more of the devices in the home are accounted for.

The table below estimated the savings for a home with three bedrooms, a kitchen, a living room, and a home office. The savings for each of these rooms was derived using actual circuits measured in the field.

Table 41: Simulated Whole-House Savings for a More Realistic Home

Room	Yearly Savings (kWh)
Home Office	0.682
Kitchen	0.219
Living Room	0.117
Bedroom 1	0.444
Bedroom 2	0.332
Bedroom 3	0.019
Dining Room	0.051
House Total	1.864
CA Total	24,232,000

With a per house savings of 1.864 kWh per year, if this home represents every home in California, the yearly savings for the whole residential sector would be 24.2 GWh per year.. For more information of energy savings, please visit the *Energy Consumption and Savings Potential Estimates* section below.

5.6 Market Impacts

With the advancements of power electronics, it is relatively easy to implement some sort of active PFC in nearly all applications of a switching power supply. It can often be implemented

with very little additional cost, and with minimal changes to the production line of products. There would likely be a small increase in the final product price that consumers pay so that manufacturers can cover this small cost. In larger devices like televisions, computer power supplies, or game consoles, the additional cost of PFC would be negligible due to the much larger cost of the product itself.

Examples of this can be seen in today's television market. Televisions are continually evolving and increasing in size and the prices are dropping as the technologies mature. The price of the power supply and any added PFC is only a small portion of the overall price of a television.

The ability to implement PFC in electronics was developed years ago, and has continually been improved. As the number of electronic devices in homes across California continues to increase, including PFC in as many devices as possible would save energy statewide. In some cases, the inclusion of PFC could be cost prohibitive to manufacturers of low-power devices like mobile-device chargers. In these cases, it may be more practical to employ the use of house receptacles with USB ports built into them.

It would be advantageous for the PFC circuit to be included in the power supply to the USB port (within the wall receptacle enclosure) rather than a small phone charger, because the cost of implementing PFC into a cheaper item like a phone charger would represent a larger portion of the overall price and could limit consumer adoption. The figures below show two receptacles with USB ports built in. These devices are already equipped with a small circuit board that uses the 120 V supply to produce the 5 V used by USB devices. This circuit board could be improved slightly to increase the PF from 0.5 – 0.6 up to 0.9 to allow for a cost-effective means of increasing the power factor of smaller plug loads like phone and tablet chargers.

Figure 105: USB Sockets in a Receptacle Sample 1

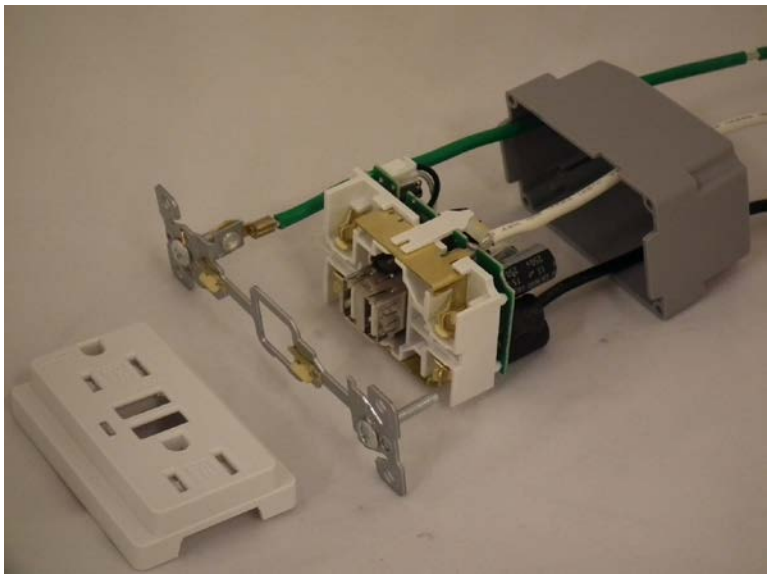
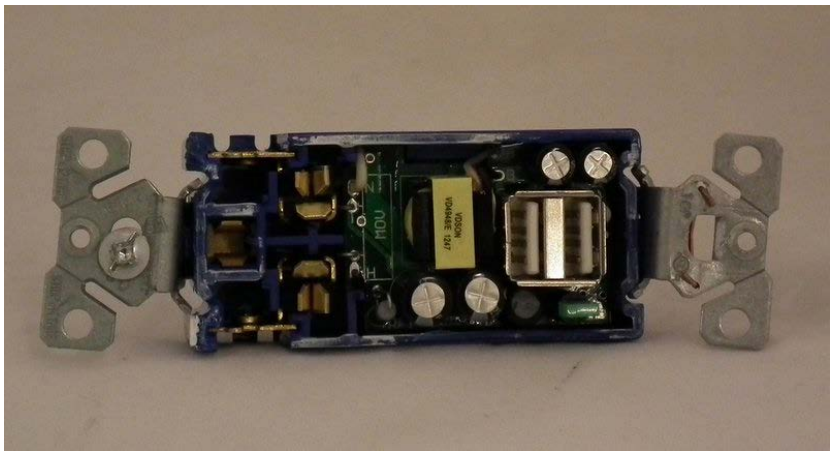


Figure 106: USB Sockets in a Receptacle Sample 2



5.7 Energy Consumption and Savings Potential Estimates

The energy savings estimates were derived in two steps. The first step was to calculate the energy savings potential of devices in the residential and commercial sectors through reputable sources such as the Annual Energy Outlook (AEO) from the Department of Energy (DoE), as well as previous EPRI research and testing, for total energy usage of end-use devices. Next, the EPRI team performed field measurements to gather real world data on real world devices as they are used in the home, and compare those findings against the estimated savings. In the residential sector, the calculated savings represent the upper limit of savings that could be realized, and the savings calculations based on field data represent the lower limit of savings. The estimates based on the field monitoring yielded a savings of 24 GWh/yr. The estimates based on the previous studies and AEO data yielded a savings of 44 GWh/yr (see below for how these savings were estimated). This created a range of 24 GWh/yr – 44 GWh/yr.

5.7.1 Initial Calculations

Using the data gathered from the laboratory and the simulations, the EPRI research team calculated the projected energy savings possible in the state of California for the residential and commercial sectors. In all of these calculations, it was assumed that 80% of the devices in the field are in need of power factor correction, and the duty cycle of every device is 70%.

To begin calculating the number of devices in the state of California, the research team used the 2013 Annual Energy Outlook (AEO) report to estimate the total energy use of devices in the residential and commercial sectors of California.

For residential calculations, the research team used energy numbers for lighting, personal computers (PCs), home audio equipment, rechargeable devices (phones, tablets, etc.), set-top boxes (STBs), video game consoles, external power supplies, televisions, and DVD/VCRs.

In the commercial calculations, the research team focused on office equipment, which is composed of PCs, laptops, monitors, and network equipment.

The total energy usage was assumed to be 11% of the entire United States figures, since the state of California holds around 11% of the population.

It was conservatively estimated that the implementation of power factor correction to increase PF to 0.9 in a residential building could produce an energy savings of about 0.15%. This percentage was based on the field data collected from California homes. Using the measurements from devices with poor PF, the losses in the wire were calculated. The wire losses were then recalculated with the current the device would require after PFC was implemented. The result was an energy savings of 0.15%. Previous work established that the savings due to PFC implementation was slightly higher than 2% in commercial buildings. Assuming a complete stock turnover, the savings would be 44 GWh/y in the residential sector, and in the commercial sector, the savings was estimated to be 197 GWh/y. This creates a total savings of approximately 241 GWh per year.

Table 42: PFC Savings Estimates and Assumptions

CA Households	**million**	**13**
Residential Energy Use (kWh/y)	billion	29.4
Commercial Energy Use (kWh/y)	billion	12.3
Energy Savings with PFC (residential)	%	.15
Energy Savings with PFC (commercial)	%	2
Energy Savings with PFC (kWh/y) (residential)	million	44
Energy Savings with PFC (kWh/y) (commercial)	million	197
Total PFC savings	GWh/yr	241

5.7.2 Applying Field Measurements to the Calculations

In the table above, the estimated energy savings in the residential sector is 44 GWh/y. However, using the field data to simulate a home (see the *Field Results* section above) yielded slightly more than 24 GWh/y. This is a significant difference and there are several possible causes for this discrepancy:

1. Lighting represents a very large segment of the total energy usage in the residential sector, roughly 14.7 TWh, according to AEO data. However, due to the meter used in the

field measurements, it was impossible to monitor any lighting loads that would be found in ceiling fixtures with making significant modifications to the wiring of the meters or the fixture. These modifications would call into question the validity of the measurements, and would have created a hazard for the homeowners. Since lighting represents 50% of the total energy used in the residential sector, depending on the penetration of low PF lighting (CFLs, fluorescent fixtures, etc.) there could be significant savings when lighting is taken into account. The inclusion of lighting in field measurement would undoubtedly bring the total residential savings closer to the estimated 44 GWh/yr.

2. The duty cycle in the calculations in the table above was assumed to be 70% for all devices. Previous estimates were based on the assumption that many of the larger devices like PCs, laptops, and game consoles were left on and idle when not in use, and not turned completely off. However, based on the samples collected in California homes, the actual duty cycles of these devices was closer to 20 – 30% active mode with very little idle mode. ***Homeowners that participated in the study were turning their devices off when not in use rather than leaving them on to idle for significant periods of time.***

3. The field measurements do not necessarily reflect the entire collection of electronic loads that could be found in a home. There are many electronic loads in a home, but the field team was limited to about 10 meters per home. In addition to a limited number of meters, there are some devices (lighting, ceiling fans, dishwashers, etc.) that are sometimes impractical to move around in a home, or a simply impossible to safely monitor. As a result, it is possible that if an entire home and every load inside could be monitored, the energy savings could increase in a meaningful way.

4. The wire runs of a "typical" home are hard to predict. Even homes with the same floor plans and the same contractors can have significant variations in the wire lengths in the circuits, and the number of receptacles and ceiling fixtures on a circuit can vary unpredictably. In this field study, the team was unable to determine the exact length of the wire runs, and it would have been extremely inconvenient for the home owners to have their circuits flipped on and off while the team assessed the exact contents of each circuit.

These findings create and upper and lower limit for residential savings of 24 GWh/yr – 44 GWh/yr. With future testing, it would be possible to gather more information for commercial and residential spaces.

5.8 Conclusion

The purpose of this project was to estimate the energy that could be saved if consumer electronics used in the residential and commercial sectors were power factor corrected to a power factor of 0.9. Through the use of laboratory, field measurements, and market research the EPRI research team developed a series of calculations to identify the upper and lower bounds of the energy that California could save each year with 100% market penetration of power factor correction. These savings are a manifestation of the reduction in the wasted power that is

dissipated as heat in the building wiring. Implementing PFC in electronic devices such as desktop computers, computer monitors, laptops, etc., reduces the current distortion present in the building wiring. This reduction in the harmonic content reduces the total root-mean squared (RMS) current, and this results in a reduction in the energy that is wasted each year.

5.8.1 Key Findings

Through the process of determining the savings potential of implementing PFC in electronic devices across California, there were several interesting discoveries that are of note.

The amount of savings in the residential sector is much smaller than previously estimated. As a result, power factor correction in residential appliances is not likely to be a cost-effective option for legislative efforts, except for large, relatively power hungry devices like televisions. However, commercial savings are more easily and cost effectively realized, and should still be considered as a viable option for codes and standards bodies such as Title 20.

Homeowners that participated in the field study were turning their devices (computers, laptops, computer monitors) off when not in use rather than leaving them on to idle for significant periods of time. Previously, estimates to determine energy consumption in residential applications of office equipment assumed a device would be turned on, used for a period of time, and then left on to sit idle while not it use. Data collected in the field shows that in the twenty-two homes surveyed, the computers and laptops were actually turned off when they were not in use, and the duty cycle was between 20% and 40%.

Since the savings potential of implementing PFC increases with higher currents, and kitchens typically house the appliances with some of the highest currents (coffee makers, toasters, microwaves, etc.), it was expected that the kitchen could provide a reduction in energy losses from PFC. However, kitchens do not present much of a savings opportunity in most cases. This is due to almost every appliance in a kitchen being either power factor corrected, a resistive load, or a motor load (such as a refrigerator). Resistive loads (toaster, coffee maker, etc.) already have a PF of 1 and do not draw a current with harmonic content so there is no room for improvement in these devices. Motor loads, such as refrigerators or dishwashers, may have a PF less than 0.9, but it is due to displacement and not distortion. Refrigerators are primarily motor loads with the fan motors and a compressor motor, and motors do not distort the current, but rather shift it out of phase with the voltage causing displacement. This type of low power factor cannot be corrected with the removal of distortion, which is the subject of this report.

5.8.2 Significance

The research contained in this report can be used to inform the Title 20 rulemaking process, and increase the overall energy efficiency of California's electronic devices. Currently, improving power factor in electronic devices is a largely untapped avenue for significant energy savings. In the United States, California is the only state to regulate PF at all, and that presently only affects televisions of 100 W or higher. This work shows that there is a much greater opportunity than televisions alone.

5.8.2.1 Title 20 Impacts

EPRI measured the power factor of a number of home electronics and appliances to determine the potential impact of statewide minimum power factor standards. As stated previously, power factor is a ratio of real power (power useful to the load) to apparent power (power sent to the load) and ranges between 0 and 1. Power factors of less than one result in additional wasted energy in the building wiring and larger distribution system and occur due to displacement and/or distortion of the current drawn by the plug load. Current distortion is caused by non-linear loads like computer power supplies and creates additional losses in building wiring when many devices operate on the same circuit. Plug load power factor can be improved by utilizing active power factor correction equipment at the device level.

With the exception of state level regulations on television power factor, no other state or federal power factor standards apply to plug loads. In California, televisions must be power factor corrected to 0.9 when they exceed 100 W during operation. Some voluntary specifications, such as the 80 Plus program and Energy Star for desktop power supplies, require specific power factor performance levels for plug loads. Many products that would benefit from improved power factor are also already subject to regulation related to other aspects of device performance.

The relative level of effort required to implement power factor correction policy was rated as high due to the diversity of products covered under potential regulations. Manufacturers from dissimilar product classes would have to be engaged and the technical implementation of power factor correction equipment evaluated. Energy savings were seen as low, but cost effective due to low per product upgrade costs. Existing state and federal device regulations may cause preemption issues and should be further studied.

Considering the above factors, the EPRI research team developed a recommended specification that could inform Title 20 policy that would require all plug-loads larger than 50 watts to have power factors of at least 0.9 at 50 and 100 percent load. With this policy, an estimated energy savings of 241 GWh per year after full stock turnover could be achieved.

This calculation was performed taking into consideration the number of electronic devices in both residential and commercial spaces in California. The majority of electronic devices in residences are identical to those devices used in commercial applications so the field and laboratory measurements are still applicable to estimating the energy savings potential in commercial buildings. For more information on these estimates, please see the Energy Consumption and Savings Potential Estimates section above.

Table 43 Power Factor Summary

POTENTIAL ENERGY SAVINGS	241 GWh per year
T20 OPPORTUNITY	• Require all plug-loads larger than 50 watts to have power factors of at least 0.9 at 50 and 100% load.

5.8.3 Future Opportunities

With additional field studies, and a larger sample size, it could be possible to update the knowledge base of devices to include new developments and their distribution in both the residential and commercial sectors. The field testing in this project took place in the residential sector, and that presents a large opportunity for future work to take place in the commercial sector to better inform the calculations for the energy savings that are possible with PFC.

CHAPTER 6: Efficient Motor-Driven Appliances Using Embedded Adjustable-Speed Drives

6.1 Background

The use of adjustable-speed drives (ASDs) saves energy. However, the energy savings benefit of using an adjustable-speed drive has only recently been appreciated. The purpose of this research was to demonstrate that the addition of adjustable speed drives to the design of widely used domestic appliances will save energy. Additionally, the research demonstrates other associated benefits that accrue. Proven published results will promote understanding and encourage the wider use of these energy saving techniques. The energy savings benefit will be further enhanced by improvements in demand response (DR) and power factor (PF). Environmental benefits will also be gained. 70% of Californians understand the connection between reduced use of electricity and reduced atmospheric pollution and are supportive of adopting beneficial technology. This research illustrates the benefits of using adjustable speed drives in domestic appliances to reduce both energy use and environmental impact.

EPRI, through its member support, has long regarded adjustable speed drives as a powerful enabling technology. EPRI's Adjustable Speed Demonstration Office (ASDO) was opened in 1993 in response to a sense that a breakthrough and revolutionary technology had come of age. Field demonstration projects undertaken used a systematic approach and highlighted the reliability, robustness, energy efficiency, and precise control that is offered by ASD systems in industrial, commercial, and institutional three-phase electrical systems. A significant outcome of the work was evidence that the control of fixed displacement compressors provided up to 40% energy reduction, enabled faster production rates, and improved product quality. This provided a sound footing for the present study of ASD-driven compressors in domestic appliances. The introduction of electronically commutated motors (ECM)—three-phase motors powered by a single-phase supply—was pivotal and allowed ASDs to be used domestically. The ECM enables single-phase power to be used in a three-phase motor. ECMs operate 40–50% more efficiently than a conventional single-phase machine that was commonly used in domestic appliances. It should be understood that industrial systems are powered by a three-phase electrical supply while domestic systems are powered by a single-phase electrical supply. Until the development of the ECM, the single-phase power supplied to homes prevented the use of ASD technology in domestic applications.

To maximize the impact of the project, domestic motor-driven appliances were identified, both plug and permanently installed loads. Data were gathered on each load with the objective of identifying four motor-driven loads that would most benefit from ASD control. The initial research revealed that a number of good potential candidates such as pool pumps, clothes washing machines, and ceiling fans had already implemented the use of ASD and advanced motor design. The approaches that had been taken to achieve early market transformation for these products were used as the basis for the approaches recommended for the four appliances

selected for this study. Refrigerator/freezers, clothes dryers, central ducted HVAC systems, and single-room HVAC systems were selected, and representative samples of the four ASD controlled appliance groups were tested alongside non-ASD versions. The results obtained from the side-by-side comparative testing were used to predict the impact of 100% penetration of ASDs and advanced motor configurations. These laboratory results were compared with the market predictions. The tests also demonstrated that when ASD control is implemented, demand response can be implemented at will. Additionally, the use of correctly figured ASD systems ensures that power factor is maintained at a high level.

6.2 Technical Overview

6.2.1 Motor and ASD Technology

Electric motors are used to convert electrical energy into mechanical work. To be energy efficient, this conversion requires a dynamic match of motor output power to the applied load power requirement. ASD technology provides a means of converting single-phase power into an electrical format that provides energy-efficient speed control for a three-phase electric motor.

This technology provides a means of closely matching energy requirements to power delivery. It also enables the electrical power delivered from an electric motor to match the energy required to complete a task. Adjustable speed drive technology permits the use of a high-efficiency three-phase motor to convert electrical power to mechanical power and, in turn, displaces low-efficiency single-phase electric motors. This technology facilitates energy efficiency in domestic appliances and offers a variety of associated benefits that reduce material costs and avoid wear and tear.

6.2.2 The Fundamentals of Electric Power Delivery

Electric power is generated and transmitted in a three-phase configuration. However, for economy, each phase is separated and distributed singly to domestic residences. This distribution method originated as the supply for residential electric lighting, and the method of delivery remains unchanged.

6.2.3 The Fundamentals of Electric Motor Operation

An electric motor requires a rotating flux, which is inherently provided in a three-phase delivery system. As residential requirements for electricity have changed to include electric motors, phase shift has been improvised to operate motors. Single-phase power with phase shift supplied to the motor—managed by capacitors, centrifugal switches, and such—reduces the efficiency of the motor by 30%. Additionally, devices that facilitate single-phase motor operation can also compromise reliability.

6.2.4 The Fundamentals of an Adjustable Speed Drive

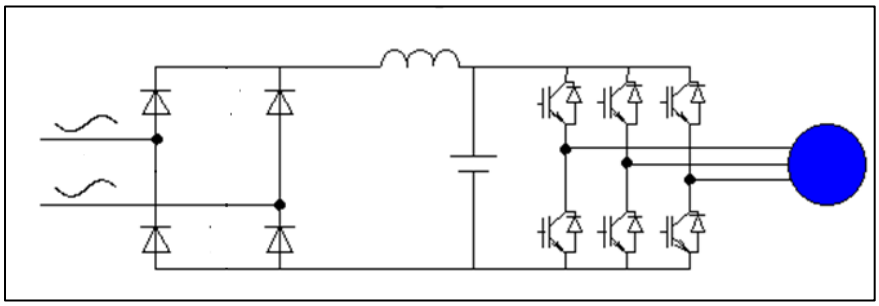
The following describes the functions and characteristics of adjustable speed drives.

Adjustable speed drives are configured to remove and manipulate the frequency provided by the utility and thus adjust the speed of the device. This is done by passing the AC input voltage from the utility through a full-wave rectifier bridge. The output of the rectifier bridge is a relatively smooth DC supply. Additional “smoothing” is provided by a capacitor bank, which

serves as a source of reactive power for the motor. The smoothed DC voltage can be converted into the required output voltage and frequency by an inverter bridge circuit that uses pulse width modulated techniques.

Alternating polarity blocks of DC are sequenced such that the required voltage and frequency are produced. Change in voltage is achieved by increasing the width of the blocks. Change in frequency is achieved by the rate of change of polarity. Fundamental to the wave form generation is a base switching frequency, which will be in the range of 2 to10 kHz. This pulse width modulation (PWM) waveform is changed by the action of the motor into a sinusoidal current waveform providing efficient motor operation.

Figure 107: Voltage-Fed ASD System with Input Diode Rectifier, DC Link, Inverter, and Motor



The width of the pulses is sinusoidally modulated (narrower pulses getting progressively wider and then narrower for each half cycle). Figure 108 and Figure 109 are a simplified form representing pulse width modulation showing one and two cycles, respectively. In real terms, for example, a 60-Hz waveform generated from a 5-kHz modulation frequency would contain 41 pulses in each half cycle and 82 in a complete cycle. Figure 110 shows a pulse-modulated current wave form.

Figure 108: Diagrammatic Representation of Sinusoidally Modulated DC Pulses (One Cycle)

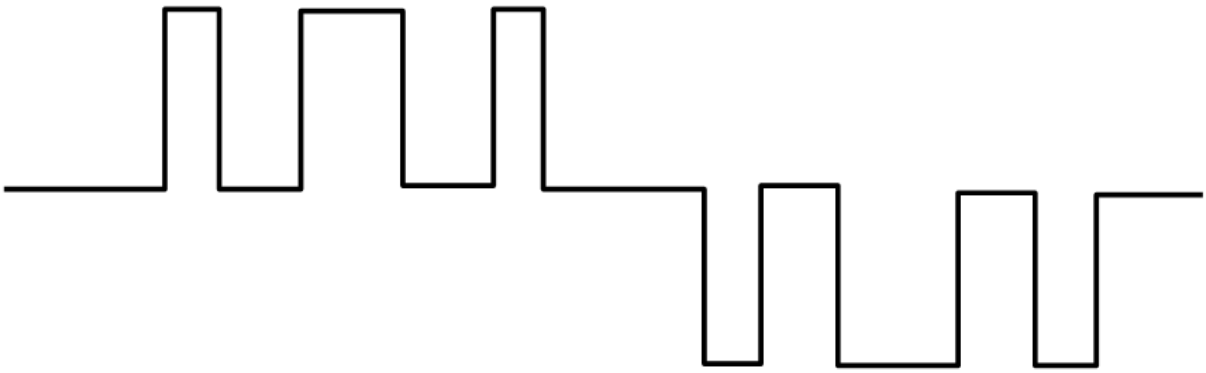


Figure 109: Diagrammatic Representation of Sinusoidally Modulated DC Pulses (Two Cycles)

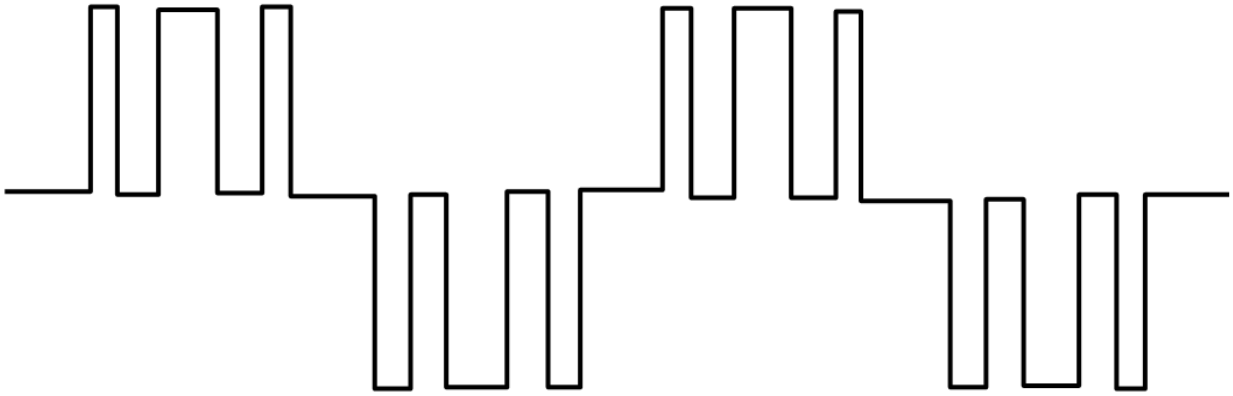
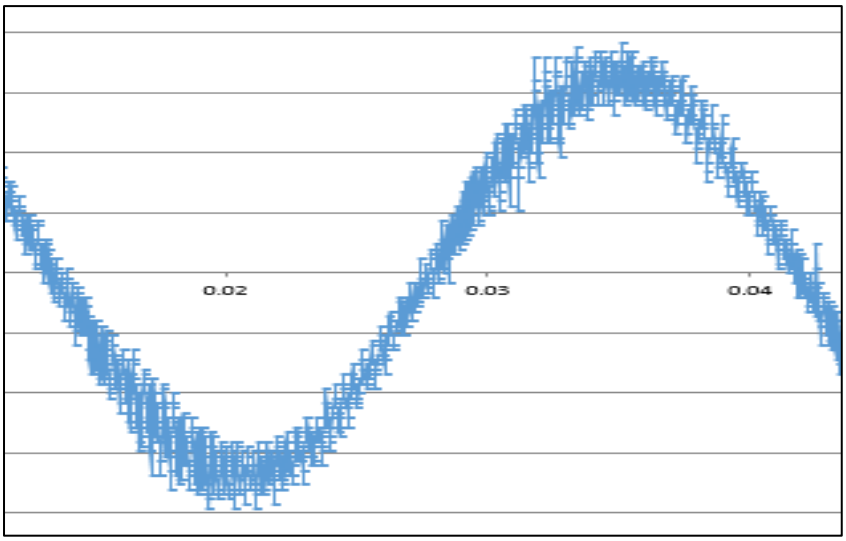


Figure 110: Pulse Width Modulated Current Waveform



The invention of the insulated gate bipolar transistor (IBGT) and the application of the digital signal processor (DSP) during the 1990s transformed the cost, size, and performance of adjustable speed drives. Performance increased while both cost and size decreased. These improvements are supported by the displacement of asynchronous induction motors by highly efficient, compact, synchronous induction motors. A tremendous change has occurred: there now exists a technologically superior drive, a motor with improved topology, and the availability of very efficient scroll or reciprocating compressors—a truly powerful combination. An example of a refrigerator/freezer 500-W adjustable speed drive and associated synchronous motor is shown Figure 111 and Figure 112.

Figure 111: Pul ASD 50-Hz to 150-Hz Refrigerator Motor Controller

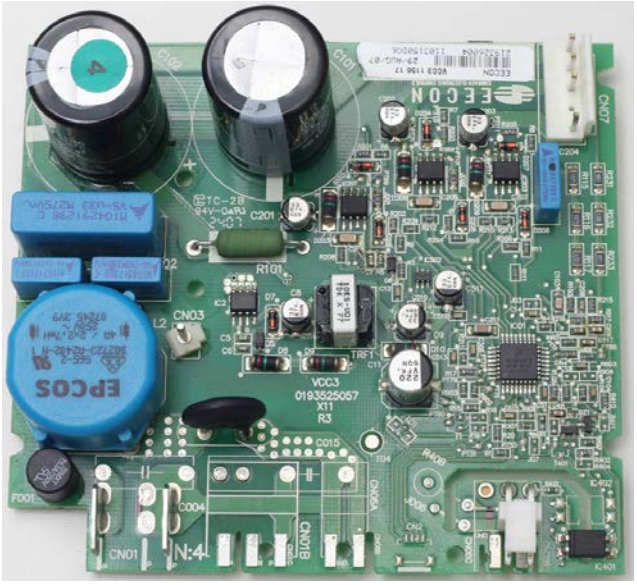


Figure 112: Compact, Three-Phase Salient Pole Synchronous Induction Motor

In contrast, examples of a low-efficiency, bulky, single-phase, single-speed standard asynchronous induction motor stator and squirrel cage rotor are shown in Figure 113 and Figure 114. These are typical of the conventional motor construction widely in use today.

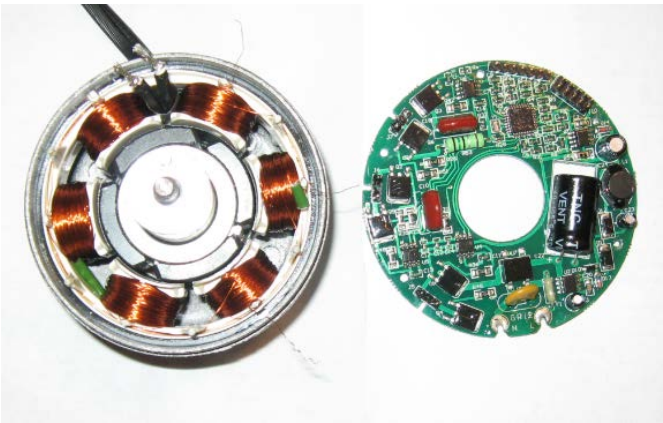
Figure 113: Split Phase Stator Winding

Figure 114: Squirrel Cage Rotor

6.2.4.1 Electrically Commutated Motors (ECM).

ECMs are readily available. They are the most recent addition to the energy savings arsenal. Their major contribution to energy conservation is the displacement of low-efficiency single-phase machines with a high-efficiency electric drive system. They can be used as fixed speed or adjustable speed delivery systems. They have high power factor input and very low losses. They can be used to replace evaporator and condenser fans in refrigerator/freezers, and they are now commonly found in ceiling fans (Figure 115).

Figure 115: Electronically Commutated Motor



The use of adjustable speed controlled motors captures a number of benefits. ECMs are effectively an ASD with a motor and are used in place of conventional single-phase motors. When adopted for use, they:

- Permit the use of smaller, lighter, and more efficient three-phase electric motors. This reduces the cost of the equipment and the cost of manufacture because smaller quantities of raw materials are used. This is turn preserves raw materials and benefits the environment.
- Eliminate motor starting inrush current transients. This reduces wear and tear on starting components and driven parts. It reduces stress on motor windings and improves reliability by providing gentle control of the motor and load.
- Eliminate start-and-stop noise events. Motor starting becomes gradual rather than abrupt, and this avoids those noise transients that occur from the movement of compressor housings and refrigerant lines.
- Provide closed loop control of power that enables accurate and continuous power matching to the load. The use of a permanent magnet synchronous motor enables precise speed control.
- Enable mechanical noise bands to be avoided, which results in continuous quiet operation throughout wide speed ranges. Digital control provides discrete speeds to be selected from the continuous range of speeds available. These selected speeds are customarily chosen to minimize noise.

- Provide all of the "wattless" (kVar) power required by the electric motor. The capacitors connected to the DC link in the ASD provide all of the reactive or wattless requirements of the motor.
- Provide thermal and short-circuit protection required for the load system. The ECM/ASD electronics contain a thermal model of the motor, preventing short-term and long-term thermal damage to the motor.
- Provide speed that is higher than the highest speed (3600 rpm) available from single-phase motors. The ASD can provide frequency higher than 60 Hz, which enables motor speed to be limited only by the mechanical capability of the motor rotating parts.
- Include hard-wired algorithms that match the motor performance to the specific load. The ECM/ASD logic is optimized for each load, which enables the microcontroller to be hard programmed for optimum performance.
- Provide external links for remote control that could be employed for programmed demand response. The ASD logic is readily adaptable for Wi-Fi control.
- Operate at high power factor. The ECM/ASD power circuit contains modulation control that maximizes input power factor.
- Function efficiently using a three-phase supply (20–60% improvement over original single-phase motor) and provide control over a wide speed range.
- Provide accurate speed control that avoids asynchronous induction motor "slip" and eliminate losses associated with "slip." This offers higher reliability because phase shifting items are eliminated.

ECMs/ASDs are currently used within a limited number of market available refrigerator/freezers, clothes dryers, ducted central HVAC systems, and ductless single-room HVAC systems (those appliances types chosen for this study) and benefit in a variety of ways from the introduction of adjustable speed drive technology. Though available in the marketplace, models have not been widely utilized. This lack of market penetration could potentially be from limited public exposure and education regarding the benefits of ASDs.

6.2.4.2 Refrigerator/Freezers.

Refrigerator/freezers are prolific in California and nationwide. They are prime candidates for conversion to adjustable speed compressor operation because they are produced in high volume and used in almost every household. They offer the opportunity for energy savings in single households as well as cumulative energy savings through reduced demand collectively on the grid. Along with energy savings, improved power factor will reduce energy loss in the distribution system and offer opportunities for demand response. ASD control is well proven and available in several retail products.

Refrigerator/freezers each contain three motors: the compressor motor, the evaporator fan motor, and the condenser fan motor. Typically, these motors are inefficient, single-phase, single-

speed asynchronous induction motors.Figure 116 amd Figure 117 show common refrigerator/freezer system components.

Figure 116: Basic Refrigerant Path Common to Refrigerator/Freezer Systems

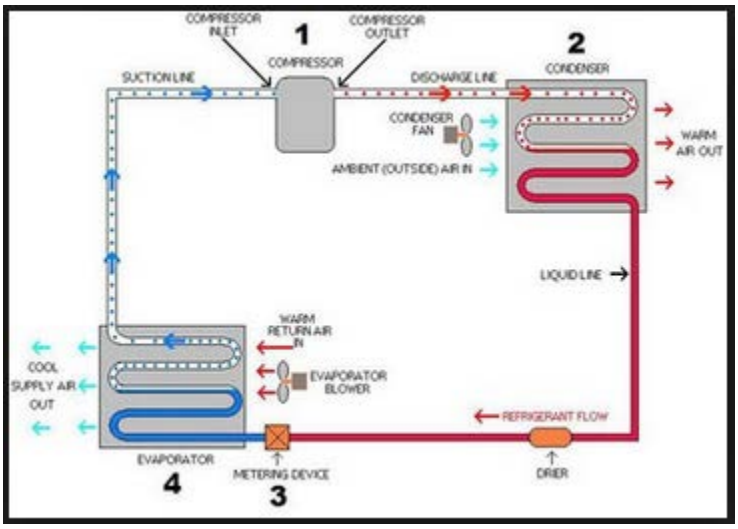
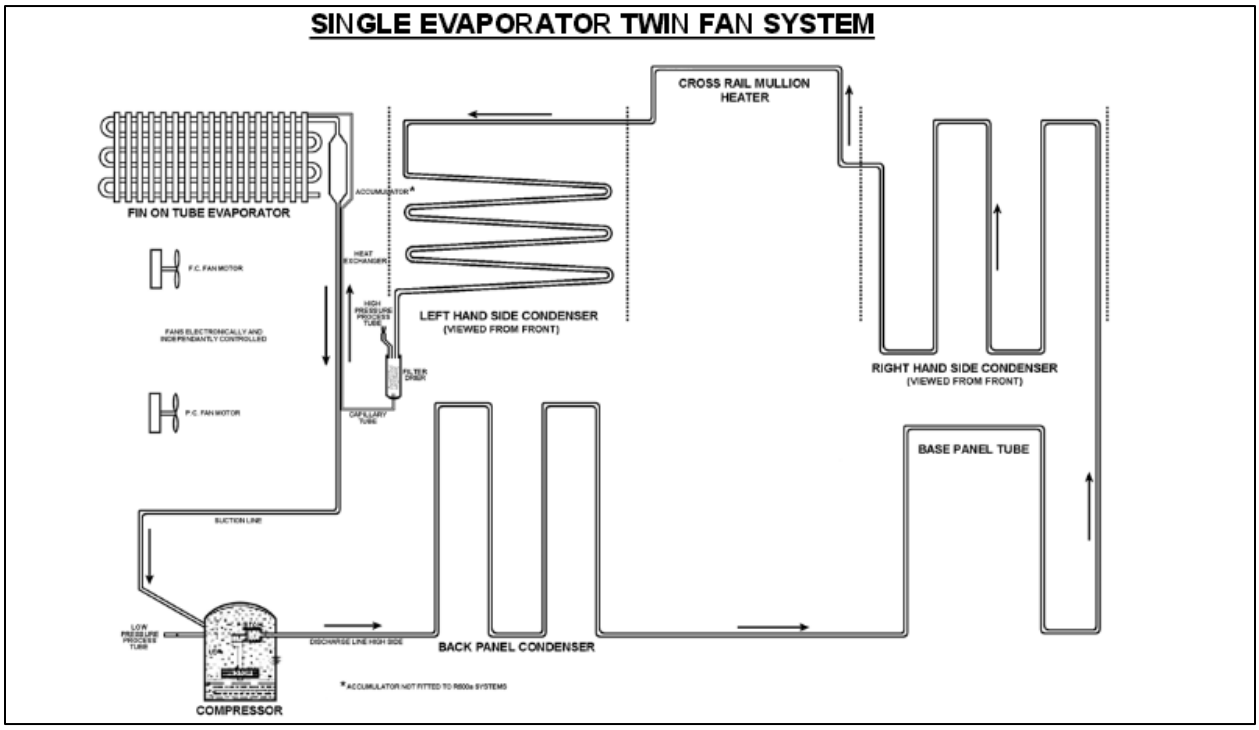
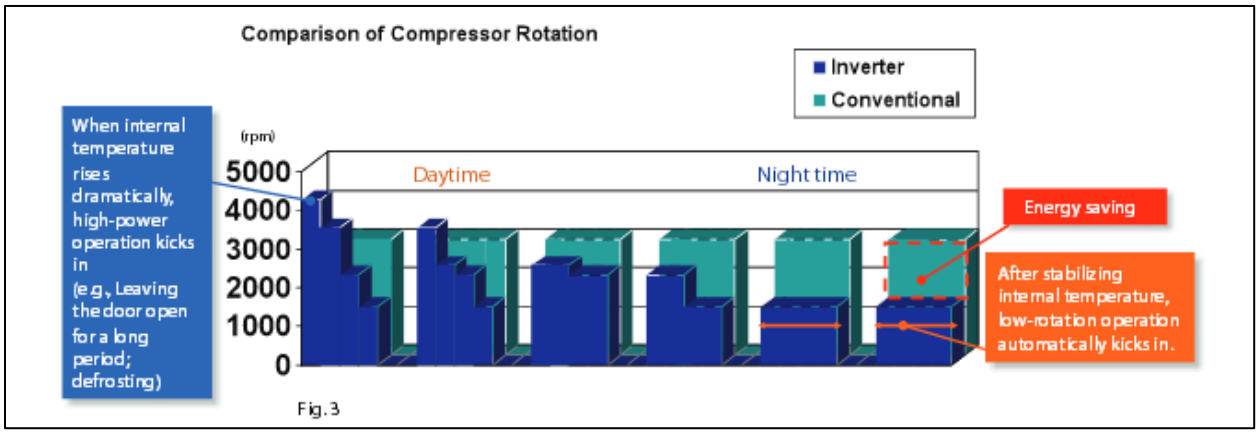


Figure 117: Practical Layout of the Refrigerator/Freezer Heat Exchanger Components



Panasonic, a manufacturer of hermetically sealed adjustable speed driven compressors, has published data illustrating considerable energy savings (Figure 118). Perlick, also a manufacturer of domestic refrigerators, has published an estimate for refrigerator compressor energy savings of 44%. A dynamic model is available at www.perlick.com.

Figure 118: Energy Reduction Achieved by Using Adjustable Speed Control of the Compressor Motor



Note that *ASD control* is often referred to as *inverter control*. Once an inverter or ASD is introduced into the design of a refrigerator/freezer, new approaches can be taken to enhance the potential for energy savings. Reduced compressor capacity can be used for all normal loads, and peak requirements can be handled by raising the compressor speed Figure 118). Unexpected and additional benefits were observed (Figure 119 and figure 120).

Figure 119: Opportunities to Optimize Compressor Capacity Once Speed Control Has Been Implemented

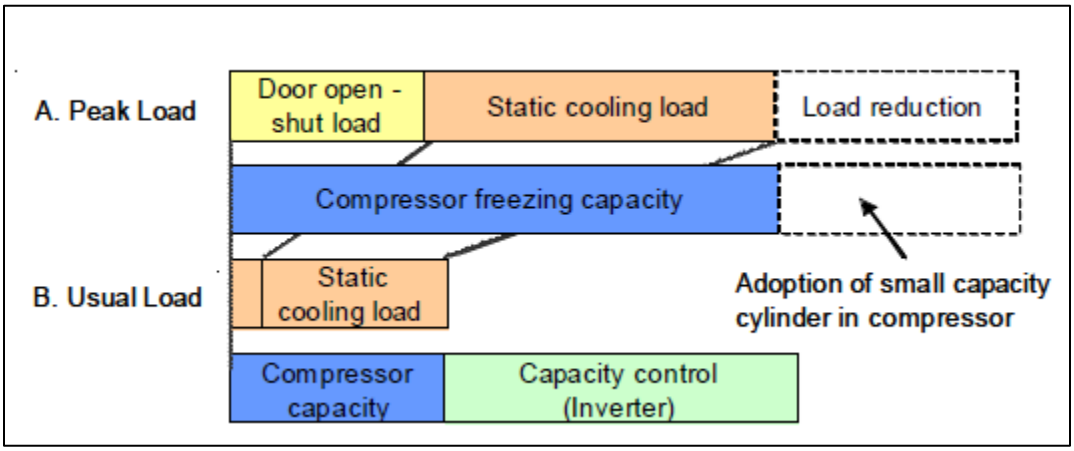


Figure 120: Panasonic Reports a Significant Noise Reduction Over a Wide Frequency Range

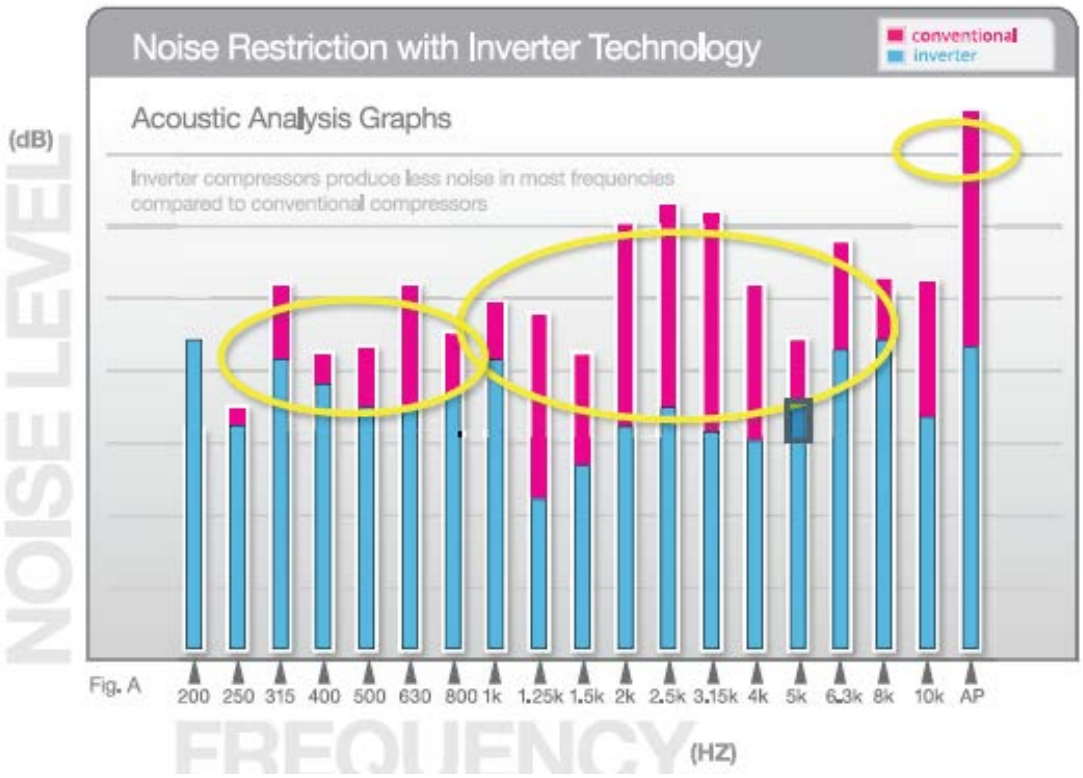
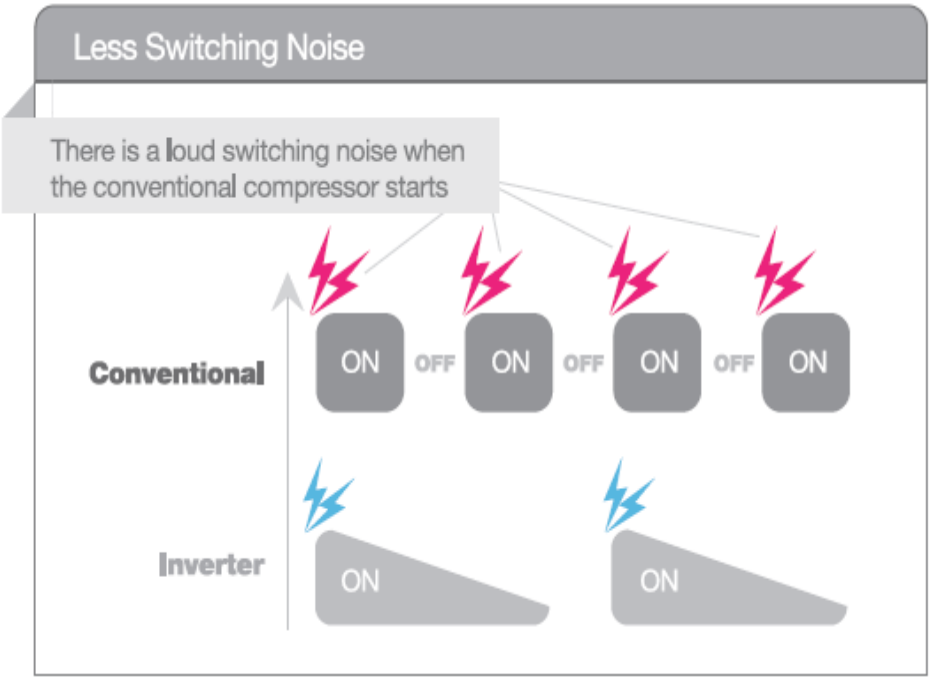


Figure 121: Panasonic Reports a Significant Reduction in Noise Transients

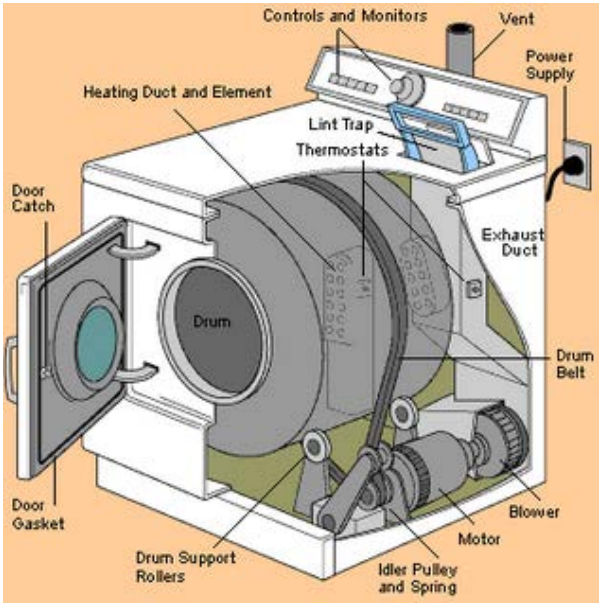


6.4.2.3 Clothes dryers.

Throughout all of the homes in California that use clothes dryers, 30% use electric heat and 70% use gas heat.

All dryers presently in use in California use a vent/duct to carry away moist air from the appliance. In removing moist air from the clothes, the moisture duct typically carries away 6% of conditioned air from the dwelling. [28] Electric dryers use resistive heat to move moisture from clothes. A typical resistive heat clothes dryer is shown in Figure 122. A single motor is used to turn the clothes drum and drive a fan to draw air through the dryer system. Drying times achieved with the traditional ducted resistive dryer have been matched to average clothes wash cycles.

Figure 122: GE GTDP400EMWS: Typical Resistive Clothes Dryer



28http://www.energystar.gov/ia/products/downloads/ENERGY_STAR_Scoping_Report_Residential_Clothes_Dryers.pdf

Figure 123: Electric Dryer Performance

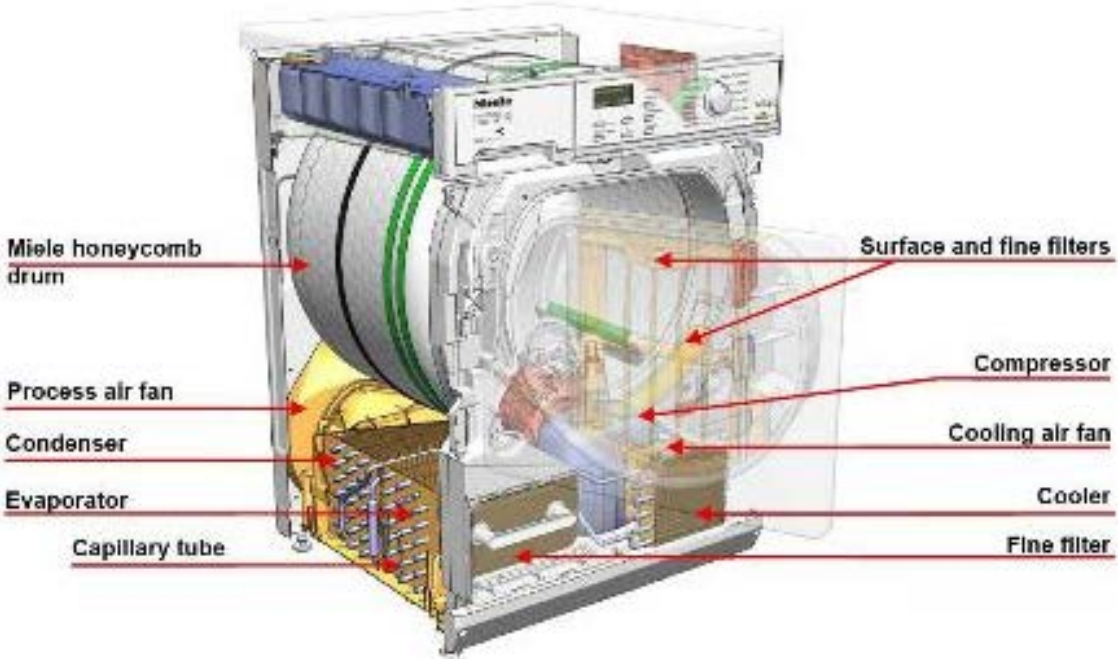
Energy Efficiency Standards for Gas Clothes Dryers and Electric Clothes Dryers. The energy factor of gas clothes dryers that are consumer products and electric clothes dryers that are consumer products shall be not less than the applicable values shown in Table Q.

Table Q
Standards for Clothes Dryers

Appliance	*Minimum Energy Factor (lbs/kWh)*
Electric, standard clothes dryers	3.01
Electric, compact, 120 volt clothes dryers	3.13
Electric, compact, 240 volt clothes dryers	2.90
Gas clothes dryers	2.67

Figure 124: Cut-Away View of a Ductless Heat Pump Clothes Dryer

Figure 125: Cut-Away View of a Ductless Heat Pump Clothes Dryer Showing Main Components



A single motor is used to turn the clothes drum and drive a fan that circulates air within the appliance. A hermetically sealed compressor and motor forces refrigerant through condenser and evaporator heat exchanger surfaces. The differential temperature between the heat exchangers is used to move moisture from the air into liquid that is subsequently drained.

6.4.2.4 Ducted central HVAC systems.

New equipment concepts for domestic heating and cooling have recently been made available. For heat pump HVAC operation, standard existing HVAC technology, in cooling mode, uses a single fixed-speed refrigerant compressor that drives refrigerant in a closed loop (Figure 126). In heating mode, the process is reversed using a reversing valve that directs refrigerant in the opposite direction (Figure 127). This system offers a wide range of temperature control (figure 128), which has been further enhanced by new and improved refrigerants (for example, R410A and other new control mechanisms such as wet injection). These systems were designed for peak weather conditions and used on/off operation. Modulation was used to match heating and cooling requirements. The ASD-driven compressor technology now available provides a continuous match between compressor output and heating or cooling requirements. The way in which output is matched to requirement affects performance and efficiency.

Figure 126: Typical Heat Pump Cooling Mode

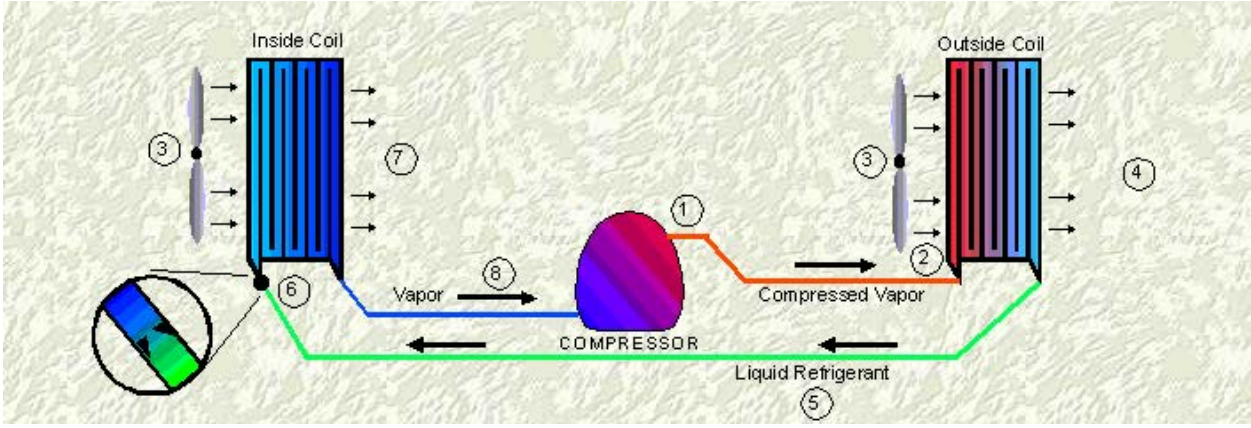


Figure 127: Typical Heat Pump Heating Mode

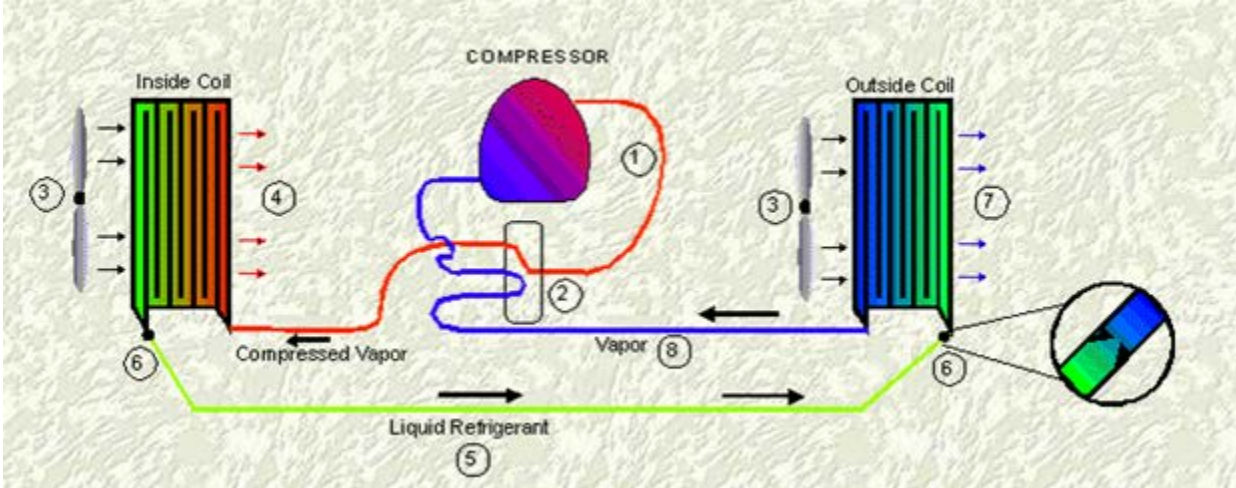
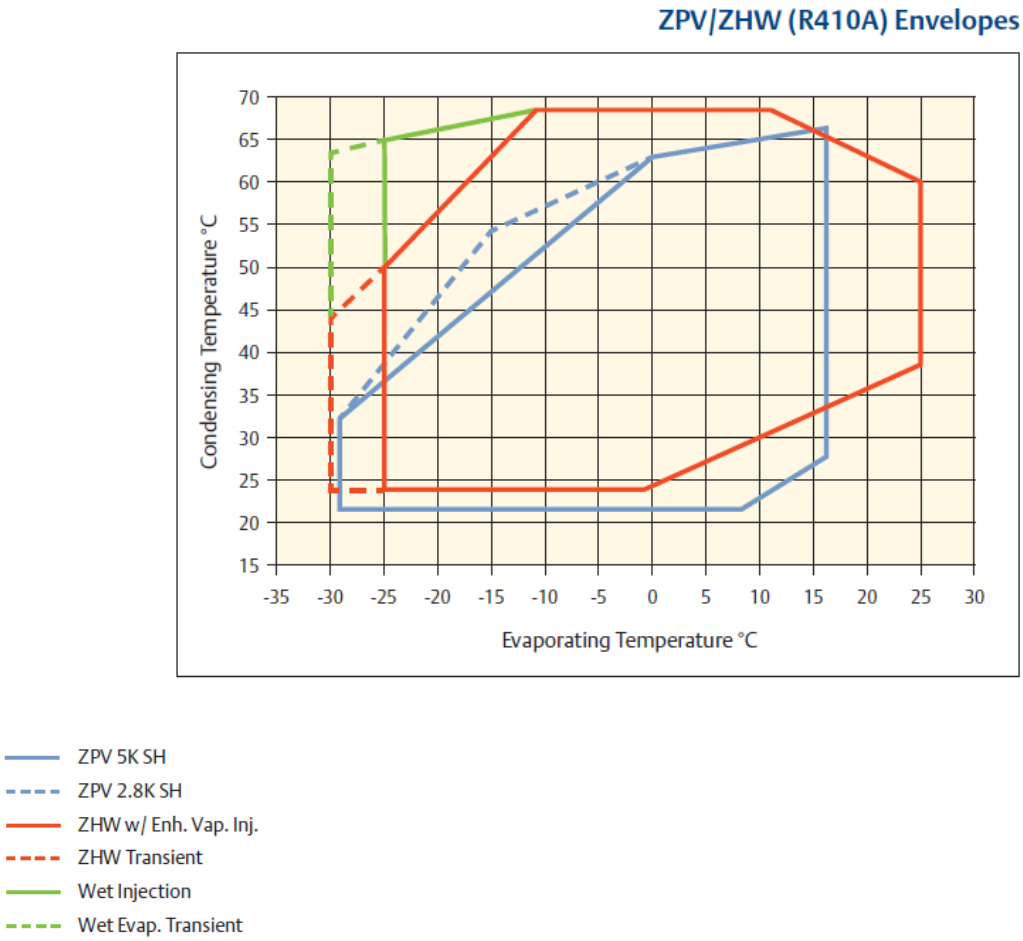


Figure 128: Range of Heating and Cooling



6.2.5 Performance and Efficiency

Performance and efficiency are improved when ASD control is used in HVAC systems. Emerson manufactures a compressor with ASD control optimized for high-efficiency (18+SEER) air conditioning and heat pump applications that offers improved performance and efficiency. This new Copeland Scroll Compressor is used in Trane units. Emerson states:

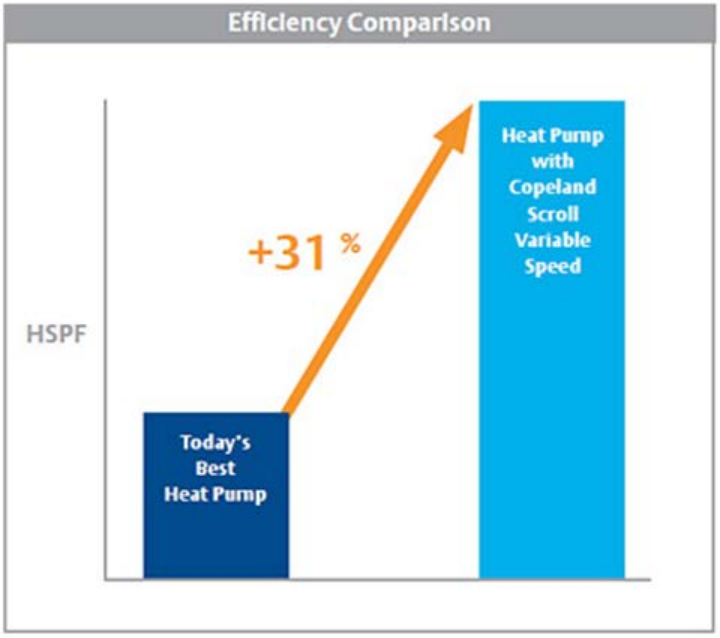
Our newest compressor technology innovation delivers superior system performance, including:

- Enhanced 3:1 capacity turndown for better dehumidification and light load efficiency.
- Now with a 20% improvement in capacity turndown.
- Nearly 60% over-speed capability for hotter air supply.
- Up to 13 HSPF (Heating Seasonal Performance Factor), 31% greater efficiency than today's best heat pumps on the market.

- The ability to constantly maintain a hotter air supply—even during low ambient winter conditions.[29]

ASD control has provided a means to improve heat pump performance. Previously, speed was limited to 3,600 rpm and restricted heat pump capacity. Recent equipment using ASDs has been designed to operate up to 7,000 rpm (Copeland) and 10,000 rpm (Bristol, under development). This new higher speed capability has provided higher temperature heat. Speed control provides accurate temperature control. Together this equates to increased comfort in the living space (Figure 129 and Figure 130).

Figure 129: ASD Controlled Heat Pump Performance Improvement

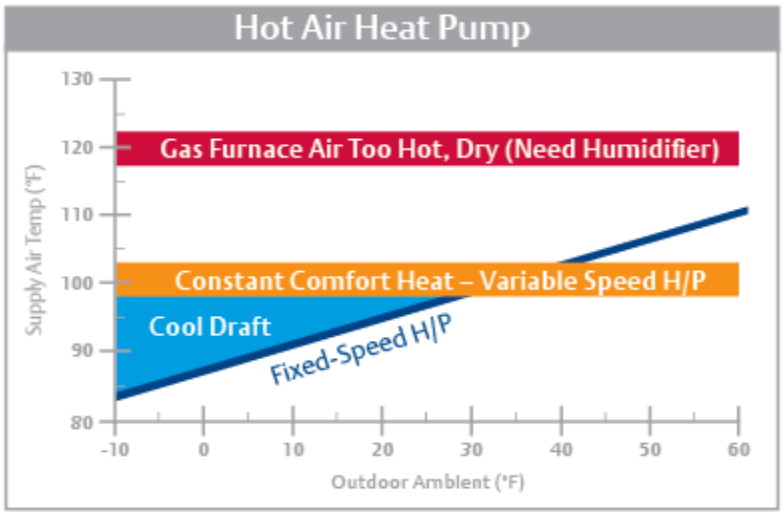


*The unmatched performance of Copeland Scroll Variable Speed adds up to nearly $500 in annual **energy cost savings** for homeowners over traditional heat pumps.*

Note: *Adjustable* and *variable* are used interchangeably in the marketplace. EPRI uses *adjustable* because it is an accurate description of the speed control available. *Variable*, as a descriptive term, could convey an implied variability or lack of accurate control.

[29] http://www.emersonclimate.com/en-us/products/compressors/scroll_compressors/copeland_scroll_residential/Pages/copeland_scroll_variable_speed_compressors.aspx#sthash.Sq2E1D5W.dpuf

Figure 130: ASD Controlled Heat Pump Performance Improvement as Documented by Emerson



Copeland Scroll variable speed compressors let you deliver that technology promise. With integrated electronics and built-in compressor protection and diagnostics - our variable speed technology provides year round comfort that homeowners will appreciate.

6.2.5.1 Ductless single-room HVAC systems.

Applying adjustable speed drive technology to ductless single-room HVAC systems saves energy. Compressor noise in the room is avoided. Wall mounting the appliance is possible, so window obstruction and loss of light is avoided. It provides improved room temperature stability, humidity control, and heat pump performance. The appliance operates quietly because mechanical resonances and start/stop noise events are avoided. High power factor is provided, and demand response is available.

New equipment concepts for domestic heating and cooling have recently been made available that can be applied to ductless single-room air conditioners.

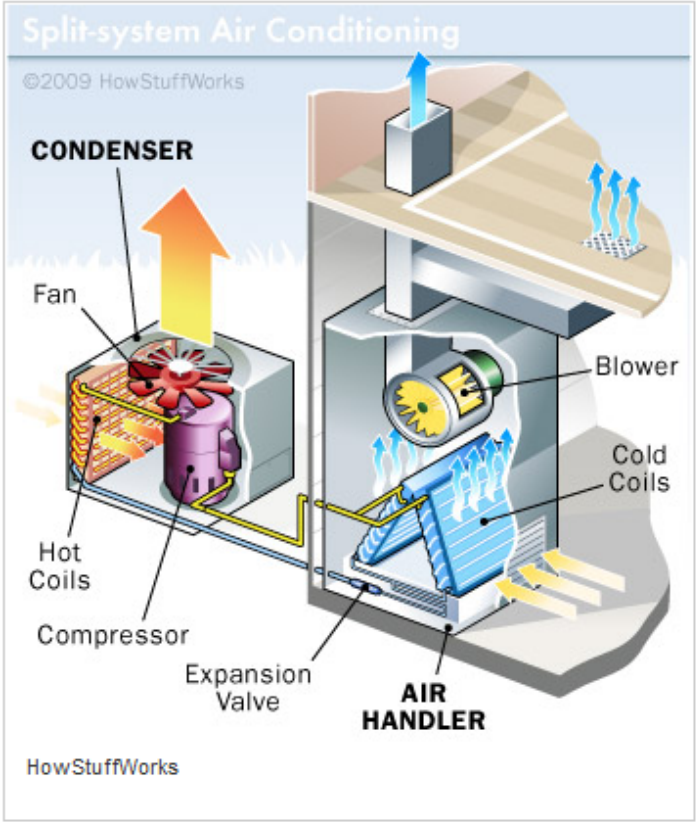
Window AC units are the usual method of cooling individual rooms. Traditional window air conditioning units are typically very noisy; they obstruct light, obscure the window area, and compromise security. Their operation tends to be disruptive and has a negative effect on the comfort of room occupants (Figure 131).

Figure 131: Typical Window Air Conditioning Unit Partially Obscuring the Window Area

The new concept for ductless single-room HVAC splits the appliance into two parts: an internal wall-mounted evaporator enclosure and an external floor-mounted compressor and condenser. The evaporator contains an evaporator heat exchanger and a fan. The external unit contains the ASD electronics, a speed-controlled hermetically sealed compressor, and a condenser fan. This configuration improves energy efficiency by matching the cooling capacity of the compressor to the load. The heat pump capability is significantly improved. Additional aesthetic benefits accrue: noise levels become whisper quiet, and window and window treatment obstruction is removed.

In Figure 132, the left-hand side shows the configuration of a new concept split-system single-room HVAC unit. The right-hand side describes a conventional "window" single-room HVAC system.

Figure 132: Contrasting Single-Room HVAC Systems



Window and Split-system AC Units

A window air conditioner unit implements a complete air conditioner in a small space. The units are made small enough to fit into a standard window frame. You close the window down on the unit, plug it in and turn it on to get cool air. If you take the cover off of an unplugged window unit, you'll find that it contains:

- A compressor
- An expansion valve
- A hot coil (on the outside)
- A chilled coil (on the inside)
- Two fans
- A control unit

The fans blow air over the coils to improve their ability to dissipate heat (to the outside air) and cold (to the room being cooled).

The wall-mounted unit to the left of the window is a split configuration with the compressor unit floor-mounted outside. The window-mounted unit to the right of the picture contains all of the components of the cooling appliance (Figure 133).

Figure 133: Contrasting Single-Room Ductless HVAC Systems in Operation in the Same Space

Figure 134: Split Ductless Single-Room HVAC Components

Both heating and cooling are available. Wall mounting offers placement selection independent of windows and facilitates the distribution of conditioned air. A wireless remote controller includes a variety of control options.

6.3 Opportunity

The use of ASD speed control in domestic appliances offers a number of advantages: energy savings, reduced noise, extended component life, lower environmental impact, and the availability of demand response. The greatest advantage remains to be harvested—a wider beneficial use of speed control in domestic applications. The results of comparative testing of familiar appliances, with and without speed control, as detailed in this report show that speed control offers very positive benefits to householders as well as utility providers. Industrial applications operating on three-phase power have, for many years, been able to take advantage of the benefits offered by variable speed. The ECM effectively allows households that are provided single-phase power to use appliances that operate on three-phase power. The challenge is to use the ECM and variable speed control to the fullest. Single-phase motors are, in comparison to ECMs, "energy hogs." The task is to identify where single-phase motors are used, investigate the application, and consider the implication of switching motor type. Care should be taken to ensure that the new application works seamlessly with the system, but essentially all heat pumps and air circulation fans would benefit from ASD control.

6.3.1 Test Results Refrigerator/Freezer

6.3.1.1 Equipment Tested

The following two refrigerator/freezers were approximately equal in size.

- GE Profile with ASD control
- Kenmore non-ASD control

6.3.1.2 Methodology

The testing procedure examined the operation of differently controlled compressors, one in each refrigerator. The results obtained from an ASD controlled compressor were compared with results from a standard single-speed compressor. Separately, bench testing was performed on evaporator and condenser fans of the type typically found in refrigerator freezers. These components were tested with and without ASD control.

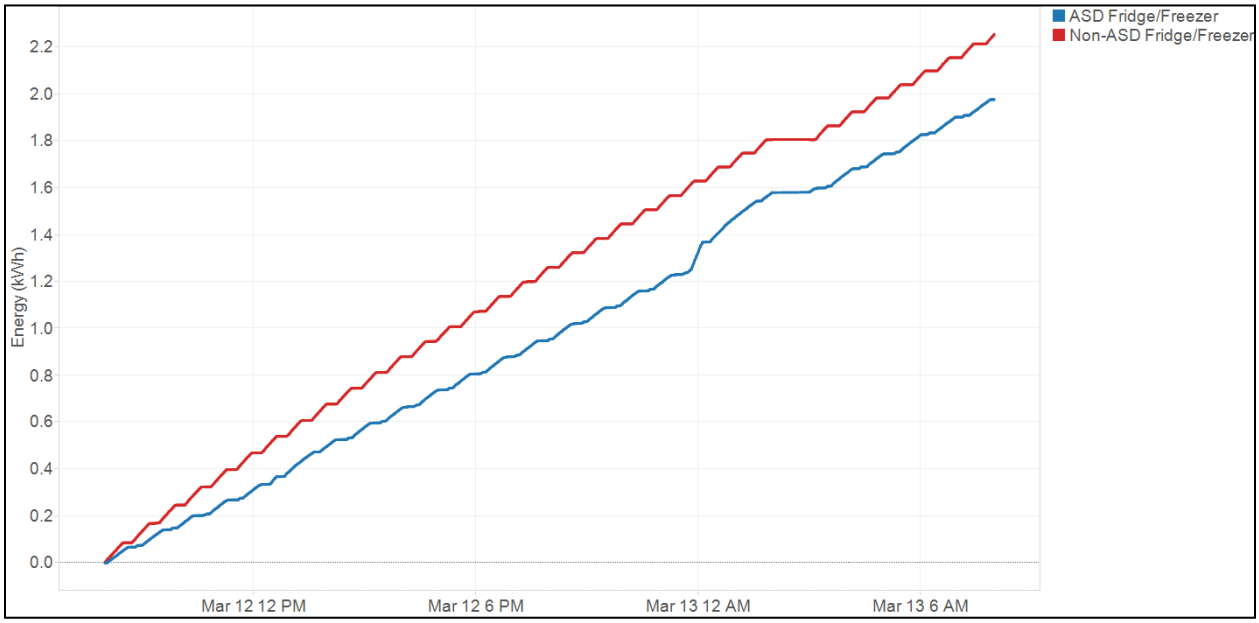
In testing the compressors, room temperature water was added to the refrigerator cabinet to simulate an average household usage pattern. Over a 24-hour period, water was replaced with room temperature water at regular intervals. All input power characteristics of each refrigerator/freezer were measured and recorded.

In testing the fans, the losses of conventional condenser fans were measured and compared with the losses of electronically commutated replacements. Similarly, losses in conventional evaporator fan systems were compared.

6.3.1.3 Results

During a 24-hour period, the non-ASD controlled refrigerator/freezer unit consumed 4.6 kWh compared with the ASD controlled GE Profile that consumed 3.7 kWh (Figure 135). This is equivalent to savings of 19.6% or 0.9 kWh in a 24-hour period, which equates to 328 kWh/yr.

Figure 135: Comparison of Energy Used by ASD and Non-ASD Refrigerators/Freezers



The improved energy performance demonstrated in this series of side-by-side tests was achieved by the use of an ASD controlled compressor.

Additional energy savings may be obtained from the refrigerator by substituting energy efficient ECM fan motors for the standard low-efficiency evaporator and condenser fan motors. The impact of the losses from the evaporator motor not only waste energy in the operation of the motor as it moves cooled air in the appliance, but also, the wasted energy heats the already cooled air—thereby partially destroying the work carried out by the compressor.

In considering fan motor efficiencies, additional bench tests were completed on a typical refrigerator condenser fan assembly, not the unit tested above. The condenser fan motor was replaced with an electrically commutated motor. Similarly, bench tests were completed on a typical refrigerator evaporator fan. The use of ASD control on the condenser fan yielded a 47% increase in efficiency. The test of the evaporator fan suggests that the same benefits would accrue if an ECM were applied (Table 43 andTable 44).

Table 44: Bench Rest Results of Refrigerator Condenser Fan

Motor Type	Speed (rpm)	Loaded with Fan (Watts)	No Fan (Watts)	Fan Load (Watts)	Efficiency (%)
Original	1448	20	16	4	20
ECM	1550	6	4	4	67
Difference	+102	-14	-12	0	+47

Table 45: Bench Test Results of a Typical Refrigerator Evaporator Fan

Motor Type	Speed (rpm)	Loaded with Fan (Watts)	No Fan (Watts)	Fan Load (Watts)	Efficiency (%)
Original Shaded Pole	2879	51	41	10	19.6

Research completed by Purdue University[30] stated that conversion of a compressor from fixed speed on/off control to adjustable speed control has the potential to reduce compressor energy consumption by 30%. This research paper also identified the following breakdown of energy use in the refrigerator/freezer: compressor and electric motor use 69%, evaporator and electric fan motor use 14%, condenser and electric fan motor use 8%, and 8% is associated with capillary tubes.

This same research suggests that the conversion of a standard refrigerator to adjustable speed compressor operation should provide a power savings of 30% (potential savings from compressor) x 69% (proportion of total power associated with the compressor) = 20.7%.

The tests performed for the EPRI/Energy Commission study yielded very similar results (19.6% compared with 20.7%).

In bench testing standard and energy efficient motors suitable for evaporator and condenser duties, it was found that an improvement of 40% could be expected. An evaporator fan runs continuously[31], which provides a potential energy conservation of 40% (evaporator fan energy savings proportion) x 14% (proportion of total power associated with the evaporator fan) = 5.6%. A condenser fan runs 64%[31] of the total time x 40% (potential energy conservation) x 8% (proportion of total power associated with the condenser fan) = 2%.

A complete conversion would provide energy savings of 19.6% (compressor) + 5.6% (evaporator fan) + 2% (condenser fan) = 27.2%.

Market research on California concluded that there are 18,000,000 refrigerator/freezers that consume a total of 15,787 GWh/yr.

[30] http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1614&context=iracc

Extrapolating from tests results obtained, 19.6% savings could be expected from 100% market penetration of ASD controlled compressors in refrigerator/freezers.

Therefore, projected energy savings are calculated to be 15,787 GWh/yr x 0.196 = 3,094 GWh/yr, if 100% of California refrigerators were converted to units using ASD controlled compressors.

Extrapolating from test predictions:

Predicted energy savings of 328 kWh/yr (the values shown above from EPRI's laboratory testing) from each of 18,000,000 refrigerator/freezers in California is equivalent to 5,904 GWh/yr.

Estimated energy savings for a projected 100% penetration of ECMs associated with evaporator and condenser fan motors is 1,200 GWh/yr. This is based on energy conservation of 5.6% for the evaporator fan +2% for the condenser fan, a total of 7.6% savings, equivalent to 15,787 GWh/yr x 0.076 = 1,200 GWh/yr.[31,32]

6.3.2 Clothes Dryers

6.3.2.1 Equipment Tested

- Panasonic NH-P80G1 ASD controlled
- Bosch EcoLogixx7 single-speed

6.3.2.2 Methodology and Results

Table 45 summarizes the result of six total valid runs. Each test (slow or fast) was conducted three times in accordance with DOE test requirements. Run-to-run variation for per-cycle energy consumption was 13% for fast tests and 8% for slow tests. In addition to describing energy consumed per cycle, the energy-weighted power factor, drying time, remaining moisture content (RMC) in the load at the end of the run, and the combined energy factor (CEF) is listed for each run. RMC is calculated by taking the total weight of the test load after drying and subtracting the "bone dry" weight of the test load before wetting. Then this difference is expressed as a percentage of the bone dry weight. Initial runs with the normal dryness setting did not dry the load enough, so the runs shown here were done on the highest dryness setting. Most of these were still not dry enough, but the runs are considered valid because there were no other options. CEF is the efficiency metric for clothes dryers as defined by the DOE 2013 test procedure. This efficiency metric is a ratio of the pounds of bone dry clothing dried and the total energy consumption of the clothes dryer (includes active mode energy consumption and standby mode energy consumption).

31 http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1614&context=iracc

32 http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1611&context=iracc

Table 46: Data Summary for Six Valid Runs

Speed	Energy Per cycle (kWh/cycle)	Energy Weighted Power Factor	Drying Time (min)	Remaining Moisture Content (RMC) of Load	Combined Energy Factor (lbs/kWh)
Fast	1.14	0.82	88	2.3%	6.33
Fast	1.12	0.82	88	3.2%	6.46
Fast	1.27	0.83	99	1.8%	5.69
Average	**1.18**	**0.82**	**92**	**2.4%**	**6.16**
Slow	0.95	0.83	103	3.0%	7.55
Slow	1.02	0.83	109	3.0%	7.09
Slow	1.03	0.83	112	2.9%	7.02
Average	**1.00**	**0.83**	**108**	**3.0%**	**7.22**

In Figure 136, one can see that the rpm is initially high, but then it is reduced in several steps that manifest themselves as sudden reductions in power draw.

Figure 136: Power Draw Over Time for Slow Mode

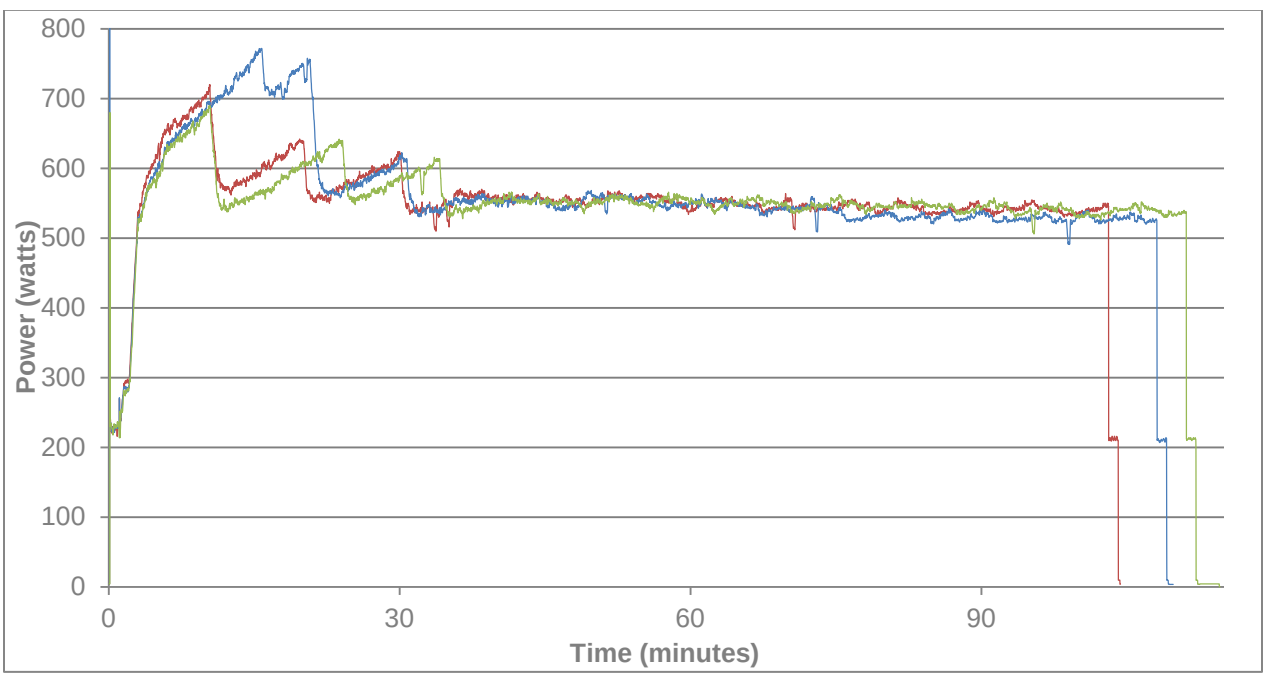
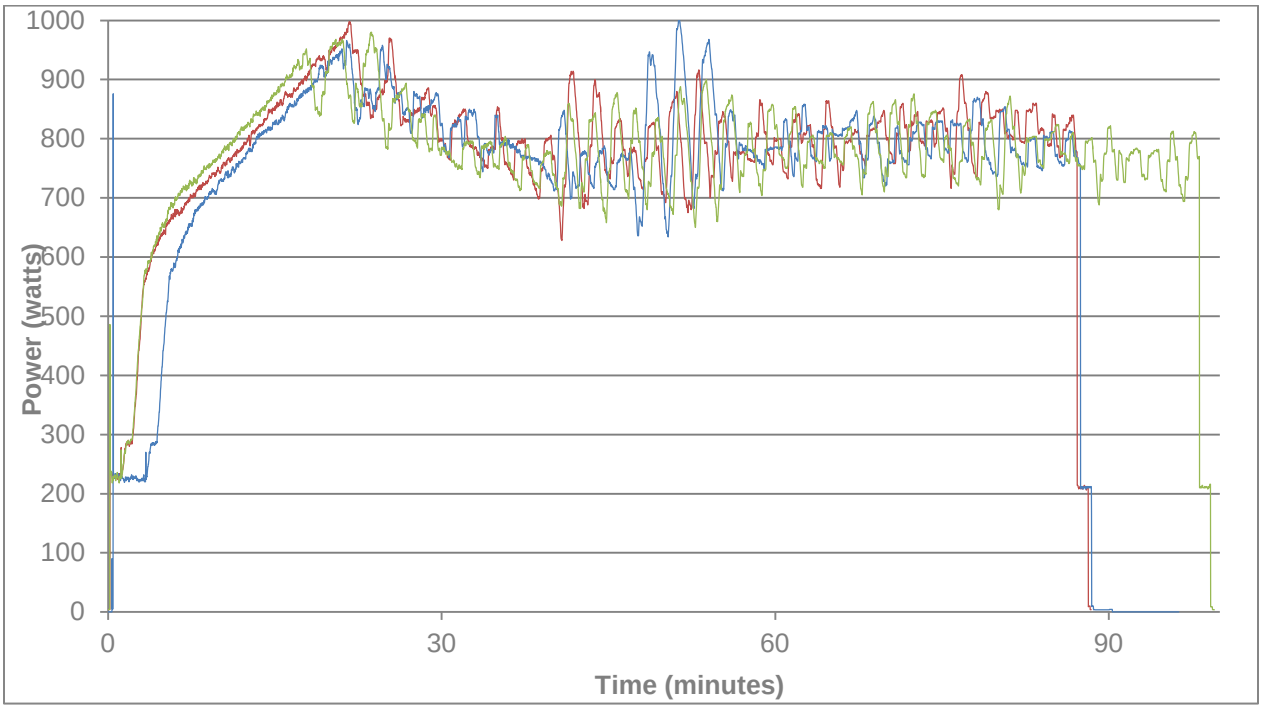


Figure 137 shows the more consistent and increased power draw of the fast mode.

Figure 137: Power Draw Over Time for Fast Mode



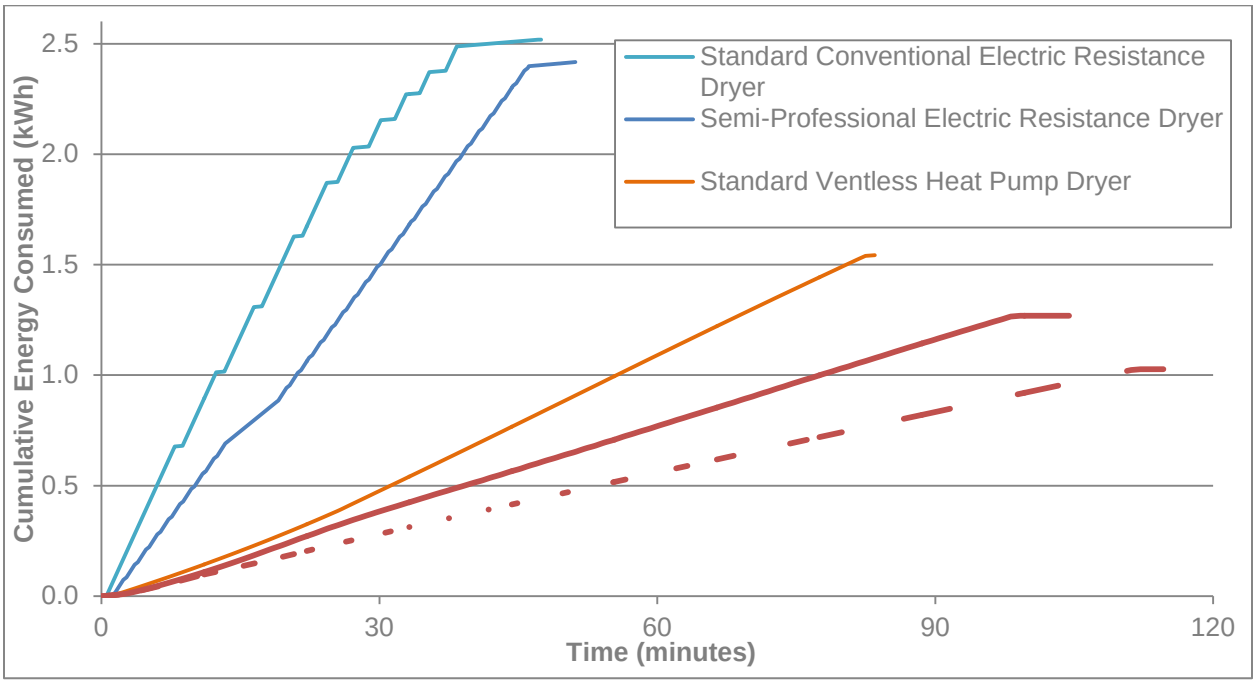
In Figure 138, the slopes of the cumulative energy correspond to the power draw Figure 136 and Figure 137. Correspondingly, the lowest slope (least power used) is the slow ASD, then fast ASD, then semi-professional heat pump dryer,33 then a semi-professional electric resistance dryer,34 and finally a standard conventional electric resistance dryer.35 Note that the cumulative energy used is also in the same ordering as the power draw (slope).

[33] This standard European heat pump clothes dryer costs approximately $3,500, significantly more than the ASD heat pump dryer.

[34] Although this model is listed as a residential electric clothes dryer, it costs significantly more than the average electric resistance clothes dryer sold in the United States—approximately $1500.

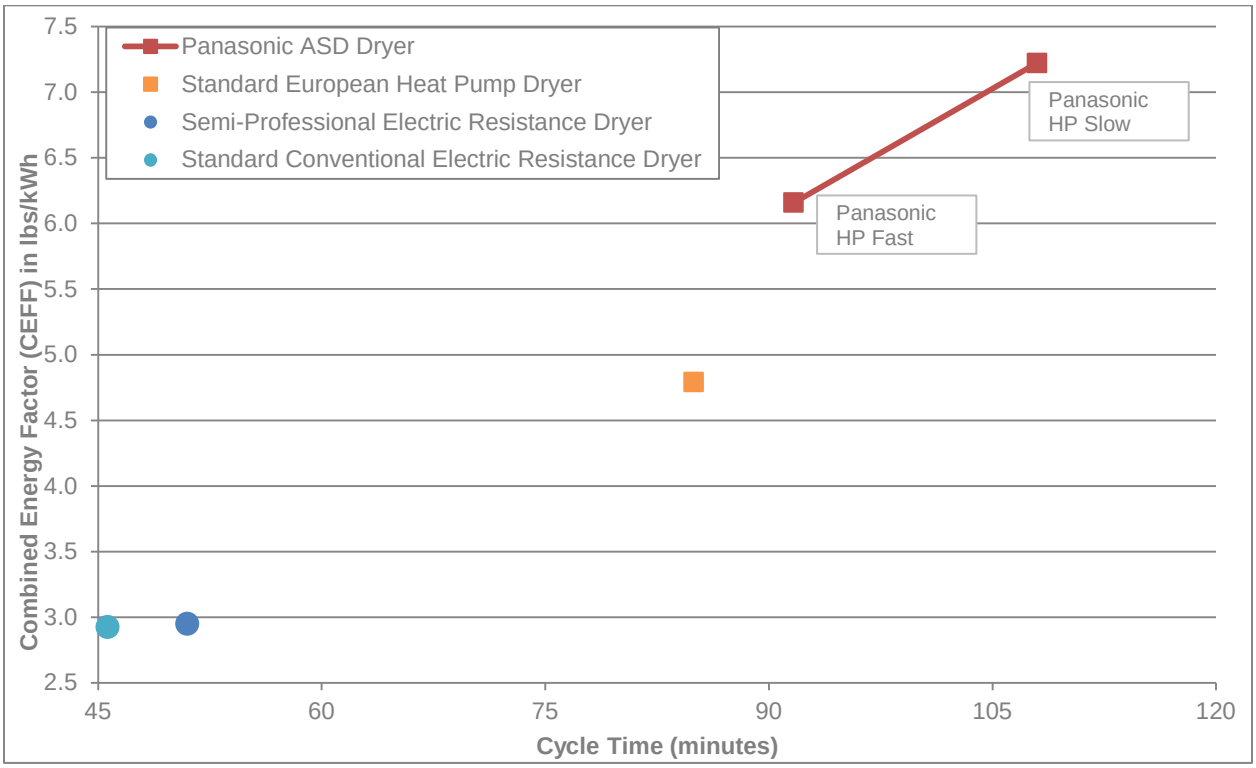
[35] This is a newer conventional electric resistance dryer sold in the United States for approximately $900.

Figure 138: Cumulative Energy Consumption over Drying Time for ASD Dryer vs. Heat Pump and Electric Resistance Dryers



Dryer efficiency (CEF) is plotted versus drying time across five scenarios in Figure 138. There is a clear trade-off of drying time and efficiency, both between dryers and within the ASD dryer. The semi-professional heat pump dryer is much more expensive than residential heat pump dryers. The fast mode of the ASD dryer was similar to that of other heat pump dryers previously tested (the data are for other test procedures and so are not shown). The slow mode of the ASD dryer is generally slower and more efficient than that of other heat pump dryers previously tested. The high-efficiency conventional dryer was also semi-professional and therefore more expensive. However, there are less expensive dryers with similar performance.

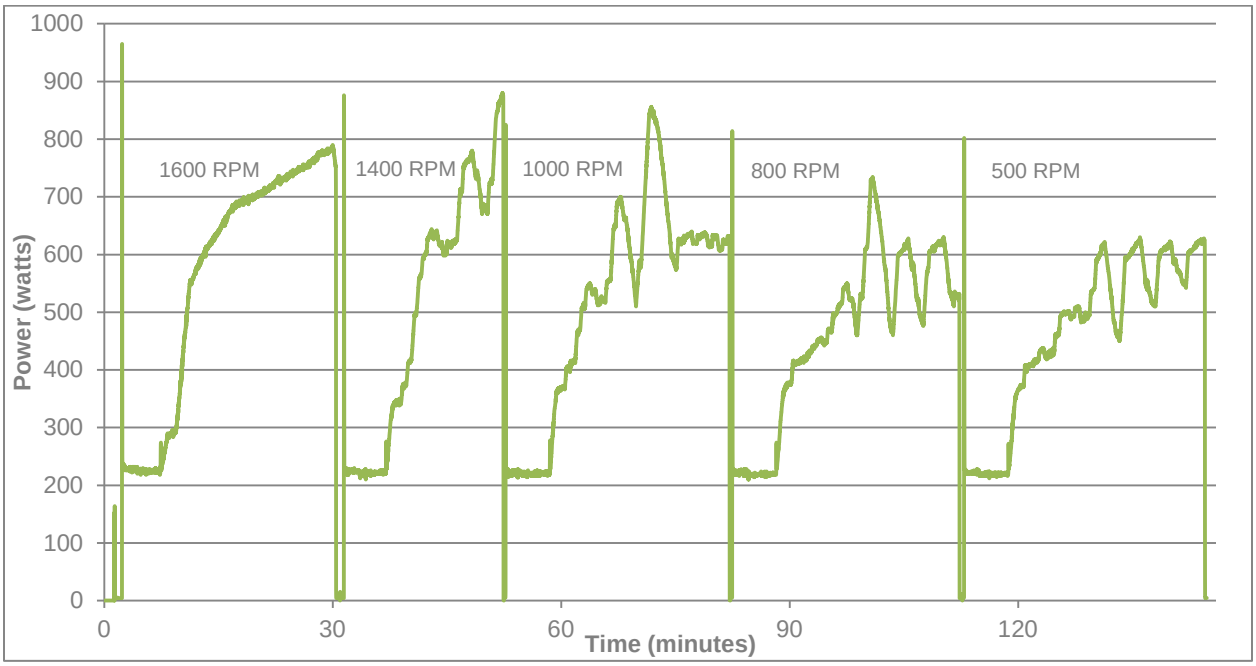
Figure 139: Dryer Efficiency vs. Drying Time for ASD Dryer vs. Heat Pump and Electric Resistance Dryers



6.3.2.3 Power Draw at Different ASD RPM

The display has an indication of the rpm. However, this does not update in real time, despite the fact that that the rpm is changing, especially in the slow mode. There is a button to control the rpm, but this can be engaged only when the cycle is not running. Therefore, the cycle was started at 1600 rpm, turned off the cycle, set it to 1400 rpm, turned it back on, and repeated with 1000 rpm, 800 rpm, and 500 rpm. With these interruptions, the behavior is not the same as if the rpm changed in the middle of the cycle. However, some qualitative conclusions can be drawn. At 500 rpm, the power stabilized to a similar value that the slow cycle did, so the slow cycle likely stabilized at 500 rpm. At 1600 rpm, the ramping was similar to the initial part of the fast and slow runs, so these runs likely started at 1600 rpm.

Figure 140: ASD Dryer Power Draw at Five Different RPMs



In all of the other heat pumps previously tested, there was a steady power ramp upward and then an asymptote. It is expected that the power draw would be at least proportional to the rpm at given cold and hot heat exchanger temperatures because higher rpm would require more refrigerant to be compressed per time, and there would be slightly higher pressure difference to overcome. This would mean more than a factor of three ratio in power draw in the entire rpm range. It does appear that the fast run is on a trajectory for a significantly higher power draw than is ever realized. It is unclear why the fast run did not allow even higher power draw and therefore faster drying, but it could be because the power electronics of the ASD are costly and were being maxed out around 1 kW of total dryer power draw.

The manufacturer's website says that the supply air temperature to the drum varies from 45°C (113°F) to 69°C (156°F) depending on the mode[36]. As expected, the ASD on fast mode dried more quickly and was less efficient. However, the drying times are still not competitive with those of conventional electric resistance dryers. The economics of heat pump dryers appear to be favorable in some locations, and they have gained significant market share in Europe. However, the competition in Europe is typically electric resistance condensing dryers, which are less efficient, slower, and more expensive than the vented dryers common in the United States. Therefore, it is not clear that heat pump dryers will become popular in the United States.

36 http://www.panasonic.co.uk/html/en_GB/Products/Laundry/Overview/Tumble+Dryer+with+Inverter+Heat+Pump+Technology/Flexible+Drying+Options+with+Inverter+Technology/10287115/index.html

If they do, an ASD can cost effectively allow consumers the ability to save even more energy if they are not in a hurry.

Extrapolating from the dryer tests results obtained:

- 50% energy savings could be anticipated from 100% market penetration of heat pump ductless clothes dryers that, utilize ASD controlled compressors. Therefore, energy savings = 3,950 GWh/yr x 0.50 = 1975 GWh/yr.
- DOE estimates that each dryer operates 283 dryer cycles per year.
- ECOVA tests anticipate 1.2 kWh savings per cycle, which translates to savings of 283 x 1.2 kWh = 340 kWh/yr.
- California has approximately 3,120,000 electric clothes dryers.
- Assuming 100% market penetration of ductless heat pump dryers in California, the predicted energy savings would be 1,061 GWh/yr.
- DOE estimates a 6% penalty on HVAC systems created by ducted clothes dryers. The use of ductless heat pump dryers will avoid this penalty for anticipated net energy savings.

Reported energy consumption for ASD heat pump clothes dryers is listed in Figure 141.

Figure 141: ASD Dryer Energy Consumption

Power Consumption

Programme		Additional function	Load	Final spin speed in a washing machine	Power consumption	Time (mins)
Cotton/ Colours	Cupboard Dry	Eco	8 kg	1600 r/min	1.34 kWh	2:10
				1000 r/min	1.54 kWh	2:30
		Speed	8 kg	1600 r/min	1.60 kWh	1:42
				1000 r/min	1.80 kWh	2:02
	Iron Dry	Eco	8 kg	1600 r/min	1.10 kWh	1:40
				1000 r/min	1.30 kWh	2:00
		Speed	8 kg	1600 r/min	1.30 kWh	1:10
				1000 r/min	1.50 kWh	1:30
Easy-care	Cupboard Dry	Eco	4 kg	1000 r/min	0.70 kWh	1:10
	Iron Dry	Eco	4 kg	1000 r/min	0.60 kWh	0:50

1) The results shown here comply with EN 61121. Each result indicates the value required until the end of each programme with the Drying Level 3 and Anti-crease process ON set. Power consumption and time during Anti-crease process are not included.
2) The power consumption, and times indicated in the table, may vary depending on variations in room temperatures, types and amounts of laundry, voltage fluctuations, and which optional functions are used.

- Ducted HVAC System

6.3.2.4 Equipment Tested

- Green Speed Trane 25VNA024A0030 ASD controlled
- 4SHP13LE124P fixed speed

6.3.2.5 Methodology

Laboratory testing was conducted in the thermal laboratory at the EPRI Knoxville, Tennessee facility on two air-source heat pumps in cooling operation at and away from SEER rating conditions. The tested systems consisted of a single compressor speed, fixed fan speed system at the federal minimum of 13 SEER, and a variable capacity system rated at 19.5 SEER. The variable capacity system was approximately two to three times the wholesale cost of the single-speed system and near the industry lead in SEER for similar type systems. Variable capacity systems have the ability to modulate the amount of capacity output that is provided to a conditioned space. Variable capacity can be achieved by a variable speed compressor, variable

speed fans, and internal system controls. Within Standard 210/240, the procedure for determining SEER varies depending on the type of system under consideration. The methodology used to determine SEER becomes more intricate with the complexity of the system type. A single-speed system requires the least amount of testing and analysis to evaluate SEER, whereas a variable speed system requires further testing and more comprehensive analysis to determine SEER.

At the EPRI laboratory, the variable capacity system was tested at high, intermediate, and low compressor speeds. The total capacity, latent capacity, and efficiency of the two tested systems were compared at and away from SEER conditions. Since the variable capacity system could operate at three compressor speed levels, the systems were mostly compared with similar sensible capacity loads. At standard AHRI testing conditions, an indoor temperature of 80°F (27°C) dry bulb and 67°F (19°C) wet bulb and an outdoor temperature of 95°F (35°C), the variable capacity system at high compressor speed demonstrated an efficiency increase of 11.1% and a dehumidification decrease of 13.4% when compared to the single-speed system. Away from standard conditions at an indoor temperature of 75°F (24°C) dry bulb and 63°F (17°C) wet bulb and an outdoor temperature of 85°F (29°C), the variable capacity system at low compressor speed demonstrated an efficiency increase of 12.5% and a dehumidification decrease of 53.8% when compared to the single-speed system. Higher efficiency within the variable capacity system was in part due to a larger heat exchanger coil size within the system. At part load conditions, the ability of the variable capacity system to operate at a decreased compressor speed and maintain full use of the heat exchanger surface also allowed for increased efficiency. Lower dehumidification within the variable capacity system was due to a higher airflow rate per amount of capacity output and an increased operating evaporator temperature.

Within Standard 210/240, indoor temperature is assumed to be 80°F (27°C) dry bulb and 67°F (19°C) wet bulb or 50% relative humidity (RH) during the SEER calculation process. Typically in residential applications, air is returned to the HVAC system at or near room conditions, so in a sense the standard is assuming that a residential occupant is setting his or her thermostat at 80°F (27°C). Load calculations are frequently required by building and energy codes across the United States using Air Conditioning Contractors of America (ACCA) calculations or some equivalent. Within ACCA manuals, the recommended indoor air temperature assumption is 75°F (24°C) and 50% RH (63°F [17°C]) wet bulb) for wet coil climates and 45% relative humidity for dry coil climates. Fundamentally in HVAC systems, capacity and efficiency increase with increasing indoor wet bulb temperature. Therefore, a given HVAC system would have higher capacity and efficiency at an indoor condition of 80°F (27°C) dry bulb, 67°F (19°C) wet bulb. Laboratory data of the variable capacity system were compared between indoor air conditions of 80°F (27°C) and 75°F (24°C) with a constant relative humidity of 50% and constant outdoor temperature of 95°F (35°C). From the indoor temperature of 80°F (27°C) to 75°F (24°C), a 10.3% decrease in capacity and an 8.5% decrease in efficiency were observed in the laboratory data.

SEER is based on assumptions of indoor temperature, outdoor temperature, airflow resistance, and dehumidification that may not accurately represent certain applications and climates. Variable capacity systems further complicate the determination of SEER, as variable capacity systems are tested at fixed compressor and fan speeds. In real-world operation, variable

capacity systems are frequently adjusting capacity, power consumption, and thus the efficiency of a system. Due to the methodology and assumptions within Standard 210/240, SEER may or may not be an accurate indicator of energy efficiency for certain applications, climates, and system types.

A single-speed and adjustable speed heat pump were tested under identical conditions.

Both systems were air-source, ducted systems rated at a nominal capacity of 2 tons.

The systems were examined at 80°F (27°C) dry bulb and 67°F (19°C) wet bulb and a varied outdoor temperature (Figure 142 and Figure 143).

6.3.2.6 Results

Figure 142: Comparison of Cooling Capacity Between ASD and Non-ASD Ducted Central HVAC System

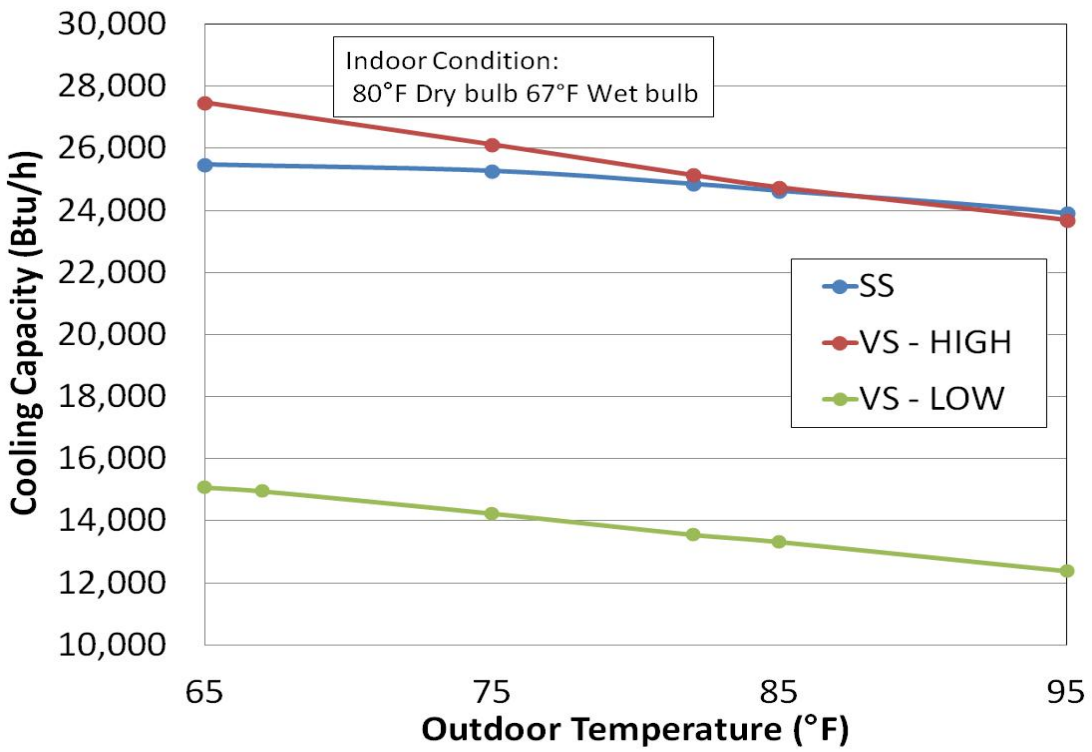
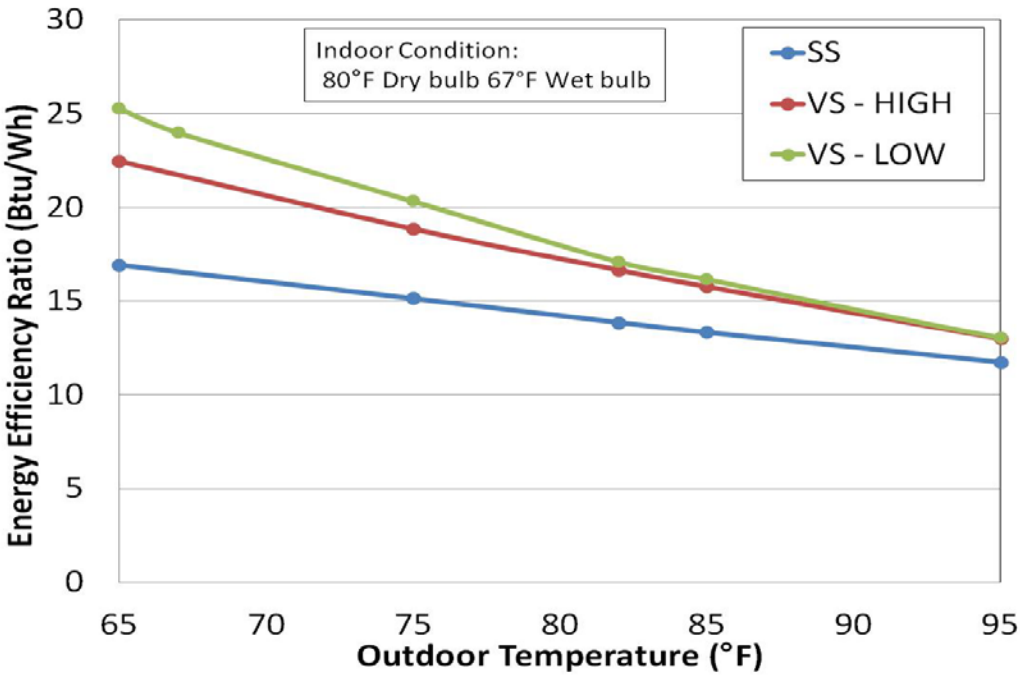


Figure 143: Comparison of Energy Efficiency Ratio Between ASD and Non-ASD Ducted Central HVAC System



6.3.2.4 Summary of Results

- Annual energy consumption savings of 36% (533 kWh)
- Single-speed system consumes 1,482 kWh/yr
- ASD system consumes 949 kWh/yr
- 533 kWh are saved

Extrapolating from the test results obtained:

36% energy savings is anticipated from 100% market penetration of the ASD controlled compressors used in ducted central HVAC equipment.

Therefore, energy savings = 5,321 GWh/yr x 0.36 = 1,916 GWh/yr.

Predicted energy savings of 533 kWh/yr from each of 6,500,000 ducted central HVAC systems in California is equivalent to savings of 3,465 GWh/yr.

Conservatively, energy savings for 100% penetration of ASD controlled compressors in ducted central HVAC systems is estimated to be 1,916 GWh/yr.

6.3.3 Ductless Single-Room HVAC System

6.3.3.1 Equipment Tested

- Mitsubishi FE12NA ASD controlled

- Conventional window unit Frigidaire FRA106CV1 fixed speed

6.3.3.2 Methodology

A ductless heat pump, mini-split system was compared to a window unit using performance data from NREL (Figure 144 and Figure 145).

6.3.3.3 Results

Figure 144: Comparison of Energy Efficiency Ratio Between ASD and Non-ASD Ducted Central HVAC System

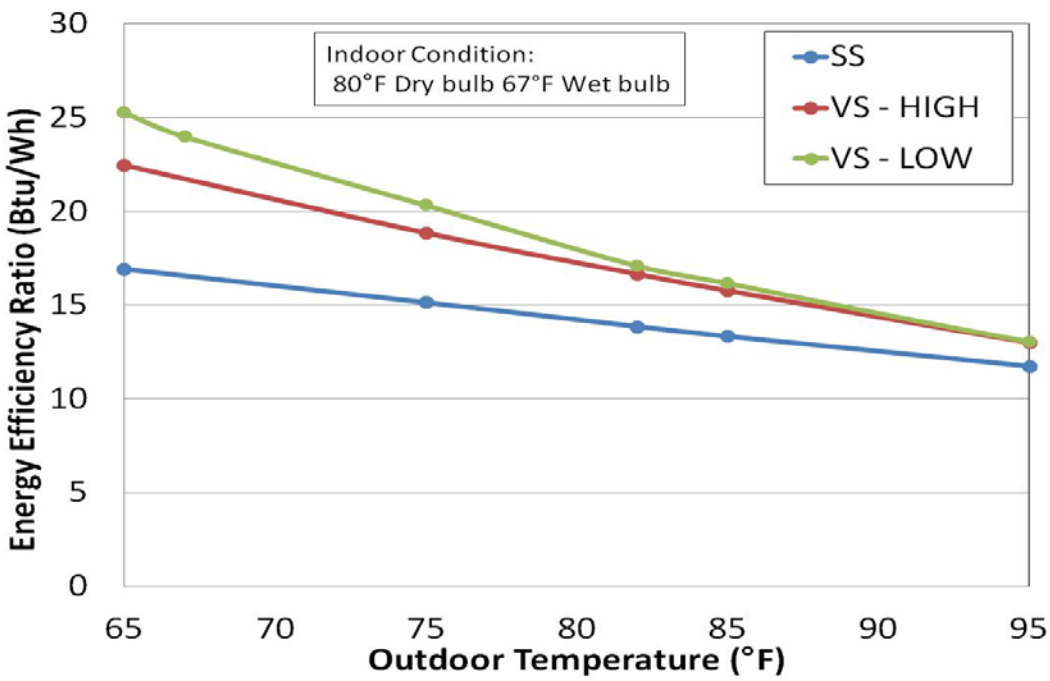
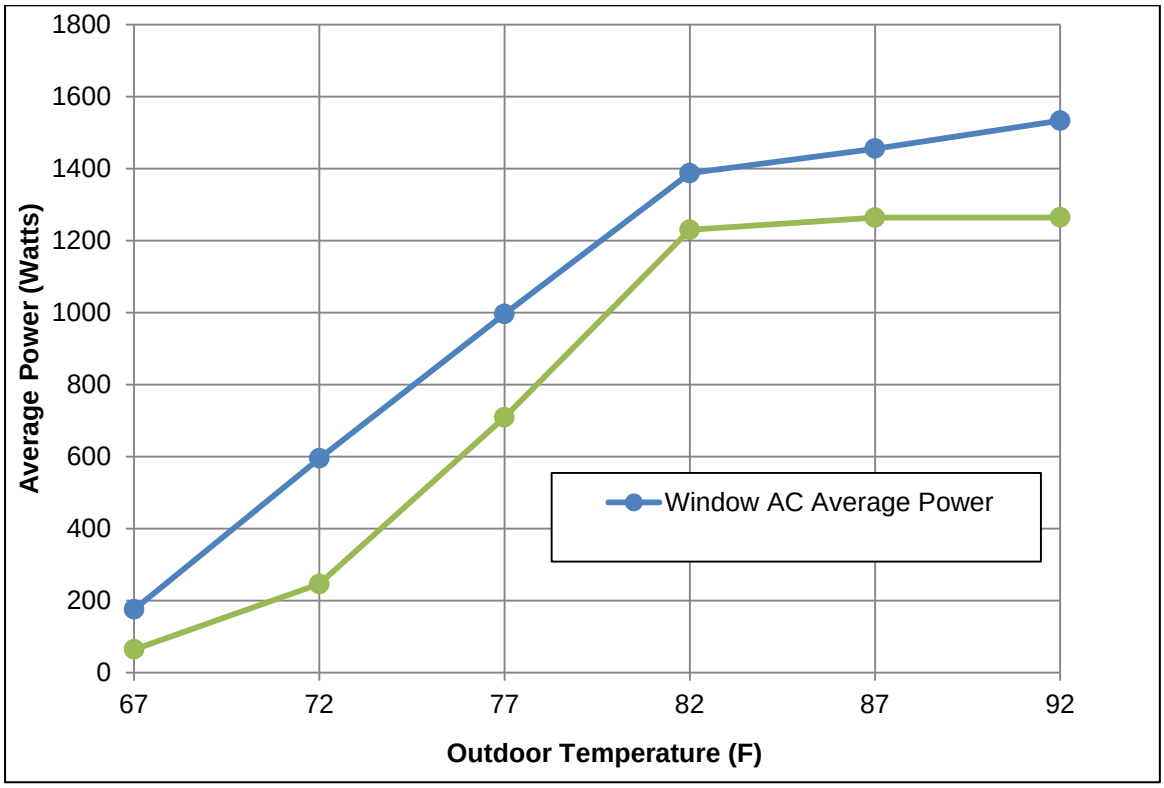


Figure 145: Comparison of the Average Power Used by a Window AC Unit and a Ductless Heat Pump



6.3.3.4 Summary of Results

- Annual energy savings consumption 54% (624 kWh)
- Window unit consumes 1,148 kWh
- Ductless heat pump (DHP) consumes 524 kWh
- 624 kWh are saved

Extrapolating from tests results obtained by EPRI:

54% energy savings is anticipated from 100% market penetration of the ASD controlled compressors used in ductless single-room HVAC equipment.

Therefore, energy savings = 351 GWh/yr x 0.54 = 190 GWh/yr.

Predicted energy savings of 624 kWh/yr from each of 1,950,000 ductless single-room HVAC equipment in California is equivalent to 1,267GWh/yr.

Conservatively, energy savings for 100% penetration of ASD controlled compressors in ductless single-room HVAC equipment is estimated to be 190 GWh/yr.

6.3.4 Summary of Testing Results

The predicted results are of such a wide range that further investigation is warranted.

Market projections and test results are summarized in Table 46 and Table 47, respectively.

These results represent the potential energy savings that may be anticipated from the use of ASD controlled compressors. Further energy savings can be achieved for each application by using speed control of fans.

An investigation of the introduction of fan control in a refrigerator/freezer application indicated that further savings of 1,200 GWh/yr could be achieved.

The ductless clothes dryer would yield a further 6% savings on HVAC costs equivalent to 5,321 GWh/yr x 0.06 = 319 GWh/yr because conditioned air would no longer be wasted.

Table 47: Summary of Market Projections

Appliance	CA Units (M)	Market Projection Energy Use (GWh/yr)	Market Projection Savings
Refrigerator/Freezer	18.4	15,787	6,237 GWh/yr
Ductless Clothes Dryer	3.1	3,950	1,105 GWh/yr
Central Ducted HVAC	6.5	5,321	2,607 GWh/yr
Ductless Room HVAC	1.9	351	142 GWh/yr

Table 48: Summary of Test Results

Appliance	CA Units (M)	Unit Savings Prediction (% or kWh/yr)	Annual Savings Prediction
Refrigerator/Freezer	18.4	19.6% or 328 kWh/yr	3,094 GWh/yr
Ductless Clothes Dryer	3.1	50% or 340 kWh/yr	1,061 GWh/yr
Central Ducted HVAC	6.5	36% or 533 kWh/yr	3,465 GWh/yr
Ductless Room HVAC	1.9	54% or 624 kWh/yr	1,267 GWh/yr

6.4 Market Impact

Adjustable speed control in domestic appliances offers a variety of benefits that are attractive in terms of energy savings and the environment. In general, operating costs are lower, energy is saved, there is less operating noise, component life is extended, and the environmental impact is reduced; consumers experience palpable reward. They save energy, save money, and experience lower levels of appliance noise.

The major benefit achieved thus far is from speed control of compressors within appliances; this equipment design modification typically offers 20% energy savings. The latest refrigerator/freezers provide these benefits.

Heating and cooling systems, both ducted central and ductless single-room HVAC, using speed control show a marked improvement in performance. As with the refrigerator/freezer, energy is saved, noise is reduced, and environmental benefits accrue. Less noise equates to better room and building comfort. With respect to single-room HVAC systems, the ductless design is impressively quiet and completely dissimilar to its older counterpart; it offers comfort from whisper-quiet noise levels. These are tangible advantages to be gained. Temperature excursions are reduced, and comfort levels are improved. Humidity control becomes much tighter because stop/start features are replaced with a ramped condition change. Reduced operating cycles in the compressor will increase compressor life by 40%. Motor life doubles. Temperature levels improve 10°C or more. Higher speed available from the ASD controlled compressor improves heat pump performance. There is potential for further improvement; ECMs fitted on evaporator and condenser fans will provide greater noise reduction and further energy savings. The availability of demand response offers remote monitoring and control that helps plan energy use at peak times.

Ductless clothes dryers that use a heat pump save 50% of electrical energy and 6% of HVAC energy costs; conditioned air remains in the building rather than being exhausted as takes place with a conventional ducted dryer. A ductless dryer can be placed anywhere. It does not release humidity into the air and produces no lint.

6.5 Title 20 Impacts

The use of ASDs in domestic appliances is accepted and has proven beneficial. Research has shown there are benefits to be gained in terms of energy efficiency from using variable control in domestic products. T20 regulations can be useful in extending the adoption of this technology. Federal policy has addressed this. The Energy Star program has embraced specification standards that offer an efficiency increase of 10% over the Federal standards. It is likely that these standards will remain unchanged for at least 4 years. The opportunity to develop California T20 regulations on appliances that incorporate ASDs was explored in detail. The matrix determining the recommendation status is set out below (Figure 146). Recommended opportunities were based on expectations of cost effective high energy savings that require relatively low levels of effort for implementation. Refrigerator/freezers were good candidates as were both ducted and ductless domestic HVAC systems, ductless appearing to offer higher returns per unit (Figure 147). Of these appliances, refrigerator/freezers are used in

almost all households in California. HVAC units are used in 50% of households. This distribution will affect the benefits gained from the use of ASDs in these appliances. Presently ductless dryers are unavailable in California.

Figure 146: Opportunity Grading Scale

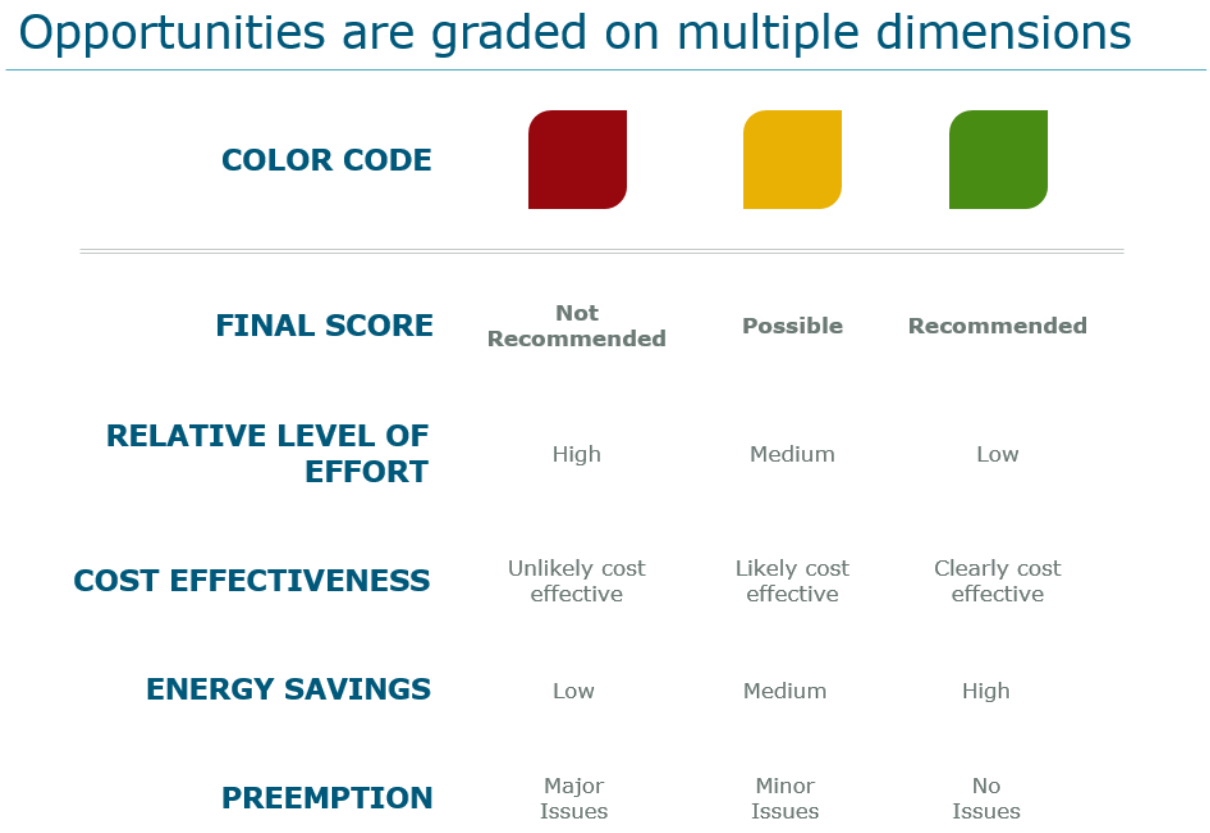


Figure 147: Opportunity Evaluation of Residential Refrigerators/Freezers

An evaluation of the results for refrigerator / freezers is summarized in the figure below:

Table 49: Range Results for Appliances Utilizing ASD Control

APPLIANCE	REFRIGERATOR/ FREEZER GWh/y	DUCTED A/C GWh/y	DUCTLESS A/C GWh/y	CLOTHES DRYER GWh/y (PRODUCT NOT AVAILABLE IN CA)
STAGE OF PROJECT				
ORIGINAL MARKET PREDICTION	6,237	2,067	142	1,105
SIDE BY SIDE TESTING	3,094	3,465	1,267	1,067
NEW TITLE 20	1,400			

The DOE standard for central air-conditioning that became effective January 1, 2015 differentiates energy efficiency levels according to different climate conditions within the country. In northern climates, the seasonal energy efficiency ratio (SEER: Btu/Wh) is designated 13, and generally does not require an ASD. However, in warmer southern climates that include California, SEER is designated 14, which generally does require an ASD.

With respect to room air conditioners, a new Federal standard took effect June 1, 2014.

Unfortunately, the DOE test procedure measures these units at maximum outdoor temperature only, rather than at varying temperature. This assessment that addresses peak conditions rather than varying conditions indicates that an ASD would show no benefits and so the technology was not considered. A further ruling is anticipated in 2017 that could allow an opportunity revise the testing procedure for more meaningful results. However, it is still not clear that the incorporation of an ASD would be cost effective because the duty cycle of room air conditioners is generally lower than central air conditioners. Economies of scale also come into play when dealing with ASDs but, given these reservations, it is likely that the addition of variable speed in this application would offer substantial benefits.

The analysis of potential for effective Title 20 legislation would suggest that energy efficiency benefits would accrue from further ASD control of refrigerator/freezers. Additionally, ASD control of HVAC household applications offers potential for substantial energy savings. There are significant comfort/life quality benefits that come along with ASD control of HVAC, particularly in applications that use a heat pump.

CHAPTER 7:
Technology Transfer Plan and Execution

7.1 Program Objectives/Introductions

The objective of this program was to develop and demonstrate consumer electronics and motorized appliances using advanced electronics that save energy, reduce peak demand, and reduce pollution for the citizens of California. The program consisted of five projects that focus on improvements in kiosks and multimedia computers, home audio equipment, residential induction cooktops, power factor corrected electronics, and adjustable speed drives to achieve these benefits. The following paragraphs describe these projects, including characterization of equipment types and desirable attributes sought by market participants in selecting equipment.

7.1.1 Project 1: Kiosks and Multimedia Computers

This project investigated the efficiency of typical low-end kiosks, point of sale terminals and high-end multimedia computers; integrate the best of class components into these devices, and demonstrate the performance of this improved equipment.

7.1.1.1 Kiosks

Characterization of Kiosks:

Kiosks, in this study, are defined as encompassing the "low end" of the computing market, where computing end-use applications include point-of-sale, e-mail/ Internet terminals, automated teller machines (ATMs), automated check-in kiosks, and a variety of other application-focused, low-intensity client computing tasks. Applications studied emphasize applications of general interest, including:

- Financial services/ATM kiosks
- HR/application kiosks
- Photo kiosks
- Internet kiosks
- Travel/check-in kiosks
- Concert/travel/movie ticketing kiosks
- Point-of-sale/self-service checkout kiosks
- Bill payment/order entry kiosks
- Government kiosks
- Visitor management/security kiosks
- Building directory/way finding kiosks

Desirable Attributes of Kiosks:

Functionality in the form of clarity of display, volume control, response time (boot up from startup, power saving, screen saving), accessibility, and simplicity (ease of use, fewer key strokes, screen navigation, minimum need for training tutorials). Reliability is needed as evidenced by durability, weather resistance (temperature, water tolerance), security (tamper proof, hacker proof, and identity safety), environmental control (effective cooling), effective cooling, and ease of maintenance/cleaning. Low cost is desirable. Peripherals including printers should be easily integrated into the kiosk and provide peripheral/printer function and ease of paper replacement. Computer capability should be sufficient to perform all desired functions including enabling integration of the kiosk with marketing and other functions.

Attributes of Kiosks of Interest to Market Participants:
Each of the attributes noted above may have different utility for each participant in the supply chain from users to operator to owner to specifier to distributor to manufacturer.

Typical elements in successful kiosk implementation are outlined in a web posting providing a snapshot of typical kiosk design, application, and deployment:

- Kiosk design
- Application development
- Hardware purchasing
- Hardware integration
- Testing
- Installation
- Ongoing maintenance
- Repair and parts replacement

Kiosk specification and purchasing is typically conducted in several ways: one-on-one between the user/owner and the kiosk manufacturer (typical of chains and larger customers) and with an intermediary third-party reseller (such as a computer manufacturer, software developer, or marketing firm) providing a bridge between the user/owner and the kiosk manufacturer.

Kiosk Improvements:

Improvements in kiosks are expected to be principally in the area of improved power factor and improved computer efficiency (using lower power processors, memory, graphics chips, and hard drives, for example) and replacement of existing personal computers with more flexible and lower power-use tablet computers (iPad and Android).[37]

---

37 The use of tablets should consider issues arising from use of a device designed for personal, consumer use that is used in a repetitive commercial setting. These issues include structural requirements and duty

7.1.1.2 Multimedia Personal Computers

Characterization of Multimedia Personal Computers:

Multimedia personal computers perform resource-intensive multimedia tasks including "high-end" gaming and home media computing applications. Typical tasks and typical devices were covered in this study include gaming, media storage/management, high-definition video playback/streaming, and media processing/design. Most units are owned by the gamer, but some units may reside in commercial gaming establishments.[38]

Desirable Attributes of Multimedia Personal Computers:

Functionality in the form of ease of use, fast response time, high-definition graphics, and reliable operation is required. This typically entails use of a high-end graphics card, fast processor, large amounts of RAM, superfast hard drives, and lots of throughput. Other desirable features include a DVD burner/reader, a variety of inputs, and a large number of USB ports. The operating system must be user friendly. The best computing devices are compact to save desk space. Cost is not often a major issue for high-performance advanced systems although it may be for starter gamers and for gaming establishments. Energy is not often an issue for gamers, but it might be of interest to gaming establishments.

Multimedia Personal Computers Attributes of Interest to Market Participants:

Each of the attributes noted above may have different utility for each participant in the supply chain from users to operator to owner to specifier to distributor to manufacturer.

Novice gamers might buy their computers directly from Hewlett Packard or, for higher end machines, from Alienware (now Dell), selecting options online to configure a computer for their requirements. A more experienced gamer might select components from a source such as Maximum PC and find someone to put it together from a source such as Power PC. Or the experienced gamer might use a source such as Maximum PC to purchase components and to make their own machine. Multimedia Computer Improvements:

Multimedia personal computers improvements are expected to involve higher efficiency computers including power management (sleep mode), more efficient graphics cards, memory, power supplies and processors, and high power factor power supplies.

7.1.2 Project 2: Home Audio Equipment Efficiency Assessment

This project developed a test protocol to measure home audio equipment efficiency, verify the protocol, and identify energy efficient designs for home audio devices.

---

cycle, screen life and warranties associated with use in a kiosk, mounting issues, theft considerations, tampering, insufficient brightness, real-time monitoring of functionality, remote updating, and lack of support for thumb drives. Security considerations with tablets include locking the tablet to the apps associated with that kiosk, blocking access to tablet settings, and protection of customer data.

38 A typical gaming establishment has many computers and many games and sells time to the users. An example of one of these gaming stores is at www.euphnet.com.

7.1.2.1 Test Procedures and Regulations

The project used the latest Energy Star test method for audio/visual equipment as the starting point for protocol improvements. (Energy Commission regulations cover standby power for selected audio equipment types.[39]) The Energy Star test method covers operational modes including auto power down (APD) into sleep mode, input power, voltage, total harmonic distortion, frequency, ambient temperature (18°C to 28°C), and ambient relative humidity (10% to 80%), power measurement, audio sources, speaker output, sleep mode power, output volume, amplifiers, and other functions. Products covered are "mains-connected product that offers audio amplification and/or optical disc player functions". Test procedure improvements to be explored include measuring and setting limits on idle mode power and active mode power vs. sound volume.

7.1.2.2 Home Audio Equipment to be Studied and Improvement Opportunities

Audio equipment was investigated in this project includes receivers, separate components, Blu-ray disc players, compact audio, DVD players, sound bars/powered speakers, subwoofers, docks, and home theater in a box. Energy efficiency improvements should not seriously detract from the sound quality of the devices, their cost, and size. Areas that were explored include minimizing standby power without causing sleep mode to clip the first part of a sound after a period of inactivity, minimizing power when a device is plugged in but is off, minimizing idle mode power, and using the most efficient components (power supplies, amplifiers, etc.) that are also cost effective, provide quality sound, and are compatible with the application (size and other issues).

7.1.2.3 Home Amplifier Classes

Four basic categories of amplifiers—Class A, Class B, Class AB, and Class D—are described by EPRI and International Rectifier based on their output signal:

- Class A: With this type of amplifier, the output devices are continuously conducting for the entire power cycle. This topology has the least distortion and is the most linear, but at the same time, since it is always on, it is the least efficient.
- Class B: This type of amplifier output device conducts for only half the sinusoidal cycle (one transistor conducts in the positive region, and one conducts in the negative region). If there is no input signal, no current flows in the output devices. This class of amplifier

---

39 California standby power standards for compact audio equipment and DVD recorders and players and Blu-ray players permit standby power for compact audio equipment of 2 W for products without an illuminated clock display and 4 W for products with an illuminated clock display. DVD and Blu-ray players and recorders are allowed 3 W in the standby mode. (2010 Appliance Efficiency Regulations, Singh, H., and Rider, K., California Energy Commission, December 8, 2010 http://www.energy.ca.gov/2010publications/Energy Commission-400-2010-012/Energy Commission-400-2010-012.PDF)

These regulations are generally less stringent than ENERGY STAR specifications and do not cover products that consume large amounts of energy such as receivers, speakers, soundbars, and Home Theater in a Box.

is more efficient than Class A but has some issues with linearity at the crossover point, due to the time it takes to turn between devices.

- Class AB: This amplifier type, a combination of Classes A and B, is one of the most common types of power amplifier used. Each device is conducting for more than half a cycle but less than the whole cycle, so the inherent non-linearity of Class B designs is overcome without the inefficiencies of a Class A design.
- Class D: This class of amplifier is also known as a switching or pulse width modulation (PWM) amplifier. In this type of amplifier, the switches are either fully on or fully off, significantly reducing the power losses in the output devices.

The table below illustrates the efficiencies of amplifier types. As can be seen, an area deserving attention is the possible use of Class D switch mode amplifiers to substitute for linear Class AB amplifiers and save as much as 60% of the energy use.

Table 49: Approximate Efficiency of Home Audio Amplifier Types (%)

	Amplifier Type			
Source	**Class A**	**Class B**	**Class AB**	**Class D**
Laverty, eHow[40]	30	65		90
Bohn			50	90
Wikipedia		50	50	90
Lewis, HiWave	20	50	50	90
Gonzalez, Texas A&M	25 max	78.5 max	78.5 max	100 max, 80 to 90 actual
Guy, National Semi				80 to 95, mostly mid 80s
Zed Audio		50		80 to 95

Reducing energy use by adopting more efficient but more costly amplifiers can have the ancillary benefits of reduced product size and consequent lower shipping weight and lower shipping and storage cost due to smaller heat sinks as well as reduced building cooling requirements.

7.1.2.4 Key Drivers for Home Audio Equipment Selection

Attributes often sought by purchasers in selecting home audio equipment center on desired sound quality, equipment cost, size, and availability (response time).

---

40 Classes of RF Amplifiers, Laverty, Shea, eHow, downloaded August 3, 2012 http://www.ehow.com/list_5972437_classes-rf-amplifiers.html

7.1.3 Project 3: Residential Induction Cooktop

This project studied the benefits of more widespread use of induction cooking on residential cooking energy use. Effort focused on options to make induction cooking compatible with non-ferrous cookware, including the use of higher frequency induction heating for this purpose.

7.1.3.1 Characterization of Residential Cooktops

Unlike conventional cooktops that cook by heating the burner/element from below and transferring heat to the cookware, magnetic induction cooking uses electricity to produce a magnetic field in the cookware that heats the cookware through eddy currents, skin effect, and magnetic hysteresis. Induction heating uses an alternating current magnetic field to induce eddy currents that heat the cooking vessel. In addition, the alternating current creates a skin effect, forcing the current to flow in a thin layer with corresponding high resistance and high heating effect. With ferrous materials, the alternating current creates a pulsating magnetic field that causes friction and heating in the material, known as hysteresis losses. With non-ferrous materials, the eddy currents and skin effects need to be increased since the hysteresis effect will not be present. This can be accomplished by increasing the frequency of the alternating current magnetic field.

7.1.3.2 Desirable Attributes of Residential Induction Cooktops

Some of the attributes often sought by purchasers of cooktop equipment include cooking time, temperature control, ease of use, ease of maintenance, and safety. Equipment cost is important as is the ability to use available cookware (as opposed to the need for purchasing special cookware needed to enable the use of magnetic induction cooktops).

Magnetic induction cooktops have flat surfaces that are easy to clean. Flameless cooking is safer as is the cooler cooktop. Cooking is faster since the energy is delivered directly to the cookware. Cooking times to boil 2 quarts of water were as follows: induction, 286 seconds; halogen, 540 seconds; electric coil, 590 seconds; and gas, 498 seconds.

Because induction cooktops heat the cookware directly, less energy is required than if heat is transferred from the hot cooktop to the cookware as with conventional gas and electric cooktops. Efficiencies of alternative cooktops found in available published literature are shown in the following table.

Table 50: Residential Cooktop Efficiency

Type of Cooktop	**Efficiency (%)**					
Source	KB&B	Mncgloble	CookTek	DOE	HV	EPRI
Induction	84	90	90	84	90	92
Gas	40	50	40	40	55	47
Halogen	71	60	58	70		72
Electric Coil		55	47		65	

Magnetic induction efficiency values range from 84% to 90%, considerably better than other cooktop alternatives. Higher efficiency saves energy and money and keeps the kitchen cooler.

7.1.3.3 Undesirable Attributes of Residential Induction Cooktops

Disadvantages of induction are higher cost, the need for cooking vessels made of magnetic materials, and the need for air circulation clearance directly below the cooktops.

Cost of induction cooktops incorporated into oven assemblies as integrated units are around $1400 to $1500; high-end electric cooktops are around $500 to $700, and top-of-the-line gas cooktops are around $600 to $1000. Residential countertop induction units of the type to be improved in this program are available from as low as $100 to more than $500.

7.1.3.4 Residential Induction Cooktop Technology Improvements

This study developed induction cooking units that do not require ferrous cookware. There are Japanese induction units that use high frequency magnetic fields to induce currents in any conductive cookware. This should provide a considerable advantage to those who do not desire the purchase of new cookware when switching to induction cooktops from other cooktop means. Attributes to be featured in the new and improved induction cooking products align with what market participants desire in selecting cooktops: short cooking time, good temperature control, reasonable cost, ease of cleaning, and maintenance and safety (cool cooking surfaces). This congruence of project goals and attributes desired by the consumer should facilitate market acceptance of the new and improved induction cooktops resulting from this project.

7.1.4 Project 4: Power Factor Correted Electronics Technology

This project characterized the power factor of existing residential appliances, lighting, home electronics, and home entertainment equipment; determine the cost of enhancing this power factor to approach unity; assess the utility benefits of achieving this improved power factor; and present results to codes and standards setting bodies and other market participants in order to encourage changes to codes and standards and specifying and purchase decisions that result in improved power factor and better utilization of the utility distribution system.

7.1.4.1 What Is Power Factor?

Power factor quantifies the relationship between *working power*—the power actually consumed—and the *capacity* that must be supplied by the utility to make this working power available. Working power is expressed in kilowatts or kW (1 kilowatt = 1,000 watts). The total capacity required is expressed in kilovolt-amperes, or kVA (electrical equipment such as generators and transformers are rated in kVA). Power factor is the ratio of the working power to the total capacity required to provide this power—or kW/kVA.

Resistive loads such as heating elements or incandescent lamps have a power factor of 1. Inductive loads such as motors or ballasts draw current that lags the voltage while capacitive loads draw current that lead the voltage. Both inductive and capacitive loads display reactance, requiring reactive power that results in power factors of less than 1. With inductive loads, for example, the line current consists of two components: the magnetizing current (required to sustain the magnetic field strength of the machine) and the power producing current. The

magnetizing current component creates reactive power that does not do useful work but requires current flow between the utility generator and the load. The real power producing current is measured by the real power. Apparent power is the vector sum of real and reactive power. Power factor is the ratio of real power to apparent power.

Improved power factor can reduce utility capacity requirements (and corresponding resistance losses in the utility distribution system) as well as unload facility wiring, permitting more equipment to be run without increasing electric service.

7.1.4.2 Power Factor of Residential Equipment

Power supplies are devices that supply electric power to an electrical load, often by converting one form of electrical energy to another, such as converting alternating current to direct current or controlling voltage or current. They may be implemented as stand-alone devices or hardwired into the load.

Switched mode power supplies are most often used in computers and other home and commercial electronics equipment to convert AC power to DC power, passing the current through a high frequency inductor or transformer. Power factor has become an issue of concern for computer manufacturers. Switched mode power supplies have traditionally been a source of power line harmonics and have a very poor power factor. Typical switching power supplies rectify the input power and utilize a capacitor filter in order to provide a DC bus voltage. The typical power factor of such a conversion is approximately 0.6. Some switch-mode power supplies use filters or additional switching stages in the incoming rectifier circuit to improve the waveform of the current taken from the AC line. This adds to the circuit complexity. Many computer power supplies built in the last few years now include power factor correction built right into the switched-mode supply and may advertise the fact that they offer a 1.0 power factor.

Switch-mode supplies replaced linear supplies in computers due to cost, weight, and size improvement. Linear regulated power supplies generally use a transformer to step down the AC input voltage and rectify the secondary voltage and then utilize a capacitor filter to create the DC voltage to the input of the regulator stage. The transformer improves the power factor of the input just slightly compared to the typical switching power supply.

There are many configurations of three-phase rectifiers. In the simplest case, a full-wave rectifier is used in conjunction with a single three-phase bridge rectifier. The resulting ripple frequency is six times the input AC frequency, and the power factor is generally approximately 0.7. A configuration using both delta and wye secondaries results in a ripple frequency 12 times the input AC frequency. The power factor of this configuration is approximately 0.8. More sophisticated approaches utilize even more secondaries in order to produce higher ripple frequencies and better power factor. The characteristics (including efficiency, size, weight, response, frequency, and power factor correction) of linear and switched mode power supplies and their selection for various applications is discussed in an EPRI report on power supply maintenance and application.

Estimates indicate that 400 million to 500 million new linear and switched mode power supplies are sold in the United States each year. EPRI tested a sample set of 15 power supplies that represent the following equipment categories: televisions (CRT3, LCD, plasma, and OLED); digital picture frames; Fit-PC (innovative desktop computer); DTV (digital television) converter; Blu-ray DVD player; laptop applications; video game applications (X-Box 360, Wii); and self-amplified speaker applications. Selected results showed that the power factor ranged from 0.51 to 0.65 for 10 digital picture frames tested. For a Blu-ray player, the power factor was 0.157 when the Blu-ray device was off and 0.558 when the Blu-ray device was on. Only two of the seven laptop computers tested were power factor corrected, and none of the video game power supplies were power factor corrected.

Appliance and lighting equipment were studied to assess the power factor of these loads in a typical residence. Fluorescent lighting was found to demonstrate a power factor of approximately 0.85, HVAC equipment 0.77, clothes washers 0.33, clothes dryers 0.46, refrigerators 0.84, and dishwashers 0.60. The combined power factor of all electronic loads in the home was 0.93. Increased use of CFLs, other lamps that replace incandescent lamps, and advanced appliances and home electronics is likely to reduce the combined power factor of the home.

Compact fluorescent lamps with input power less than 25 W typically display power factors of around 0.6. CFLs typically are limited only to the control of the 3rd and 5th harmonics.

The DOE mandates minimum acceptable power factors of 0.7 and 0.9, respectively, for residential and commercial LED lights.

Normal power factor ballast/HID (high-intensity discharge) lamp combinations have a power factor of approximately 50%. High power factor ballast/HID combinations have a power factor or 90% or greater.

Simple inductive (magnetic) ballasts for fluorescent lamps have a power factor less than 1. Simple electronic ballasts may also have low power factor due to their rectifier input stage.

7.1.4.3 Power Factor Correction

Active power factor correction utilizes electronics to force the input current to look like a reflection of the input voltage (that is, resistive). The result of this type of correction typically results in power factor of greater than 0.98 and harmonic distortion of less than 3%. Power factor correction typically introduces electrical capacitance in parallel with an activated inductive electrical load to offset the reactance of the inductive load.

Sizing, selection, and placement of capacitors for power factor correction are described in a report prepared for DOE. It is common to locate capacitors near a large inductive load or groups of loads. For residential applications, it is likely that individual capacitors would be used with each inductive load that needs power factor correction. Switched capacitors are those that are energized when the load is energized. Fixed capacitors are always energized. Reactive power is almost constant for many inductive loads; therefore, sizing and operating equipment to be heavily loaded rather than lightly loaded will improve equipment power factor.

7.1.4.4 Market Issues and Residential Power Factor

Residential customers are not typically billed for low power factor. Unless they have circuits in the house that are at the limit or over the limit of their capacity that can ameliorated by improved power factor, improving their power factor provides them with no quantitative benefit. Including power factor in residential utility billing or in building or equipment codes and standards is the most straightforward way of getting residential customers to improve their power factor.

7.1.5 Project 5: Adjustable-Speed Drives

This project quantified the savings potential of widespread adoption of adjustable-speed drives (ASDs) in motor-driven consumer applications, select the equipment that could benefit most from the use of ASDs, and conduct testing to assess the benefits of incorporating ASDs in these equipment types.

7.1.5.1 Characterization of Equipment Amenable to Adjustable Speed Drives

Devices that operate over a range of speed, capacity, torque, or other attributes need to be modulated. This modulation can be accomplished with on-off operation, throttling with control valves, unloading, or other means.

7.1.5.2 Desirable Attributes of Adjustable-Speed Drives

Adjustable speed drives typically control the speed or torque of motors by varying their frequency and are typically 92% to 95% efficient. Adjustable speed drives provide more efficient operation than alternative means of modulation.

Adjustable speed drives provide opportunities to continuously control processes. Soft starting, ramping, and braking (acceleration control) result in smoother equipment operation and should therefore reduce system maintenance and improve system reliability. Special operating patterns including bi-directional motor applications are possible with adjustable speed drives.

Disadvantages of adjustable speed drives are higher initial cost, harmonics that could cause facility interference, motor heating at low speeds, and the typical temperature and contamination constraints of electronic equipment.

In this task, improvements in adjustable speed drive technology are expected to be applied to residential appliances that have not previously used adjustable speed drives, such as clothes dryers and refrigerator/freezers. Adjustable speed drives will also be applied to air conditioning applications where they have been used but have not become widespread. Adjusting speed to meet the load provides smooth operation in addition to the elimination of start and stop transients under off-design, part load operation. With air conditioners, low-speed compressor operation is equivalent to having a smaller compressor and correspondingly oversized heat exchangers, resulting in lower temperature differences and respectively higher equipment efficiencies. These benefits translate to lower energy bills, better controllability, and overall smoother operation and greater equipment reliability. All of these attributes align with desirable characteristics sought by residential consumers. Marketing materials that stress these improvements and give the consumer a clear picture of how these might overcome the increased equipment cost, possible introduction of harmonics, and other disturbances will

facilitate the acceptance of the new and improved ASD-driven equipment studied in this project.

7.2 Preface

This technology transfer plan follows the general rationale, framework, and methodology of a technology plan prepared for the Energy Commission under a previous study of displacement ventilation and ultraviolet light technology use in schools. The current plan deals with different technologies and largely residential applications. The current report closely follows the previous plan in the areas of market barriers, deliverables templates and information on existing organizations that are targets of both plans (e.g. governments, utilities, HVAC organizations). In addition to the discussion of completely different technologies and, to a large extent, different audiences, the current report updates information on organizations, contacts and efforts that would be common to both plans.

7.3 Market Barriers

Impediments to implementation of new technology have been characterized as market barriers (Table 51) in the market transformation literature. Market barriers can be overcome with suitable market interventions resulting in the desired market influence (Table 52).

Table 51 lists traditional market barriers, as outlined by Eto et al. Accompanying each of the market barriers are possible approaches suggested for addressing that barrier.

Missing from the barriers presented in Eto's report are cost-related impediments. The reasoning by Eto is that cost in itself is not a barrier; it is an effect. Effectively overcoming the barriers listed in Table 51 will result in reduced transaction costs, increased market penetration and resultant reduced cost of production, and lower prices. Eto implies that rebates or other financial incentives do not have a lasting effect on the market.

Recent evidence shows that rebates may indeed have a transformative effect on the market, increasing customer acceptance and manufacturer volume and resulting in economies of scale. These effects can be sustainable even after rebates have been removed. Thus, high first cost is included in Table 51 Cont. as a barrier, and rebates and other financial incentives are offered as possible approaches to overcoming this barrier.

Most of the possible approaches to overcoming market barriers involve providing information in the form of guidelines, presentations, tours, training, fact sheets, brochures, technical assistance, product directories, case studies, publicity, testimonials, or combinations of these information products. Information products are also required to convince utilities and other possible funding sources of the desirability of financial incentives and the appropriate levels for these incentives. Producing information products with compelling messages and delivering them to the right people at the right place at the right time is the heart of the market connections project. This technology transfer plan outlines the what, who, when, and where of this effort.

Table 51: Market Barriersto Adopting Improved Technologies (Improved Consumer Electronics and Motorized Appliances) and Possible Approaches to Reducing These Barriers

Market Barriers	Approaches to Reducing These Barriers
A. Information or search costs: costs of identifying efficient Consumer Electronics and Motorized Appliances products and practices.	"Directory" of improved Consumer Electronics and Motorized Appliances products and their characteristics and performance; for specifiers and installers.
B. Performance uncertainties: need to experience performance of improved Consumer Electronics and Motorized Appliances technology as affected by their unique operating conditions, practices, or preferences.	Case studies documenting performance. Testimonials from colleagues with similar requirements.
C. Asymmetric information and opportunism: sellers of improved Consumer Electronics and Motorized Appliances know more than buyers; obtaining equivalent information may be costly or impossible for the buyer.	Information on ownership costs, energy, performance, and other attributes from a reputable third party to assist the buyer/specifier in making a selection/purchase decision. Training, technical assistance.
D. Hassle or transaction costs: costs of acquiring improved Consumer Electronics and Motorized Appliances.	Guidelines for specifying, buying, and installing a product; training and technical assistance.
E. Hidden costs: unexpected operation, monitoring, servicing, and maintenance costs.	Guidelines for operating, monitoring, servicing, and maintaining improved products for facilities and maintenance personnel.
F. Access to financing: lack of recognition of life cycle cost savings; lack of accounting for energy efficiency, health, and productivity improvements in borrowing costs.	Information for Energy Service Companies (ESCOs), specifiers, sources of funding on the benefits of improved Consumer Electronics and Motorized Appliances.
G. Bounded rationality: use of rules of thumb (such as a two-year payback period) that limit the scope of consideration for a given decision.	Case studies documenting cost effectiveness and other advantages to overcome rules of thumb that might otherwise inhibit consideration.
H. Organization practices: rules, policies, and practices that make it difficult to adopt new technologies.	Case studies focused on economic, health, and productivity benefits that overcome the bureaucratic tendency to be risk averse. Requires strong message showing benefits.
I. Misplaced or split incentives: institutional relationships where the person charged with deciding on adopting a new technology is not the person who benefits from it.	Case study information to help the manager/specifier understand the energy, health, and productivity benefits of the new technologies.
J. Product or service unavailability: higher prices or unavailability because of newness.	Aggressive publicity and market interventions, creating demand for product, reducing prices.

Market Barriers	Approaches to Reducing These Barriers
K. Externalities: costs (such as environmental costs) not reflected in the price.	Provide information on the how improved Consumer Electronics and Motorized Appliances technologies reduce energy use and thus reduce CO_2 production and global warming.
L. Nonexternality mispricing: other factors moving price away from cost, such as ratemaking based on average costs.	Provide information focused on convincing the local utility to provide training and financial incentives that reflect the economics of "integrated resource planning."
M. Inseparability of product features: desirable features are coupled with features not of interest to the purchaser.	Not applicable.
L. Nonexternality mispricing: other factors moving price away from cost, such as ratemaking based on average costs.	Provide information focused on convincing the local utility to provide training and financial incentives that reflect the economics of "integrated resource planning."
M. Inseparability of product features: desirable features are coupled with features not of interest to the purchaser.	Not applicable.
N. Irreversibility: purchase decisions are irreversible to the extent that a purchased product has a usable life and is not likely to be replaced during that useful life.	Can the technologies be deployed in retrofit situations? If retrofits are possible, provide clear instructions on modifying the building for these retrofits and how to install the product.
O. High purchase price: immature product using new technology/components and low initial manufacturing volume results in high product cost and high purchase price.	Rebates or other financial incentives can reduce product acquisition cost for the user and bolster manufacturer volume to enhance economies of scale.
P. Codes and standards: existing codes and standards may not properly account for attributes of improved Consumer Electronics and Motorized Appliances technologies, making it difficult to favorably deploy the technologies in their most suitable applications.	Document performance of the improved Consumer Electronics and Motorized Appliances technology, providing evidence that a waiver or alteration is required in the existing codes and standards. Prepare, package, and present the information to influential individuals and organizations to affect desired changes.

7.3.1 Overcoming Market Barriers

The objective of the market connection project was to improve the market focus of the Program's technology products and thereby increase the public benefits of the Energy Commission's investments.

This technology transfer plan addresses potential market barriers affecting the implementation of consumer electronics and motorized appliances using advanced electronics technologies and actions needed to overcome these barriers. Influential market participants are identified, and their market roles are described as well as barriers that inhibit market penetration of new technologies and actions needed to overcome these barriers.

Specifiers and other decision makers tend to favor systems and technologies that have performed well for them in the past. As such there often exists a very substantial resistance to change. Information needs to be provided to overcome this resistance to change, to minimize performance uncertainties, and to reduce the extra effort and consequent cost of deploying new technologies. Different decision makers have different roles in the specifying, supply, or funding process/value chain. Specific market interventions are suggested to address the market barriers influencing the decisions of each decision maker/market participant.

Information products are described in the following paragraphs that address market barriers inhibiting the adoption of new technologies for each of the market participants.

Information resources that are available to market participants are tabulated according to the information source. Meetings, publications, and periodicals that could serve as vehicles for disseminating desired information products to market participants are listed for each type of market participant. A suggested action plan is provided, listing the information products to be developed, the avenues for disseminating the products, and the dates for delivery of the publications to these venues.

Codes and standard issues, actions needed to address these issues, and organizations involved in setting and monitoring codes and standards are tabulated. The actions are time-phased to be consistent with availability of program information and input needs of codes and standards setting bodies.

7.4 Market Influences/Actions Needed

Table 52 provides a list of market participants/market actors and their functions in the market. For each market participant, market barriers that could impede the adoption of new technologies in California are tabulated along with suggested generic actions/interventions that could overcome these barriers.

There are several parties involved in the utilization, specification, installation, operation, and financing of improved Consumer Electronics and Motorized Appliance technologies. The main function of each of these market participants is described in Table 52 Each of these functions (chains of market participants) interacts and overlaps to the extent that one function/chain can influence another. For example, a product that is not easy to use, operate, or maintain will not be favored by users/utilizers. This information is likely to be passed on to specifiers who are consequently not likely to specify the product for future installations.

Each chain of market participants has particular needs that must be satisfied if a new technology is to be specified, financed, installed, operated, and utilized. Most technology product attributes are universally required across all of the functions/chains, but some are particularly critical to a subset of the market participants. Information products need to focus their contents on the attributes most important to the market participants or chain of market participants they are designed to address.

Funders, for example, will be interested in cost effectiveness, particularly first cost, as well as cost/energy savings.

Utilities offering rebates or other incentives to new technologies will also want to know how the technologies save energy compared to conventional systems.

Organization facilities officials are concerned with planning, obtaining funding, selecting the architect and engineering firm(s), approving the project scope, and tracking expenditures and project progress. Officials are concerned with project specifications that can cost-effectively provide an outstanding workplace or retail environment.

Specifiers will also be interested in cost effectiveness and how well the system performs compared to specifications. Reduced energy use, improved worker and consumer performance, and reliable operation will also be of great interest to this market function/chain. The more technically oriented participants in the "specifier" group will need information on how well the technologies performed in terms of delivering their expected advantages. Similarly and perhaps more important are how well the perceived disadvantages have been overcome. The information products that are focused on influencing this group will therefore pay particular attention to documenting proven performance advantages and how perceived disadvantages have been and can be overcome.

Suppliers need to see or anticipate demand for their product. Information that provides well-accepted performance evaluation, third-party testimonials—delivered through the most effective channels to specifiers and others in the supplier chain—will encourage dealers and distributors to stock the product and manufacturers to produce it. If utilities can be influenced to provide financial incentives, this would be a major step toward increasing product availability and reducing acquisition cost.

Installers would be most receptive to receiving application guidelines showing the simplest and most effective techniques for installing the new technologies and for ensuring that they are operating correctly.

Maintenance personnel/operators need checklists of time-phased maintenance procedures as well as operating manuals that could be used to keep the systems working effectively, ensuring their continued high performance.

Users of the technology such as consumers will be concerned with ease of operation, safety, indoor air quality, temperature control, and noise. A brochure for users will help them understand the virtues of improved Consumer Electronics and Motorized Appliance systems as users and will help the user to operate them correctly, ensuring that the system advantages are consistently received.

Codes and standards setting bodies need information on the performance of new technologies to ensure that they adhere to existing requirements. If the new technologies do not comply with existing requirements but nevertheless satisfy the objectives of the codes or standards, this information should be clearly provided. This will enable the language of the regulation to be changed to permit effective usage of the new technologies.

Table 52: Market Influences in Improved Consumer Electronics and Motorized Appliance Technologies in California

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Federal Government	Set codes and standards Provide funding Provide information, guidance and oversight in planning, designing, funding, building, improving and maintaining facilities and equipment	Aversion to risk Long budgeting cycle Need assistance in developing and disseminating information	Documented performance/case studies assuring code compliance or presenting information to alter codes Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies A full range of information products to permit dissemination of training, guidance and oversight to constituents
State Government	Set codes and standards Provide funding Provide information, guidance and oversight	Aversion to risk Long budgeting cycle Need assistance in developing and disseminating information	Documented performance/case studies assuring code compliance or presenting information to alter codes Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies A full range of information products to permit dissemination of training, guidance and oversight to constituents

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Local Government	Influence/set codes and standards Provide funding	Aversion to risk Long budgeting cycle	Timely presentation of documented performance/case studies assuring code compliance or presenting information to alter codes Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies
Utility	Provide funding for efficient installations Provide information guidance and oversight	Need proven performance to determine eligibility Need assistance in developing and disseminating information	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies A range of information products to permit dissemination of training, guidance and oversight to constituents
Company and Non-Profit Boards	Obtain funding, from government, utility, ESCOs Approve project scope, specifications and budget Approve selection of architect/engineering firm	Financial constraints often drive decisions to be based on low first cost Limited access to capital Short payback requirements Adherence to low bid contracting Competition for capital from staff, IT, supplies May lack skills to deal with ESCOs Risk of nonperformance when using outside contractors and new technologies	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information on improved performance/reduced absenteeism as a result from the utilization of the new technologies; showing the benefits of investing in improved Consumer Electronics and Motorized Appliance technologies Technical and financial training materials for dealing with ESCOs as a means of entering into attractive performance contracts Information on field-proven performance including design, installation and operation information for the new technologies Information products tailored to each level in the approval process/specification chain to make them more receptive to the new technologies

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Operations Manager	Obtain funding, from government, utility, ESCOs Set and approve project scope, specification and budget Select architect/engineering firm	Financial constraints drive decisions to be based on low first cost Limited access to capital Short payback requirements Adherence to low bid contracting Competition for capital from operations, staff, IT, supplies May lack skills necessary to deal with ESCOs Risk of nonperformance when using outside contractors and new technologies	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information on improved performance/reduced absenteeism as a result from the utilization of the new technologies; showing the benefits of investing in improved Consumer Electronics and Motorized Appliance technologies Technical and financial training materials for dealing with ESCOs as a means of entering into attractive performance contracts. Information on field-proven performance including design, installation and operation information for the new technologies Information products tailored to each level in the approval process/specification chain to make them more receptive to the new technologies
Business Officer	Concerned with financial issues, funding, and budgets, related to executing **specifications**	Financial decisions tend to be based on low first cost Split incentives, low construction costs may not result in lowest life cycle costs Competition for capital between operations, facility improvements, staff, IT, supplies	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information on improved performance/reduced absenteeism as a result from the utilization of the new technologies; showing the benefits of investing in improved Consumer Electronics and Motorized Appliance technologies

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Facility Planner	Construction planning, facility upgrade planning, adherence to **specifications**	Risk of nonperformance when using outside contractors and new technologies May lack skills necessary to deal with ESCOs Split incentives, low construction costs may not result in lowest life cycle costs Competition for capital from operations improvements, staff, IT, supplies	Technical and financial training materials for dealing with ESCOs as a means of entering into attractive performance contracts Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information on improved performance/reduced absenteeism as a result from the utilization of the new technologies; showing the benefits of investing in improved Consumer Electronics and Motorized Appliance technologies
Construction Manager	Construction, **installation** oversight Program management	Risk of nonperformance when using outside contractors and new technologies May lack skills necessary to deal with ESCOs	Technical and financial training materials for dealing with ESCOs as a means of entering into attractive performance contracts Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information on field-proven performance including design, installation and operation information for the new technologies
Architect	Facility appearance Follow codes and standards Arranging the space to achieve functionality Establishing budget, specifications	Risk of nonperformance when using new technologies Often measured more on low first cost (adherence to schedule and budget) than on reduced operating costs and performance improvements	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information on field-proven performance including design, installation and operation information for the new technologies

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Engineer/ Designer	Design systems to meet loads, space restrictions, and architectural requirements Design systems to comply with fire safety, energy and indoor air quality codes Specify systems that can be built within budget and installed by local trades	Risk of nonperformance when using new technologies May lack experience with the design and installation of new technologies Often measured more on low first cost (adherence to schedule and budget) than on reduced operating costs and performance improvements	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information (guidelines, presentations and training) on field-proven performance including design, installation and operation information for the new technologies Performance information on existing installations Analysis tools that account for advanced system attributes
Professional Society/Trade Association	Set test procedures and codes and standards	Assurances that new technologies meet code requirements	Documented performance assuring that the objectives of the code requirements are being met
Contractor	Responsible for installation, adhering to designer's specifications, budgets, schedule and complying with applicable codes/regulations.	Risk of nonperformance when using new technologies May lack understanding of installation requirements of new technologies.	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information (guidelines, presentations and training) on field-proven performance including design, installation and operation information

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Facility Manager	Responsible for operating the facility within budget with a good teaching environment, desiring low operating cost (energy, maintenance), and ease of control and reliability	Often understaffed May lack new technology expertise Lack of time to address problems May be wary of sophisticated equipment installation and maintenance requirements	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Information (guidelines, presentations and training) on field-proven performance and design, installation and operation for the new technologies Guidelines, presentations, training, and brochures on equipment maintenance, servicing, control and operation
Maintenance	Achieving low maintenance and repair cost, ease of operation, maintenance and repair, high reliability	Understaffed Lack of expertise with new technology Lack of time to address problems Wary of sophisticated equipment and concurrent installation and maintenance requirements Operation/maintenance differs from conventional systems	Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies. Information (guidelines, presentations and training) on field-proven performance including design, installation and operation information for the new technologies. Guidelines, presentations, training, and brochures on equipment maintenance, servicing, control and operation
Manufacturer	Production (supply), pricing and marketing of improved Consumer Electronics and Motorized Appliances	Want products with high market volume, proven performance Concerned with production volume, margins	Provide information on the advantages of the products, market need and available/anticipated support for the product. Applications guidelines for adapting off-the-shelf components into “turn-key” systems hardware and controls equipment

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Distributor	Intermediary in the supply chain. Distributors will stock products that have high demand	Want products with high market volume, proven performance	Provide information on the advantages of the products, market need and support for the product. Applications guidelines for adapting off-the-shelf components into "turn-key" systems hardware and controls equipment
Dealer/Retailer	Supplier selling to installer; wants to sell products in stock and products with high sales volume	Want products with high market volume, proven performance Concerned with complexity of installation, servicing, reliability	Provide information on the advantages of the products, market need and support for the product. Applications guidelines for adapting off-the-shelf components into "turn-key" systems hardware and controls equipment
Worker	User, concerned with ease of operation, safety, good indoor environment (temperature control, fresh air, good acoustics), attractive appearance	Unfamiliarity with new technologies Fear of the unknown Needs to operate the new technologies to produce a healthy productive environment	Fact sheets explaining the concepts of improved Consumer Electronics and Motorized Appliance technologies, and their advantages Easy to follow information on how to operate and control the systems that incorporate the new technologies
Consumer	**User**, concerned with good indoor environment (temperature control, fresh air, good acoustics), attractive appearance	Dependent on retailer for providing a healthy productive environment Fear of the unknown	Fact sheets, information in newspapers, or other vehicles explaining the concepts of improved Consumer Electronics and Motorized Appliance technologies and their advantages

Market Actor	Market Functions	Market Issues	Suggested Interventions/Stimuli
Energy Service Company (ESCO)	**Installer**, **specifier**, financer (**funder**) needs to be convinced of the economic benefits of the technology	Reluctance to accept technical and financial risk of getting involved in project dependent on technologies that are new to them State regulations regarding performance contracting Policies that focus on low first cost	Documented performance/case studies assuring code compliance or presenting information to alter codes Documented performance/case study information demonstrating the life cycle cost effectiveness of the new technologies Need fact sheets, guidelines and technical assistance/training to understand system design, installation, control and operation Materials (such as this plan) addressing the concerns of decision makers to make it easier for ESCOs to enter into performance contracts

7.5 Information Resource Channels

This section discusses possible channels for connecting with the market by disseminating program information to ensure that Program results are widely understood and widely utilized.

Program information was disseminated through the Program Advisory Committee (PAC) and through existing channels and infrastructure to facilitate efficient and effective market connection. Table 53 provides a database of information dissemination opportunities keyed to each major type of market actor/participant. Trade associations and corresponding meeting, publications, and periodicals are listed. Each meeting, publication, and periodical is an opportunity to broadcast Program findings to an influential audience. Information materials designed for specifiers was transmitted to all of the organizations associated with each link in the specifier chain. Similar efforts were made for users, suppliers, installers, funders, operators, and codes and standards setting organizations. Contact information was sought for each organization and each meeting, publication, and periodical prior to development of technology transfer materials. This was done to ensure that results are "broadcast" as quickly as possible after they were available. Key meetings and publications were identified so that papers and articles could be tailored specifically for those venues.

The technology transfer effort was conducted in several tiers. "Broadcast" materials were prepared and transmitted to each group of influential market participants through the channels listed in Table 53. Some of these materials, such as Fact Sheets, were tailored to specific constituents such as specifiers or maintenance personnel. At a more focused level, articles and presentations were e tailored to specific audiences and presented at forums or in publications designed to reach that specific audience.

Connections were made with key contacts at the organizations and venues listed Table 54, informing them of program/project objectives and the timing and extent of expected results. As project results become clear, "broadcast" publication materials were developed for each key type of market participant.

Tailored materials were produced and delivered through selected venues. These venues were revised as needed during the Project based on ongoing initial contacts with the organizations in Table 55

Table 53: Information Resources for Dissemination of Information on Improved Consumer Electronics and Motorized Appliances

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
Federal Governme nt	US EPA (United States Environmental Protection Agency) U.S. EPA Environmental Information Center 75 Hawthorne Street, 13th Floor San Francisco, CA 94105 (415) 947-8000 or (866) EPA-WEST toll free [(866) 372-9378] Energy Star Media Inquiries Molly Hooven, 202 564 2313 hooven.molly@epa.gov	Energy Star partner products meetings Webinars	Energy Star Publications, including Appliance, Office Equipment and Home Electronics Brochures Newsletters
	US DOE (United States Department of Energy) http://www.eere.energy.gov/ Homes Buildings (202) 586-9127 BTP Webmaster webmasterbtp@nrel.gov Appliances and Commercial Equipment Standards Partners in Energy Star (see EPA)	National Building Energy Code Meeting, annually in June or July All codes related events	Building technology publications, webinars, software Building Technologies Publication and Product Library
	USDOE/Building America David Lee, *Supervisor, Residential Deployment Program* David.Lee@ee.doe.gov 202 287	Technical and Stakeholder Meetings Webinars	Publications and Product Library, Appliances Energy Efficiency Measures

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
	1785	Expert Meetings Events	and Costs
Local Governme nt	Numerous, including Southern California Association of Governments, South Bay Cities Council of Governments, San Diego Association of Governments	Various, including council meetings, hearings, board meetings	
Local Utility	Major utilities assist customers concerned with planning, design, financing and other aspects of facility improvement and operation. Pacific Gas & Electric Energy Center rxmu@pge.com PG&E Foodservice Technology Center 1-800-398-3782 Southern California Edison CTAC SCE Residential Programs mediadesk@sce.com Sacramento Municipal Utility District Energy and Technology Center jnewman@smud.org . San Diego Gas & Electric Energy Innovation Center 1-800-411-7343	Training sessions held periodically at utility energy centers in Irwindale, Sacramento, San Francisco and other locations in California PG&E Classes and Seminars PG&E Foodservice Seminars SCE Workshops and Classes SMUD Workshops and Training SDG&E Seminars	PG&E Link to Energy Commission Publications PG&E Foodservice Publications SCE Document Library SMUD Saving Energy & Money SDG&E Brochures and Fact Sheets
Energy Service Company (ESCO)	Association of Energy Service Professionals International (AESP) 1-480-704-5900 stephanie@aesp.org	Events	Resource Library, Member Directory and Supplier Directory are all accessible only to members
	National Association of Energy Service Companies (NAESCO) info@naesco.org 1-202-822-1119	Events	Bookstore including case histories
Kiosk Manufactur er	Digital Screenmedia Association (DSA) Vendors	Digital Screenmedia Association Events including Consumer Engagement Technology	DSA Whitepapers DSA e-Newsletter

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
	Users/Deployers	World (CETW 2013) May 8-9, 2013, Las Vegas, NV ATMIA Conference February 19-21, 2013 Scottsdale, AZ DigitalScreenmediaAssociationWebinars	
	Kiosk Marketplace Display Technology Manufacturers	Kiosk Marketplace Webinars	Kiosk Marketplace White Papers
	ATMIA (ATM Industry Association) Amber Howell, Marketing Manager Amber@atmia.com	ATMIA Conference February 19-21, 2013 Scottsdale, AZ	ATMIA Training and Demonstrations ATMIA Consultants Newsletter Global ATM Benchmarking
Kiosk Designer, Specifier, Installer	Self Service World 1-502-241-7545	Self Service World Webinars	Self Service World White Papers
	Kiosk Solutions[41] 1 877 727 5721 sales@intouchinteractive.com		
	TE Connectivity, Elo touchsystems customerservice@elotouch.com	Elo Events Mostly in Asia and Europe in 2012 InfoComm 2012 Las Vegas 6-12	Elo case studies Strategies for successful Kiosk implementation Newsletter on touch monitors
	Arc Design Interactive Kiosk Design and Consulting[42] 1 415 318 6364 adam@arcdesignconsulting.com		ARC Interactive Kiosk Design and Consulting Design Articles

[41] Intouch Interactive Services: Hardware Consulting & Sourcing; Creative Design & Writing; Usability & Interface Design; Video & Animation; Software Installation & Development; Remote Monitoring; Content Management; Kiosk Deployment & Technical Support.

[42] Custom Kiosk Design Services: Design & Engineering for Enclosures; Sourcing and selection of components; Project budgeting and preparation of Request for Proposals and Quotes; Sourcing a custom kiosk manufacturer; Prototyping; and Management of manufacturing partner.

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
Kiosk Users	Digital Screenmedia Association (DSA) Users/Deployers	Digital Screenmedia Association Events including Customer Engagement Technology World New York City, NY November 7-8, 2012	DSA Whitepapers DSA e-Newsletter
Multimedia Computer Manufacturers	Multimedia Computers Manufacturers Directory China Multimedia Computers Manufacturers Directory India Multimedia Computer Manufacturers Association Europe Hardware and Software Manufacturers Manufacturer sites for US Companies- Typical OEM (Alienware) 1-800-254-3692 Typical OEM (HP) Gaming Desktops Typical OEM (MAC)	Computer Events compinfo	Computer Magazines and E-Zines compinfo
Multimedia Software Developers	Entertainment Software Association esa@theesa.com	Electronic Entertainment Expo, E3 2012, E3 2013,	
	Hardware and software manufacturers	Computer Events compinfo	Computer Magazines and E-Zines compinfo
	Global Science and Technology Forum 10 Anson Road, International Plaza, Singapore, 079903	5th Annual Computer Games, Multimedia & Allied Technology Technical Program info@cgames.com.sg	

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
Multimedia Computer Designers, Specifiers	Ibuypower You pick, we build 1-888-462-3899	Ibuypower forum, discussion and guidelines	Alienware Gaming Services Ibuypower newsletter
	newegg Build everything yourself gaming 1-800-390-1119		Newegg newsletter
Multimedia Computer Retailers	Retail Manufacturer sites for US Companies Typical OEM (Alienware) 1-800-254-3692 Typical OEM (HP) Gaming Desktops Typical OEM (MAC)	Computer Events compinfo Alienware Users Forum	Computer Magazines and E-Zines compinfo How to Buy a Desktop Gaming Computer Alienware Gaming Services Buyers Guides from Alienware
	Ibuypower You pick, we build 1-888-462-3899	Ibuypower forum, discussion and guidelines	Ibuypower newsletter
	newegg Build everything yourself gaming 1-800-390-1119		Newegg newsletter
Multimedia Computer Users (Manufacturing Sites)	Manufacturer site for user information Typical OEM (Alienware) 1-800-254-3692	Alienware Users Forum	Buyers Guides from Alienware Alienware Gaming Services How to Buy a Desktop Gaming Computer
	Ibuypower You pick, we build 1-888-462-3899	Ibuypower forum, discussion and guidelines	Ibuypower newsletter
	newegg Build it yourself Gaming 1-800-390-1119		Newegg newsletter
Multimedia Computer Users (Review Sites)	http://www.tomshardware.com/ usa@bestofmedia.com	Tom's hardware forums	Tom's hardware articles news
	http://www.pcreview.co.uk/	PC Review Forums	PC Review Articles Reviews
	http://www.gpureview.com/	GPU Forum, Discussion	GPU Reviews

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
Appliance Manufacturers	Association of Home Appliance Manufacturers (AHAM) The association's mission is serving the home appliance industry while delivering value to consumers through leadership, education and advocacy. info@aham.org	Events	Clothes Dryer Fact Sheet Certification Directories Appliance Performance Standards
	National Electrical Manufacturers Association (NEMA) NEMA is the trade association for the electrical manufacturing industry. Feedback Form	Programs and Events	Resources Bulletins Codes/Field Representatives, Standards and Publications
	Cookware Manufacturers Association CMA hrushing@usit.net 205 592 0389 List and links to members		Guide to Cookware and Bakeware Standards Materials Fact Sheet Brand Finder
	The Induction Site webmaster@theinductionsite.com		Induction Cooking: Makers and Products Pros and cons of induction cooking
Appliance Designers, Specifiers	Appliance Design Magazine dalpozzod@bnpmedia.com 847 763 9534	Web Features	Appliance Design Issues Appliance Design Buyers Guide International Appliance Manufacturing 2011
	Appliance Magazine News/Product Releases Tim.Somheil@ubm.com 310 445 4200	Calendar of Appliance Events	Appliance Engineer Issues Association Locator Appliance Market Data
	Home Appliance Magazine		Home Improvements
	Industrial Designers Society of America IDSA	Events	Publications

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
Appliance Retailers	National Association of Retail Dealers of America (NARDA) nardasvc@narda.com 312 648 0649	Webinar on Job Rates	Fact Sheet Blue Books, Job Rate Guides
Market Actor	**Organization/Trade Association/Professional Association**	**Key Meetings**	**Key Periodicals/Publications**
Appliance Installers	National Association of Home Builders NAHB Research Center Toolbase Services The home building industry's technical info resource		Induction Cooktop Information Manufacturers
	National Association of Retail Dealers of America (NARDA) nardasvc@narda.com 312 648 0649	Webinar on Job Rates	Fact Sheet Blue Books, Job Rate Guides
Appliance Users	Consumer Reports Provides unbiased testing and evaluation of consumer appliances, electronics, computers and other residential equipment Appliances Electronics/Computers e-mail Consumer Reports	Consumers Union Annual Meeting October 2012 annualmeeting@cu.consumer.org	Monthly magazine providing hard copy and on line articles with rating and qualitative assessment of equipment Year End Buying Guides Computer Buying Guide Electronics and Computer News
	Coin Laundry Association kim@coinlaundry.org		Buyer's Guide Resources/ Educational Materials
Home Audio Equipment Manufacturers	Consumer Electronics Association (CEA) Audio Video Retailer Division cea@CE.org 703 907 7600	International Consumer Electronic Show January 8-11, 2013, Las Vegas	Standards Research
	Wireless Speaker and Audio Association (WISA) gcollier@wisaassociation.org 408	Events CEDIA EXPO September 5-7, 2012,	White Paper

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
	616 4088	Indianapolis, IN	
Home Audio Equipment Designers, Specifiers	Acoustical Society of America asa@aip.org 516 576 2360	Key Meetings	Journal of the Acoustic Society of America Standards
	Audio Engineering Society 212 661 8528 Send e-mail	Events	Publications Including AES Journal AES Standards
Home Audio Equipment Retailers	Consumer Electronics Association (CEA) Audio Video Retailer Division Retailer Council cea@CE.org 703 907 7600	International Consumer Electronic Show January 8-11, 2013, Las Vegas	Standards Research
Home Audio Equipment Installers	Custom Electronic Design and Installation Association (CEDIA) contact form	CEDIA EXPO September 5-7, 2012, Indianapolis, IN	Electronic Lifestyles Magazine Idea Books
	Association for Quality in AV Technology for those who design and install for the benefit of the industry and all its stakeholders	Webinar Series	Training and Certification Information AV9000:2011 Standard
Home Audio Equipment Users	Association for Quality in AV Technology for those who design and install for the benefit of the industry and all its stakeholders	Webinar Series	Training and Certification Information AV9000:2011 Standard Why AV 2000?
	Consumer Electronics Association (CEA) Consumer Information cea@CE.org 703 907 7600	International Consumer Electronic Show January 8-11, 2013, Las Vegas	Standards Research Audio System Buying Guide Why Buy Better Audio?
	Home Theater Magazine editor@hometheater.com rob.sabin@hometheater.com		HT in a Box Power Amplifiers Soundbars Product Reviews Blogs

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
			Audio/Visual News
	Sound and Vision Magazine feedback@soundandvisionmag.com		Blogs Soundbars Speakers
	Stereophile Editorial		Buyers Guide Equipment Reviews Speakers Amplifiers
	Premier Guitar info@premierguitar.com		Product Reviews Amplifiers All Gear
Architect	AIA (American Institute of Architects) Committee on Education infocentral@aia.org	Events including 2012 fall conference in Seattle	AIA webinars and resources *Building Design and Construction* *Environmental Design and Construction* The official magazine of LEED
Construction Manager	CMAA (Construction Management Association of America) Info@cmaanet.org Representing architecture, engineering, construction and facilities management John McKeon jmckeon@cmaanet.org (703) 356-2622	Events Including meetings in New Orleans May 5-7, 2013 and Las Vegas October 6-8, 2013, Baltimore, May 4-6, 2014 and San Francisco, October 19-21, 2014 Webinars	CMAA Publications
Facility Manager	IFMA (International Facility Management Association) ifmahq@ifma.org	Events including World Workplace Education, Courses	Facility Management Journal Magazines and Periodicals FMLink
	Association for Facilities Engineering mail@afe.org Provides education, certification, technical information and other resources for plant and facility engineering, operations and maintenance professionals	Calendar of events *World Workplace*	Publications *Facilities Engineering Journal*

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
Maintenance	IFMA (International Facility Management Association) ifmahq@ifma.org Association for Facilities Engineering mail@afe.org	*World Workplace* AFE Events	Facility Management Journal Magazines and Periodicals FMLink
HVAC Manufacturer	AHRI (Air-Conditioning Heating and Refrigeration Institute) ahri@ahrinet.org American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) ashrae@ashrae.org	AHRI Meetings and Events ASHRAE Meetings and Events	AHRI Publications *AHRI Trends Magazine* ASHRAE Periodicals *ASHRAE Journal* *Engineered Systems* *HPAC Engineering*
HVAC Engineer/Designer	ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ashrae@ashrae.org	ASHRAE Meetings and Events Summer and Winter Meetings	ASHRAE Periodicals *ASHRAE Journal* *ASHRAE Handbooks* *Engineered Systems* *HPAC Engineering* *Consulting-Specifying Engineer*
HVAC Contractor	ACCA (Air Conditioning Contractors of America) glenn.hourahan@acca.org	ACCA Events ACCA Conference and Expo	Indoor Environment and Energy Efficiency *ACCAlert*, email newsletter *Contractor Excellence,* magazine *Contracting Business* *The Air Conditioning/Heating/Refrigeration News*
HVAC Distributor, Dealer	AHRI (Air-Conditioning Heating and Refrigeration Institute) American Society of Heating Refrigerating and Air-Conditioning Engineers	AHRI Meetings and Events ASHRAE Meetings and Events	AHRI Publications *AHRI Trends Magazine* ASHRAE Periodicals *ASHRAE Journal*

Market Actor	Organization/Trade Association/Professional Association	Key Meetings	Key Periodicals/Publications
	(ASHRAE) ACCA (Air Conditioning Contractors of America) The Heating, Air-Conditioning & Refrigeration Distributors (HARDI) hardimail@hardinet.org	ACCA Calendar of Events HARDI Events (Meetings and Webinars)	Air-Conditioning Consumers Information Directories of Contractors, Suppliers *Engineered Systems* *HPAC Engineering* HARDI recommended publications
HVAC Users	ACCA (Air Conditioning Contractors of America)	ACCA Calendar of Events	Air-Conditioning Consumers Information Directories of Contractors, Suppliers

Market connections information in Table 53 is organized by key market participant and project/equipment type in Table 54.

Table 54: Connections for Types of Key Market Participants for Each Project and Equipment Type

Project 2 Kiosks and Multimedia Computers	Project 3 Home Audio Equipment	Project 4 Residential Induction Cooktops	Project 4 Power Factor Corrected Residential Equipment	Project 5 ASDs for Home ACs, Clothes Dryers, Refrigerators
Federal Government				
US EPA (United States Environmental Protection Agency), Energy Star US DOE (United States Department of Energy), Appliances and Commercial Equipment Standards, USDOE/Building America				
State Government				
Energy Commission (California Energy Commission), Title 20, California Code of Regulations, Title 24 Standards for Buildings California State and Consumer Services Agency				
Utility				
PG&E Foodservice Technology Center				
Pacific Gas & Electric Energy Center Sacramento Municipal Utility District Energy and Technology Center San Diego Gas & Electric Energy Innovation Center Southern California Edison CTAC				

Project 2 Kiosks and Multimedia Computers	Project 3 Home Audio Equipment	Project 4 Residential Induction Cooktops	Project 4 Power Factor Corrected Residential Equipment	Project 5 ASDs for Home ACs, Clothes Dryers, Refrigerators
Manufacturers				
Digital Screenmedia Association Vendors Kiosk Marketplace ATMIA (ATM Industry Association)	Consumer Electronics Association (CEA) Audio Video Retailer Division Wireless Speaker and Audio Association (WISA)	Association of Home Appliance Manufacturers (AHAM) Cookware Manufacturers Association The Induction Site National Electrical Manufacturers Association (NEMA)	Association of Home Appliance Manufacturers (AHAM) National Electrical Manufacturers Association (NEMA) AHRI (Air-Conditioning Heating and Refrigeration Institute) ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning	Association of Home Appliance Manufacturers (AHAM) National Electrical Manufacturers Association (NEMA) AHRI (Air-Conditioning Heating and Refrigeration Institute) ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning
Multimedia Computers Manufacturers Directory China Multimedia Computers Manufacturers Directory India Multimedia				

Computer Manufacturers Association Europe Hardware and Software Manufacturers US Companies Typical OEM (Alienware) Typical OEM (HP) Gaming Desktops Typical OEM (MAC)			Engineers)	Engineers)

Project 2 Kiosks and Multimedia Computers	**Project 3 Home Audio Equipment**	**Project 4 Residential Induction Cooktops**	**Project 4 Power Factor Corrected Residential Equipment**	**Project 5 ASDs for Home ACs, Clothes Dryers, Refrigerators**
Selection, Construction, Installation, Maintenance				
Arc Design Interactive Kiosk Design and Consulting Kiosk Solutions Self Service World TE Connectivity, Elo touchsystems IFMA (International Facility Management Association) Association for Facilities Engineering	Acoustical Society of America Audio Engineering Society Custom Electronic Design and Installation Association (CEDIA) Association for Quality in AV Technology	Appliance Design Magazine Appliance Magazine Home Appliance Magazine National Association of Retail Dealers of America Association of Retail Dealers of America	Appliance Design Magazine Appliance Magazine Home Appliance Magazine National Association of Retail Dealers of America Association of Retail Dealers of America AHRI (Air-Conditioning Heating and Refrigeration Institute) ASHRAE	Appliance Design Magazine Appliance Magazine Home Appliance Magazine National Association of Retail Dealers of America Association of Retail Dealers of America AHRI (Air-Conditioning Heating and Refrigeration Institute) ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers)
You pick, we build Build everything yourself Gaming				

			(American Society of Heating, Refrigerating and Air-Conditioning Engineers)	

Project 2 Kiosks and Multimedia Computers	Project 3 Home Audio Equipment	Project 4 Residential Induction Cooktops	Project 4 Power Factor Corrected Residential Equipment	Project 5 ASDs for Home ACs, Clothes Dryers, Refrigerators
Distributors, Dealers				
Digital Screenmedia Association Vendors Kiosk Marketplace ATMIA (ATM Industry Association)	Custom Electronic Design and Installation Association (CEDIA)	National Association of Retail Dealers of America	National Association of Retail Dealers of America AHRI (Air-Conditioning Heating and Refrigeration Institute) American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) ACCA (Air Conditioning Contractors of America) The Heating, Air-Conditioning & Refrigeration Distributors (HARDI)	National Association of Retail Dealers of America AHRI (Air-Conditioning Heating and Refrigeration Institute) American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) ACCA (Air Conditioning Contractors of America) The Heating, Air-Conditioning & Refrigeration Distributors (HARDI)
Hardware and Software Manufacturers				
ESCOs				
(AESP) Association of Energy Service Professionals International. (NAESCO) National Association of Energy Service Companies.				
Retailers				
Typical OEM (Alienware) Typical OEM (HP)	Consumer Electronics Association (CEA)	National Association of Retail Dealers of America	National Association of Retail Dealers of America	National Association of Retail Dealers of America

Gaming Desktops Typical OEM (MAC)	Audio Video Retailer Division Retailer Council			

Project 2 Kiosks and Multimedia Computers	**Project 3 Home Audio Equipment**	**Project 4 Residential Induction Cooktops**	**Project 4 Power Factor Corrected Residential Equipment**	**Project 5 ASDs for Home ACs, Clothes Dryers, Refrigerators**
Users				
Digital Screenmedia Association Users/Deployers	Consumer Reports Association for Quality in AV Technology Consumer Electronics Association (CEA) Consumer Information	Consumer Reports	Consumer Reports American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) ACCA (Air Conditioning Contractors of America)	Consumer Reports American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) ACCA (Air Conditioning Contractors of America) Coin Laundry Association
Typical OEM (Alienware) You pick, we build Build it yourself Gaming				

Other organizations providing information of general interest to specifiers, utilities, users and other are presented in Table 55. The organizations and corresponding contact information in Table 53 and Table 55 were used to inform market participants and others of the relevant findings of each of the projects being conducted in this Program.

Table 55: Organizations Providing General Information Dissemination for Improved Consumer Electronics and Motorized Appliances

Organization/Program	Mission	Key Publications	Key Meetings	Key Periodicals
USGBC (United States Green Building Council) http://www.usgbc.org LEED for homes http://www.usgbc.org/DisplayPage.aspx?CMSPageID=2135 leedinfo@usgbc.org	Coalition of building industry leaders to promote cost effective energy efficient green buildings	LEED Equipment and Appliances http://www.leeduser.com/credit/CI-2009/EAc1.4 leedinfo@usgbc.org	2013 Greenbuild Int'l Conf./Expo, Nov 20-22, 2013 Philadelphia, PA http://www.eventsinamerica.com/events/2013-greenbuild-international-conference-expo/ev4d51741675354/ *LEED Training Workshops* at locations nationwide	Newsletters
Alliance to Save Energy http://ase.org/ 202-857-0666 Ron Kweller, Director Media Relations 202-530-2203 rkweller@ase.org	Promotes energy efficiency worldwide through research, education and advocacy	State by state information and publications http://ase.org/resources/browse/189	Key events: http://ase.org/events Programs, codes and standards http://ase.org/programs	Efficiency News
American Council for an Energy Efficient Economy http://www.aceee.org/	Catalyst for transfer of ideas between utilities, researchers and energy efficiency practitioners	Conference proceedings http://www.aceee.org/publications	Summer Study on Buildings, Asilomar, Pacific Grove, CA August 2012 and 2014 http://www.aceee.org/conferences	Newsroom
SBIC (Sustainable Buildings Industry Council) klowry@sbicouncil.org 202 628 7400	Supports technology-driven, energy efficient sustainable design and construction	Residential Programs	Link to ASHRAE, NAHB and North Carolina Sustainable Energy Association events http://www.sbicouncil.org/events	Newsletters http://www.sbicouncil.org/images/maynewsletter.pdf

Organization/Program	Mission	Key Publications	Key Meetings	Key Periodicals
Consortium for Energy Efficiency (CEE) 617 589 3949 http://www.cee1.org/ Mark Hoffman Deputy Executive Director mhoffman@cee1.org Residential Sector http://www.cee1.org/resid/resid-main.php3	Establishes feasible efficiency levels that utilities and others can use for rebates and other incentives	Home appliances, including Fact Sheet http://www.cee1.org/resid/seha/seha-main.php3 Consumer electronics, including Program Guide http://www.cee1.org/resid/rs-ce/rs-ce-main.php3 .	Summer Program and Industry Partner Meetings http://www.cee1.org/cee/mtg/mtg-main.php3	News Archive
Savings by Design http://www.savingsbydesign.com	Funded by California utility customers and administered by California's investor-owned utilities Provides services and incentives to help raise energy performance to a top priority for architects and building owners	Links to investor-owned utility programs PG&E Publications: "Savings by Design," handbook, fact sheet and brochure	Training sessions held periodically at utility energy centers	Links to Energy Design Briefs for energy efficient options including HVAC options from Energy Design Resources

7.6 Codes and Standards

Reference to codes and standards and their possible influence on design, installation, and operation of improved Consumer Electronics and Motorized Appliance Technologies has been made in previous sections Table 55 shows some of the organizations that deal with codes and standards issues that could impact deployment of improved Consumer Electronics and Motorized Appliance Technologies. Greater insight into the codes and standards issues and the possible ramifications of their application to improved Consumer Electronics and Motorized Appliance Technologies, as currently promulgated, were developed as the project unfolds.

At this time, the following issues appear to be most important:

- No regulations or guidelines exist for most of the products or enhancements to be studied in this Program.
- The most relevant codes and standards that could effectively incorporate the energy efficiency and power factor improvements found in this Program are likely to be embodied in Title 20 and Title 24. In order to maximize the impact of the improvements found in this Program, proposed changes to Title 20 and Title 24 may need to be presented at Energy Commission workshops where public comment on rules changes are obtained.

Table 56 provides summary information on the organization concerned with codes and standards as they apply to the products being studied in this Program. The desirable attributes of the improved product(s) were documented, as they became available, into white papers/brochures and other communications tailored to effect required changes in codes and standards. The White Papers and Fact Sheets were designed to ensure fair treatment for the products and technologies improved in this study and present product attributes in a manner that encourages their adoption in the applicable codes and standards. The White Papers were based on current study results but also included documentation from recent literature to reinforce the key points being made.

Consideration and acceptance of these white papers were enhanced by existing and newly developed strong contacts with codes setting bodies and those that influence these bodies. This will speed the process of adopting the codes and standards recommendations made in the white papers by ensuring that the materials are submitted to the most influential individuals and groups and are in the format that will facilitate their acceptance.

7.6.1 Interactions with Codes and Standards Organizations

Connections were made with each of the relevant codes and standards setting organizations that need to recognize the improvements of energy efficiency and other attributes found in the current study. The objectives of these connections are to determine changes needed to the applicable codes, the best manner of effecting the code changes, including what information is needed, how to present this information, when to present it, and to whom it should be presented. Building rapport with the individuals and groups with the necessary expertise and influence will facilitate the best formulation and delivery of White Papers and ensure the best reception and acceptance of these materials.

Connections with relevant ASHRAE Technical Committees (TCs) identified in Table 56 could be important in effecting changes to standards in those portions of the study that deal with improving HVAC equipment. These are anticipated to be:

- TC 1.11, Electric Motors and Motor Control, if products selected in Task 5 (power factor improvement) and Task 6 (adjustable speed drives) use HVAC motors and drives. TC 1.11 needs to understand and provide information to their peers and to the standing committees for Standards 90.1 and 90.2 about effective use of efficient variable speed drives and high power factor motors, inverters, and other equipment.

- TC 8.7, Variable Refrigerant Flow, uses variable speed drives in their compressors and fans and would therefore also be interested in Task 5 and 6 results.

Participation in the activities of these committees could be useful in establishing and utilizing connections to facilitate incorporation of study results.

Once the meeting schedules for Title 24, part 6, and Title 20 revisions were set, a plan was developed for connecting with the individuals and groups that will influence getting changes made that affect treatment of the technologies being studied in this Program.

For Savings By Design, connections were made via e-mail and telephone contact with influential individuals in both these groups. PAC members and other mutual contacts were utilized to facilitate communication with these organizations.

Connections with AHRI, GSA, LEED, and Energy Star were made through e-mail interactions and telephone contact with colleagues at AHRI and EPA and contact with PAC members belonging to other relevant organizations.

Table 56: Codes and Standards Organizations and Issues Relating to Consumer Electronics and Motorized Appliance Technologies in California

Organization	Function	Issue	Action Needed	Applicable Documents
California Energy Commission	Responsible for promulgating energy efficiency standards including the California Code of Regulations, Title 24, Part 6, California Energy Code relating to building energy efficiency	Title 24, part 6 deals with Building and HVAC equipment and operation.	Get information to Title 24 decision makers in a timely manner to ensure that product enhancements are treated properly.	2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Energy Commission-400-2008-001-CMF, December 2008, effective January 1, 2010
	California Code of Regulations, Title 20, Public Utilities and Energy, Chapter 4 Energy Conservation, Article 4, Appliance Efficiency Regulations	Title 20, Chapter 4, Article 4 deals with appliance energy efficiency.	Get information to Title 20 decision makers in a timely manner to ensure that product enhancements are treated properly.	2009 Appliance Efficiency Regulations, Energy Commission 400-2009-13, August 2009
Division of State Architect http://www.dsa.dgs.ca.gov	They check compliance of building plans with all codes and standards.	DSA needs to be made aware of desired changes to State Codes.	Get information to DSA decision makers in a timely manner to ensure that product enhancements are treated properly.	2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings

Organization	Function	Issue	Action Needed	Applicable Documents
ICC (International Code Council) http://www.icbo.org Consolidation of BOCA (Building Officials and Code Administrators International), ICBO and SBCCI in January 2003	The California Energy Code cited above has been published by the ICC, 500 New Jersey Avenue, NW 6th Floor, Washington, DC 20001	Title 24, part 6 deals with Building and HVAC equipment and operation.	Get information to Title 24 decision makers in a timely manner to ensure that product enhancements are treated properly. These will then be incorporated by ICC into new standards.	2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Energy Commission-400-2008-001-CMF, December 2008, effective January 1, 2010
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) http://www.ashrae.org	Sets guidelines and standards for heating, ventilating, and air-conditioning equipment. Technical committees (TCs) provide oversight on issues that might impact codes and standards. TCs that might be concerned with the products in this Program are as follows: TC 1.11, Electric Motors and Motor Control, if products selected in Tasks 5 & 6 use HVAC motors and drives. TC 1.11 is concerned with electric motors (including hermetic) used in HVAC and refrigeration systems and the protection and control of	TC 1.11 members need to understand and provide information to their peers and to TCs 90.1 and 90.2 about effective use of efficient variable speed drives and high power factor motors, inverters and other equipment.	Keep TC1.11 informed of advances in Electric HVAC Motors and Motor Control technology developed in Tasks 5 and 6.	TC1.11 Scope
		TC 8.7 members use variable speed drives in their compressors and fans and would therefore be interested in Tasks 5 and 6 results.	Keep TC8.7 informed of advances in Electric HVAC Motors and Motor Control technology developed in Tasks 5 and 6.	TC8.7 Scope
		ASHRAE 90.1-2010 provides minimum requirements for the energy-efficient design, construction, and operation and maintenance of buildings	Work with TC members and Standards Committee members to ensure	"ASHRAE Standard 90.2-2007, Energy Standard for Buildings Except Low-Rise

Organization	Function	Issue	Action Needed	Applicable Documents
	such motors. TC8.7, Variable Refrigerant Flow, uses ASDs and would also have interest in Program results if products selected in Tasks 5 & 6 use HVAC motors and drives. ASHRAE also has standards for non-residential buildings (90.1) and residential (90.2) encouraging use of efficient technologies.	except low-rise residential buildings.	that Program results are incorporated into Standard 90.1.	Residential Buildings".
		ASHRAE 90.2-2010 provides minimum requirements for the energy-efficient design, construction, and operation and maintenance of low-rise residential buildings.	Work with TC members and Standards Committee members to ensure that Program results are incorporated into Standard 90.2.	"ASHRAE Standard 90.2-2007, Energy Standard for Low-Rise Residential Buildings".
AHRI (Air-Conditioning Heating and Refrigeration Institute) ahri@ahrinet.org	Develops test procedures in compliance with ASHRAE and ANSI standards. Publishes product ratings.	Ensure that the test procedures for HVAC equipment incorporate technology with high power factor and energy-efficient motors and drives and adequately measure and reflect the benefits of this equipment.	Keep AHRI informed regarding project results	AHRI 1210 (I-P)-2011: Performance Rating of Variable Frequency Drives
U.S. General Services Administration (GSA), Office of the Chief Architect	GSA oversees the buildings, products, services, technology, and other workplace essentials to support federal workers located in government-owned and leased buildings. GSA strives to provide superior workplaces for federal workers and	GSA needs to be made aware of the advantages to the U.S. Government before it will consider codifying the use of the equipment improved in this Program.	Keep GSA informed regarding project results. Work with GSA to assure proper application and operation of improved technologies	Facility Standards for the Public Building Service P100, November 2010 Chapter 5 Mechanical Engineering Chapter 6 Electrical Engineering

Organization	Function	Issue	Action Needed	Applicable Documents
	facilitate procurement of state-of-the-art commercial products and services.			
US EPA (United States Environmental Protection Agency) and USDOE Energy Star 202 564 2313 hooven.molly@epa.gov	ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy helping to save money and protect the environment through energy efficient products and practices.	Products studied in this Program need to be covered by Energy Star and other EPA programs.	Provide Program information to EPA for inclusion in ongoing and emerging EPA programs	Energy Star Publications, including Appliance, Office Equipment and Home Electronics Brochures Newsletters
United States Green Building Council (USGBC)	LEED Green Building Certification System Oversees LEED (Leadership in Energy and Environmental Design) and the Green Building rating system for new construction and major renovation of commercial and residential buildings.	The rating system assigns points based on the attributes of the site and building. Certification criteria need to include the products and improved efficiency and power factor levels developed in this Program.	White papers should be addressed to LEED staff presenting improvements found in our study and the need for including the products and improved efficiency levels in LEED rating system criteria.	
USDOE (Department of Energy) Appliance and Commercial	The U.S. Department of Energy's Appliances and Commercial Equipment Standards Program (the Program) develops test	Examine whether the products being improved in this study are already included in this DOE program. These are as follows: **Residential Products**	Provide information to DOE Appliance Efficiency Standards personnel for	See links in Residential Products and Commercial Equipment sites for applicable standards

Organization	Function	Issue	Action Needed	Applicable Documents
Equipment Efficiency Standards	procedures and minimum efficiency standards for residential appliances and commercial equipment.	Battery Chargers & External Power Supplies, Ceiling Fans & Ceiling Fan Light Kits, Central Air Conditioners & Heat Pumps, Clothes Dryers, Clothes Washers, Condensing Units, Cooking Products, Dehumidifiers, Direct Heating Equipment, Dishwashers, Furnace Fans Furnaces and Boilers Pool Heaters Refrigerators & Freezers, Room Air-conditioners, Set-top Boxes & Network Devices, Small Duct, High Velocity Air Conditioners, Water Heaters **Commercial Equipment** ASHRAE Products, Automatic Ice Makers, Clothes Washers, Commercial & Industrial Fans, Blowers, & Fume Hoods, Commercial & Industrial Pumps Distribution Transformers Electric Motors Furnaces & Boilers Packaged Terminal Air Conditioners & Heat Pumps Small Electric Motors Unitary Air Conditioners & Heat	inclusion in ongoing and emerging DOE programs.	and reports.

Organization	Function	Issue	Action Needed	Applicable Documents
		Pumps Walk-In Coolers and Walk-In Freezers Water Heaters		
National Electrical Manufacturers Association (NEMA) NEMA is the trade association for the electrical manufacturing industry. Feedback Form	Standardization Policies NEMA standards and guideline publications are the result of a voluntary consensus standards development process.	While NEMA administers the process and establishes rules to promote fairness in the development of consensus, it does not write the document and it does not independently test, evaluate, or verify the accuracy or completeness of any information or the soundness of any judgments contained in its standards and guideline publications.	Provide information to NEMA personnel for inclusion in ongoing and emerging NEMA programs.	Codes/Field Representatives, Standards and Publications Adjustable Speed Drives
Audio Engineering Society (AES)	The AES is the society of audio professionals providing educational resources, leadership in the development of new standards and technologies, and forums for the exchange of creative and scientific information.	The AES consists of audio engineers, researchers, broadcast technicians, acousticians, sound mixers, equipment designers, consultants, DSP engineers, students, educators, technical directors, systems installers, mastering engineers and others who will be a key audience for utilizing and codifying study results. Members of AES are likely to be a key audience for utilizing	Make AES and its members aware of project results.	Standards in print available for purchase Encompass the following fields: **Digital audio**: Digital audio measurements, interfaces & synchronization, networks, file exchange, and pro-audio uses of the IEEE 1394 serial bus; **Preservation and restoration of audio recordings**: Analog

Organization	Function	Issue	Action Needed	Applicable Documents
		and codifying study results.		recording, transfer technologies, library & archive systems, storage & handling, metadata and forensic audio; **Acoustics**: Sound-source modeling, loudspeakers and microphones; and **Interconnections**: Connectors, connector usage and EMC practices
Cookware Manufacturers Association (CMA)	The CMA is a not-for-profit trade association owned by the manufacturers of cookware, bakeware and kitchenware with substantial operations and headquarters in the United States. The CMA helps develop engineering standards for the industry, disseminates information to consumers, retailers and manufacturers, and offers forums for members to learn about the latest advances in manufacturing, retailing, distribution and materials.	Members of CMA are likely to include manufacturers of induction cooking cookware and will be a key audience for utilizing and codifying study results.	Make CMA and its members aware of cook-off results and other study results.	The CMA Technical Engineering Standards Manual For Cookware & Bakeware, should include study results This Manual encompasses voluntary standards for cookware and bakeware. Designed for use by engineers, cookware and bakeware designers and production personnel, the standard is a comprehensive 95 page manual covering

Organization	Function	Issue	Action Needed	Applicable Documents
				all aspects of materials, material testing, minimum gauges, standard sizes and capacities
Savings By Design http://www.savingsbydesign.com PG&E Contact SMUD Contact SCE Contact SDG&E Contact	Funded by California utility customers and administered by California's investor-owned utilities. Provides services and incentives to help raise energy performance to a top priority for architects and building owners. Training sessions are held periodically at utility energy centers. Design assistance is available for design strategies, modeling, and systems integration. Financial incentives are available to owners and the design team when a new non-residential building exceeds the minimum Savings By Design Thresholds. The whole building incentive approach is triggered when the savings exceeds 10% of	Changes adopted for Title 24 would have an impact on Savings By Design. Output of the current Energy Commission study with regard to HVAC and Appliance energy use could have an impact on Savings By Design.	Follow the progress of Savings By Design to ensure that their requirements are being addressed. Facilitate incorporation of Program study into their ratings and information materials including their Energy Design Resources materials.	Savings By Design Resources Program Handbook eQuest EnergyPro Savings by Design Participant Handbook Energy Design Briefs are provided, for energy efficient alternatives including HVAC options, as part of Energy Design Resources on the Savings By Design web site.

Organization	Function	Issue	Action Needed	Applicable Documents
	Title 24 standards and can achieve a maximum level of $500K when savings equal or exceed 30% of Title 24 standards. Categories for incentive opportunities are lighting/daylighting, hot water, HVAC&R, and building envelope improvements.			

7.6.2 Codes and Standards Deliverables

The codes and standards effort will result in the production of a number of information products designed to overcome the information gaps outlined in Section 2 that impede the realization of the benefits of the improved consumer electronic and motorized appliances being studied in this Program.

Information products consisted of two main types of deliverables: White Papers and Fact Sheets. White Papers were designed to influence the code setting bodies identified in Table 58 to change their codes to permit recognition of the improved products developed in this Program. Fact Sheets designed to enable market participants to understand study results have been described in Section 5 of this plan, and this information will not be repeated here. A tabulation of White Papers and Fact Sheets/Tech Briefs anticipated to be delivered in this Program is presented in Section 6.

7.6.3 Codes and Standards White Papers

White Papers were prepared for codes and standards issues relating to product improvements developed in this study. The White Papers presented information that provides a rationale for modifying the code or standard being addressed to account for the attributes of the improved technology. For example, a White Paper was presented to the Energy Commission to justify Kiosks being covered in Title 20, what levels should be set for product compliance, and what categories of functionality (kiosk application) and components/configuration (tablets, better power supplies, etc.) should be specified. The White Paper provided an overview of how the Kiosk computer works in terms of attributes and advantages. This included a description of size, efficiency, power factor, and speed. The White Paper described other important attributes such as functionality in the form of ease of use, clear displays (bright, visual acuity), volume control, response time (boot-up from startup, power saving, screen saving) and simplicity (ease of use, minimum key strokes, minimum need for training tutorials). Other important attributes were reliability as evidenced by weather resistance (temperature, water tolerance), security (tamper proof, hacker proof, identity safety), environmental control (effective cooling), and ease of cleaning. Cost is an important issue. Computer capability should be sufficient to perform all desired functions including enabling integration of the kiosk with marketing and other functions.

White Papers included an overview of the current situation; technical and “regulatory” issues; performance and cost information found in the current study that supports changes to the current codes and standards; information from other relevant studies; and recommended codes and standards changes.

The White Papers were reviewed with experts that included Program personnel experienced in achieving code changes as well as PAC members and other selected industry experts. This ensured that all procedures and techniques recommended in the White Paper are consistent with best current practice, the latest research findings, and the needs of market participants in California.

7.6.4 Change Proposals

In most cases, Change Proposals will be needed as a follow-up to the White Papers in order to effect codes and standards revisions. These Change Proposals must follow precise and involved formats and requirements and are often subjected to intense and repeated public scrutiny and consequent revision cycles. The preparation of these proposals, while desirable, cannot be effectively pursued to successful completion under the scope of this Project.

7.7 Technology Transfer Products

The market connections effort will result in the production of a number of information products designed to overcome the market barriers outlined in Section 2 to influence the market participants identified in Section 3 using the information dissemination channels described in Section 4 to produce the desired market effects.

The types of products to be produced will include the following:

- Fact sheets, tech briefs, brochures, and flyers
- White Papers
- Journal Articles/Technical Papers
- Presentations
- "Word of Mouth" contacts using the materials above

The specific materials and activities to be provided are listed as follows.

7.7.1 Fact Sheets

The fact sheet format will likely consist of the following material:

- A Description of the Situation (Describe the problem and the current technology being used.)
- The Technology (Describe the technology, what it looks like, how it works, and how this differs from current practice. Provide a schematic or photo of the technology.)
- Advantages and Opportunities (Clearly outline the advantages of the new or improved technology and situations where it can best be applied.)
- Applications (Provide examples of effective applications with initial cost and operating cost clearly stated.)
- Case Studies (Describe the testing performed in the study, provide a photograph of the test installations(s), describe the problems overcome, benefits, challenges/lessons learned that can help someone avoid a similar problem, and provide information from the product testers.)

- Sources of Information (Provide authoritative references, opportunities to obtain additional information and technical assistance in implementing the new or improved technology.)
- Other Issues (If applicable, present information on ancillary issues, applicable codes and standards, health and human performance improvement; things not covered in the main body of the fact sheet.)

A substantial amount of the Fact Sheet material will be useful for all audiences. Additional material was provided with more details addressing areas of concern to a particular market participant. For example, demonstrated cost effectiveness is likely to be more important to funders, specifiers, and energy service companies than it would be to users or workers. Users on the other hand would mostly be interested in ease of operation, safety, indoor environment (temperature control, fresh air, and good acoustics), and attractive appearance—factors that influence the working, residential, or retail environment.

Facilities and maintenance personnel will want to see evidence of reliability as well as ease of operation and information on installation and maintenance requirements.

White papers will be developed with the main objective of influencing codes and standards bodies to adopt the findings of the current Projects to encourage improved products that provide higher energy efficiency and/or power factor than existing products. Some of the material in the white papers may be suitable for dissemination to other market participants and as such may be used directly or in summary format for these audiences (for example, specifiers, manufacturers, dealers, retailers, consumers).

7.7.2 White Papers

The white paper format would consist of the following material:

- Overview: Explanation of the position including a historical perspective for current circumstances
- Issues: Technical and "regulatory" issues including the problem and the resulting opportunity customized for the code, standard, or program being addressed
- Project Results: Performance and cost information found in the current project(s)
- Other Data: Information from relevant studies that supports the white paper recommendations
- Recommended Actions: Code language, modeling, acceptance/compliance approaches customized for the code, standard, or program being addressed

7.7.3 Journal Articles/Technical Papers

Contacting appropriate engineering journals and trade publications to place two articles (drafted by the project leads) that explain the benefits of improved Consumer Electronics and Motorized Appliance Technologies.

7.7.4 Presentations

Presentation materials for explaining the benefits of improved Consumer Electronics and Motorized Appliance Technologies at appropriate forums to promote understanding of this equipment among officials with the goal of including these systems in specifications for new and major modernizations.

7.7.5 "Word of Mouth" Contacts

- Creating a "word of mouth" movement by involving opinion leaders in the process of convincing them of the benefits of improved Consumer Electronics and Motorized Appliance Technologies
- Helping project technical staff work closely with influential market participants (for example, the PAC) to ensure that the project is shaped to meet their needs and that the results are accepted by their peers
- Working with manufacturers (other than the Program participants) to promote awareness of the market need for developing a new line of products or adapting existing products suitable for improved Consumer Electronics and Motorized Appliance Technologies

Program staff attended key meetings to "get the word out" to professionals and other influential market participants. Program staff interacted with Federal and State Government personnel in the normal course of their business; professionals at technical meetings, utilities, customers, and users at utility energy centers across the state; and a range of experts and market participants at the Program Advisory Committee meetings.

Results from the projects were delivered to the market participants identified in previous sections.

Based on the comparison of expected project improvements and the desirable attributes favored by market participants in selecting and purchasing products, it appears likely that the kiosk/multimedia computer project, the home audio project, and the power factor project will produce results that are geared toward energy savings and utility system improvements rather than attributes that purchasers will find compelling. Based on this assessment, codes and standards white papers will be written with the objective of getting project results incorporated into marketplace offerings by requiring those attributes via codes and standards changes. These white papers were written and delivered for all five of the projects in this Program.

The induction cooking and the adjustable speed drive projects, on the other hand, will provide product improvements with attributes that make them more desirable to specifiers and purchasers. For these projects, fact sheets, tech briefs, and other materials produced that combine the energy efficiency improvements with the other improvements for the induction cooking project (reduced cooking time, better temperature control, ease of maintenance, safety, and use of more typical cookware) and for the adjustable speed drive project (smooth operation, lower energy bills, better controllability, higher reliability) that consumers are likely to favor.

Table 57: Timing and Delivery of Expected Technology Transfer Materials

Task/Area	Product	Audience(s)	Expected Delivery Date
Task 2 Kiosks	Kiosk Codes and Standards White Paper	Codes and Standards Officials	February 2014
	White paper posting (if results warrant publication or presentation)	Manufacturers, Users, Dealers, and Specifiers	February 2014
Task 2 Multimedia Computers	Multimedia Computer Codes and Standards White Paper	Codes and Standards Officials	February 2014
	White paper information on Multimedia Computers	Manufacturers, Users, Dealers, and Specifiers	February 2014
Task 3 Home Audio Equipment	Codes and Standards White Paper for improving Home Audio equipment	Codes and Standards Officials	February 2014
	White paper information on Home Audio equipment	Manufacturers, Users, Dealers, and Retailers	February 2014
Task 4 Induction Cooking	Improved Induction Cooking White Paper	Codes and Standards Officials	February 2014
	Induction Cooking Tech Brief/Fact Sheet	All Market Participants	February 2014
	Improved Induction Cooking Journal Article (if results warrant publication or presentation)	Manufacturers, Specifiers, and Users	February 2014
Task 5 Power Factor Improvements	Residential Power Factor Codes and Standards White Paper for Energy Commission	Energy Commission and other Codes and Standards Officials	February 2014
	White paper information on improved Residential Power Factor	Manufacturers, Users, Dealers, and Retailers	February 2014
Task 6 Adjustable Speed Drives	Tech Brief/Fact Sheet for ASD for ACs	All Market Participants	February 2014
	Journal Article or Presentation, Forum posting (if results warrant publication or presentation)	Manufacturers, Specifiers, and Users	February 2014
	AC ASDs Codes and Standards White Paper	Codes and Standards Officials	February 2014

7.8 Summary/Conclusions and Plan Execution

This draft technology transfer plan provides a time-phased tabulation and description of documents to be published and distributed to disseminate Program results and to increase the market penetration of the improved Consumer Electronics and Motorized Appliance Technologies being studied. The plan addresses market barriers that often impede the adoption of new or improved technologies and analyzes the roles of influential market participants in the funding, specification, installation, and operation of these technologies. Information dissemination channels are outlined for each set of market participants, including publications, periodicals, websites, and upcoming meetings. Technology transfer materials are described that can overcome market barriers for the influential market participants. Anticipated technology transfer deliverables are tabulated with the expected delivery dates and channels.

The general approach to development of the technology transfer deliverables was to provide materials of general interest such as Fact Sheets that can be distributed to a broad set of market participants and categories of market participants. When there is information in these materials that is most useful for a specific group such as facilities personnel, this information was identified as such. A second category of deliverables consisted of those produced specifically for a group of market participants such as technical papers, journal articles, and tailored presentations to be produced for a specific audience at a particular time and place.

White papers were written with the objective of presenting project results in a compelling manner in order to influence codes and standards officials to revise their regulations to upgrade efficiency and/or power factor requirements of the products covered. These white papers may also be used, wholly or in part, as resource materials to inform other market participants of project results.

Progress reports were given to Program participants, the Energy Commission, and the Program Advisory Committee on progress made in working to the plan outlined in this document.

Plan execution consisted of distribution of the white papers and selected other deliverables to key market participants through the organizations identified in Tables 7-3, 7-4, 7-5, and 7-6, and followed up with presentations to suit the needs of members of these organizations. Executing the plan outlined in this document should provide strong connections between the Program results and the market, resulting in increased market acceptance of the Program results and the improved Consumer Electronics and Motorized Appliance Technologies studied.

GLOSSARY

Term	Definition
APD	Auto Power Down
CPU	Central Processing Unit
EPRI	Electric Power Research Institute
HTiB	Home Theater in a Box
PC	Personal Computer
PFC	Power Factor Corrector

REFERENCES

A Report on Energy Efficiency of Consumer Electronic Devices, EPRI, Palo Alto, CA: 2009. 1017892.

American Society for Testing and Materials. ASTM F 1521-13. *Standard Test Methods for Performance of Range Tops.* Updated 2012.

"Amplifier Efficiency," Zed Audio Corporation, March 1, 2005 http://www.zedaudiocorp.com/Technical/Amplifier-Efficiency.pdf

Assessment of Emerging Technologies, EPRI Draft Report Energy Commission-500-06-007, June 2009.

Association of Home Appliance Manufacturers (AHAM), *Household Tumble Type Clothes Dryers,* AHAM HLD-1-1992.

B. Fortenbery and J. G. Koomey, *Assessment of the Impacts of Power Factor Correction in Computer Power Supplies on Commercial Building Line Losses.* Prepared for the California Energy Commission, Contract #500-04-030. March 31, 2006.

B. Fortenbery, *Home Audio Efficiency Testing*, EPRI Advisory Council. September 17, 2012.

B. Urban, V. Tiefenbeck, K. Roth. *Energy Consumption of Consumer Electronics in U. S. Homes in 2010,* Final Report to the Consumer Electronics Association (CEA), Fraunhofer Center for Sustainable Energy Systems. 2011.

C. Calwell and P. May-Ostendorp, "80 Plus: A strategy for Reducing the Inherent Environmental Impacts of Computers," 2005 IEEE International Symposium, 2005.

C. Donnelly and K. Dayem, Survey of Potential Energy-Efficient Design Techniques for Home Audio Devices, Ecova. September 12, 2012.

California Code of Regulations, Title 24, Building Standards Code, Part 3, California Electrical Code. California Building Standards Commission, Sacramento, CA: 2010.

California Energy Commission (Energy Commission), *Computers, Codes and Standards Enhancement (CASE) Initiative, For PY 2013: Title 20 Standards Development, Analysis of Standards Proposal for Computers,* Docket Number: 12-AAER-2A; Consumer Electronics, August 6, 2013, http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2A_Consumer_Electronics/California_IOUs_Standards_Proposal_Computers_UPDATED_2013-08-06_TN-71813.pdf

California Energy Commission (Energy Commission), *How Low Can You Go? A White Paper on Cutting Edge Efficiency in Commercial Desktop Computers.* Energy Commission-500-2012-065. May 2012.

California Energy Demand: 2006-2016. California Energy Commission. 2006.

Comparison of Commercial Range Top Performance Test Methods. Food Service Technology Center (FSTC) Report 5011.02.16. Fisher-Nickel. 2003.

Custom Kiosk Design Services: Design & Engineering for Enclosures; Sourcing and selection of components; Project budgeting and preparation of Request for Proposals and Quotes; Sourcing a custom kiosk manufacturer; Prototyping; and Management of manufacturing partner.

D. Bohn, "Car and Home Audio Amplifier Classifications," downloaded June 22, 2012 http://www.moodym.com/audio/ampclass.html

Databeans, *2013 Audio Power Amplifiers*, 2013.

Delforge and C. Wold, "The Impact of Graphics Cards on Desktop Computer Energy Consumption," September 2012.

E. Wanless, "Cost Effective Computer Efficiency," ET12PGE5251, January 2013.

Ecos, *NRDC Final Report on Power Use of Audio Systems*, 2009.

Ecova, "Memorandum to Pacific Gas and Electric Company Describing Updated Discrete Graphics Processing Unit Testing Results," January 2013.

"Electronic Amplifier," from Wikipedia, downloaded June 22, 2012 http://en.wikipedia.org/wiki/Electronic_amplifier

Energy Commission Directive 2013

Energy Information Administration (EIA), *Annual Energy Outlook 2013: With Projections to 2040*.

Energy Information Administration (EIA), *International Energy Outlook 2013*.

ENERGY STAR® Program Requirements, Product Specification for Audio/Video, Test Method, USEPA, July 2012 https://www.energystar.gov/ia/partners/product_specs/program_reqs/Audio_Video_Program_Requirements.pdf?a928-5a42

ENERGY STAR® Program Requirements, Product Specification for Audio/Video, Eligibility Criteria, Version 3.0, USEPA, August 3, 2012 https://www.energystar.gov/ia/partners/product_specs/program_reqs/Audio_Video_Program_Requirements.pdf?a928-5a42

EPRI Report on 7 Injection Mold Machines

Euromonitor International, *Home Audio and Cinema in the US*, 2013.

F. Porter, Suzanne, L. Moorefield, and P. May-Ostendorp, *Final Field Research Report.* Final Field Research Report by Ecos Consulting to the California Energy Commission. 2006. Available from http://www.efficientproducts.org/documents/Plug_Loads_CA_Field_Research_Report_Ecos_2006.pdf

"Fluorescent Lamp," Wikipedia, Revised July 12, 2012.

G.A McCoy and J.G. Douglass, "Energy Management for Motor Driven Systems," Washington State University for the Bonneville Power Administration, Reproduced by the Office of Industrial Technologies, U.S. Department of Energy, Reproduced November 18, 2003 http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/NN0116.pdf

G.A. McCoy and J.G. Douglass, *Energy Management for Motor Driven Systems,* Washington State University for the Bonneville Power Administration, Reproduced by the Office of Industrial Technologies, U.S. Department of Energy, Reproduced November 18, 2003 http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/NN0116.pdf

Gartner, "Gartner Says That Consumers Will Store More Than a Third of Their Digital Content in the Cloud by 2016," June 2012, http://www.gartner.com/newsroom/id/2060215.

H. Singh and K. Rider. *2010 Appliance Efficiency Regulations*. California Energy Commission. Energy Commission-400-2010-012. 2010.

"HID Lamp Service Guide," Howard Lighting Products, March 15, 2011 http://www.howardlightingproducts.com/Documents/ProductLiterature/HIDLampServiceGuide.pdf

"Induction Cooking Basics," *Renesas Technology Europe,* August 19, 2008 http://www.ent.mrt.ac.lk/~thumeera/teaching/Note/Induction_Cooking.pdf

"Induction Cooking Basics," *Renesas Technology Europe,* August 19, 2008 http://www.ent.mrt.ac.lk/~thumeera/teaching/Note/Induction_Cooking.pdf

Induction Cooking Performance and Demonstration, EPRI, Palo Alto, CA: 2003. 1008976.

Induction Cooktop Performance: How Pan Sizes Impact Energy Input. Food Service Technology Center (FSTC) Report 5011.99.68. Fisher-Nickel: March 1999.

Intouch Interactive Services: Hardware Consulting & Sourcing; Creative Design & Writing; Usability & Interface Design; Video & Animation; Software Installation & Development; Remote Monitoring; Content Management; Kiosk Deployment & Technical Support.

Items A to N are from J. Eto, R. Prahl, and J. Schlegel, *A Scoping Study on Energy-Efficiency Market Transformation by California Utility DSM Programs,* LBNL-39058, UC-1322, July 1996.

J. Guy, "Class D Amplifier FAQ," *National Semiconductor,* 2009 http://www.national.com/assets/en/appnotes/ClassDAmplifierFAQ.pdf

J. Honda and J. Adams, "Application Note AN-1071 Class D Audio Amplifier Basics," *International Rectifier,* February 4, 2008 http://www.irf.com/technical-info/appnotes/an-1071.pdf

J. Koomey et al., "Implications of Historical Trends in the Electrical Efficiency of Computing," *IEEE Annals of the History of Computing,* 2011.

J. Leung, "Induction vs. Gas Stovetops," University of British Columbia, UBC APSC 262 Sustainability Project. March 3, 2011.

J. Leung, "Induction vs. Gas Stovetops," University of British Columbia, UBC APSC 262 Sustainability Project. March 3, 2011.

J. Lewis, "Efficient Amplification for Real World Audio," HiWave Technologies, April 25, 2012 http://www.eetimes.com/design/audio-design/4371713/Efficient-amplification-for-real-world-audio

K. R. Govindan, "Power Factor Improvement," http://www.energymanagertraining.com/Journal/Power%20Factor%20Improvement.pdf

K.R. Govindan, "Power Factor Improvement," Kavoori Consultants, 8-06-2004 http://www.energymanagertraining.com/Journal/Power%20Factor%20Improvement.pdf

KEMA, Inc. *2009 California Residential Appliance Saturation Study*, California Energy Commission. Publication number: Energy Commission-200-2010-004-ES. 2010.

M. Blatt, *Advanced HVAC Systems for Improving Indoor Environmental Quality and Energy Performance in California K-12 Schools, Technology Transfer Plan,* For the California Energy Commission, February 13, 2004.

M. Bohr and M. Kaizad, "Intel Introduces Tri-Gate Transistors for Superior Performance," May 2011, http://www.intel.com/content/www/us/en/silicon-innovations/revolutionary-22nm-transistor-technology-presentation.html.

M. Fleischman, "Rotel RSX-1562 A/V Receiver," *Home Theater Magazine,* 2012. Available from: http://www.hometheater.com/content/rotel-rsx-1562-av-receiver

M. Fremer, "Pioneer Elite SC-57 A/V Receiver," *Home Theater Magazine,* 2011. Available from: http://www.hometheater.com/content/pioneer-elite-sc-57-av-receiver

M. Gonzalez. and E. Sanchez, "Nonlinear Control Techniques for Low-Voltage, Low-Power Applications: Class D Audio Amplifiers," Texas A&M University, April 12, 2011 http://amesp02.tamu.edu/~sanchez/ECEN%20607%20Class%20D.pdf

M. Misakian et al., *Regarding Electric Energy Savings, Power Factors and Carbon Footprints: A Primer,* NIST Technical Note 1654, 11-13-2009 http://www.nist.gov/manuscript-publication-search.cfm?pub_id=903669

N. Rhoades, "Fundamental Overview of Heating by Induction," April 22, 2006 http://www.abiscus.com/HV/InductionHeating.pdf

National Electrical Code (NEC) 2011. National Fire Protection Association, Quincy, MA: 2010.

P. Schmid and A. Roos, "How Much Power Does Low-Voltage DDR3 Memory Really Save?" July 2010, http://www.tomshardware.com/reviews/lovo-ddr3-power,2650.html

"Power Factor Correction Chapter 8," October 7, 2005
http://www.edacafe.com/books/PSpice/san63267_ch08.pdf

"Power Factor Correction Chapter 8," October 7, 2005
http://www.edacafe.com/books/PSpice/san63267_ch08.pdf

Power Factor Correction Handbook: Choosing the Right Power Factor Controller Solution. ON Semiconductor, Phoenix, AZ: 2011. HBD853/D.
http://www.onsemi.com/pub_link/Collateral/HBD853-D.PDF

"Power Factor Correction Techniques in LED Lighting," *ECN Magazine,* August 16 2011,
http://www.ecnmag.com/products/2011/08/power-factor-correction-techniques-led-lighting

Power Quality Implications of Compact Fluorescent Lamps in Residences, Prepared by: Lamp Section of the National Electrical Manufacturers Association, Rosslyn, VA 22209, April 16, 1999
http://standby.iea4e.org/files/otherfiles/0000/0053/1999_NEMA_LSD_8-1999.pdf

"Power Supplies Types," Wikipedia, Last modified July 12, 2012.

"Power Supplies Types," Wikipedia, Last modified July 12, 2012.

Power Supply Maintenance and Application Guide, EPRI, Palo Alto, CA: 2001. 1003096.

Products currently covered include wine chillers; freezers; walk-in coolers and freezers; refrigerated vending machines; automatic commercial ice makers; water-source and ground-source heat pumps; computer room air conditioners; various types of storage and instantaneous water heaters; pool and spa heaters, pumps, and motors; external power supplies; and consumer audio and video equipment.

R. G. Lawrence, "The Adjustable Speed Synchronous Motor Drive Matures," EE Mods 2011 paper 051.

R.J. Underhill and K. Dulaney, "Future Residential Load Characteristics," Advanced Energy, January 28, 2011
http://www.advancedenergy.org/ci/services/testing/files/Future%20Residential%20Load%20Characteristics%20Report.pdf

"Research into the Effects and Implications of Increased CFL Use," March 2010
http://www.concerninglight.com/2010-03_Final-Report_comprehensive.pdf

S. Laverty, "Classes of RF Amplifiers," *eHow*, downloaded August 3, 2012
http://www.ehow.com/list_5972437_classes-rf-amplifiers.html

Shop for residential induction cooktop units on Google, January 18, 2013
http://www.ajmadison.com/b.php/Induction;110120+Volts;Cooktops/N~29+1148+4294962678?mv_pc=gg&mv_ca=gencook&ajparam-cid=cooking&gclid=CO7kvJrs8rQCFaGPPAodRRYA1Q http://restaurant-supplies.katom.com/cat/induction-

range.html?cmpid=Google_Countertop%20Induction%20Cooker&gclid=CPmxteHs8rQCFcKPPAodr0sASg

"Standby Power Summary Table," Lawrence Berkeley National Laboratory. http://standby.lbl.gov/archives/summary-table.html, accessed Feb 27, 2014.

"Strategies for Successful Kiosk Implementation," elo Touch Solutions, 2013 http://www.elotouch.com/Solutions/CaseStudies/kioskwp.asp

Technical Support Document for Residential Cooking Products (Docket Number EE-RM-S-97-700), Volume 2: Potential Impact of Alternative Efficiency, Levels for Residential Cooking Products, Lawrence Berkeley National Laboratory, Prepared for the U.S. Department of Energy, March 3, 2002.

Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers, Dehumidifiers, and Cooking Products, and Commercial Clothes Washers, Appendix 6A: Cooktops and Ovens: Determination of Energy-Using Components, U.S. DOE, EERE-2006-STD-0127. March 2009.

Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers, Dehumidifiers, and Cooking Products, and Commercial Clothes Washers, Chapter 6: Energy Use Determination, U.S. DOE, EERE-2006-STD-0127. March 2009.

Telephone conversation with John Wells jwells@kiosk.com of Kiosk.com on March 7, 2012.

Transparency Market Research, "Global Household Induction Cook-tops Market: Global Industry Analysis, Size, Share, Growth, Trends, and Forecast, 2012 – 2018," Transparency Market Research Report. 2013.

TWICE, Study: Worldwide Soundbar Sales Double in '11. 2012. Available from http://www.twice.com/article/484581-Study_Worldwide_Soundbar_Sales_Double_In_11.php.

U.S. EPA, ENERGY STAR Program Requirements for Consumer Audio and DVD products: Version 1.0. 2002, United States Environmental Protection Agency. Available from http://www.energystar.gov/ia/partners/product_specs/program_reqs/archive/audio_dvd_prog_req_v1.pdf?7165-77bb.

U.S. EPA, *ENERGY STAR Program Requirements Product Specification for Audio/Video: Final Version 3.0*. 2012, United States Environmental Protection Agency. Available from http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/audio_video/Final_Version_3_AV_Program_Requirements.pdf?5c95-9855.

U.S. EPA, *ENERGY STAR Unit Shipment and Market Penetration Report Calendar Year 2012 Summary,* United States Environmental Protection Agency. Available from http://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2012_USD_Summary_Report.pdf?7470-f6df

U.S. Office of the Federal Register, "Energy Conservation Program: Test Procedures for Conventional Cooking Products with Induction Heating Technology; Notice of proposed rulemaking," 10 Federal Register 430. January 2013.

U.S. Office of the Federal Register, *Code of Federal Regulations, Title 47, Telecommunication. Part 18, Industrial, Scientific, and Medical Equipment,* Washington, DC. October 1998.

U.S. Office of the Federal Register. *Code of Federal Regulations, Title 10, Energy. Part 430, Subpart B, Appendix I: Uniform Test Method for Measuring the Energy Consumption of Conventional Ranges, Conventional Cooking Tops, Conventional Ovens, and Microwave Ovens,* Washington, DC. January 2012.

"Understanding and Improving Your Power Factor," DTE Energy, Downloaded 6-15-2012 http://www.dteenergy.com/businessCustomers/largeBusinesses/electric/powerFactor.html

United States Bureau of Labor Statistics, "Computer and Internet Use at Work Summary," August 2005, http://www.bls.gov/news.release/ciuaw.nr0.htm.

United States Census Bureau, "Computer and Internet Use in the United States," 2010, http://www.census.gov/hhes/computer/.

United States Energy Information Association, "Annual Energy Outlook 2012," 2013.

United States. (1989), *Statistical Needs for a Changing U.S. Economy,* Washington, DC: Congress of the U.S., Office of Technology Assessment.

Updated Macroeconomic Analysis of Climate Strategies Presented in the March 2006 Climate Action Team Report - Final Report, Economics Subgroup California Climate Action Team. October 2007. Page 12.

"Variable Speed Drives," CTG006, Carbon Trust, March 2007 http://www.energylab.es/fotos/081105155611_5gf9.pdf

W. C. Moreland, "The Induction Range: Its Performance and Its Development Problems," *IEEE Transactions on Industry Applications*, vol. TA-9, no. 1, January/February 1973 pages 81–86.

"What is Induction Cooking?" February 6, 2010 http://www.mncgloble.com/other-files/induction-stoves.pdf

"What is Power Factor?" Sylvania, August 15, 2000 http://ceolas.net/Docs/Sylvania_on_CFL_Power_Factor.pdf

"What is Power Factor?" Sylvania, August 15, 2000 http://ceolas.net/Docs/Sylvania_on_CFL_Power_Factor.pdf

APPENDIX A:
Power Levels of Desktop Computers

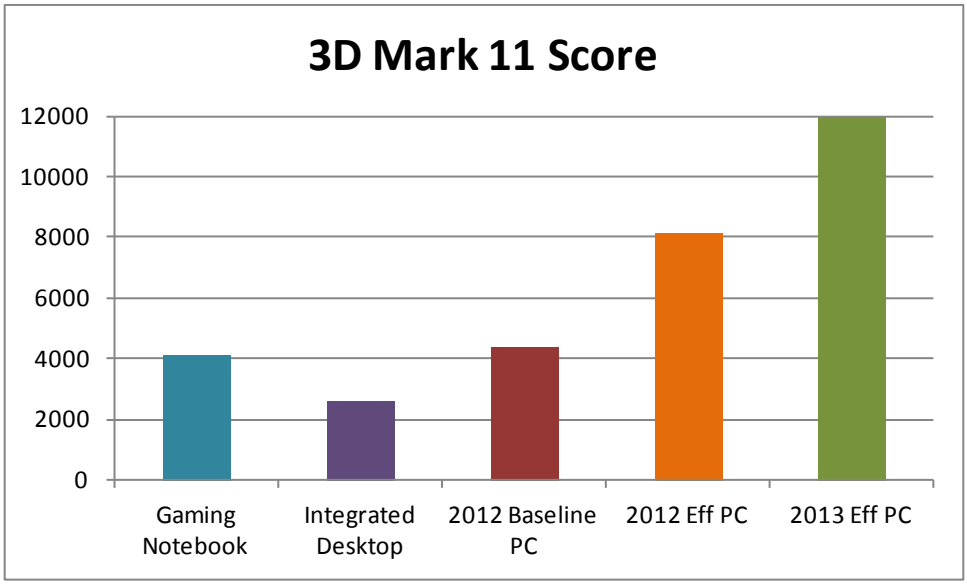
Table 1: Power Levels of Desktop Computers

	2012 Baseline Desktop	2012 Efficient Desktop	2013 Efficient Desktop	Razer Blade Notebook	iMac Integrated Desktop
Standby Power (W)	0.3	0.8	0.54	0.51	0.24
Sleep Power (W)	1.7	1.2	2.41	0.73	1.01
Short Idle Power (W)	56.9	42.1	38.87	9.62	15.62
Long Idle Power (W)	58.3	44.4	38.70	9.55	15.58
Annual Energy Use (kWh/year)	255	195	173	37	70

Note: Power draw results exclude the monitor; different duty cycles were used for desktops and notebooks.

APPENDIX B:
3D Mark 11 Score

Figure 1: 3D Mark 11 Scores



APPENDIX C:
Modified ENERGY STAR Test Method

Applicability

The Modified ENERGY STAR test requirements are dependent upon the feature set of the product under evaluation. The following guidelines shall be used to determine the applicability of each section of this document:

- Power mode tests (Section 5) shall be performed on every product.
- Optical disc player tests (Section 6) shall be performed on any dedicated optical disc product capable of playback of audio and/or video stored on optical media (for example, CD, SA-CD, DVD, Blu-ray Disc).
- Audio amplification tests (Section 7) shall be performed on any product that offers Audio Amplification.
- Tests of the auto-power down (APD) function (Section 7.1) shall be performed on all products except those subject to third-party performance standards that prohibit APD.

For example, a typical Home Theater in a Box system with an integrated DVD player/recorder and audio amplifiers would be subject to the power mode tests in Section 5 and the full-spectrum audio amplifier tests in Section 7. In contrast, a stand-alone optical disc player would likely be subject only to the power mode tests in Section 5 and the optical disc player tests in Section 6.

Test Setup

- Test Setup and Instrumentation: Test setup and instrumentation for all portions of this procedure shall be in accordance with the requirements of IEC 62301, Ed. 2.0, "Measurement of Household Appliance Standby Power," Section 3, "General Conditions for Measurements." In the event of conflicting requirements, the Modified ENERGY STAR test method shall take precedence.
- Input Power: Input power shall be as specified in Table C-1 and Table C-2.
- Ambient Temperature: Ambient temperature shall be from 18°C to 28°C.
- Relative Humidity: Relative humidity shall be from 10% to 80%.

Table 1: Input Power Requirements for Products with Nameplate Rated Power Less Than or Equal to 1500 W

Nameplate Rated Power Less Than or Equal to 1500 W Market	Voltage	Voltage Tolerance	Maximum Total Harmonic Distortion	Frequency	Frequency Tolerance
North America, Taiwan	115 Vac	+/- 1.0%	2.0%	60 Hz	+/- 1.0%
Europe, Australia, New Zealand	230 Vac	+/- 1.0%	2.0%	50 Hz	+/- 1.0%
Japan	100 Vac	+/- 1.0%	2.0%	50/60 Hz	+/- 1.0%

Table 2: Nameplate Rated Power Greater Than 1500 W

Market	Voltage	Voltage Tolerance	Maximum Total Harmonic Distortion	Frequency	Frequency Tolerance
North America, Taiwan	115 Vac	+/- 4.0%	5.0%	60 Hz	+/- 1.0%
Europe, Australia, New Zealand	230 Vac	+/- 4.0%	5.0%	50 Hz	+/- 1.0%
Japan	100 Vac	+/- 4.0%	5.0%	50/60 Hz	+/- 1.0%

Test Conduct

- As-shipped Condition: Products must be tested in their "as-shipped" configuration. For products that offer a choice of user-configurable options, all options shall be set to their default condition unless settings must be changed to utilize all speakers. If the device has different low power modes that can be manually selected, the measurement shall be taken with the device in the version of the mode that the power button on the remote control or front panel will initiate.
- Unit Under Test (UUT) Control: The UUT shall be controlled with the factory-supplied remote control (I/R or RF) to the extent possible. For units that do not ship with a remote control or for functions that cannot be exercised with the supplied remote control, control interfaces on the face or body of the UUT may be used.
- Measurement Location: All input power measurements shall be taken at a point between the ac power source and the UUT.
- Multi-component Systems: For products composed of multiple components in separate housings, all components shall be connected together in a typical end-use configuration. Power shall be measured as a sum of the measurements at each unique plug connection.

- Signal Input Location: If the UUT does not have accessible signal input terminals, test signal input may be through the device antenna, optical disc player, or other accessible means typical of customer use. An effort should be made to equalize input signal power (dB) between different inputs.
- Audio Sources: Pink noise with an amplitude of 0.8 should be used as the audio signal. Signal should be in phase and with identical signals. An attempt should be made to equalize the volume out of each channel unless Section A above instructs otherwise.
- Video Sources: SD and HD "dynamic broadcast" video content from IEC 62087 Ed. 3.0 shall be used as the video source for optical disc player tests in Section 6. If the UUT supports HD media, HD media should be used for testing.
- Output Volume: UUT output volume shall be set to minimum for the duration of all tests except as noted in the audio amplifier test procedures in Section 7.
- Speaker Placement: A sound pressure meter will be used during the test. Sound pressure measurements should be measured 2 meters from all speakers. The sound pressure meter must be able to measure the full spectrum of the audio source as well as provide both dBA and dBZ measurements. In units with multiple speakers, speakers must be placed according to the manufacturer-provided manual; however, distance between each speaker and the sound meter shall be 2 meters.
- Battery Powered Devices: If the UUT contains rechargeable batteries or can be integrated with another device that contains rechargeable batteries, all batteries shall be fully charged prior to the start of testing and shall remain in place for the duration of testing.
- Amplifiers: For devices with multiple independent audio amplifiers, all amplifiers shall be connected and tested simultaneously.
- Speaker Outputs:
    - If the UUT includes speaker outputs and no speakers, connect a speaker across each pair of output terminals. The same speaker should be used in all tests, and its characteristics (frequency response, model, impedance) should be provided with the test results.
    - If the UUT includes speakers, the included speakers must be used in all tests.
- AV Signal Interconnections: If the UUT offers several audio and video interconnection options, select and configure the system with one of the following interconnections, in order of preference: HDMI, component, S-video, and composite. However, if the order of preference does not appear to be the typical way to use a device, use the typical connector (a dock will most likely be used with a media player or phone). Only the connections needed to perform the test shall be connected at the time of test.

- Networking/Control Protocols: If the UUT offers several Networking/Control Protocol options, each must be connected to the Internet. If prompted to update firmware, firmware must be updated.

Pre-Test UUT Initialization

Prior to the start of testing, the UUT shall be initialized as follows:

- Set up the UUT per the instructions in the supplied operating manual.
- If the UUT includes rechargeable batteries, ensure that all batteries are in a fully charged state.
- Connect the UUT to the power source.
- Power on the UUT and perform initial system configuration, if prompted.
- Ensure that all audio tone controls are set to default.
- Ensure that UUT settings (display brightness, etc.) are in their as-shipped configuration.
- Connect the UUT to the signal source and test equipment. The input signal shall comply with the requirements in Section 3.
- Wait 15 minutes or until the unit has completed initialization and is ready for use.
- Measure and record the AC input voltage.
- Record all applicable fields in the provided Product Testing Spreadsheet.

Test Procedures for All Products

The following tests shall be performed on all products.

Auto Power Down (APD) Function

- Configure the UUT in a typical On Mode, Active State, with APD timing set to the default value.
- Stop the UUT from performing any Primary Functions, and turn off any input signal applied to active AV inputs to cause the UUT to APD.
- Begin measuring the elapsed time to APD after the product ceases performance of all Primary Functions due to disconnection of signal.
- Measure and record the average power before APD over a 60-cycle period once the device power has stabilized.
- Allow the UUT to automatically power down.
- Verify that the device is in the expected APD low-power state and record the time to APD.

- Measure and record the average power after APD over a 60-cycle period once the device power has stabilized.
- *Idle State*
- Configure the UUT in a typical Sleep Mode or Off Mode operational state.
- Press the power button or otherwise switch the unit into an On Mode operational state, such that no active content is playing.
- Wait at least 60 seconds.
- Measure and record the average power over a 60-cycle period once the device power has stabilized.
- *Sleep Mode*
- Configure the UUT in a typical On Mode operational state.
- Switch the UUT into a Sleep Mode low-power operational state.
- Measure and record the average power over a 60-cycle period once the device power has stabilized.

Test Procedures for Optical Disc Players

The following tests shall be performed on any product capable of playback or recording of audio and/or video on optical disc media (for example, CD, DVD, Blu-ray Disc).

Video Playback Test

- Insert/install the removable media and begin playback of IEC 62087 video content. Use the highest quality content that the player supports.
- Measure and record the average power over a 60-cycle period once the device power has stabilized.

Test Procedures for Products with Audio Amplification

- Connect an input of the UUT to the audio source signal as described in the AV Signal Interconnections above.
- Set up a sound pressure meter in a place equally spaced (2 meters) between all speakers.
- Measure the room's ambient sound pressure level.
- Turn up the volume of the UUT until it reaches the first sound pressure level (dBA) on the testing spreadsheet. Input signal power should have been equalized with other input types being used during the test.

- Collect power measurements for both the input power to the device from the wall and measured sound pressure level in dBA and dBZ.
- Turn up the volume on the UUT until it reaches the next sound pressure level.
- Collect power measurements for the input power to the device from the wall.
- Repeat Steps 38 and 39 until the full sound pressure level range has been tested or until the device reaches its maximum volume.

Energy Commission Home Audio Test Spreadsheet

Power measures should be taken at each of the following sound pressure levels per the test method above: 45 dBA to 100 dBA at intervals of 5 dBA. Proper hearing protection should be used during testing.

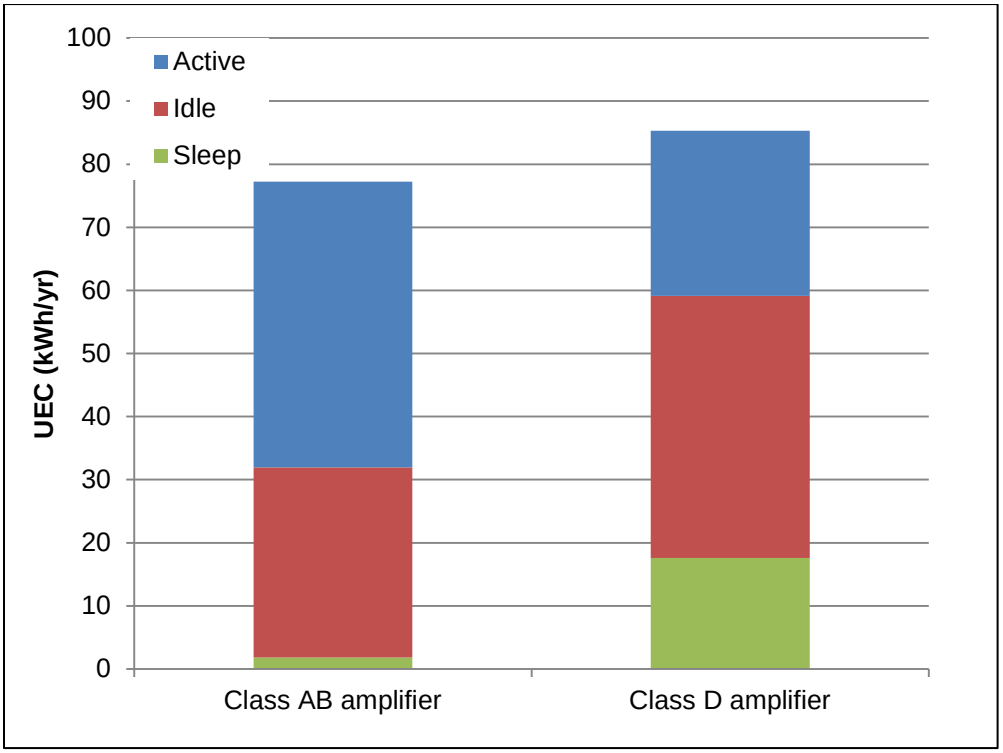
UUT Name						
Test Points	**Measured Sound Pressure**		**Electrical Measurements**			
SPL (dBA)	*SPL (dBA)*	*SPL (dBZ)*	*Voltage (V)*	*Current (A)*	*Power Factor*	*Power (W)*
45						
50						
55						
60						
65						
70						
75						
80						
85						
90						
95						
100						

APPENDIX D:
Estimated Energy Consumption for Class AB Versus Class D Amplifiers

Although the type of amplifiers used in most of the devices tested were unable to be determined, it was determined that two of the five receivers tested use Class D amplifiers. It was assumed that the remaining three receivers tested used Class AB amplifiers.

UECs were estimated for a Class D and AB amplifier based on EPRI power measurements of two Class AB and two Class D receivers and are compared in Figure. As expected, the active mode energy is less for the tested Class D amplifiers. However, due to higher idle and standby power draw, the Class D amplifiers tested have overall greater energy use. Note that only two amplifiers of each type were measured; thus the UECs are uncertain. In addition, the UEC for receivers estimated by Urban et al. (2011) is lower than even those measured by EPRI.

Figure 1: Unit Energy Consumption by Mode for a Class D Amplifier Compared to a Class AB Amplifier, Measured by EPRI



APPENDIX E:
Cooking Efficiency Test Data

Tables E-1 through E-7 show the data recorded for each unit from the cooking efficiency testing, with each test procedure and cooking load weight specified.

The test procedures are abbreviated in the tables as follows:

A: water heating procedure similar to ASTM F1521 and ANSI Z83.11, where a quantity of water—either 3 lb or 10 lb –is heated from 70°F to 200°F.

I: water simmer procedure similar to IEC 60350, where 6 lb of water is heated from 68°F to 194°F and held above 194°F for 15 minutes.

Table 1: Induction Cooker A Efficiency Test Measurements

Test Procedure	Power Setting	Vessel Size	Cooking Load (lb)	Efficiency
A	50%	Large	10	75.1%
A	50%	Large	10	74.4%
A	50%	Large	10	75.3%
A	100%	Large	10	77.8%
A	100%	Large	10	77.9%
A	100%	Large	10	77.2%
A	50%	Small	3	76.8%
A	50%	Small	3	76.1%
A	50%	Small	3	76.4%
A	100%	Small	3	77.8%
A	100%	Small	3	76.9%
A	100%	Small	3	77.5%
I	100–25%	Large	6	62.3%
I	100–25%	Large	6	62.2%
I	100–25%	Large	6	62.5%

Table 2: Induction Cooker B Efficiency Test Measurements

Test Procedure	Power Setting	Vessel Size	Cooking Load (lb)	Efficiency
A	50%	Large	10	76.3%
A	50%	Large	10	75.7%
A	50%	Large	10	75.3%
A	100%	Large	10	77.9%
A	100%	Large	10	76.9%
A	100%	Large	10	76.7%
A	50%	Small	3	76.5%
A	50%	Small	3	75.2%
A	50%	Small	3	75.8%
A	100%	Small	3	74.8%
A	100%	Small	3	76.1%
A	100%	Small	3	75.1%
I	100–25%	Large	6	74.0%
I	100–25%	Large	6	62.1%
I	100–25%	Large	6	62.1%

Table 3: Conventional Electric Range Efficiency Test Measurements

Test Procedure	Power Setting	Vessel Size	Cooking Load (lb)	Efficiency
A	50%	Large	10	82.8%
A	50%	Large	10	82.1%
A	50%	Large	10	79.9%
A	100%	Large	10	86.1%
A	100%	Large	10	82.5%
A	100%	Large	10	81.6%
A	50%	Small	3	49.1%
A	50%	Small	3	49.0%
A	50%	Small	3	46.6%
A	100%	Small	3	39.6%
A	100%	Small	3	41.7%
A	100%	Small	3	43.1%
I	100–25%	Large	6	74.8%
I	100–25%	Large	6	69.0%
I	100–25%	Large	6	69.2%

Table 4: Natural Gas Range Efficiency Test Measurements

Test Procedure	Power Setting	Vessel Size	Cooking Load (lb)	Efficiency
A	50%	Large	10	40.0%
A	50%	Large	10	40.7%
A	50%	Large	10	44.4%
A	100%	Large	10	34.9%
A	100%	Large	10	36.9%
A	100%	Large	10	33.8%
A	100%	Small	3	20.2%
A	100%	Small	3	19.7%
A	100%	Small	3	21.6%
I	100–25%	Large	6	27.0%
I	100–25%	Large	6	29.8%
I	100–25%	Large	6	33.9%

Table 5: Electric Cooktop Market Survey

Brand	Width (inch)	Number of Burners	Max Element Power (W)	Price
Kenmore Electric 4120 (coil)	30	4	2400	$283
Maytag MEC4536WB (coil)	36	5	2350	$404
GE JP626WKWW (coil)	36	4	2400	$449
Whirlpool Radiant G7CE3034XS	30	4	3000	$624
Whirlpool Radiant W5CE3625AB	36	5	2500	$649
Kenmore Radiant 41279	30	4	3200	$891
Whirlpool Radiant G9CE3065XB	30	5	2500	$899
GE JP356SMSS	30	4	2700	$899
Whirlpool Radiant G9CE3675XB	36	5	3000	$1,170
Thermador CEM365FS	36	5	2500	$1,224
KitchenAid KHRT7720	30	4	3700	$1,289
Kenmore 44119	30	4	4400	$1,350
Kenmore Elite 44129	36	4	3200	$1,458
Kenmore Elite 44123	36	4	3200	$1,548
GE PP989SNSS	30	5	3000	$1,649

Table 6: Induction Cooktop Market Survey

Brand	Width (inch)	Number of Burners	Max Element Power (W)	Price
Summit SINC424220	24	4	1800	$855
Summit SINC430220	30	4	1800	$860
Whirlpool GCI3061XB	30	4	3200	$1,210
Bosch NIT3065UC	30	4	3600	$1,375
Frigidaire FGIC3667MB	36	5	3500	$1,439
GE Profile PHP900DMBB	30	4	3700	$1,440
Electrolux hybrid EW30CC55GB	30	4	3400	$1,524
Frigidaire FPIC3695MS	36	5	3400	$1,529
Fagor IFA80BN	32	4	2800	$1,600
Electrolux hybrid EW36CC55G	36	5	3400	$1,660
Electrolux W36IC60LB	36	5	4800	$1,709
LG LCE30845	30	4	3300	$1,799
Electrolux EW36IC60LS	36	5	4800	$1,799
GE PHP960SMSS	36	5	3700	$1,799
GE PHP960DMBB	36	5	3700	$1,899
Bosch NIT5665UC	36	5	2800	$2,250
Bosch NIT8665UC	36	5	4400	$2,429
Thermador CIT365KM	36	5	4600	$2,999

Table 7: Gas Cooktop Market Survey

Brand	Width (inch)	Number of Burners	Max Element Power (Btu)	Price
Whirlpool W3CG3014XB	30	4	10,500	$270
Whirlpool W5CG3024Xb	30	4	12,500	$330
Maytag MGC4430BDB	30	4	12,500	$386
Maytag MGC4436BDB	36	5	12,500	$431
Maytag MGC7536WS	36	5	15,000	$791
GE JGP633SETSS	36	5	11,000	$809
Whirlpool G7CG3064XS	36	4	17,000	$918
Whirlpool G7CG3665XS	36	5	17,000	$979
Frigidaire FGGC3645KS	36	5	17,000	$989
Whirlpool GLS3665RS	36	5	15,000	$1,079
LG LCG3611ST	36	5	17,000	$1,079
Frigidaire FGGC3665KS	36	5	17,000	$1,079
GE PGP966SETSS	36	5	15,000	$1,199
GE Café CGP350SETSS	30	5	20,000	$1,259
GE JGP970BEKBB	36	5	15,000	$1,299
Electrolux EW36GC55GS	36	5	18,000	$1,304
GE PGP976SETSS	36	5	17,000	$1,599
GE CGP650SETSS	36	5	20,000	$1,699
GE PGP986SETSS	36	5	20,000	$1,699

APPENDIX F:
Single-Line Residential Drawings

Figure 1: Single-Line Drawing of a Small Residence

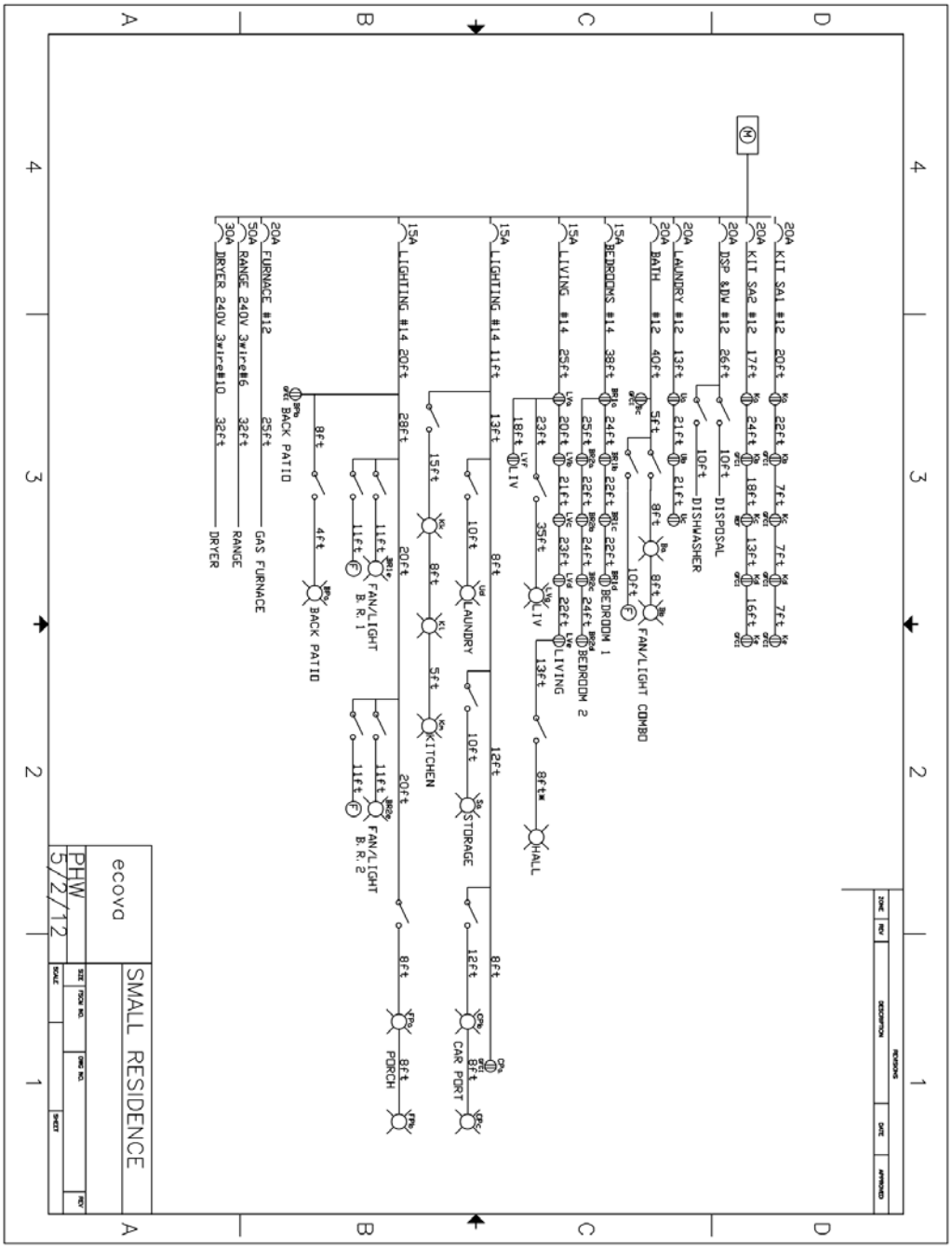


Figure 2: Single-Line Drawing of a Medium Residence

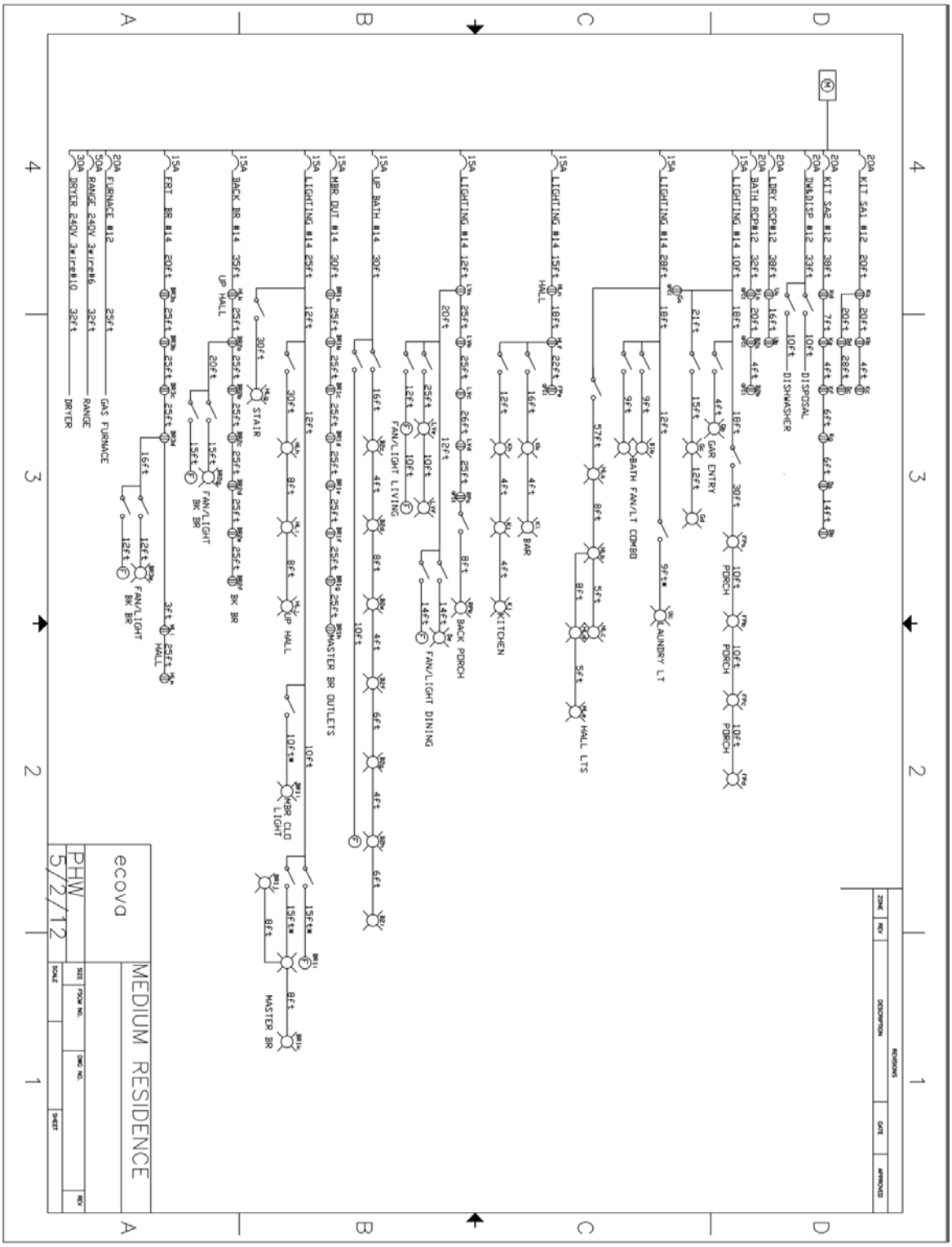
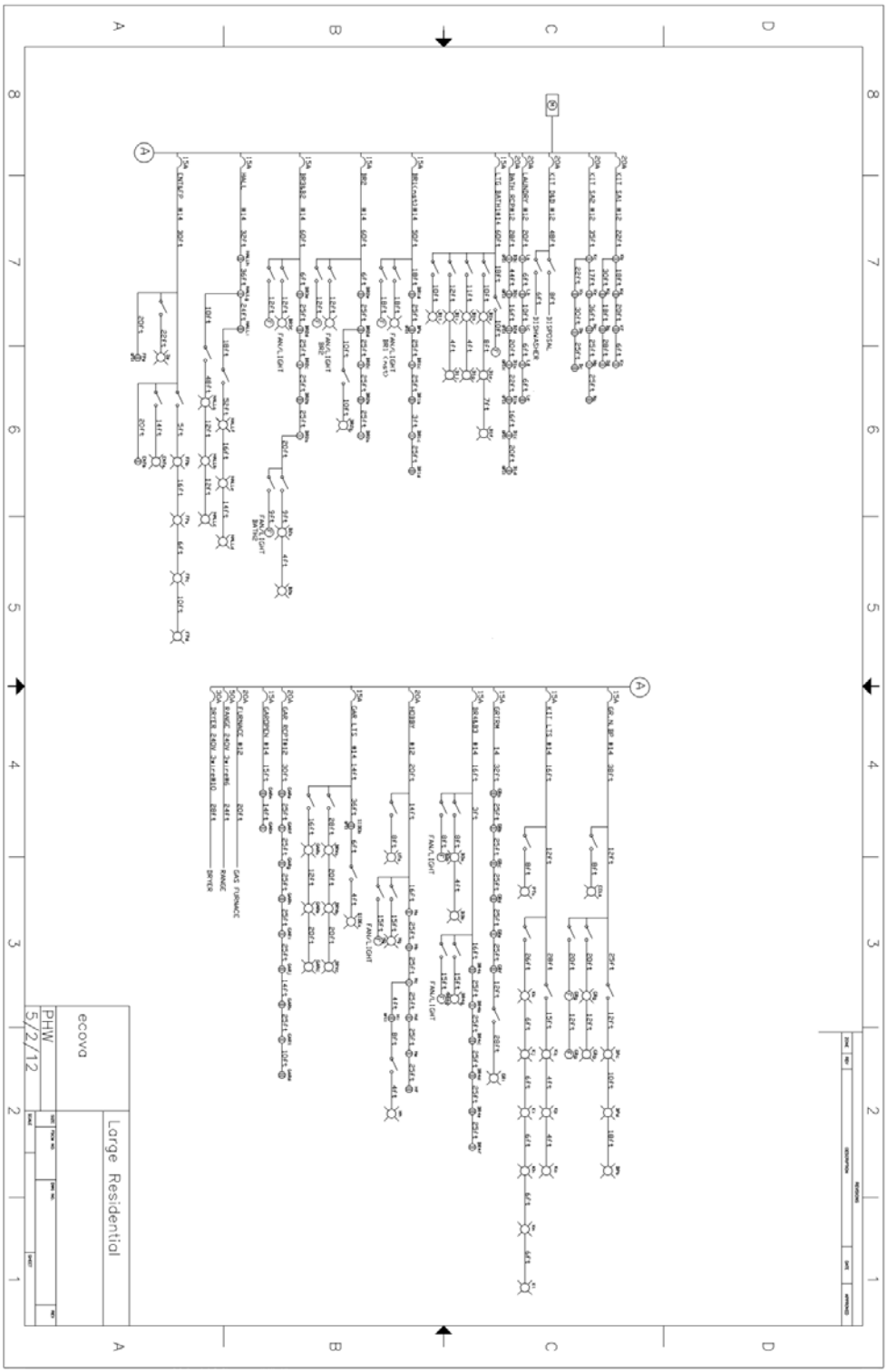



Figure 3: Single-Line Drawing of a Large Residence