PRELIMINARY TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS:

REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

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EXECUTIVE SUMMARY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

ES.1 OVERVIEW OF PRELIMINARY ACTIVITIES

Section 6295(o)(2)(A) of 42 U.S.C. requires the U.S. Department of Energy (DOE) to establish energy conservation standards that are technologically feasible and economically justified, and would achieve the maximum improvement in energy efficiency. This executive summary summarizes the preliminary activities that DOE conducted in consideration of amended energy conservation standards for refrigerators, refrigerator-freezers, and freezers. The executive summary describes the preliminary activities and summarizes key results from DOE's preliminary analyses. Additionally, the executive summary delineates issues identified during the analyses about which DOE seeks comments from interested parties. These issues are highlighted in the public meeting presentation and are further discussed in chapter 2 of the preliminary technical support document (TSD).

Figure ES.3.1 presents a summary of the analytical components of the standards-setting process and illustrates how key results are generated. The focal point of the figure is the center column, labeled "Analyses." The columns labeled "Key Inputs" and "Key Outputs" show how the analyses fit into the process and how they relate to each other. Key inputs are the types of data and other information that the analyses require. Some key information is obtained from public databases. DOE collects other inputs from interested parties or persons having special knowledge and expertise. Key outputs are analytical results that feed directly into the standards-setting process. The issues on which DOE seeks comment from interested parties derive from the key results that are generated by the preliminary analyses. Arrows connecting analyses show the types of information that feed from one analysis to another.

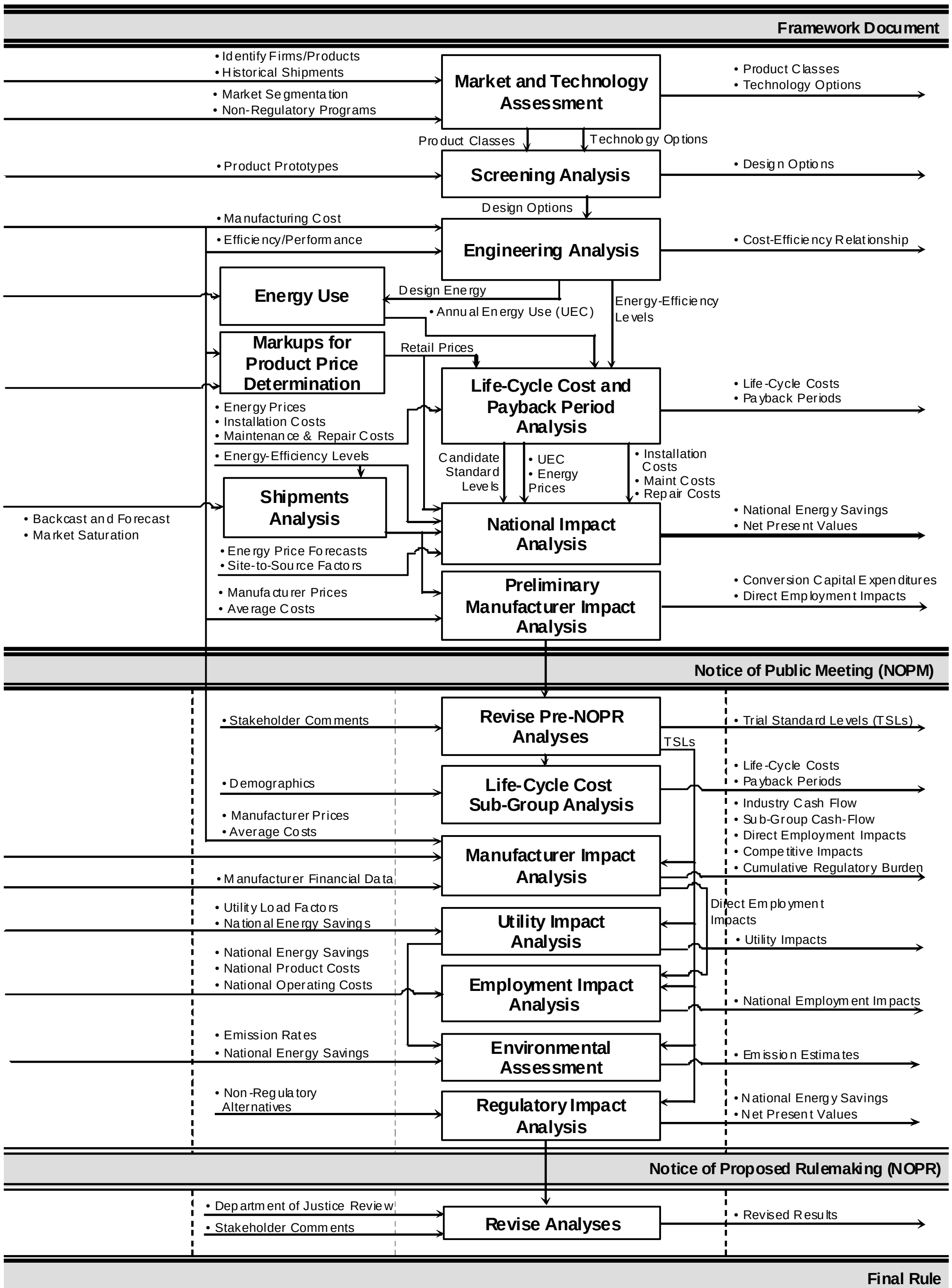

Figure ES.1.1 Flow Diagram of Analyses for the Refrigerator, Refrigerator-Freezer, and Freezer Rulemaking Process

ES.2 OVERVIEW OF THE PRELIMINARY ANALYSES AND THE PRELIMINARY TECHNICAL SUPPORT DOCUMENT

For the preliminary stage, DOE publishes a notice of public meeting (NOPM) in the *Federal Register*, which announces the availability of the preliminary technical support document, the date and place of the public meeting, and presentation materials interested parties may review before the public meeting. In addition, the NOPM highlights the major analyses DOE developed in the preliminary stage of the rulemaking.

The preliminary TSD describes each preliminary analysis in detail, providing detailed descriptions of inputs, sources, methodologies, and results. Chapter 2 of the preliminary TSD provides an overview of each preliminary analysis, the comments received in response to the analytical approaches DOE described in the framework document, and DOE's responses to those comments. The following chapters of the preliminary TSD address the analyses performed for the preliminary stage of the rulemaking.

A market and technology assessment (MTA) characterizes the relevant product markets and technology options, including prototype designs (chapter 3).

A screening analysis reviews each technology option to determine whether it is technologically feasible; is practicable to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse impacts on health and safety (chapter 4).

An engineering analysis develops cost-efficiency relationships that show a manufacturer's cost of achieving increased efficiency. DOE uses manufacturer markups to convert manufacturer production cost (MPC) to manufacturer selling price (MSP) (chapter 5).

A markups analysis converts the manufacturer costs derived from the engineering analysis to consumer equipment prices (chapter 6).

An energy use analysis determines the annual energy use in the field of the considered products (chapter 7).

Life-cycle cost (LCC) and payback period (PBP) analyses calculate, at the consumer level, the discounted savings in operating costs throughout the estimated average life of the covered products, compared to any increase in the product's installed cost likely to result directly from the imposition of a given standard (chapter 8).

A shipments analysis forecasts product shipments, which then are used to calculate the national impacts of standards on energy consumption, the net present value (NPV) of consumer costs and savings, and future manufacturer cash flows (chapter 9).

A national impact analysis (NIA) assesses the cumulative national energy savings (NES) from standards and the NPV of consumer costs and savings associated with standards at different efficiency levels (chapter 10).

A preliminary manufacturer impact analysis (MIA) assesses the potential impacts of energy conservation standards on manufacturers, such as effects on expenditures for capital conversion, marketing costs, shipments, and research and development costs (chapter 12).

The remaining chapters of the preliminary TSD address the analyses to be performed for the NOPR stage:

- A life-cycle cost analysis for subgroups evaluates the effects of energy conservation standards on various national subgroups of the population (chapter 11).
- A utility impact analysis examines impacts of energy conservation standards on the generation capacity of electric utilities (chapter 13).
- An employment impact analysis examines the effects of energy conservation standards on national employment (chapter 14).
- An environmental assessment examines the effects of energy conservation standards on various airborne emissions (chapter 15).
- A regulatory impact analysis examines the national impacts of non-regulatory alternatives to mandatory energy conservation standards (chapter 16).

ES.3 KEY RESULTS OF THE ANALYSIS

The following sections describe in detail the key analyses DOE performed in support of the TSD.

ES.3.1 Market and Technology Assessment

When initiating an analysis of potential energy efficiency standards for appliance, DOE develops information for the products concerned on the present and past industry structure and market characteristics. This activity assesses industries and products both quantitatively and qualitatively, based on publicly available information.

When evaluating and establishing energy conservation standards, DOE generally divides covered products into product classes by the type of energy used or by capacity or other performance-related features that affect efficiency. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q)) Table ES.3.1 describes all of the product classes being considered in this rulemaking.

Table ES.3.1 Product Classes for Refrigeration Products

No.	Product Class
Classes Listed in the CFR (10 CFR 430.32(a))	
1	Refrigerator-freezers with manual defrost
2	Refrigerator-freezers—partial automatic defrost
3	Refrigerator-freezers—automatic defrost with top-mounted freezer without TTD* ice service
4	Refrigerator-freezers—automatic defrost with side-mounted freezer without TTD ice service
5	Refrigerator-freezers—automatic defrost with bottom-mounted freezer without TTD ice service
6	Refrigerator-freezers—automatic defrost with top-mounted freezer with TTD ice service
7	Refrigerator-freezers—automatic defrost with side-mounted freezer with TTD ice service
8	Upright freezers with manual defrost
9	Upright freezers with automatic defrost
10	Chest freezers and all other freezers except compact freezers
11	Compact** refrigerators and refrigerator-freezers with manual defrost
12	Compact refrigerator-freezers—partial automatic defrost
13	Compact refrigerator-freezers—automatic defrost with top-mounted freezer and compact all-refrigerators—automatic defrost
14	Compact refrigerator-freezers—automatic defrost with side-mounted freezer
15	Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer
16	Compact upright freezers with manual defrost
17	Compact upright freezers with automatic defrost
18	Compact chest freezers
Classes Proposed to be Established during this Rulemaking	
1A	All-refrigerators—manual defrost
3A	All-refrigerators—automatic defrost
5A	Refrigerator-freezers—automatic defrost with bottom-mounted freezer with TTD ice service
10A	Chest freezers with automatic defrost
11A	Compact all-refrigerators—manual defrost
13A	Compact all-refrigerators—automatic defrost

* TTD = through the door
** Compact refrigerators, refrigerator-freezers, and freezers have less than 7.75 cubic feet (220 liters) total refrigerated volume and are less than 36 inches (0.91 m) in height.

The product classes listed in Table ES.3.1 as proposed to be established during this rulemaking include the following:

- Product Class 5A was identified as Product Class 19 in the framework document. DOE is proposing to adopt the modified designation 5A to maintain consistency with Canadian Standards.

- Product Class 10A was identified as Product Class 20 in the framework document. DOE is proposing to adopt the modified designation 10A to maintain consistency with Canadian Standards.
- Product Classes 1A, 3A, 11A, and 13A are proposed as a result of proposed new test procedures which involve modification of compartment temperatures. According to these test procedures the energy use of all-refrigerators decreases, while that of the other products of existing Products Classes 1, 3, 11, and 13 increases significantly. Establishing meaningful energy standard levels for the all-refrigerators requires that they be separated from the other products of the existing product classes.

The CFR establishes the test procedures for refrigerators, refrigerator-freezers, and freezers. (10 CFR part 430, subpart B, appendices A1 and B1) DOE has initiated a separate rulemaking to amend these test procedures. The proposed amendments address a number of issues that have emerged since the last test procedure revisions, including updating the reference to the AHAM HRF-1 test standard, modifying the test procedures for icemakers, specifying procedures for test sample preparation, modifying the test procedures for convertible compartments and special-purpose compartments, modification of the definition for anti-sweat heaters to include those that prevent sweat on interior surfaces, various test procedure language corrections, incorporating test procedures for variable anti-sweat systems previously addressed in waivers, establishing new compartment temperatures and volume calculation methods, modification to test procedures for advanced defrost systems, and modification of the definition of refrigerator-freezers to exclude combination freezer-wine storage products.

For the residential refrigeration products that are the topic of this rulemaking, DOE addressed as part of the market assessment (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory initiatives for improving product efficiency, and (3) trends in product characteristics and retail markets. This information provided data and resource material throughout the analysis.

DOE reviewed literature and interviewed manufacturers to develop an overall understanding of the residential refrigeration products industry in the United States. Industry publications, including trade journals, literature from manufacturers, government agencies, and trade organizations provided the bulk of the information, including (1) manufacturers and their market share; (2) shipments by product type; (3) product information; and (4) industry trends. Chapter 3 of the preliminary TSD describes the market analysis and resulting information.

DOE typically uses information about existing and past technology options and prototype designs to determine which technologies and combinations of technologies manufacturers use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies to be considered. The identified technologies initially include all those DOE believes are technologically feasible.

DOE developed its list of technologically feasible technologies for refrigeration products based on a review of trade publications, technical papers, and manufacturer literature and through consultation with manufacturers of components and systems. Because existing products contain many technologies for improving product efficiency, product literature and direct examination provided additional information. Before performing the screening analysis, DOE removed from the list those technologies for which the energy consumption could not be adequately measured using the relevant DOE test procedure.

ES.3.2 Screening Analysis

The screening analysis examines whether identified technologies (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; and/or (4) have adverse impacts on health and safety. As part of this analysis, DOE develops an initial list of options for enhancing efficiency from the technologies that the technology assessment identified as feasible. In consultation with interested parties, DOE reviews the list to assess whether the technologies: (1) are practicable to manufacture, install, and service; (2) would adversely affect product utility or availability; or (3) would have adverse impacts on health and safety. In the subsequent engineering analysis, DOE further examines the technology options that it did not remove from consideration in the screening analysis.

ES.3.3 Engineering Analysis

The engineering analysis (chapter 5) establishes the relationship between the cost of manufacturing residential refrigeration products and their efficiency. This relationship serves as the basis for calculating costs and benefits of modified product designs for consumers, manufacturers, and the Nation. Chapter 5 describes the product classes DOE analyzed, the representative baseline units, the efficiency levels DOE considered, the methodology DOE used to develop the manufacturing production cost model, and the cost-efficiency results.

ES.3.3.1 Product Classes Analyzed

The engineering analysis analyzed seven key product classes that cover the range of product classes within the residential refrigeration product category and represent approximately 90% of the shipments of these products. Based on its analysis of three product classes of standard-size refrigerator-freezers, two product classes within standard-size freezers, and two product classes within compact refrigerators and freezers, DOE generated seven cost-efficiency curves. The fourteen products serving as prototypical baseline-efficiency products for the analysis are described in Table ES.3.2. Chapter 5 includes additional details on the representative product classes and the cost-efficiency curves developed as part of the engineering analysis.

DOE also reviewed the energy efficiency equations that define existing Federal energy conservation standards for refrigerators, refrigerator-freezers, and freezers and the impact which the proposed new energy test procedure would have on these equations. The proposed test procedure includes compartment temperature changes and changes to the method for determining compartment volumes. New energy efficiency equations representing current baseline efficiency products tested using the proposed test procedure were developed. In addition, these equations were examined to determine whether the slopes of the energy/adjusted volume curves are appropriate for the key product classes examined for the engineering analysis.

The slopes of these curves determine whether the efficiency levels defined by the curves are more stringent for larger products as compared with smaller products.

Table ES.3.2 Baseline-Efficiency Product Descriptions

Product Class	Total Volume (ft^3)	Annual Energy Use (kWh)*
3	16	455
	21	511
5	18.5	560
	25	593
7	22	672
	26	729
9	14	621
	20	758
10	15	397
	20	484
11	1.7	317
	4	345
18	3.4	213
	7	279

*Annual Energy Use based on current DOE Energy Test Procedure

ES.3.3.2 Manufacturing Cost Assessment

DOE estimated the manufacturing costs associated with an increase in energy efficiency for each of the residential refrigeration product classes analyzed. The assessment method involved disassembling model units, analyzing the materials and manufacturing processes, analyzing the design approaches manufacturers use, and developing a spreadsheet model to describe costs. DOE built a detailed model for assessing manufacturing cost that estimates manufacturer production cost. DOE also aggregated manufacturers' costs to maintain confidentiality of the data. DOE obtained input from interested parties on the manufacturing cost model inputs. Chapter 5 of the preliminary TSD includes information on the inputs used to determine the manufacturing cost, including material, labor, and overhead prices. Chapter 5 also includes information on the various components and features incorporated into designs for residential refrigeration products.

DOE's engineering analysis produced cost-efficiency curves for the seven representative refrigeration product classes. The cost-efficiency curves are described by the efficiency levels DOE analyzed and the increase in manufacturer selling price (MSP) required to improve a baseline-efficiency product to each of the considered efficiency levels. Table ES.3.2 through Table ES.3.4 present the key results of the engineering analysis. The maximum technology levels determined for the product classes (average of the two products analyzed for each product class) ranged from 45% to 56% except for product class 11, for which the level was 75%. Incremental cost curves were developed for efficiency levels up to 45% for all product classes but product class 7, for which the 45% level was higher than the 41% maximum technology level determined for one of the products of this class. DOE proposed a maximum technology level of 30% in the framework document. Stakeholders commented during the framework workshop that the maximum level should be increased to 35%. DOE extended this level to 45% when the analysis indicated that higher efficiency levels could be attained. However, although the analyses, as described in chapter 5 of this TSD, indicated that some product classes could attain even higher efficiency levels, DOE did not extend incremental cost curves further due to expectations that higher levels would not be cost effective.

Table ES.3.3 Incremental Manufacturer Selling Price Results for Standard-Size Refrigerator-Freezers

Efficiency Level (percent less than baseline energy use)	**Product Class**		
	3: Refrigerator-freezers — automatic defrost with top-mounted freezer without TTD ice service	5: Refrigerator-freezers — automatic defrost with bottom-mounted freezer without TTD ice service	7: Refrigerator-freezers — automatic defrost with side-mounted freezer with TTD ice service
10%	$3.50	$1.80	$11.18
15%	$7.68	$5.79	$18.96
20%	$16.39	$13.72	$54.26
25%	$34.92	$31.38	$106
30%	$62.06	$45.06	$167
35%	$104	$110	$229
40%	$156	$183	$311
45%	$208	$251	N/A

Table ES.3.4 Incremental Manufacturer Selling Price Results for Standard-Size Freezers

Efficiency Level (percent less than baseline energy use)	**Product Class**	
	9: Upright freezers with automatic defrost	10: Chest freezers and all other freezers except compact freezers
10%	$6.41	$2.35
15%	$11.45	$6.05
20%	$13.57	$24.08
25%	$27.51	$29.26
30%	$46.58	$34.84
35%	$76.82	$74.35
40%	$124	$77.12
45%	$197	$137

Table ES.3.5 Incremental Manufacturer Selling Price Results for Compact Refrigerators and Freezers

Efficiency Level (percent less than baseline energy use)	Product Class	
	11: Compact refrigerators and refrigerator-freezers with manual defrost	18: Compact chest freezers
10%	$3.36	$6.05
15%	$6.32	$9.65
20%	$8.85	$34.03
25%	$20.56	$42.62
30%	$21.63	$60.19
35%	$26.77	$63.00
40%	$39.24	$75.22
45%	$57.49	$89.70

ES.3.4 Markups to Determine Product Price

The markups analysis (chapter 6) develops appropriate markups in the distribution chain to convert the estimates of manufacturer cost derived in the engineering analysis to consumer prices. In developing markups, DOE determined the distribution channels for refrigeration products and the markup associated with each party in the distribution channel. For refrigeration products, DOE estimated markups taken by retailers, along with sales taxes. DOE developed separate markups for baseline products (baseline markups) and for the cost increase associated with improvements required to produce more-efficient products (incremental markups). Table ES.3.5 summarizes the markups developed for refrigeration products. Note that the manufacturer markup has already been incorporated into the incremental costs presented in the tables of Section ES.3.3.

Table ES.3.6 Markups for Refrigeration Products

Markup	Baseline	Incremental
Manufacturer	1.26	
Retailer	1.45	1.15
Sales Tax	1.069	

ES.3.5 Energy Use Characterization

The energy use characterization provides the basis for developing the energy savings from higher-efficiency appliances used in the LCC and subsequent analyses. The DOE test procedure provides standardized results that can serve as the basis for comparing the performance of different appliances used under the same conditions, but actual usage in the field may differ from usage estimated by the test procedure. DOE conducted a review of studies that measured the field consumption of refrigerator-freezers to compare such measurements to the

DOE ratings, which confirmed that measurements of field energy use often vary considerably from the rated usage as determined by the DOE test procedure.

To determine the field energy use by products that would meet possible energy efficiency standards, DOE used data from the Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey (RECS). RECS is a national sample survey of housing units that collects statistical information on the consumption of and expenditures for energy in housing units along with data on energy-related characteristics of the housing units and occupants. RECS provides enough information to establish the type (*i.e*., product class) of refrigeration product used in each household, and also provides an estimate of the household's energy consumption attributable to refrigerators or freezers. As a result, DOE was able to develop a household sample for the representative product classes for standard-size units. DOE did not use RECS for compact refrigerators and freezers because a large fraction of these products are used outside the residential sector.

DOE treated the RECS reported field energy consumption, referred to as FEC_{RECS}, as the actual consumption of the refrigeration product(s) in that household. Energy use for a household's refrigerator or freezer is known to vary depending on its operating conditions, the behavior of its users, and other factors. DOE characterized field energy use of each product by using a multiplicative 'usage adjustment factor' (UAF) that adjusts the energy use from its test energy consumption to reflect these factors.

To develop a UAF for each RECS household, DOE utilized information that RECS provides on the size (*i.e*., volume), age and the product class of the refrigeration product. DOE determined for each household's unit the corresponding maximum allowable tested energy consumption, referred to as TEC_{STD}, based on the energy conservation standard that was in effect at the time the household purchased the refrigeration product. Using FEC_{RECS} and TEC_{STD}, DOE then developed the UAF for each household to capture the combined effects of consumer behavior (*e.g*., door openings), operating conditions (*e.g*., room temperature and humidity), and product characteristics (*e.g*., efficiency relative to the minimum allowable). The UAF represents the adjustment that needs to be made to the maximum allowable tested energy use to arrive at the field energy consumption of the refrigeration product. For households that reported having ENERGY STAR refrigeration products, DOE calculated tested energy consumption based on the ENERGY STAR criteria in effect at the time the household purchased the refrigeration product. Chapter 7 provides more details on the methods, data, and assumptions used for developing UAFs.

Tables ES.3.6 through ES.3.8 present the average annual energy use for the representative product classes at each considered energy efficiency level. The tables for standard-sized products show the average annual energy consumption calculated according to the proposed DOE test procedure and if the products were used in the appropriate RECS 2005 household sub-samples ("field"). The table for compact appliances shows the average annual energy consumption according to the proposed DOE text procedure, using a distribution of product volumes based on the California Energy Commission's appliance database.

Table ES.3.7 Standard-Size Refrigerator-Freezers: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Product Class					
	3: Refrigerator-freezers — automatic defrost with top-mounted freezer without TTD ice service		5: Refrigerator-freezers — automatic defrost with bottom-mounted freezer without TTD ice service		7: Refrigerator-freezers — automatic defrost with side-mounted freezer with TTD ice service	
	Proposed Test (kWh)	Field (kWh)	Proposed Test (kWh)	Field (kWh)	Proposed Test (kWh)	Field (kWh)
Baseline	534	657	652	699	756	1087
10%	481	591	587	629	680	979
15%	454	558	554	594	643	924
20%	428	526	522	559	605	870
25%	401	493	489	524	567	815
30%	374	460	456	489	529	761
35%	347	427	424	454	491	707
40%	321	394	391	419	454	652
45%	294	361	359	384	-	-

Table ES.3.8 Standard-Size Freezers: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Product Class			
	9: Upright freezers with automatic defrost		10: Chest freezers and all other freezers except compact freezers	
	Proposed Test (kWh)	Field (kWh)	Proposed Test (kWh)	Field (kWh)
Baseline	717	980	428	623
10%	646	882	385	561
15%	610	833	364	530
20%	574	784	342	498
25%	538	735	321	467
30%	502	686	300	436
35%	466	637	278	405
40%	430	588	257	374
45%	394	539	235	343

Table ES.3.9 Compact Refrigerators and Freezers: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Product Class	
	11: Compact refrigerators and refrigerator-freezers with manual defrost (kWh)	18: Compact chest freezers (kWh)
Baseline	325	313
10%	292	282
15%	276	266
20%	260	250
25%	244	235
30%	227	219
35%	211	203
40%	195	188
45%	179	172

ES.3.6 Life-Cycle Cost and Payback Period Analyses

Stipulating new energy conservation standards for products results in changes in consumer operating expenses—usually a decrease—and changes in consumer price—usually an increase. DOE analyzed the net effect of amended standards on consumers by evaluating the LCC using the cost-efficiency relationship derived in the engineering analysis, as well as the energy costs derived from the energy use characterization. Inputs to the LCC calculation included the installed cost to the consumer (purchase price plus installation cost), operating costs (energy expenses), the lifetime of the appliance, and a discount rate. Because DOE found no evidence that repair or maintenance costs change as the efficiency of refrigeration products increases, it excluded those costs from its analysis.

Because the installed cost of a product typically increases while operating cost typically decreases in response to new standards, there is a time in the life of products having higher-than-baseline efficiency when the net operating-cost benefit (in dollars) since the time of purchase is equal to the incremental first cost of purchasing the higher-efficiency product. The length of time required for products to reach this cost-equivalence point is known as the payback period (PBP).

DOE conducted the LCC and PBP analyses using values that reflect energy consumption in the field. DOE identified several input values for estimating the LCC, including retail prices, energy prices, discount rates, and product lifetimes. DOE used EIA's energy price data to determine prices for electricity in 2007 and used projections of these energy prices from EIA's Annual Energy Outlook 2009 to estimate future energy prices. DOE developed discount rates from estimates of the finance cost for consumers that purchase refrigeration products.

Because the basis for the lifetime estimates in the literature for refrigeration products is uncertain, DOE used actual data sources to estimate the distribution of refrigerator and freezer lifetimes in the field. By combining survey results from RECS and the U.S. Census's *American Housing Survey* with the known history of appliance shipments, DOE estimated the fraction of appliances of a given age still in operation. The survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an average and median appliance lifetime.

To accurately estimate the share of consumers that would be affected by a standard at a particular efficiency level, DOE's LCC analysis considered the projected distribution of product efficiencies that consumers purchase under the base case (i.e., the case without new energy efficiency standards). DOE refers to this distribution of product of efficiencies as a base-case efficiency distribution. DOE developed base-case efficiency distributions for each of the seven representative product classes. These distributions were developed from industry supplied data for the year 2007 and were comprised of product efficiencies ranging from existing baseline levels (i.e., meeting existing energy conservation standards) to levels meeting and exceeding ENERGY STAR levels. DOE then projected these distributions to the year that new standards are assumed to become effective (2014). To forecast the base-case efficiency distribution for each representative product class, DOE accounted for change in the market shares of ENERGY STAR appliances based on historical trends. Using the projected distribution of product efficiencies for each product class, DOE randomly assigned a specific product efficiency to each sample household. If a household was assigned a product efficiency that is greater than or equal to the efficiency of the standard level under consideration, the LCC calculation would show that this household is not impacted by that standard level.

Table ES.3.9 through Table ES.3.15 show the results of the LCC and PBP analyses for the representative product classes at each considered energy efficiency level. Figures presented in Chapter 8 show the range of LCC savings and PBPs for all of the efficiency levels considered for each product class. Chapter 8 provides more details on the methods, data, and assumptions used for the LCC and PBP analyses.

Table ES.3.10 Product Class 3, Top-Mount Refrigerator-Freezer: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact	Households with Net Benefit	Median	Average
Baseline	$591	$77	$1,505	-	-	-	-	-	-
10%	$595	$71	$1,434	$71	0.0%	18.5%	81.5%	0.6	0.7
15%	$599	$67	$1,398	$106	0.0%	13.0%	86.9%	0.9	1.1
20%	$609	$64	$1,368	$137	0.1%	13.0%	86.8%	1.5	1.7
25%	$631	$60	$1,343	$162	2.6%	0.0%	97.4%	2.8	3.2
30%	$665	$56	$1,329	$176	7.0%	0.0%	93.0%	4.0	4.6
35%	$716	$52	$1,333	$172	16.5%	0.0%	83.5%	5.6	6.4
40%	$781	$48	$1,350	$155	28.2%	0.0%	71.8%	7.3	8.3
45%	$845	$44	$1,367	$138	36.3%	0.0%	63.7%	8.5	9.7

Table ES.3.11 Product Class 5, Bottom-Mount Refrigerator-Freezer: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact	Households with Net Benefit	Median	Average
Baseline	$1,758	$70	$2,591						
10%	$1,759	$69	$2,581	$11	0.0%	88.5%	11.5%	0.3	0.4
15%	$1,759	$69	$2,576	$16	0.0%	88.4%	11.6%	0.7	0.8
20%	$1,760	$68	$2,571	$20	0.0%	88.4%	11.6%	1.2	1.4
25%	$1,782	$64	$2,542	$49	14.8%	0.0%	85.2%	5.1	6.0
30%	$1,799	$60	$2,508	$83	11.2%	0.0%	88.8%	4.6	5.4
35%	$1,879	$55	$2,538	$54	44.1%	0.0%	55.9%	9.5	11.0
40%	$1,969	$51	$2,577	$14	60.5%	0.0%	39.5%	12.6	14.7
45%	$2,053	$47	$2,610	-$19	67.0%	0.0%	33.0%	14.3	16.6

Table ES.3.12 Product Class 7, Side-by-Side Refrigerator-Freezer with TTD: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact	Households with Net Benefit	Median	Average
Baseline	$1,459	$116	$2,840						
10%	$1,463	$113	$2,804	$35	0.0%	74.3%	25.7%	1.1	1.3
15%	$1,469	$108	$2,759	$80	0.1%	31.6%	68.4%	1.5	1.6
20%	$1,499	$104	$2,738	$102	3.1%	31.6%	65.4%	3.8	4.2
25%	$1,563	$97	$2,724	$116	23.8%	0.0%	76.2%	6.7	7.6
30%	$1,638	$91	$2,722	$117	32.7%	0.0%	67.3%	8.1	9.0
35%	$1,714	$84	$2,721	$119	38.5%	0.0%	61.5%	8.9	9.9
40%	$1,815	$78	$2,744	$95	46.2%	0.0%	53.9%	10.1	11.2

Table ES.3.13 Product Class 9, Upright Freezers: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact	Households with Net Benefit	Median	Average
Baseline	$505	$113	$2,064						
10%	$511	$104	$1,942	$122	0.0%	19.4%	80.6%	0.7	0.8
15%	$517	$98	$1,870	$194	0.0%	1.6%	98.4%	0.9	1.1
20%	$520	$92	$1,793	$271	0.0%	0.5%	99.5%	0.7	0.9
25%	$537	$87	$1,731	$333	0.0%	0.4%	99.6%	1.3	1.5
30%	$561	$81	$1,675	$389	0.3%	0.2%	99.6%	1.8	2.1
35%	$598	$75	$1,633	$432	1.2%	0.0%	98.8%	2.5	3.0
40%	$656	$69	$1,611	$453	4.0%	0.0%	96.0%	3.5	4.3
45%	$745	$63	$1,621	$443	9.9%	0.0%	90.1%	5.0	6.0

Table ES.3.14 Product Class 10, Chest Freezers: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Households with Net Cost	Households with No Impact	Households with Net Benefit	Median	Average
Baseline	$325	$69	$1,275						
10%	$328	$63	$1,196	$79	0.0%	15.3%	84.8%	0.4	0.5
15%	$332	$60	$1,153	$122	0.0%	1.1%	98.9%	0.8	1.0
20%	$355	$56	$1,127	$148	1.2%	0.2%	98.6%	2.5	3.0
25%	$361	$53	$1,085	$190	0.7%	0.2%	99.2%	2.4	2.8
30%	$368	$49	$1,044	$231	0.4%	0.2%	99.4%	2.3	2.7
35%	$416	$46	$1,044	$231	5.3%	0.0%	94.7%	4.2	4.9
40%	$420	$42	$999	$276	3.7%	0.0%	96.3%	3.8	4.4
45%	$493	$39	$1,024	$251	13.8%	0.0%	86.2%	6.0	6.9

Table ES.3.15 Product Class 11, Compact Refrigerators: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Consumers with Net Cost	Consumers with No Impact	Consumers with Net Benefit	Median	Average
Baseline	$166	$33	$325						
10%	$170	$30	$314	$12	4.2%	2.9%	92.8%	1.4	1.3
15%	$173	$28	$309	$16	8.1%	2.6%	89.4%	1.7	1.7
20%	$176	$26	$305	$21	9.3%	2.6%	88.1%	1.8	1.8
25%	$191	$25	$311	$14	34.1%	1.7%	64.2%	3.4	3.3
30%	$192	$23	$304	$21	26.9%	0.0%	73.2%	2.9	2.8
35%	$198	$21	$303	$23	30.5%	0.0%	69.6%	3.1	3.0
40%	$214	$20	$310	$15	44.6%	0.0%	55.4%	4.0	3.9
45%	$236	$18	$324	$1	62.2%	0.0%	37.8%	5.3	5.1

Table ES.3.16 Product Class 18, Compact Freezers: LCC and PBP Results

Efficiency Level (percent less than baseline energy use)	Life-Cycle Cost			Life-Cycle Cost Savings				Payback Period (years)	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings	Consumers with Net Cost	Consumers with No Impact	Consumers with Net Benefit	Median	Average
Baseline	$207	$34	$399						
10%	$214	$30	$388	$11	9.6%	5.0%	85.4%	2.4	2.3
15%	$218	$29	$382	$16	11.7%	0.0%	88.3%	2.5	2.5
20%	$248	$27	$403	-$4	65.8%	0.0%	34.2%	6.7	6.8
25%	$259	$25	$404	-$5	65.6%	0.0%	34.4%	6.7	6.7
30%	$281	$24	$416	-$17	76.5%	0.0%	23.5%	7.9	7.9
35%	$284	$22	$410	-$11	69.3%	0.0%	30.7%	7.1	7.1
40%	$299	$20	$415	-$16	72.0%	0.0%	28.0%	7.4	7.4
45%	$317	$19	$423	-$24	75.9%	0.0%	24.1%	7.8	7.8

ES.3.7 Shipments Analysis

Shipment forecasts are needed to calculate for each product being considered the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE's shipments models consider shipments for new homes and replacements. Rather than simply extrapolating a current shipments trend, the analysis uses driver input variables to forecast sales in each market segment. For new housing units, annual product shipments are equal to the number of new housing units built multiplied by the purchase rate, which is determined by the market share of the product under consideration. To estimate shipments due to replacements, the models use sales in previous years and assumptions about the product lifetime, which determine how long an appliance is likely to remain in use. Chapter 9 of the TSD provides additional detail on the shipments analysis.

Figure ES.3.1 through Figure ES.3.4 illustrate the forecasted base-case shipments for all of the product classes included in this rulemaking.

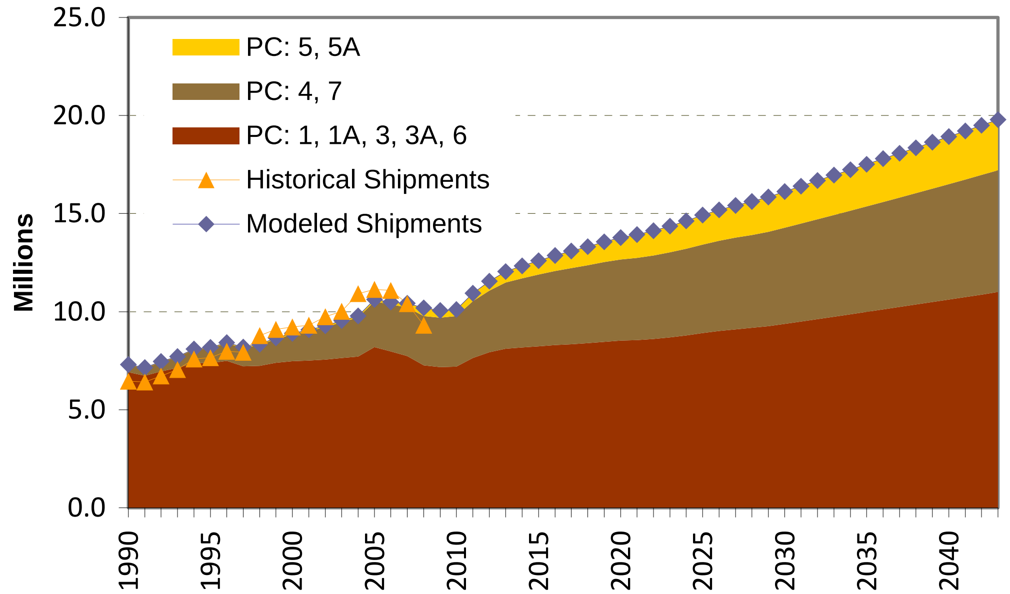

Figure ES.3.1 Forecasted Shipments (Base Case) for Standard-Size Refrigerator Freezers

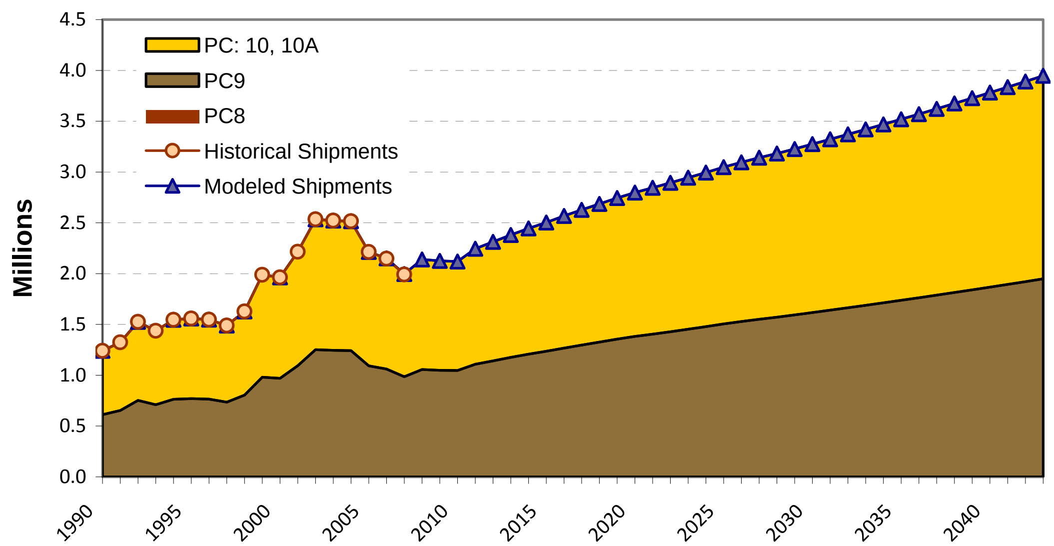

Figure ES.3.2 Forecasted Shipments (Base Case) for Standard-Size Freezers

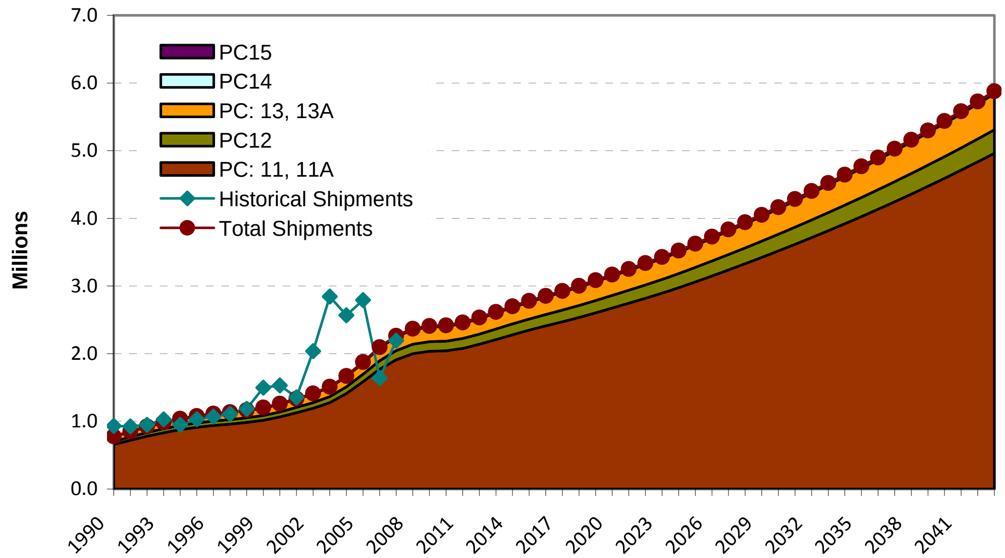

Figure ES.3.3 Forecasted Shipments (Base Case) for Compact Refrigerators

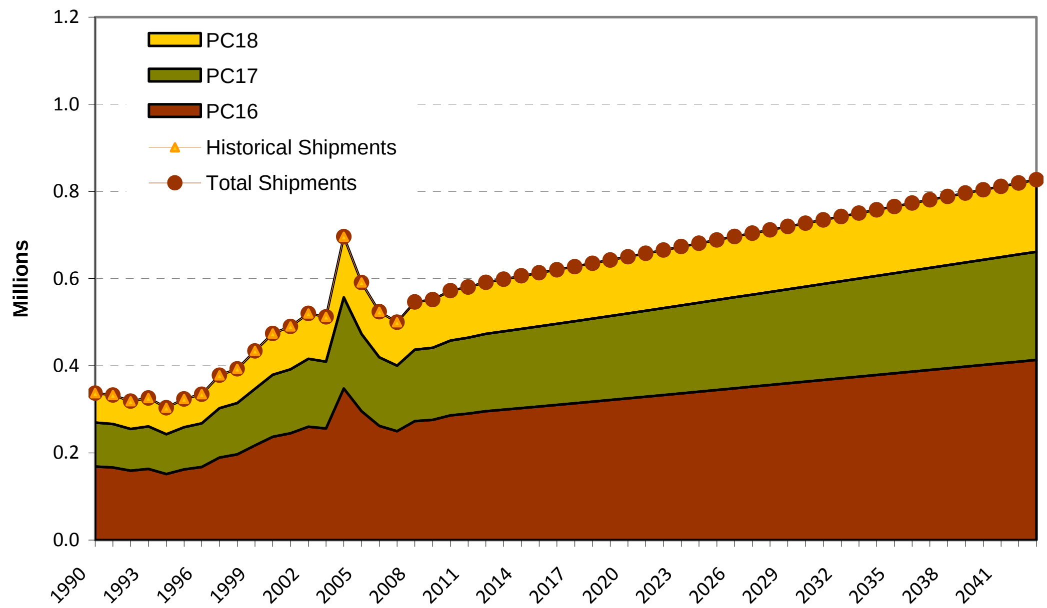

Figure ES.3.4 Forecasted Shipments (Base Case) for Compact Freezers

ES.3.8 National Impact Analysis

The NIA estimates the following national impacts from possible candidate standard levels for residential refrigeration products: (1) national energy savings (NES); (2) monetary value of energy savings to consumers of the considered products due to standards; (3) increased total installed costs to consumers of the considered products due to standards; and (4) the net present value (NPV) of energy savings (difference between value of energy savings and increased total installed costs). DOE prepared an NES spreadsheet model to forecast energy savings and national consumer economic costs and savings resulting from new standards. The model uses typical values for inputs.

A key component of DOE's estimates of NES and NPV is the trend in energy efficiency forecasted for the base case (without new standards) and each of the standards cases (with new standards). To forecast the base-case efficiency distribution for each representative product class, DOE accounted for change in the market shares of ENERGY STAR appliances based on historical trends. For its determination of standards-case efficiency distributions, DOE used a "roll-up + ENERGY STAR" scenario to establish the distribution of efficiencies for the year that amended standards are assumed to become effective (i.e., 2014) and subsequent years. DOE assumed that product efficiencies in the base case that did not meet the standard level under consideration would "roll up" to meet the new standard level in 2014. It further assumed that the ENERGY STAR program and related efforts would continue to promote efficient appliances after the introduction of amended standards in 2014, and that this would lead to increased market shares for products with efficiency above the standard level. Chapter 10 provides additional details on this and other aspects of the NIA analysis.

To estimate the national impacts of all of the product classes considered in this rulemaking, DOE allocated the consumer equipment costs and annual energy consumption of the representative product classes analyzed in detail in the engineering and LCC and PBP analyses to the product classes associated with each representative product class. The following list indicates which product classes were associated with each of the representative product classes:

- Top-mount refrigerator-freezers: product classes 1, 1A, 2, 3, 3A, and 6; represented by product class 3.
- Bottom-mount refrigerator-freezers: product classes 5 and 5A; represented by product class 5.
- Side-by-side refrigerator-freezers: product classes 4 and 7; represented by product class 7.
- Upright freezers: product class 9 only.
- Chest freezers: product classes 8, 10, and 10A; represented by product class 10.
- Compact refrigerators: product classes 11, 11A, 12, 13, 13A, 14, and 15; represented by product class 11.
- Compact freezers: product classes 16, 17, and 18; represented by product class 18.

ES.3.8.1 National Energy Savings

DOE calculated annual NES as the difference between national energy consumption in the base case (without new efficiency standards) and in each higher efficiency standard case. DOE estimated energy consumption and savings based on site energy and converted the electricity consumption and savings to source energy. Cumulative energy savings are the sum of the annual NES, which DOE determined over specified periods.

The NES results shown in Table ES.3.16 through Table ES.3.18 are cumulative to 2044 and are shown as primary energy savings in quads (quadrillion Btu's).

Table ES.3.17 Standard-Size Refrigerator-Freezers: Cumulative NES Results (quads)

Efficiency Level (percent less than baseline energy use)	Top-Mount Refrigerator-Freezer*	Bottom-Mount Refrigerator-Freezer**	Side-by-Side Refrigerator-Freezer***
10%	1.10	0.04	0.31
15%	1.69	0.06	0.73
20%	2.35	0.20	1.31
25%	3.01	0.37	1.91
30%	3.65	0.53	2.50
35%	4.20	0.57	2.93
40%	4.78	0.73	3.35
45%	5.28	0.77	-

* Includes product classes 1, 1A, 2, 3A, and 6 as well as product class 3.
** Includes product class 5A as well as product class 5.
*** Includes product class 4 as well as product class 7.

Table ES.3.18 Standard-Size Freezers: Cumulative NES Results (quads)

Efficiency Level (percent less than baseline energy use)	Upright Freezers*	Chest Freezers**
10%	0.34	0.23
15%	0.55	0.37
20%	0.75	0.50
25%	0.96	0.63
30%	1.15	0.76
35%	1.34	0.87
40%	1.51	1.00
45%	1.63	1.07

* Includes product class 9 only.
** Includes product classes 8 and 10A as well as product class 10.

Table ES.3.19 Compact Refrigerators and Freezers: Cumulative NES Results (quads)

Efficiency Level (percent less than baseline energy use)	Compact Refrigerators*	Compact Freezers**
10%	0.13	0.03
15%	0.20	0.04
20%	0.27	0.06
25%	0.32	0.07
30%	0.38	0.08
35%	0.44	0.09
40%	0.48	0.10
45%	0.52	0.11

* Includes product classes 11A, 12, 13, 13A, 14, and 15 as well as product class 11
** Includes product classes 16 and 17 as well as product class 18

ES.3.8.2 Net Present Value

DOE calculated net monetary savings each year as the difference between total savings in operating costs and increases in total equipment costs in the base case and standards cases. DOE calculated savings over the life of the product. DOE used discount rates of 7 percent and 3 percent to discount future costs and savings to the present. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of increased total installed costs. The NPV results for the representative product classes are shown in Table ES.3.19 through Table ES.3.21 as the discounted value of the net savings in dollar terms.

Table ES.3.20 Standard-Size Refrigerator-Freezers: Discounted Cumulative NPV Results

Efficiency Level (percent less than baseline energy use)	Top-Mount Refrigerator-Freezer*		Bottom-Mount Refrigerator-Freezer**		Side-by-Side Refrigerator-Freezer***	
	3% Discount Rate *(billion 2008$)*	**7% Discount Rate** *(billion 2008$)*	**3% Discount Rate** *(billion 2008$)*	**7% Discount Rate** *(billion 2008$)*	**3% Discount Rate** *(billion 2008$)*	**7% Discount Rate** *(billion 2008$)*
10%	13.39	5.08	0.50	0.19	3.68	1.35
15%	20.16	7.60	0.73	0.27	8.52	3.11
20%	26.57	9.79	2.13	0.70	11.89	3.82
25%	31.08	11.01	1.98	0.40	14.15	3.94
30%	33.86	11.35	1.61	0.01	15.12	3.42
35%	34.26	10.57	1.43	-0.19	16.17	3.20
40%	32.78	8.75	0.60	-0.91	15.73	2.22
45%	31.53	7.18	0.40	-1.12	-	-

* Includes product classes 1, 1A, 2, 3A, and 6 as well as product class 3.
** Includes product class 5A as well as product class 5.
*** Includes product class 4 as well as product class 7.

Table ES.3.21 Standard-Size Freezers: Discounted Cumulative NPV Results

Efficiency Level (percent less than baseline energy use)	Upright Freezers*		Chest Freezers**	
	3% Discount Rate *(billion 2008$)*	7% Discount Rate *(billion 2008$)*	3% Discount Rate *(billion 2008$)*	7% Discount Rate *(billion 2008$)*
10%	4.52	1.59	3.11	1.10
15%	7.21	2.53	4.78	1.68
20%	9.92	3.48	6.04	2.03
25%	12.23	4.23	7.68	2.60
30%	14.28	4.86	9.14	3.07
35%	15.82	5.25	9.61	3.06
40%	16.62	5.29	11.01	3.52
45%	16.54	4.98	10.51	3.09

* Includes product class 9 only.
** Includes product classes 8 and 10A as well as product class 10.

Table ES.3.22 Compact Refrigerators and Freezers: Discounted Cumulative NPV Results

Efficiency Level (percent less than baseline energy use)	Compact Refrigerators*		Compact Freezers**	
	3% Discount Rate *(billion 2008$)*	7% Discount Rate *(billion 2008$)*	3% Discount Rate *(billion 2008$)*	7% Discount Rate *(billion 2008$)*
10%	1.00	0.43	0.20	0.08
15%	1.39	0.59	0.30	0.12
20%	1.81	0.76	0.08	0.00
25%	1.45	0.55	0.10	0.00
30%	1.97	0.78	0.00	-0.06
35%	2.12	0.83	0.09	-0.02
40%	1.72	0.59	0.06	-0.05
45%	0.92	0.17	0.01	-0.08

* Includes product classes 11A, 12, 13, 13A, 14, and 15 as well as product class 11.
** Includes product classes 16 and 17 as well as product class 18.

ES.3.9 Preliminary Manufacturer Impact Analysis

The preliminary MIA focuses on manufacturers of residential refrigeration products. Potential impacts include financial effects, both quantitative and qualitative, that might result from new energy conservation standards and lead to changes in manufacturing practices for refrigerators, refrigerator-freezers, and freezers. DOE identified potential impacts through interviews with manufacturers and other interested parties. Chapter 12 of the preliminary TSD includes details on the key issues DOE identified during the preliminary MIA.

DOE found key issues regarding the following for residential refrigeration products:

- Increased conversion costs;
- Impact to U.S. production and jobs;
- Cumulative regulatory burden;
- Impact to product utility;
- Current economic conditions;
- Circumvention and enforcement; and
- Technical difficulty to achieve new standards

DOE conducted the preliminary MIA by first identifying products, methods, and practices used in the residential refrigeration products industry. Next, DOE determined how energy efficiency improvements affect cost, production, and various other manufacturing metrics. Finally, DOE interviewed manufacturers for feedback. DOE developed and distributed a questionnaire for use during the interviews. At the beginning of the interview process, DOE interviewed manufacturers and adjusted the analysis as appropriate, based on the feedback received. During the interviews, DOE also examined any additional effects on competition, manufacturing capacity, direct employment, and the cumulative burden of other regulations affecting manufacturers, as well as several issues raised by individual manufacturers.

ES.4 ISSUES ON WHICH DOE SEEKS PUBLIC COMMENT

DOE is interested in receiving comments on all aspects of this preliminary analysis. DOE especially invites comments or data to improve DOE's analysis, including data or information that will respond to the following questions or concerns that were raised in response to the framework document and in preparation of the preliminary TSD.

ES.4.1 Use of the Proposed Designations for Product Classes 5A and 10A

Two possible new product classes were identified in the framework document and designated product class numbers 19 and 20. DOE proposes to redesignate these product classes as 5A and 10A to maintain harmonization with Canadian Standards, as requested in comments received during the framework comment period. See chapter 2, section 2.2.1.1, of the preliminary TSD.

ES.4.2 Establishment of Separate Product Classes for All-Refrigerators

The proposed new energy test procedure uses new compartment temperatures. For refrigerators with freezer compartments and for refrigerator-freezers, the temperature of the fresh food compartment during the test would be reduced from 45 ˚F to 39 ˚F under the new test procedure. The freezer temperature for refrigerator-freezers would be reduced from 5 ˚F to 0 ˚F.

For both of these products, measured energy use would be significantly higher, in the range from 12 to 15%. For all-refrigerators, the compartment temperature would be increased from 38 ˚F to 39 ˚F under the new test procedure, which would reduce measured energy use by roughly 3%. Product classes 1, 3, 11, and 13 include products such as refrigerators with freezer compartments and refrigerator-freezers, whose energy use would increase, as well as all-refrigerators, whose energy use would decrease. In order to maintain a meaningful and fair energy conservation standard for these product classes, DOE proposes that new product classes be established for the all-refrigerators. DOE seeks comment on this proposal.

ES.4.3 Possible Combination of Product Classes 1 and 2, and Product Classes 11 and 12

Shipments of refrigerators and refrigerator-freezers of product classes 1 and 2 are very low, significantly less than 1% of the shipments of residential refrigeration products. DOE believes that the shipments of refrigerator-freezers of product class 12 are also very low. The energy standards for product classes 1 and 2 are currently identical. While the energy standard for product class 12 is considerably less stringent that the standard for product class 11, there is no clear technical basis that DOE can currently discern for the difference. Product classes 1 and 11 include refrigerators and refrigerator-freezers with manual defrost. Product classes 2 and 12 include refrigerator-freezers with partial automatic defrost. Both product class groups have manual defrost evaporators serving the freezer compartments. However, product classes 2 and 12 include an evaporator serving the fresh food compartment that does not require manual defrost. Typically this evaporator would warm sufficiently during the compressor off-cycle to melt frost. For this reason, there is no defrost cycle involved that would add energy use. DOE invites comment on whether these pairs of product classes should be combined, thus eliminating product classes 2 and 12.

ES.4.4 Approach for Development of Baseline Energy Use/Adjusted Volume Relationships under the Proposed Test Procedure

In a separate rulemaking, DOE expects to propose new test procedures based in part on the updated version of AHAM Standard HRF-1-2008. The test procedures would include modified compartment temperatures and a modified volume calculation method. In general, if test procedure revisions affect the measured efficiency of a product, the required efficiency levels must be adjusted based on test results with the new test procedure for products which are minimally compliant under the previous test procedure. (U.S.C. 6293(e)(2)) AHAM provided data for some key product classes showing the differences in energy test results of the two test procedures. DOE developed curves relating energy use and adjusted volume for minimally-compliant products based on use of the modified test procedure for all of the product classes relying in part on the AHAM data. DOE proposes to use these curves, discussed in Chapter 5 of the preliminary TSD, as the basis for the new energy conservation standards to be proposed initially in the NOPR phase of the rulemaking. DOE invites comment on the approach used to develop the curves and the resulting energy use represented by the curves.

ES.4.5 Possible Modification of the Baseline Energy Use/Adjusted Volume Curve Slope

During manufacturer interviews conducted as part of the preliminary process, some manufacturers indicated that some of the energy vs. adjusted volume curves of the current energy conservation standards for residential refrigeration products have slopes that are not consistent with actual energy trends. DOE concluded during the engineering analysis that the cost and energy analysis conducted for two different sizes of product of each product class was not sufficiently precise to allow accurate predictions of size-based differences in the cost-efficiency trends for the products analyzed. Hence, correction of the slopes of the energy vs. adjusted volume curves is not possible based on the differences in incremental cost curves of the two sizes analyzed for each product class. DOE conducted an energy use analysis to investigate this issue more directly. The analysis shows that the slope of the baseline-efficiency energy use curve may be too low for product class 5. Similarly, the slope of the curve for product class 4 may be too low (While DOE did not directly analyze this product class, the trend for product class 7 would apply to product class 4 with an adjustment for the TTD ice feature present in product class 7 -- TTD ice is not present in product class 4). The DOE analysis investigating this issue is discussed in Chapter 5. DOE invites comment on whether an adjustment to the slopes of the baseline energy use relationships based on proposed test procedures is warranted for any of the product classes and by how much. DOE requests information supporting comments indicating the need for such slope changes.

ES.4.6 Variation of Product Characteristics as Compared with Teardown Products

DOE selected representative refrigeration products for detailed investigation. This investigatory work encompassed a variety of activities, including reverse engineering, physical teardown, manufacturing cost analysis, energy use analysis, and cost-effectiveness analyses regarding energy-reducing design options. DOE requested detailed design data for refrigeration products during the framework phase of the work, as embodied in Table A-10 of the framework document. Manufacturers, however, did not provide data in response to this request. Such design data would have allowed consideration of the variation of product designs, particularly variation of the costs to achieve reductions in energy use. DOE requests comment on the variation of refrigeration product designs and the distribution of incremental costs to achieve energy use reductions.

ES.4.7 Development of Energy Standards for Low-Volume Products

The TSD describes possible approaches to the development of energy standards for low-volume products which were not directly analyzed during the preliminary analysis. The percent reduction in energy use for most of these product classes would be based on the percentage reduction established for similar product classes. These approaches are presented in Chapter 2, Section 2.15. DOE requests comments on these approaches.

ES.4.8 Field Energy Use of Standard-Size Refrigeration Products

Energy use of a household’s refrigerator or freezer is known to vary depending on its operating conditions, the behavior of its users, and other factors. DOE characterized field energy use of a refrigeration product by using a multiplicative ‘usage adjustment factor’ (UAF) that adjusts the energy use from its test energy consumption to reflect these factors. The household sample used to calculate life-cycle costs for standard-sized products exhibits a wide range of UAFs for each product class, with mean values ranging from 1.08 for product class 5 to 1.48 for product class 10. A literature survey conducted by DOE confirms that an average UAF over the lifetime of a refrigeration product is likely to be greater than one. This literature spans most of the last two decades, but relatively few studies have been published recently. DOE invites comment and additional data regarding the relationship between field and test energy consumption for contemporary refrigeration products.

ES.4.9 Field Energy Use of Compact Refrigeration Products

DOE did not find any usable data on the typical field energy consumption of compact products. Therefore, for compact refrigerators and freezers, DOE assumed that the average field energy use of units of the representative sizes used in its analysis is the same as the energy use calculated by the DOE test procedure. DOE assumed that the variability of energy use of compact products in the field is solely a function of volume. To represent the distribution of volumes in the field, DOE used data from the 2008 California Energy Commission appliance model database. DOE invites comment and additional data regarding the relationship between field and test energy consumption for compact refrigeration products.

ES.4.10 Repair and Maintenance Costs

Because DOE did not find any evidence that repair and maintenance costs change as refrigeration product efficiency increases, it did not include these costs in its analysis. DOE invites comment on this approach and requests any specific information showing the extent to which repair and maintenance costs change as refrigeration product efficiency increases beyond the baseline levels used in DOE’s analysis.

ES.4.11 Lifetime of Compact Refrigeration Products

When DOE applied the average lifetime for a compact refrigerator given in Appliance magazine (10 years) to historical shipments, its model yielded a compact refrigerator stock that was more than double the existing stock indicated by the EIA’s RECS and Commercial Building Energy Consumption Survey (CBECS). DOE therefore calibrated the average lifetime to match the existing stock of compact refrigerators as given by the surveys. The resulting calculated mean lifetime is 5.62 years. DOE invites comment on its approach for estimating the lifetime for compact refrigerators and freezers.

ES.4.12 Base Case Efficiency Distributions

To accurately estimate the share of consumers that would be affected by a standard at a particular efficiency level, DOE’s LCC and PBP analyses considered the projected distribution of product efficiencies that consumers would purchase in the base case (i.e., the case without amended energy efficiency standards). DOE’s projection takes into account growth in market share of ENERGY STAR refrigeration products in the coming years. DOE invites comment on the approach used to forecast base-case market shares of the considered efficiency levels.

ES.4.13 Forecasted Market Shares of Top-Mount vs. Side/Bottom-Mount Refrigerator-Freezers

DOE developed a simple model to forecast the market share of top-mount refrigerator-freezers relative to side- and bottom-mounted products. This model was based on the historical consumer preferences of homeowners as a whole, as well as high-income homeowners, the historical market share differences between rental and owner-occupied households, and historical market shares of top-, side- and bottom-mount products in total shipments. The model forecasts that the market share of top-mount refrigerator-freezers will fall slowly, reaching 58.3% in 2015, 56.2% in 2025, and 54.7% in 2035, with the remainder of shipments divided between side- and bottom-mount products in a ratio fixed by their relative sales in 2008. DOE seeks comment on its approach.

ES.4.14 Maturity of Vacuum Insulation Panels for High Volume Production

The engineering analysis indicates that dramatic reductions in energy use are possible in many of the product classes. The reductions depend on use of a number of design options, including vacuum insulation panels (VIPs). VIPs are currently used in refrigeration products, indicating that this technology is a viable design option. The use of VIPs adds dramatically to the MSP estimates, up to $300 in the preliminary analyses. The LCC analysis indicates that efficiency levels incorporating VIPs are economically justified. Hence, DOE anticipates that standard levels may be proposed at levels requiring much more widespread use of VIPs in future products. DOE collected information regarding the viability of VIPs during the preliminary analysis. However, the importance of this technology to the preliminary results indicates that a more careful review is warranted of its viability for high volume production. DOE invites comments on this issue and also requests information that would allow such an assessment to be conducted.

ES.4.15 Clarification of the Distinction between Manual Defrost and Automatic Defrost for All-Refrigerators

DOE is considering adding product classes 1A and 3A for all-refrigerators with manual and automatic defrost. It is uncertain whether there are any products of the proposed product class 1A, because all-refrigerators typically use off-cycle defrost, which does not require manual initiation. Manual defrost "is accomplished by natural or manual means with manual initiation and manual termination of the over-all defrost operation". AHAM HRF-1-1979 DOE requests comment on the interpretation that off-cycle defrost is a form of automatic defrost for all-refrigerators. DOE also requests comment on whether there are any all-refrigerator products on the market that use manual defrost.

ES.4.16 Analysis of Built-In Products

Comments made during the framework meeting and comment period and discussion of potential addition of product classes for built-in products is discussed in Chapter 2 of the preliminary TSD. DOE seeks additional technical and cost information on built-in products that would aid in assessment of whether the costs to achieve higher efficiency levels are significantly higher with these products.

ES.4.17 Technical Data for Alternative Foam-Blowing Agents

Stakeholders indicated during the framework meeting and comment period that DOE should consider the effect of potential climate change legislation on the rulemaking analyses (see Chapter 2 of the preliminary TSD). DOE seeks up to date technical data on the resistivity differences and the impact to thermal performance of alternative foam-blowing agents.

ES.4.18 Likely Scenarios for Alternative Foam-Blowing Agents

DOE seeks comment on the likely scenarios for manufacturers, assuming that laws such as the current pending legislation banning HFC's are passed. Specifically, DOE seeks information regarding the timing of switching to alternative agents.

ES.4.19 Valuing Air-Borne Emission Reductions

DOE will conduct an environmental assessment as part of the next phase of the standards rulemaking; the NOPR. The primary environmental effects of energy conservation standards for refrigeration products are to reduce power plant emissions resulting from reduced consumption of electricity. DOE will assess these environmental effects by using NEMS-BT to provide key inputs to its analysis. The portion of the environmental assessment that will be produced by NEMS-BT considers carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Hg). DOE also plans on monetizing the emission reductions due to standards consistent with methods used in recent DOE standards rulemakings pertaining to refrigerated beverage vending machines and commercial clothes washers. For example, in the case of CO_2, DOE used values ranging from $5 to $55 per metric ton of CO_2 to value the emission savings due to standards. DOE invites comments on the approaches for monetizing the emission savings due to energy conservation standards.

CHAPTER 1. INTRODUCTION

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This preliminary technical support document (preliminary TSD) is a stand-alone report that provides the technical analyses and results supporting the information presented in the preliminary notice of public meeting (NOPM) and executive summary for residential refrigerators, refrigerator-freezers, and freezers. This preliminary TSD reports on the preliminary activities and analyses conducted in the period preceding the notice of proposed rulemaking (NOPR) of this rulemaking.

1.2 OVERVIEW OF STANDARDS FOR RESIDENTIAL REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

The Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163 (42 United States Code (U.S.C.) 6291–6309), established an energy conservation program for major household appliances. The National Energy Conservation Policy Act of 1978 (NECPA), Pub. L. 95-619, amended EPCA to add Part C[a] of Title III (42 U.S.C. 6311–6317), which established an energy conservation program for certain industrial equipment. Additional amendments to EPCA give DOE the authority to regulate the energy efficiency of several products, including residential refrigerators, refrigerator-freezers, and freezers—the products that are the focus of this document. The amendments to EPCA in the National Appliance Energy Conservation Act of 1987 (NAECA), Pub. L. 100-12, established energy conservation standards for refrigerators, refrigerator-freezers, and freezers, as well as requirements for determining whether these standards should be amended. (42 U.S.C. 6295(b))

NAECA first established performance standards for residential refrigerators, refrigerator-freezers, and freezers, and further required that DOE conduct two cycles of rulemakings to determine if more stringent standards are justified.[b] (42 U.S.C. 6295(b)) On November 17, 1989, DOE published a final rule in the *Federal Register* updating the performance standards; the new standards became effective on January 1, 1993. 54 FR 47916. Subsequent to this final rule, DOE determined that new standards for some of the product classes were based on incomplete data and incorrect analysis. As a result, DOE published a correction that amended the new standards for three product classes: (1) refrigerators and refrigerator-freezers with manual defrost, (2) refrigerator-freezers—automatic defrost with bottom-mounted freezer but without through-the-door (TTD) ice service, and (3) chest freezers and all other freezers. 55 FR 42845 (Oct. 24, 1990). DOE updated the performance standards once again for refrigerators, refrigerator-

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[a] Part C has been redesignated Part A-1

[b] Definition of “refrigerators”, “refrigerator-freezers”, and “freezers” is provided in chapter 3 of the preliminary TSD.

freezers, and freezers by publishing a final rule in the *Federal Register* on April 28, 1997. 62 FR 23102. The new standards became effective on July 1, 2001. By completing a second standards rulemaking, DOE had fulfilled its legislative requirement to conduct two cycles of standards rulemakings.

Stakeholders submitted a petition in 2004 requesting that DOE conduct another rulemaking to amend the standards for residential refrigerator-freezers. In April 2005, DOE granted the petition and conducted a limited set of analyses to assess the potential energy savings and economic benefit of new standards. DOE issued a report in October 2005 detailing the analyses.[1] The analysis examined the technological and economic feasibility of new standards set at Energy Star levels effective in 2005 for the two most popular product classes of refrigerators: top-mount refrigerator-freezers without TTD features and side-mount refrigerator-freezers with TTD features. DOE confined its updated analysis to these two classes because they accounted for a majority of current product shipments. Depending on assumptions about the impact that standards would have on market efficiency, DOE estimated that amended standards at the 2005 Energy Star levels would yield between 2.4 to 3.4 quads,[c] with an associated economic impact to the Nation ranging from a burden or cost of $1.2 billion to a benefit or savings of $3.3 billion.[d]

DOE published draft data sheets containing energy-savings potentials for refrigerator-freezers in October 2005 as part of its fiscal year 2006 schedule-setting process. These data sheets summarized the following in table format: (1) the potential energy savings from regulatory action in cumulative quads from 2010 to 2035, (2) the potential economic benefits or burdens, (3) the potential environmental or energy security benefits, (4) the status of required changes to test procedures, (5) other regulatory actions, (6) recommendations by interested parties, (7) evidence of market-driven or voluntary efficiency improvements, (8) regulatory issues, and (9) the 2005 priority. The data sheets for refrigerators and refrigerator-freezers were based on the October 2005 draft technical report analyzing potential new amended energy conservation standards for residential refrigerator-freezers described above. This report and the associated data sheets provided input to the setting of priorities for rulemakings activities. Other products were given a higher priority, and limited rulemaking work on refrigerators and freezers was carried out in the following years prior to the enactment of the Energy Independence and Security Act of 2007 (EISA).

EISA, signed into law on December 19, 2007, requires that DOE publish a final rule no later than December 31, 2010, to determine whether to amend the standards in effect for refrigerators, refrigerator-freezers, and freezers manufactured on or after January 1, 2014. As a result, DOE is embarking on a standards rulemaking for these products to comply with the requirements of EISA.

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[c] A quad represents a quadrillion Btu (or 10^{15} Btu).

[d] Economic impact based on a discount rate of 7 percent real.

1.3 PROCESS FOR SETTING ENERGY CONERVATION STANDARDS

Under EPCA, when DOE is studying new or amended standards, it must consider, to the greatest extent practicable, the following seven factors (42 U.S.C. 6295 (o)(2)(B)(i)):

1) the economic impact of the standard on the manufacturers and consumers of the affected products;

2) the savings in operating costs throughout the estimated average life of the product compared to any increases in the initial cost or maintenance expense;

3) the total projected amount of energy savings likely to result directly from the imposition of the standard;

4) any lessening of the utility or the performance of the products likely to result from the imposition of the standard;

5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard;

6) the need for national energy conservation; and

7) other factors the Secretary considers relevant.

Other statutory requirements are set forth in 42 U.S.C. 6295 (o)(1)–(2)(A), (2)(B)(ii)–(iii), and (3)–(4) and 42 U.S.C. 6316(e).

DOE considers stakeholder participation to be a very important part of the process for setting energy conservation standards. Through formal public notifications (i.e., Federal Register notices), DOE actively encourages the participation and interaction of all stakeholders during the comment period in each stage of the rulemaking. Beginning with the Framework Document and during subsequent comment periods, interactions among stakeholders provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether or not to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C. 6313(a)(6)(B)(i)) Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. (42 U.S.C. 6313(a)(6)(A)) To determine whether economic justification exists, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the seven factors listed above. (42 U.S.C. 6295 (o)(2)(B)(i))

After the publication of the framework document, the energy conservation standards rulemaking process involves three additional, formal public notices, which DOE publishes in the Federal Register. The first of the rulemaking notices is a NOPM, which is designed to publicly vet the models and tools used in the preliminary rulemaking and to facilitate public participation before the NOPR stage. The second notice is the NOPR, which presents a discussion of comments received in response to the NOPM and the preliminary analyses and analytical tools; analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for each product. The third notice is the final rule, which presents a discussion of the comments received in response to the NOPR; the revised analyses; DOE's weighting of these impacts; the amended energy conservation standards DOE is adopting for each product; and the effective dates of the amended energy conservation standards.

In September 2008, DOE published a notice of public meeting and availability of the framework document. 73 FR 54089 (September 18, 2008). The framework document, *Rulemaking Framework for Residential Refrigerators, Refrigerator-Freezers, and Freezers*, describes the procedural and analytical approaches DOE anticipated using to evaluate the establishment of amended energy conservation standards for these products. This document is available at: http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/refrigerator_freezer_framework.pdf.

Subsequently, DOE held a public meeting on September 29, 2008, to discuss procedural and analytical approaches to the rulemaking. In addition, DOE used the public meeting to inform and facilitate involvement of interested parties in the rulemaking process. The analytical framework presented at the public meeting described the different analyses, such as the engineering analysis and the consumer economic analyses (i.e., the life-cycle cost (LCC) and payback period (PBB) analyses), the methods proposed for conducting them, and the relationships among the various analyses.

Table 1.3.1 Analyses Under the Process Rule

Preliminary Analyses	NOPR	Final Rule
Market and technology assessment	Revised ANOPR analyses	Revised analyses
Screening analysis	Life-cycle cost sub-group analysis	
Engineering analysis	Manufacturer impact analysis	
Energy and water use determination	Utility impact analysis	
Markups for equipment price determination	Environmental assessment	
Life-cycle cost and payback period analysis	Employment impact analysis	
Shipments analysis	Regulatory impact analysis	
National impact analysis		
Preliminary manufacturer impact analysis		

During the September 2008 public meeting, interested parties commented about numerous issues relating to each one of the analyses listed in Table 1.3.1. Comments from interested parties submitted during the framework document comment period elaborated on the issues raised during the public meeting. DOE attempted to address these issues during its preliminary analyses and summarized the comments and DOE's responses in chapter 2 of the preliminary TSD.

As part of the information gathering and sharing process, DOE organized and held interviews with manufacturers of the residential refrigerators, refrigerator-freezers, and freezers considered in this rulemaking as part of the engineering analysis. DOE selected companies that represented production of all types of products, ranging from small to large manufacturers, and included the Association of Home Appliance Manufacturers (AHAM) member companies. DOE had four objectives for these interviews: (1) solicit manufacturer feedback on the draft inputs to the engineering analysis; (2) solicit feedback on topics related to the preliminary manufacturer impact analysis; (3) provide an opportunity, early in the rulemaking process, to express manufacturers' concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

DOE incorporated the information gathered during the engineering interviews with manufacturers into its engineering analysis (Chapter 5) and the preliminary manufacturer impact analysis (Chapter 12). Following the publication of the preliminary analyses and the NOPM public meeting, DOE intends to hold additional meetings with manufacturers as part of the consultative process for the manufacturer impact analysis conducted during the NOPR phase of the rulemaking.

DOE developed spreadsheets for the engineering, LCC, PBP, and national impact analyses for each product. For each product, DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed a national impact analysis spreadsheet that calculates the national energy savings (NES) and national net present values (NPVs) at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of amended energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for refrigerators and freezers (http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html).

1.4 STRUCTURE OF THE DOCUMENT

This ANOPR TSD outlines the analytical approaches used in this rulemaking. The TSD consists of fourteen chapters, an environmental assessment, a regulatory impact analysis, and appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to this rulemaking, and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the rulemaking process.
Chapter 3	Market and Technology Assessment: characterizes the market for the considered products and the technologies available for increasing equipment efficiency.
Chapter 4	Screening Analysis: identifies all the design options that improve efficiency of the considered products, and determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer price and increased efficiency.
Chapter 6	Markups for Equipment Price Determination: discusses the methods used for establishing markups for converting manufacturer prices to customer equipment prices.
Chapter 7	Energy Use Determination: discusses the process used for generating energy-use estimates for the considered products as a function of standard levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the effects of standards on individual customers and users of the equipment and

compares the LCC and PBP of equipment with and without higher efficiency standards.

Chapter 9 Shipments Analysis: discusses the methods used for forecasting shipments with and without higher efficiency standards, including how equipment purchase decisions are economically influenced and how DOE models this relationship with econometric equations.

Chapter 10 National Impact Analysis: discusses the methods used for forecasting national energy consumption and national economic impacts based on estimates of future equipment efficiency, new construction and building starts, and annual equipment sales in the absence and presence of higher efficiency standards.

Chapter 11 Life-Cycle Cost Subgroup Analysis: discusses the effects of standards on different subgroups of consumers and compares the LCC and PBP of equipment with and without higher efficiency standards for these consumers.

Chapter 12 Manufacturer Impact Analysis: discusses the effects of standards on the finances and profitability of equipment manufacturers.

Chapter 13 Utility Impact Analysis: discusses the effects of standards on electric and gas utilities.

Chapter 14 Employment Impact Analysis: discusses the effects of standards on national employment.

Environmental Assessment for Residential Refrigerators, Refrigerator-Freezers, and Freezers: discusses the effects of standards on three pollutants—sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury—as well as carbon emissions.

Regulatory Impact Analysis for Residential Refrigerators, Refrigerator-Freezers, and Freezers: discusses the impact of non-regulatory alternatives to efficiency standards.

Appendix 5-A Engineering Data

Appendix 5-B ERA Model Development and WinERA User Manual

Appendix 7-A Literature Survey of Energy Consumption by Residential Refrigerator-Freezers

Appendix 7-B	Data for Estimating Distribution of Refrigerator and Freezer Size in the RECS Sample
Appendix 8-A	User Instructions for LCC and PBP Spreadsheets
Appendix 8-B	Uncertainty and Variability
Appendix 8-C	Consumer Retail Prices for Baseline Residential Refrigerator-Freezers and Freezers
Appendix 8-D	Household Discount Rate Distributions
Appendix 9-A	Relative Price Elasticity of Demand for Appliances
Appendix 10-A	User Instructions for Shipments and NIA Spreadsheets
Appendix 10-B	National Equipment and Operating Costs
Appendix 12-A	MIA (Preliminary MIA Questionaire)

REFERENCES

[1] U.S. Department of Energy. *Technical Report: Analysis of Amended Energy Conservation Standards for Residential Refrigerator-Freezers*. October 2005. <http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrigerator_report_1.pdf >

CHAPTER 2. ANALYTICAL FRAMEWORK, COMMENTS FROM INTERESTED PARTIES, AND DOE RESPONSES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 2. ANALYTICAL FRAMEWORK, COMMENTS FROM INTERESTED PARTIES, AND DOE RESPONSES

2.1 INTRODUCTION

Section 6295(o)(2)(A) of 42 United States Code (U.S.C.) requires the U.S. Department of Energy (DOE) to set forth energy conservation standards that are technologically feasible and economically justified, and would achieve the maximum improvement in energy efficiency. This chapter provides a description of the general analytical framework that DOE uses in developing such standards. The analytical framework is a description of the methodology, the analytical tools, and relationships among the various analyses that are part of this rulemaking. For example, the methodology that addresses the statutory requirement for economic justification includes analyses of life-cycle cost (LCC), economic impact on manufacturers and users, national benefits, impacts, if any, on utility companies, and impacts, if any, from lessening competition among manufacturers.

The analyses performed as part of the preliminary analysis stage and reported in this preliminary technical support document (preliminary TSD) are listed below.

- A market and technology assessment to characterize the relevant product markets and existing technology options, including prototype designs.
- A screening analysis to review each technology option and determine if it: is technologically feasible; is practical to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse impacts on health and safety.
- An engineering analysis to develop cost-efficiency relationships that show the manufacturer's cost of achieving increased efficiency. DOE determines the increased cost to the consumer through an analysis of engineering markups, which convert manufacturer production cost (MPC) to manufacturer selling price (MSP).
- An energy use analysis to determine the annual energy use of the considered products.
- LCC and payback period (PBP) analyses to calculate, at the consumer level, the discounted savings in operating costs (less maintenance and repair costs) throughout the estimated average life of the covered products, compared to any increase in the installed cost for the products likely to result directly from imposition of the standard.
- A shipments analysis to forecast product shipments, which then are used to calculate the national impacts of standards on energy, net present value (NPV), and future manufacturer cash flows.
- A national impact analysis (NIA) to assess the aggregate impacts at the national level of the NPV of total consumer LCC and national energy savings (NES).
- A preliminary manufacturer impact analysis to assess the potential impacts of energy conservation standards on manufacturers, such as impacts on capital conversion expenditures, marketing costs, shipments, and research and development costs.

The analyses DOE will perform in the subsequent Notice of Proposed Rulemaking (NOPR) stage include those listed below. In addition, DOE will revise the analyses it performed during the preliminary analysis stage based on comments and new information received.

- An LCC subgroup analysis to evaluate variations in customer characteristics that might cause a standard to affect particular consumer sub-populations, such as low-income households, differently than the overall population.
- A manufacturer impact analysis to estimate the financial impact of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity.
- A utility impact analysis to estimate the effects of proposed standards on electric, gas, or oil utilities.
- An employment impact analysis to assess the aggregate impacts on national employment.
- An environmental impact analysis to provide estimates of the effects of amended energy conservation standards on emissions of carbon (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NOx), and mercury.
- A regulatory impact analysis to present major alternatives to proposed amended energy conservation standards that could achieve substantially the same regulatory goal at a lower cost.

DOE developed this analytical framework and documented its findings in the Rulemaking Framework Document for Refrigerators, Refrigerator-Freezers, and Freezers (September 18, 2008). DOE presented the analytical approach to interested parties during a public meeting held on September 29, 2008. The framework document is available at http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html.

In response to the publication of the framework document and the framework public meeting, DOE received numerous comments from interested parties regarding DOE's analytical approach. This chapter (chapter 2) of the preliminary TSD summarizes the key comments DOE received from interested parties and describes DOE's responses to those comments. In addition, in subsequent sections of this chapter, DOE has summarized any significant changes in analytical approach made since publishing the framework document that DOE used in its preliminary analyses. Lastly, in the executive summary of the preliminary TSD, DOE identified a number of issues for which DOE seeks public comment. DOE has explained each of those issues in the relevant analysis sections below.

2.2 MARKET AND TECHNOLOGY ASSESSMENT

When DOE begins an energy conservation standards rulemaking, it develops information that provides an overall picture of the market for the products considered, including the nature of the products, the industry structure, and market characteristics for the products. This activity consists of both quantitative and qualitative efforts based primarily on publicly available information. The subjects addressed in the market assessment included manufacturers, trade associations, and the quantities and types of products sold and offered for sale. DOE examined manufacturers of residential refrigeration products, which included both large and small and foreign and domestic manufacturers. DOE also examined data supplied by the key trade association for this product category, the Association of Home Appliance Manufacturers (AHAM). DOE also reviewed shipment data collected by AHAM and *Appliance* Magazine. Finally, DOE also reviewed other energy efficiency programs from utilities, individual states, and other organizations. Chapter 3 of the preliminary TSD provides additional details on the market and technology assessment.

DOE reviewed relevant literature and interviewed manufacturers to develop an overall picture of the residential refrigeration products industry in the United States. Industry publications and trade journals, government agencies, and trade organizations provided the bulk of the information, including: (1) manufacturers and their market shares; (2) shipments by product type (i.e., refrigerator, freezer, etc.); (3) product information; and (4) industry trends.

Subsequent sections of this chapter of the preliminary TSD describe the comments DOE received in response to its review of the market for the framework document. The analysis developed as part of the market and technology assessment is described in chapter 3 of the preliminary TSD.

2.2.1 Definitions

In the framework document, DOE delineated 20 different product classes for residential refrigeration products. Of these, 18 product classes based on the following characteristics are already contained in the CFR: type of unit (refrigerator, refrigerator-freezer, or freezer), geometric configuration for refrigerator-freezers (freezer mounting on top, side, or bottom), size of the cabinet (standard or compact), type of defrost system (manual, partial, or automatic), and presence or absence of through-the-door (TTD) ice service. DOE proposed two additional product classes (designated 19 and 20 in the framework document) beyond those presented in the CFR: automatic defrost refrigerator-freezers with bottom-mounted freezer and TTD ice service and chest freezers with automatic defrost.

DOE received comments on the product definitions presented in the framework document. In response, DOE reviewed the definitions for refrigerators, refrigerator-freezers, and freezers to determine scope of coverage as it pertains to the new product classes designated 19 and 20 in the framework document, and examined the DOE refrigerator test procedure to determine product classification for products with convertible compartments. Discussion of these issues is presented below.

2.2.1.1 Automatic Defrost Refrigerator-Freezers with Bottom-Mounted Freezer and with TTD Ice Service and Chest Freezers with Automatic Defrost

DOE received several comments regarding the classification of automatic defrost refrigerator-freezers with bottom-mounted freezer and TTD ice service. AHAM stated that DOE should re-label its proposed product class 19 as product class 5A so as to be consistent with Canadian product class definitions. (AHAM, No. 11 at p. 3) Natural Resources Canada (NRCan) agreed with that view and added that DOE should classify its proposed product class 20 as product class 10A. (NRCan, No. 16 at pp. 2-3)

DOE believes that harmonization with international standards is important to reduce the costs of compliance and should be done whenever possible. DOE concurs with AHAM and NRCan and has re-designated product classes 19 and 20 as product classes 5A and 10A, respectively, to maintain consistency with Canadian standards.

2.2.1.2 Refrigeration Products with Convertible Compartments

Interested parties submitted a number of comments about convertible compartments to DOE. The American Council for an Energy-Efficient Economy (ACEEE), the Appliance Standards Awareness Project (ASAP), the Consumer Federation of America (CFA), the National Consumer Law Center (NCLC), the Natural Resources Defense Council (NRDC), the Northeast Energy Efficiency Partnerships (NEEP), the Northwest Power and Conservation Council (NPCC), Pacific Gas and Electric (PG&E), and Southern California Edison (SCE) submitted a joint comment to DOE, hereafter referred to as the "Joint Comment," stating that: (1) the test procedure should be updated to reflect product configurations that are currently on the market; (2) convertible bottom-drawer refrigerator-freezers should be rated with the convertible drawer operating as a freezer, which is not the way some of these products have been rated for ENERGY STAR; and (3) the convertible bottom-drawer refrigerator-freezer should be rated as bottom-mount refrigerator-freezer (product class 5A). (Joint Comment, No. 10 at pp. 2,3)

Whirlpool Corporation (Whirlpool) agreed that convertible bottom-drawer products should be considered to be "classification 19", adding that units with convertible compartments must be tested in their highest-energy state. (Whirlpool, Public Meeting Transcript, No. 7 at p. 62-63, No. 17 at p. 4) However, both Whirlpool and General Electric (GE) clarified that testing of a convertible compartment as a freezer may define the product as something other than a bottom-mount refrigerator-freezer with TTD ice, and that the product should be rated the way it is tested. (Whirlpool, Public Meeting Transcript, No. 7 at p. 63-64; GE, Public Meeting Transcript, No. 7 at p. 63-64) AHAM made a similar statement, adding that a convertible automatic defrost bottom-mount refrigerator-freezer equipped with no ice or water dispenser should be classified under product class 5 and that it should be tested with the convertible compartment operating as a freezer compartment in one test and as a fresh food compartment in a second test to determine which configuration has the highest energy use. (AHAM, No. 11 at p. 4)

Several of the comments noted that the requirement to test a convertible compartment in its highest-energy state comes from AHAM Standard HRF-1, the 1979 edition of which is referenced by the current DOE energy test procedure for refrigerators and refrigerator-freezers.

DOE has learned that the convertible bottom-drawer product that prompted the question posed in the framework document is no longer on the market, but that a different product with convertible compartments was introduced by another manufacturer. This second product is rated in the ENERGY STAR database with one of the convertible compartments operating as a freezer compartment, and one operating as a fresh food compartment. DOE does not intend at this time to establish a new product class based on such a configuration. DOE agrees with stakeholder comments regarding the requirement that a convertible-compartment product be rated with the compartment in its highest energy-use position under the current DOE energy test procedures. In the NOPR addressing possible amendments to the test procedure, DOE considers whether the test procedure should be modified to improve clarity regarding this test requirement.

DOE further notes that issues associated with multiple compartments and/or separate temperature control of drawers or otherwise isolated spaces within compartments will present a challenge to the energy test procedure that will require consideration as such features are more frequently added to products. For example, the test procedure does not indicate clearly how to adjust temperature setpoints and how to average compartment temperatures for a refrigerator-freezer that has multiple fresh food compartments, multiple freezer compartments, or large internal sub-compartments that have separate temperature control. DOE notes that working Group 12 of Technical Committee 59 of the International Electrotechnical Commission (IEC) is developing IEC 62552, an international test procedure for refrigerators, refrigerator-freezers, and freezers. The issue of establishing test procedures to accurately address such product features has been discussed as part of the IEC test procedure development. DOE anticipates that future DOE energy test revisions will consider approaches adopted by the IEC test procedure to address these issues.

2.2.2 Product Classes and Scope of Coverage

When evaluating and establishing energy conservation standards, DOE generally divides covered products into product classes by the type of energy used, capacity, or performance-related features that affect efficiency. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q))

DOE received several comments from interested parties regarding the product classes and their organization. Specifically, DOE received comments regarding whether to include built-in refrigeration products and wine storage products as additional product classes.

2.2.2.1 Built-In Refrigeration Products

DOE received several comments on the inclusion of built-in refrigeration products as a separate product class. Sub Zero-Wolf, Inc. (Sub-Zero) requested that DOE establish separate product classes for built-in refrigeration products because they provide distinct utility and have limited potential for energy improvement compared to conventional freestanding units. Sub-Zero cited the distinction made for compact products in the previous refrigerator energy conservation standard rulemaking as an example of establishment of separate product classes for products for which options for efficiency improvements are limited. Sub-Zero also noted that built-in products are a niche market with low production volumes, comprising perhaps 1.5% of all residential refrigeration product shipments. (Sub-Zero, Public Meeting Transcript, No. 7 at pp. 61-62 and No. 9 at pp. 1-3) The Edison Electric Institute (EEI) agreed, suggesting that DOE include built-in products as a separate product class. (EEI, No. 13 at p. 3) The Joint Comment disagreed, stating that DOE should not include built-in refrigeration products as a separate product class because built-ins provide the same service and amenity to consumers as standalone units, and they believe that manufacturers will find ways to make built-ins that meet performance standards similar to standalone units. The Joint Comment also notes that built-in units can already exceed ENERGY STAR and the Consortium for Energy Efficiency (CEE) Tier 1 and Tier 2 efficiency levels. (Joint Comment, No. 10 at p. 3),

Sub-Zero further detailed the request for built-in product classes in a written comment. (Sub-Zero, No. 9 at p. 1-3) This comment suggests the following possible built-in product classes.

- Built-in auto defrost top mount refrigerator-freezer w/o TTD ice and auto defrost all-refrigerators
- Built-in auto defrost top mount refrigerator-freezer w/TTD ice
- Built-in auto defrost bottom mount refrigerator-freezer w/o TTD ice
- Built-in auto defrost bottom mount refrigerator-freezer w/TTD ice
- Built-in auto defrost side-by-side refrigerator-freezer w/o TTD ice
- Built-in auto defrost side-by-side refrigerator-freezer w/TTD ice
- Built-in auto defrost upright freezer
- Built-in compact refrigerators, refrigerator-freezers, and freezers

Sub-Zero also pointed out in the written comment a number of design differences between built-in products and conventional products that make achieving higher efficiency levels more difficult for built-in products. (Sub-Zero, No. 9 at p. 2) These include the following.

- More doors and drawers than conventional units, which leads to greater gasket length and door frame/gasket thermal load.
- Limited access to condenser airflow since the products must be designed to be constrained by installation between cabinets.
- More firm constraints on increases in exterior dimensions to allow increase in insulation thickness.
- Use of glass doors.
- Design for multiple compartments of different temperatures.
- More complex hinge systems, which impact the ability to insulate the cabinet in the hinge region.

DOE notes that establishment of separate product classes must be based on consumption of a different kind of energy, or a different capacity or other performance-related feature that other products within a product group do not share. The Secretary must consider such factors as the utility to the consumer of such a feature and other factors as the Secretary deems appropriate, and any rule prescribing a higher or lower level of energy use or efficiency shall include an explanation of the basis on which such higher or lower level was established. (42 U.S.C. 6295(q))

Based on information received in discussions with manufacturers during the preliminary phase of the rulemaking, DOE is aware that achieving ENERGY STAR qualification for built-in products typically requires the use of more high-efficiency components. A conventional refrigerator-freezer, for example, typically requires use of a brushless DC condenser fan motor and a high-efficiency single-speed compressor to meet ENERGY STAR, whereas a built-in refrigerator-freezer generally requires use of brushless DC fan motors for both the condenser and evaporator, and a variable speed compressor. The cost of achieving ENERGY STAR based on these technical differences is estimated to be $43, as summarized in Table 2.2.1 below.[a] DOE understands that the differential for achieving ENERGY STAR could be more or less, depending on the design details of the built-in product.

Table 2.2.1 Typical Cost Differential for Built-in Product ENERGY STAR Compliance as Compared with a Conventional Product

Conventional Refrigerator-Freezer		**Built-In Refrigerator-Freezer**	
Design Change	Cost Impact	Design Change	Cost Impact
Increase Compressor EER from 5.5 to 6.25	$10.50	Replace Compressor with Variable-Speed Compressor	$50
Add Brushless DC Condenser Fan Motor	$3.75	Add Brushless DC Condenser and Evaporator Fan Motors	$3.75 (condenser) $3.50 (evaporator)
TOTAL	$14.25		$57.25
Difference			$43

Built-in products can be built into the kitchen cabinetry in a way that is not possible for conventional products. Some of the design details associated with this unique utility can impact energy use. These products do not consume a different type of energy from conventional products. While a difference in the ability to achieve higher efficiency levels is noted, DOE does not have sufficient information to conclude that built-in products cannot meet efficiency levels that might be considered for future standards. DOE acknowledges that the cost of achieving higher efficiency levels is greater for built-in products. DOE has not sufficiently completed an assessment of the cost differences associated with built-ins (as compared to conventional products of the high-volume product classes) and for this reason has not made a determination at

[a] Cost assumptions for design changes are described in greater detail in Chapter 5 Engineering Analysis of the TSD.

this preliminary stage regarding establishment of separate product classes for these products. DOE will work to complete this assessment as the rulemaking process progresses.

2.2.2.2 Wine Storage Products

DOE received a number of comments on the subject of adding of wine storage products as a new product class covered under this rulemaking. Nearly all of these comments were in support of establishing a new product class for wine coolers. AHAM, ASAP, and PG&E all stated at the framework public meeting that DOE should include a separate product class for wine storage products. (AHAM, Public Meeting Transcript, No. 7 at pp. 58-59; ASAP, Public Meeting Transcript, No. 7 at p. 46-47; PG&E, Public Meeting Transcript, No. 7 at pp. 43-44) Specifically, these comments suggested that DOE create two separate product classes for wine storage products: those with manual defrost, and those with automatic defrost. EEI, Natural Resources Canada (NRCan), Whirlpool, Sub-Zero, and the Joint Comment expressed support for this position in their written comments as well. (EEI, No.13 at pp. 2-3; NRCan, No. 16 at pp. 2-3; Whirlpool, No. 17 at pp. 4-5; Sub-Zero, No. 9 at p. 3; Joint Comment, No. 10 at p. 3)

PG&E, however, modified its position in its written comment, stating that DOE should not establish new product classes for wine storage products at this time. The comment points out that the State of California already regulates these products, and that a Federal standard would supersede any State regulations. The comment further suggests that consideration is being given to strengthening the California energy standards for wine storage products and to expand the scope of product coverage, and that DOE introduction of a wine storage product class would limit California's ability to take advantage of these energy savings opportunities. (PG&E, No. 14 at pp. 1-2)

DOE notes that the definitions of refrigerators and refrigerator-freezers in the Energy Policy and Conservation Act (EPCA) do not include specification of temperature levels. DOE defined refrigerators as "designed for storage of food at temperatures above 32°F and below 39°F" in order to assure that refrigerator temperature levels are suitable for storage of food. (66 FR 57845, November 19, 2001) Wine coolers, which control for higher temperature levels, are therefore excluded from the product category of refrigerators. Because wine coolers are not defined either in the statute or regulations as part of this product category, or as a separate and independent product category, they are not covered products. Hence, DOE is not considering wine coolers as part of this rulemaking.

2.2.3 Technology Assessment

As part of the market and technology assessment, DOE developed a list of technologies to consider for improving product efficiency. Initially, these technologies encompass all those that DOE believes are technologically feasible. DOE then removed those technology options whose energy consumption could not be adequately measured by the existing DOE test procedure. Finally, DOE also removed technologies that do not change or affect the energy efficiency metrics of these products before moving on to the screening analysis. Chapter 3 of the preliminary TSD includes the detailed list of all technology options identified for each type of refrigerator, refrigerator-freezer, and freezer. Comments on the selection of technologies identified in the framework document are discussed in section 2.3.

2.3 SCREENING ANALYSIS

After DOE identified the technologies in the technology assessment that could potentially improve the energy efficiency of residential refrigeration products, DOE conducted the screening analysis. The purpose of the screening analysis is to evaluate the technologies to determine which options to consider further and which options to screen out. DOE consults with industry, technical experts, and other interested parties in developing a list of technologies for consideration. DOE then applied the screening criteria to determine which technologies are unsuitable for further consideration in this preliminary rulemaking. Chapter 4 of the preliminary TSD, the screening analysis, contains details on the criteria that DOE used.

Using the screening analysis DOE, in consultation with interested parties, examined whether various technologies described in chapter 3 of the TSD: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; and (4) have adverse impacts on health and safety. In the engineering analysis, DOE further considered the efficiency-enhancement options (i.e., technologies) that it did not screen out in the screening analysis.

2.3.1 Screening Methodology

DOE received several comments regarding its methodology for screening technologies. The Joint Comment stated that DOE has been too quick to screen out technologies in previous rulemakings, that “manufacturers are much better at finding the lowest cost path to compliance than the Department”, and that DOE should review results of previous rulemakings to validate whether the methodology has been successful. (Joint Comment, No. 10 at p. 4) The comment did not indicate what would constitute success of the methodology, nor did it specifically address the criteria used to evaluate the technologies. Whirlpool commented that the screening analysis should also examine whether various technologies are proprietary. If they are, they should be excluded as technology options from the engineering analysis. (Whirlpool, No. 17 at p.5) On the other hand, AHAM stated in both the framework public meeting and in written comments that it believes the screening criteria are appropriate. (AHAM, No. 11 at p.5 and Public Meeting Transcript, No. 7 at p. 76)

DOE concurs with AHAM that the screening criteria are appropriate. The criteria are explicitly delineated in 10 CFR 430 subpart C appendix A section 4.(a)(4). DOE does not believe that a formal review of previous rulemakings to evaluate whether its screening methodology is “successful” is necessary. The time delay between the preliminary phase of the rulemaking and the effective date of the new standards is sufficiently long that some technologies appropriately screened out initially may be viable when the standards become effective. DOE is cognizant of the process used and the results achieved in previous rulemakings and has evaluated the technologies in this rulemaking by rigorously applying the criteria in section 2.3 based on currently available information. Also, DOE acknowledges the need to exclude proprietary technologies from the engineering analysis and has done so where appropriate in this rulemaking.

2.3.2 Alternative Foam-Blowing Agents

AHAM and Whirlpool both recommended that DOE add alternative foam-blowing agents to the list of technologies under consideration for the screening analysis. (AHAM, No. 11 at p.5; Whirlpool, No. 17 at p. 5) DOE understands the intent of the comment to be that DOE should consider the impact of potential climate change legislation or direct EPA action limiting the use of greenhouse gases (GHGs) such as HFC-245fa. During investigation of technologies, DOE was not able to identify refrigerant blowing agent technology options that (1) have not been phased out in the past due to ozone depletion issues, and (2) provide better thermal performance than HFC-245fa, which is used extensively in the industry. Manufacturers confirmed during preliminary discussions that there are no available blowing agent options with better thermal performance.

Manufacturers indicated during interviews that they have concerns about alternative foam-blowing agents which might have to be adopted as a result of potential climate change legislation regulating emissions of GHGs. HFC-245fa has a global warming potential (GWP) referenced to that of carbon dioxide (CO_2) of about 1,000, but its conductivity is lower than all commonly known allowable alternative chemicals that are not GHGs. Hence, switching to a different foam-blowing agent will increase energy use of refrigeration products. Manufacturers expect that new legislation limiting the use of HFC blowing agents and refrigerants will be passed before the amended conservation standards for refrigerators goes into effect in 2014. For this reason, manufacturers have requested that DOE consider alternative foam-blowing agents in the analysis.

DOE points out that, because there are no alternative blowing agents that will improve efficiency, it is not appropriate to include this option in the list of technologies. An enforced transition to blowing agents with reduced global warming potential but higher thermal conductivity has the potential to make achieving high efficiency levels more difficult and more costly However, DOE cannot consider legislation that has not yet been enacted or rules that have not yet been established in determining its proposed standard levels before such legislation becomes law or before such rules have been established, regardless of the likelihood of these occurrences. Nevertheless, DOE acknowledges that climate change legislation could be enacted before the refrigeration products final rule is published. DOE also recognizes the additional challenge posed to the refrigeration products industry by potential limitations on HFC usage. For these reasons, the Department will consider conducting additional analyses addressing possible transition to alternative foam-blowing agents, to allow adjustment of the analysis results in a timely fashion in the case that such climate change legislation is enacted during the rulemaking process. Such analysis would consider the likely effect of increased energy consumption resulting from thermal conductivity increase of likely alternatives. This issue is discussed further in sections 2.10 and 2.10.4 of this chapter, as well as in the manufacturing impact analysis in chapter 12.

2.3.3 Alternative Refrigerants

A number of stakeholders commented about the inclusion of alternative refrigerants as a technology option in the screening process. Both AHAM and Whirlpool stated that DOE should exclude hydrocarbon refrigerants because they are regulated by safety organizations such as Underwriters Laboratories (UL) that restrict the usage of these substances to quantities under 50 grams due to flammability. (AHAM, Public Meeting Transcript, No. 7 at p. 117; Whirlpool, Public Meeting Transcript, No. 7 at p. 72-73) Alternatively, GE stated that there are processes in place at the Environmental Protection Agency (EPA) to approve of hydrocarbon substances as safe for use as alternative refrigerants. (GE, Public Meeting Transcript, No. 7 at p. 73)

The dominant refrigerant currently used in the U.S. is HFC-134a. A possible replacement refrigerant is R-600a, isobutane. R-600a is used extensively throughout the world in residential refrigerators and has a better thermodynamic efficiency than HFC-134a. However, R-600a is a hydrocarbon and is flammable.

DOE excluded consideration of R-600a in the engineering analysis because concerns regarding its acceptance by UL and under the EPA's Significant New Alternatives Policy (SNAP) program have not been resolved. Current safety regulations limit the use of hydrocarbon refrigerants to quantities that are insufficient for most residential refrigeration applications. Underwriters Laboratories (UL) has established that no more than 50 g of isobutane can escape an appliance before requiring stringent safety testing, which essentially caps the allowable limit of R-600a at 50 g. This quantity is not enough for the typical residential refrigerator. Further, while thermodynamic efficiency of R-600a may be better than that of HFC-134a, it is not clear that the efficiency level of the alternative refrigerant is higher in practice.

2.4 ENGINEERING ANALYSIS

The engineering analysis (chapter 5) establishes the relationship between the manufacturing production cost and the efficiency for each residential heating product. This relationship serves as the basis for cost/benefit calculations in terms of individual consumers, manufacturers, and the Nation. Chapter 5 discusses product classes DOE analyzed, the representative baseline units, the incremental efficiency levels, the methodology DOE used to develop the manufacturing production costs, the cost-efficiency curves, and the impact of efficiency improvements on the considered products.

In the engineering analysis, DOE evaluates a range of product efficiency levels and their associated manufacturing costs. The purpose of the analysis is to estimate the incremental manufacturer selling prices (MSPs) for a product that would result from increasing efficiency levels above the level of the baseline model in each product class. The engineering analysis considers technologies not eliminated in the screening analysis. The LCC analysis uses the cost-efficiency relationships developed in the engineering analysis.

DOE typically structures its engineering analysis around one of three methodologies: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options used to achieve such increases; and/or (3) the reverse-engineering or cost-assessment approach, which involves a “bottom-up” manufacturing cost assessment based on a detailed bill of materials derived from tear-downs of the product being analyzed.

For the preliminary analysis, DOE used a modified approach combining the design-option approach and the efficiency-level approach. DOE conducted energy modeling and manufacturing cost modeling to determine the cost impact of groups of design options which combined can achieve defined efficiency levels. Reverse engineering of existing products was used to provide calibration of the manufacturing cost models. DOE selected several baseline and high-efficiency products on which to conduct teardowns, which also provided an initial indication of cost-efficiency relationships for certain product classes. This step involved physically disassembling commercially available products, consulting with outside experts, reviewing publicly available cost and performance information, and modeling equipment cost. Product data and energy testing were used to calibrate the energy models. Data requested from the industry was used to compare with data from the DOE analyses. The efficiency levels that DOE considered in the engineering analysis are attainable using technologies currently available on the market and incorporating these technologies into residential refrigeration products. Chapter 5 of the preliminary TSD describes the methodology that DOE used to perform the engineering analysis and derive the cost-efficiency relationship.

In response to the approach outlined in the framework document, DOE received comments regarding the following issues: (1) efficiency levels; (2) compartment temperatures; (3) product classes; and (4) manufacturing cost analysis. Discussion of these issues is set forth below.

2.4.1 Efficiency Levels

ACEEE and PG&E both stated that DOE should extend the cost-efficiency curves to 35 percent lower energy than the federal standard. ACEEE mentioned that there are currently products on the market that exceed 30 percent below federal standards and that tax credits could increase the product volumes at these efficiency levels. (ACEEE, Public Meeting Transcript, No. 7 at p. 105; PG&E, Public Meeting Transcript, No. 7 at p. 106) In response, Whirlpool stated that a 35 percent efficiency improvement is unrealistic and would be limited because of high costs. (Whirlpool, No. 17 at p. 8) Additionally, Whirlpool and AHAM both recommended that DOE conduct analysis for an efficiency level between baseline and 15 percent because 15 percent represents a very significant change in efficiency and because the change in the test procedure (lower compartment temperatures for refrigerator-freezers) may make achieving the 15% level even more difficult for some products. (Whirlpool, No. 17 at p. 8; AHAM, No. 11 at p. 7)

The development of cost-efficiency curves to higher efficiency levels does not dictate the level at which new standards will be set and provides fuller insight regarding the cost levels required to achieve higher efficiencies. This is important, in particular, to provide an understanding of the cost impact of a potential new ENERGY STAR level associated with each new baseline efficiency level. Therefore, DOE has extended the analysis up to efficiency levels of 35 percent or more, as appropriate. In response to the comments of AHAM and Whirlpool, DOE has also included a 10 percent efficiency level in the analysis.

DOE also received comments from AHAM and Whirlpool regarding the definition of efficiency levels under the new test procedure.[b] Specifically, AHAM and Whirlpool stated, "These percentages should not be applied directly to baseline values obtained using the new test procedure. These percentages, when applied to baselines using the current test procedure are realistic." (Whirlpool, No. 17 at p. 7; AHAM, No. 11 at p. 7) DOE interprets these statements to mean that energy use for a percentage efficiency level would be defined to be equal to the new-test baseline energy use minus the percentage efficiency level multiplied by the current-test baseline energy use. This definition is illustrated below in Eq. 2.4.1.

$$\boxed{New\ Energy\ Level = NTP_{Baseline} - \left(A \times CTP_{Baseline}\right)} \qquad \textbf{Eq. 2.4.1}$$

Where:

New Energy Level =	energy consumption associated with efficiency level A,
$NTP_{Baseline}$ =	baseline energy as calculated using the new test procedure,
A =	efficiency level, expressed as a percentage, and
$CTP_{Baseline}$ =	baseline energy as calculated using the current test procedure.

For example, if the current baseline for a product is 500 kWh, and the new-test baseline energy use is 600 kWh, the 20 percent efficiency level would be 500 kWh, which is actually a 16.7 percent reduction from 600 kWh.

DOE believes that this method is not appropriate as a definition for efficiency levels under the new test procedure because: (1) it is confusing given that the energy use reduction would generally be less than the percent efficiency level; and (2) it is expected that a product at a given percentage efficiency level using the current test would exhibit the same percentage efficiency level using the new test. Expressed in another way, an ENERGY STAR product should have similar sensitivity to the test procedure change as would a baseline energy product. DOE did not adopt the definitions suggested by AHAM and Whirlpool for these reasons.

[b] As described in Section 3 Market and Technology Assessment, DOE is proposing adopting provisions of the updated AHAM Standard HRF-1-2008 test procedure, which specifies new compartment temperatures that will increase energy test energy consumption for many product classes.

2.4.2 Compartment Temperatures

AHAM, GE, Sub-Zero, and Whirlpool all submitted comments stating that DOE should use the temperatures and volumes from the new test procedure when performing its engineering analysis. (AHAM, Public Meeting Transcript, No. 7 at p. 86 and No. 11 at p. 6; GE, Public Meeting Transcript, No. 7 at p. 87; Sub-Zero, No. 9 at p. 4; and Whirlpool, No. 17 at p. 7)

DOE agreed with the manufacturers' suggestion and conducted its engineering analysis using the new temperatures and volumes.

2.4.3 Product Classes

DOE received a number of comments regarding product classes and the representative units that were selected for its teardown analysis. AHAM commented on DOE selection of an 18 ft^3 product class 5 product, indicating that 17 ft^3 or 19 ft^3 sizes would be more appropriate, based on shipment data showing limited shipment of 18 ft^3 products. AHAM also stated that the units selected for product classes 3, 7, 9, 10, 11, and 18 were representative of the typical volume for each class (AHAM, Public Meeting Transcript, No. & at p. 98-99, No. 11 at p. 5) Whirlpool commented that the volumes of the proposed teardown units for the product classes in which it participates (3, 4, 5, and 7) are representative of the industry-wide offerings. (Whirlpool, No. 17 at p. 6)

DOE points out that the total volume of the product class 5 listed as 18 ft^3 actually has a rated volume of 18.5 ft^3, which should have been rounded up to 19 ft^3. Also, DOE believes that products of this size would exhibit energy-use characteristics that are sufficiently similar to those of slightly larger or smaller sized units within the same product class. Hence, DOE continued its analysis of the 18.5 ft^3 product.

DOE received additional comments from AHAM and Whirlpool suggesting that the representative units for product class 5 should be French door bottom-mount models because they have higher heat-leakage than traditional bottom-mount units. (AHAM, Public Meeting Transcript, No. 7 at p. 67 and No. 11 at p. 4; Whirlpool, No. 17 at p. 5) On the other hand, the Joint Comment suggested that DOE should not analyze product class 5 based solely on French Door models, stating that product types should not be chosen as the baseline simply because of higher inherent heat loss because this would lead to standards biased against efficiency and the grandfathering in of inefficient designs. (Joint Comment, No. 10 at p. 3)

DOE requested information during manufacturer interviews regarding the prevalence of French Door products within product class 5. The information received suggests that more than half of product class 5 shipments are products with French Doors. Hence, DOE considers this design feature more representative of the product class than single-door designs, and DOE has carried out the analysis based on designs having French Doors.

Additionally, W.C. Wood Corporation, Ltd. (WC Wood) commented on DOE's selection only of WC Wood products to represent ENERGY STAR products for product classes 9 and 10.

WC Wood suggested that DOE also examine products from another manufacturer. (WC Wood, No. 8 at p. 1) WC Wood states that doing so would provide DOE with a broader selection from which to understand the current level of freezer manufacturing technology.

DOE acknowledges that analysis of product classes 9 and 10 could be limited if ENERGY STAR products from just one manufacturer were examined, so it procured and conducted reverse engineering analysis on similar-sized units made by another key manufacturer of these products.

2.4.4 Manufacturing Cost Analysis

DOE received several comments regarding the manufacturing cost analysis. The Joint Comment, NRDC, and PG&E all stated that DOE should review the accuracy of its cost-modeling methods from previous rulemakings, in order to identify and address inaccurate cost assumptions so that such inaccuracies are not incorporated in the refrigerator cost models for this rulemaking. (Joint Comment, No. 10 at p. 4; NRDC, Public Meeting Transcript, No. 7 at pp. 93-94; PG&E, Public Meeting Transcript, No. 7 at p. 94) Specifically, the Joint Comment states that DOE should account for the increased production levels and reduction of the learning curve associated with producing higher efficiency units.

Thorough review of the accuracy of cost modeling of past rulemakings is beyond the scope of this rulemaking. DOE recognizes the need for accuracy in determination of the cost of achieving higher efficiency levels. To that end, DOE refrains from making or using cost projections that cannot be verified based on current information, as well as from making estimates that cannot be substantiated. DOE recognizes that this leads inevitably to cost estimates that may be high after a standard takes effect. However, the Energy Independence and Security Act of 2007 (EISA) modified EPCA to require that not later than 6 years after the issuance of any final rule establishing or amending a standard, DOE shall publish either a determination that standards for the product do not need to be amended or a notice of proposed rulemaking including new proposed standards. (42 U.S.C. 6295, section 325 (m)) Hence, if the cost-effectiveness of higher efficiency standards improves significantly, the energy conservation standards can be adjusted in a subsequent rulemaking.

2.5 MARKUPS TO DETERMINE PRODUCT PRICE

DOE used markups to convert the manufacturer selling prices estimated in the engineering analysis to customer prices, which then were used in the life-cycle cost (LCC) and payback period (PBP) and manufacturer impact analyses. DOE calculates markups for baseline products (baseline markups) and for more efficient products (incremental markups). The incremental markup relates the change in the manufacturer sales price of higher-efficiency models (the incremental cost increase) to the change in the retailer or distributor sales price.

To develop markups, DOE identifies how the products are distributed from the manufacturer to the customer. After establishing appropriate distribution channels, DOE relied on economic data from the U.S. Census Bureau and other sources to define how prices are marked up as the products pass from the manufacturer to the customer. See Chapter 6 for details on the development of markups.

2.6 ENERGY USE CHARACTERIZATION

The energy use characterization, which assesses the energy savings potential from higher efficiency levels, provides the basis for the energy savings values used in the LCC and subsequent analyses. Studies show that measurements of field energy use often vary considerably from the rated usage as determined by the DOE test procedure. To determine the field energy use by products that would meet possible energy efficiency standards, DOE used data from the Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey (RECS).[1,c] RECS is a national sample survey of housing units that collects statistical information on the consumption of and expenditures for energy in housing units along with data on energy-related characteristics of the housing units and occupants. DOE used RECS to estimate the field energy usage of standard-sized refrigerator-freezers and freezers on a representative sample of housing units using these products. But DOE did not use RECS for compact refrigerators and freezers because a large fraction of these products are used outside the residential sector.

AHAM and Whirlpool expressed opposition to using RECS data for the energy use characterization. (AHAM, No. 11 at p. 8; Whirlpool, No. 17 at p. 9) They stated that the RECS data were collected in 2005 and may not be representative of the quickly changing refrigeration market. DOE uses the RECS to characterize energy use of refrigeration products because this survey is the only source that provides a nationally-representative household sample that includes estimates of energy use by refrigeration products. RECS also provides enough information to establish the type (*i.e.*, product class) of refrigeration product used in each household. Changes in the refrigeration market are not an important factor because DOE's approach provides a basis for estimating what the energy consumption would be if a household purchased a new and different product from the one they owned in 2005. As noted previously, DOE did not use RECS for compact refrigerators and freezers because a large fraction of these products are used outside the residential sector.

EEI stated that units in unconditioned areas are more likely to have low energy usage during the winter season and higher energy usage during the summer season. (EEI, No. 13 at p. 4) Although RECS does not report the precise location of the refrigerator, it does identify whether a household has a second refrigerator. For those households with two refrigerators, DOE estimated that the second unit is located in either the garage or the basement. DOE accounted for

[c] This is the most recent RECS.

the operating conditions of units located in such unconditioned areas in its calculation of the energy use of second refrigerators.

EEI stated that DOE should be careful when estimating the energy usage of compact equipment, especially since these units are more likely to be shut off most of the time (used only on social occasions) or used on a seasonal basis (e.g., college dormitories) compared to full-size units. (EEI, No. 13 at p. 4) Because DOE was not able to find suitable data on the field use of compact refrigerators and freezers, it used the DOE test procedure to calculate the annual energy use of products of different volume, and estimated the distribution of volumes in the field using model data from the California Energy Commission appliance database.[2]

In calculating energy consumption of refrigeration products, DOE considered whether it would be appropriate to include a rebound effect (also called a take-back effect), which refers to the increased energy consumption resulting from actions that increase energy efficiency and reduce consumer costs. The rebound effect assumes that consumers give up some of the potential energy savings to receive more service. AHAM stated that the rebound effect does not impact the refrigeration market because most consumers have fixed kitchen space for a refrigeration unit, so purchasing a larger unit is not possible, and refrigerator size is a function of life stage, rather than operating cost. (AHAM, No. 11 at p. 8) Whirlpool and EEI agreed with AHAM's perspective. (Whirlpool, No. 17 at p. 9; EEI, No. 13 at p. 4) DOE agrees that there is no evidence of a direct rebound effect for refrigeration products and it does not plan to include a rebound effect in its analysis.

Chapter 7 of the preliminary TSD provides more detail about DOE's approach for characterizing energy use of refrigeration products.

2.7 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

New energy conservation standards affect products' operating expenses—usually decreasing them—and consumer prices for the products—usually increasing them. DOE analyzed the net effect of amended standards on consumers by evaluating the net LCC. To evaluate the net LCC, DOE used the cost-efficiency relationship derived in the engineering analysis, along with the energy costs derived from the energy use characterization. Inputs to the LCC calculation include the installed cost of a product to the consumer (consumer purchase price plus installation cost), operating expenses (energy expenses and maintenance costs), the lifetime of the unit, and a discount rate.

Because the installed cost of a product typically increases while operating cost typically decreases in response to new standards, there is a time in the life of products having higher-than-baseline efficiency when the net operating-cost benefit (in dollars) since the time of purchase is equal to the incremental first cost of purchasing the higher-efficiency product. The length of time required for products to reach this cost-equivalence point is known as the payback period (PBP).

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analysis by modeling both the uncertainty and variability in the inputs using Monte Carlo simulation and probability distributions. DOE developed LCC and PBP spreadsheet models incorporating both Monte Carlo simulation and probability distributions by using Microsoft Excel spreadsheets combined with Crystal Ball (a commercially available add-in program).

As described above in section 2.6, DOE developed samples of individual households that use standard-size refrigeration products. By developing household samples, DOE was able to perform the LCC and PBP calculations for each household to account for the variability in energy consumption and electricity price associated with each household. As noted above, DOE did not develop a household sample for compact refrigerators and freezers since a large number of such products are used in lodging, dormitories and other commercial establishments. DOE identified several other input values for estimating the LCC, including: retail prices; discount rates; and product lifetimes. DOE characterized these values with probability distributions.

DOE developed discount rates separately for residential consumers and commercial consumers. Because some compact refrigerators and freezers are used in commercial applications, DOE developed commercial discount rates and for those commercial consumers that purchase compact refrigerators and freezers. DOE developed discount rates from estimates of the interest rate, or finance cost, applied to purchases of residential and commercial products. Following accepted principles of financial theory, the finance cost of raising funds to purchase such products can be interpreted as: (1) the financial cost of any debt incurred to purchase products, principally interest charges on debt; or (2) the opportunity cost of any equity used to purchase products, principally interest earnings on household equity.

2.7.1 Retail Prices

As described in section 2.5, DOE used markups to convert the manufacturer selling prices estimated in the engineering analysis to customer retail prices for the LCC and PBP analysis. The Joint Comment stated that analysis of past refrigerator standards has demonstrated that DOE has overestimated the increase in prices resulting from energy efficiency standards, and that DOE should revise its methodology or develop a correction factor for this rulemaking. (Joint Comment, No. 10 at p. 5) DOE recognizes that every change in minimum energy conservation standards is an opportunity for manufacturers to make investments beyond what would be required to meet the new standards in order to minimize the costs or to respond to other factors. DOE's manufacturing cost estimates, MIA interviews, and the GRIM analysis (which is conducted for DOE's NOPR) seek to gauge the most likely industry response to proposed energy conservation standards. DOE's analysis of responses must be based on currently available technology that will be non-proprietary when a rulemaking becomes effective, and thus cannot speculate on future product and market innovation.

2.7.2 Energy Prices

DOE used EIA's energy price data to determine residential and commercial prices of electricity in 2007 in 13 geographic areas. DOE used projections of those energy prices from EIA's *Annual Energy Outlook 2009* (AEO 2009) to estimate future energy prices.[3] The Joint Comment recommended that DOE conduct a sensitivity analysis using a basket of other forecasts besides the AEO, as the AEO has estimated lower electricity prices than most other forecasts. (Joint Comment, No. 10 at p. 6) DOE conducts sensitivity analysis using alternative AEO forecasts in addition to the AEO reference forecast. These alternative forecasts reflect different assumptions with respect to economic growth and other factors. In general, the range of AEO forecasts brackets long-run energy price forecasts made by other organizations.

The Joint Comment stated that DOE should consider consumers' actual benefit of saving electricity at the margin rather than use the annual average cost of electricity. They noted that due to block rate structures used in some states, the last kWh of variable charges may be significantly higher than the annual average residential rate per kWh. (Joint Comment, No. 10 at p. 6) DOE did not use marginal energy prices in the current analysis because for a base load appliance such as residential refrigeration there is little difference between marginal and average prices. While it is true that many utilities use ascending block rate tariffs, the effect this has on the difference between marginal and average prices is offset by two other features of rate structures: first, residential consumers tend to pay relatively high fixed charges, which raises the average price relative to the marginal energy price; second, seasonal rates are also very common, with summer rates typically higher, and winter rates lower, than the average (this may be reversed in winter-peaking regions). As refrigerator energy use is not seasonal, over the year the rate differences average out. These arguments help explain why there is not a large difference between marginal and average prices. However, DOE bases its decision for which price to use on a review of the available data. In particular, analysis of the Edison Electric Institute Typical Bills and Average Rates Reports for summer and winter 2008 confirms that, averaged over the year and over a wide customer base as is appropriate for refrigerators; marginal and average rates are approximately equal.[4,5]

2.7.3 Maintenance and Repair Costs

DOE considered expected changes to maintenance, repair, and installation costs for the products covered in this rulemaking. Typically, small incremental changes in product efficiency produce no, or only minor, changes in repair and maintenance costs over baseline efficiency products. Products having efficiencies that are significantly greater than baseline efficiencies can incur increased repair and maintenance costs since they are more likely to incorporate technologies that are new to the industry.

Whirlpool stated that maintenance, repair and installation (MRI) costs are, in part, a function of the complexity of the technology employed in the product and the experience level of the technicians repairing the product. Thus, if efficiency is improved through greater leverage of known technology, the assumption of little change in MRI costs is correct. However, if exotic new technologies are required to meet new efficiency levels, MRI costs could easily be double current levels. (Whirlpool, No. 17 at p. 10) DOE did not find data indicating increases in MRI costs associated with the efficiency levels considered in its analysis.

2.7.4 Product Lifetime

In DOE's October 2005 draft technical report analyzing potential new amended energy conservation standards for residential refrigerator-freezers,[6] an average product lifetime of 19 years was estimated based on information in DOE's 1995 TSD.[7] Whirlpool commented that the September 2007 issue of Appliance magazine shows an average life for refrigerators of 14 years, a low of 10 years and a high of 18 years, and that this is consistent with Whirlpool's experience. (Whirlpool, No. 17 at p. 10) The Joint Comment stated that 19 years is an accurate representation of the actual use of residential refrigerators; that many users continue to utilize their old refrigerators even after purchasing a new unit, while still others purchase used refrigerators to save up front costs; and that these factors work to increase the real product life such that DOE's assumption is reasonable. (Joint Comment, No. 10 at p. 6)

DOE found that the basis for the lifetime estimates in the literature for refrigerators and freezers is uncertain. Therefore, for standard-sized refrigerator-freezers and freezers, DOE conducted an analysis of actual lifetime in the field using a combination of shipments data and responses in RECS on the age of the refrigeration products in the homes. As described in Chapter 8, this analysis yielded an estimate of mean age for standard-sized refrigerator-freezers of approximately 17 years and for standard-sized freezers of approximately 22 years. It also yielded a survival function that DOE incorporated as a probability distribution in its LCC analysis. For compact refrigerators and freezers, DOE based the product lifetime on a combination of historical shipments, historical saturations in the housing stock, and historical saturations in the commercial building stock. As described in Chapter 8, this analysis yielded an estimate of mean age for compact refrigerators of 5 years and compact freezers of 7 years.

2.7.5 Product Energy Efficiency Distribution in the Base Case

To accurately estimate the share of consumers that would be affected by a standard at a particular efficiency level, DOE's LCC and PBP analysis considered the projected distribution of product efficiencies that consumers purchase under the base case (i.e., the case without new energy efficiency standards). DOE relied on data submitted by AHAM to estimate the base case efficiency distributions for each of the product classes that were analyzed in the LCC and PBP analysis. With respect to the distribution of future product energy efficiency in the absence of new standards, Whirlpool and EEI stated that the ENERGY STAR and the Consortium for Energy Efficiency (CEE) programs are well known and widely utilized by retailers, utilities and some state governments as voluntary market transformation programs, and that DOE should consider the future impacts of these programs in its base case projection. (Whirlpool, No. 17 at p. 11; EEI, No. 13 at p. 4) DOE agrees that the above programs are likely to affect the market and it projected an increase in the market share of ENERGY STAR appliances in the coming years for its base case forecast. Chapter 8 of the preliminary TSD provides more detail about DOE's approach for base case efficiency distributions.

2.8 NATIONAL IMPACT ANALYSIS

The national impact analysis assesses the net present value (NPV) of total consumer life-cycle cost (LCC) and net energy savings (NES) to the Nation. DOE determined both the NPV and NES for the performance levels considered for the product classes analyzed. To make the analysis more accessible and transparent to all interested parties, DOE prepared a Microsoft Excel spreadsheet model to forecast NES and the national consumer economic costs and savings resulting from new standards. The spreadsheet model uses as inputs typical values (as opposed to probability distributions). To assess the effect of input uncertainty on NES and NPV results, DOE may conduct sensitivity analyses by running scenarios on specific input variables.

2.8.1 Shipments Analysis

Forecasts of product shipments are needed to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE developed shipment forecasts based on an analysis of key market drivers for each considered product. In DOE's shipments model, shipments of products are driven by new construction as well as stock replacements.

The shipments models take an accounting approach, tracking market shares of each product class and the vintage of units in the existing stock. Stock accounting uses product shipments as inputs to estimate the age distribution of in-service product stocks for all years. The age distribution of in-service product stocks is a key input to calculations of both the NES and NPV, because operating costs for any year depend on the age distribution of the stock.

Chapter 9 of the preliminary TSD provides additional details on the shipments analysis.

Framework phase comments regarding the shipments analysis were limited to agreement by AHAM and manufacturers to support the data collection effort (e.g. AHAM, No. 11 at p. 9), and statements highlighting the success of voluntary programs such as ENERGY STAR and CEE (e.g. Whirlpool, No. 17 at p.11).

2.8.2 Efficiency Scenarios and Trends

Several of the inputs for determining NES and NPV depend on the product efficiency. DOE developed efficiency trends for the base case and standards cases. These trends specify the average annual historical and forecasted shipments-weighted product efficiencies.

In the framework document, DOE proposed to use a roll-up efficiency scenario in developing its forecasts of efficiency trends after standards take effect. Under a roll-up scenario, all products that perform at levels below a prospective standard are moved, or rolled-up, to the minimum performance level allowed under the standard. The distribution of products that meet the higher efficiency standard levels is unaffected.

The Joint Comment stated that historical data are likely to demonstrate that the roll-up scenario bears no resemblance to the historical record and should be dropped from the analysis.

It added that markets may respond with a very temporary situation where nearly all products just meet a new standards, but that it does not take long for a new distribution of efficiency performance above a new standard to emerge. The Joint Comment stated that over the analysis timeframe, a "shift" scenario is the dominant effect, and DOE should model a shift scenario that accounts for some time lag for the full shift effect to occur. (Joint Comment, No. 10 at p. 7) DOE agrees that the historical record suggests that the likely market response to new standards is that baseline models will roll-up to the standard efficiency level but some fraction of shipments will be above the minimum. In developing the energy efficiencies forecasted over time for each of the standards cases, DOE used a "roll-up + ENERGY STAR" scenario to establish the distribution of efficiencies for the year that revised standards are assumed to become effective (i.e., 2014) and subsequent years. In this scenario, product efficiencies in the base case that did not meet the standard level under consideration would roll-up to meet the new standard level in 2014. DOE assumed that new criteria would be established for ENERGY STAR refrigeration products, and that such products would gradually gain a larger market share. The details of the approach are described in Chapter 10.

2.8.3 National Energy Savings Analysis

The inputs for determining the national energy savings (NES) for each product analyzed are: (1) annual energy consumption per unit; (2) shipments; (3) product stock; (4) national energy consumption; and (5) site-to-source conversion factors. DOE calculated the national energy consumption by multiplying the number of units, or stock, of each product (by vintage, or age) by the unit energy consumption (also by vintage). DOE calculated annual NES based on the difference in national energy consumption for the base case (without new efficiency standards) and for each higher efficiency standard. DOE estimated energy consumption and savings based on site energy, and converted the electricity consumption and savings to source energy. Cumulative energy savings are the sum of the NES for each year.

The stock of a product is dependent on annual shipments and the lifetime of the product. DOE projected shipments under the base efficiency case and higher efficiency cases.

2.8.4 Net Present Value Analysis

The inputs for determining net present value (NPV) are: (1) total annual installed cost; (2) total annual savings in operating costs; (3) a discount factor; (4) present value of costs; and (5) present value of savings. DOE calculated net savings each year as the difference between the base case and each standards case in total savings in operating costs and total increases in installed costs. DOE calculated savings over the life of each product, accounting for differences in yearly energy rates. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3% and 7% to discount future costs and savings to present values.

The Joint Comment urged DOE to give primary weight to calculations based on the lower discount rate. The comment asserted that societal discount rates are the subject of extensive academic research, the weight of academic opinion is that the appropriate societal discount rate is 3% or less, and NRDC and others have presented evidence to support the adoption of a societal discount rate in the range of 2 to 3% real. (Joint Comment, No. 10 at p. 7)

DOE notes that OMB Circular A-4 references an earlier Circular A-94, which states that a real discount rate of 7 percent should be used as a base case for regulatory analysis. The 7-percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy. It approximates the opportunity cost of capital and, according to Circular A-94, is the appropriate discount rate whenever the main effect of a regulation is to displace or alter the use of capital in the private sector. OMB revised Circular A-94 in 1992 after extensive internal review and public comment. OMB found that the average rate of return to capital remains near the 7-percent rate estimated in 1992. Circular A-4 also states that when regulation primarily and directly affects private consumption, a lower discount rate is appropriate. "The alternative most often used is sometimes called the social rate of time preference…the rate at which 'society' discounts future consumption flows to their present value."[8] It suggests that the real rate of return on long-term government debt may provide a fair approximation of the social rate of time preference, and states that over the last 30 years, this rate has averaged around 3 percent in real terms on a pre-tax basis. It concludes that "for regulatory analysis, [agencies] should provide estimates of net benefits using both 3 percent and 7 percent."[9] Consistent with OMB guidance DOE did not give primary weight to results derived using a 3-percent discount rate.

DOE calculated increases in total installed costs as the difference in total installed cost between the base case and standards case (*i.e.*, once the standards take effect). Because the more efficient products bought in the standards case usually cost more than products bought in the base case, cost increases appear as negative values in the NPV.

DOE expressed savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the base efficiency case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

The national impacts analysis examines the potential economic impacts of alternative standard levels on consumers who purchase the products that meet each standard level. The Joint Comment stated that the electricity price mitigation effects of new standards on refrigeration products should be documented and the value of reduced electricity bills to all consumers quantified as a benefit. (Joint Comment, No. 10 at p. 6) DOE investigated the possibility of estimating the impact of specific standard levels on electricity prices in its rulemaking for general service fluorescent lamps and incadescent reflector lamps.[10] Whereas natural gas markets exhibit a fairly simple chain of agents from producers to consumers, the power industry is a complex mix of fuel suppliers, producers and distributors. While the distribution of electricity is regulated everywhere, its institutional structure varies, and upstream components are more complicated, with generation being priced using different methods across the country. For these and other reasons, accurate modeling of the response of electricity prices to a decrease in residential-sector demand due to standards is problematic. Thus, DOE does not plan to estimate the value of potentially reduced electricity costs for all consumers associated with revised standards.

Chapter 10 of the preliminary TSD provides additional details regarding the national impacts analysis.

2.9 LIFE-CYCLE COST SUBGROUP ANALYSIS

The LCC subgroup analysis evaluates economic impacts on selected groups of consumers who might be adversely affected by a change in the national energy conservation standards for the considered products. DOE evaluates impacts on particular subgroups of consumers primarily by analyzing the LCC impacts and PBP for those particular consumers.

AHAM stated that DOE should consider low-income households as a consumer subgroup, since refrigerators are not optional for consumers, and thus the impact of price increase on low-income and fixed-income consumers may be more pronounced than for products that are more discretionary. (AHAM, No. 11 at p. 9) DOE intends to evaluate impacts of standards on low-income and fixed-income (i.e., senior) consumers.

DOE will use the LCC spreadsheet model to evaluate impacts on consumer subgroups. DOE can analyze the LCC for any subgroup by applying the LCC spreadsheet model to only that subgroup. DOE is particularly sensitive to increases in the consumer price of the considered products, and seeks to avoid a negative economic impact on any identified consumer subgroup.

The Joint Comment stated that if the Department insists on analyzing sub-groups in the LCC analysis, it should not only quantify the effects on those that are more negatively affected, but also consider those sub-groups that are more positively affected, such as those that rent housing and have no choice in refrigerator efficiency, yet are forced to pay the energy bills. (Joint Comment, No. 10 at p. 7) It is unclear whether renters would be positively affected by revised standards, as the extent to which property owners (the purchasers of refrigerators in most cases) would pass on the higher cost of more-efficient products to tenants in the rent is uncertain. Therefore, DOE does not plan to analyze renters as a sub-group.

2.10 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

DOE performed a preliminary manufacturer impact analysis (MIA) to start to estimate the financial impact of higher energy conservation standards on manufacturers of residential refrigeration products, and calculate the impact of such standards on employment and manufacturing capacity. The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA relies on the government regulatory impact model (GRIM), an industry-cash-flow model customized for this industry. The GRIM inputs are information regarding the industry cost structure, shipments, and revenues. This includes information from many of the analyses described above, such as manufacturing costs and prices from the engineering analysis and shipments forecasts. The key GRIM output is the industry net present value (NPV). Different sets of assumptions (scenarios) will produce different results. The qualitative part of the MIA addresses factors such as equipment characteristics, characteristics of particular firms, and market and equipment trends, and includes assessment of the impacts of standards on subgroups of manufacturers. The complete preliminary MIA is described in chapter 12 of the preliminary TSD.

DOE will conduct the MIA in this rulemaking in three phases, and will further tailor the analytical framework for the MIA based on comments from interested parties. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and an interview questionnaire to guide subsequent discussions. In Phase III, DOE interviews manufacturers, and assesses the impacts of standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flow and NPV using the GRIM. DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

Until recently, DOE reported MIA results in its standards rulemakings only during the NOPR phase of the rulemaking. However, DOE is now evaluating and reporting preliminary MIA information in this preliminary analysis. DOE gathered this information during the preliminary manufacturer interviews conducted for the engineering analysis.

In response to the process outlined in the framework document for conducting the MIA, DOE received comments on the cumulative regulatory burden faced by the industry as a whole and by small, niche manufacturers in particular. Specifically, manufacturers and trade associations expressed concern over potential climate change legislation that would regulate or eliminate the use of HFCs, the regulation of refrigerants through the Environmental Protection Agency (EPA), and the regulation of potential alternative refrigerants through safety standards from organizations such as UL.

AHAM, GE, and Whirlpool all stated that DOE should consider the effects of potential climate change legislation within its analyses. All three organizations also believe that regulations restricting use of refrigerants and foam-blowing agents could be enacted by EPA in the absence of climate change legislation. This could present a major problem to manufacturers because the use of the most likely alternative refrigerant, R-600a, is currently restricted, due to safety concerns, by UL. (AHAM, No. 11 at p. 9, Public Meeting Transcript, No. 7 at pp. 116-117 and at pp. 182-183; GE, No. 15 at pp. 1-2; and Whirlpool, No. 17 at pp. 11-12)

DOE agrees that potential climate change legislation and potential regulations and restrictions by EPA would present significant challenges to refrigeration products manufacturers. If these kinds of regulations were passed before the final rule for refrigeration products, DOE would consider them in its analysis of cumulative regulatory burden during this rulemaking. However, DOE cannot, either when determining new energy conservation standards or when considering the cumulative regulatory impact of such standards, factor unenacted legislation or rules that have not yet been finalized into its analysis. DOE recognizes the substantial impact that climate change and other regulations would pose for the refrigeration products industry. DOE will consider conducting analyses addressing the impacts of the use of alternative refrigerants and foam-blowing agents possibly required by such legislation or regulations, in order to be prepared to adjust analysis results appropriately should such climate change legislation be enacted or rules be finalized during the rulemaking process. This issue is discussed also in section 2.3.2 and in chapter 12.

As part of the preliminary MIA, DOE asked manufacturers about the potential impacts of amended energy conservation standards on their business, employment levels, market share, and competitive positions within the marketplace. Manufacturers stated that conversion costs are a concern and they anticipate that significant product modifications resulting in the need for new production facilities will drive production outside of the U.S. and substantially lower domestic employment levels. Additionally, manufacturers expressed some concern about competitive position and potential industry consolidation as a result of amended energy conservation standards. As part of the NOPR phase of the rulemaking, DOE will further analyze these concerns and seek further comments from manufacturers about conversion costs and profitability. DOE will then estimate both the qualitative and quantitative impacts on the refrigeration products industry.

The following is an overview of the information DOE will collect and the analysis that will be conducted during the MIA. For more detail, see chapter 12 of the preliminary TSD.

2.10.1 Industry Cash-Flow Analysis

The industry cash-flow analysis relies primarily on the GRIM. DOE uses the GRIM to analyze the financial impacts of more stringent energy conservation standards on the industry that produces the products covered by the standard. The GRIM analysis uses many factors to determine annual cash flows from a new standard: annual expected revenues; manufacturer costs, including cost of goods sold, depreciation, research and development, selling, general, and administrative expenses; taxes; and conversion capital expenditures. DOE compares the results against base-case projections that involve no new standards. The financial impact of new standards is then the difference between the two sets of discounted annual cash flows. Other performance metrics, such as return on invested capital, are also available from the GRIM. For more information on the industry cash-flow analysis, refer to chapter 12 of the preliminary TSD.

2.10.2 Manufacturer Subgroup Analysis

Industry cost estimates are not adequate to assess differential impacts among subgroups of manufacturers. For example, small and niche manufacturers, or manufacturers whose cost structure differs significantly from the industry average, could experience a more negative impact from the imposition of standards. Ideally, DOE would consider the impact on every firm individually; however, since this usually is not possible, DOE typically uses the results of the industry characterization to group manufacturers exhibiting similar characteristics.

DOE outlined the process it uses to establish manufacturer subgroups in the framework document and sought comment from interested parties on any potential subgroups within the refrigeration products industries. AHAM and Whirlpool both commented that small, niche manufacturers should be considered because they have less access to the resources needed to develop, implement, and market newer technologies, such as alternative refrigerants. (AHAM, No. 11 at p. 9; Whirlpool, No. 17 at p. 11)

Currently, DOE is characterizing the impacts on residential refrigeration products on the residential refrigeration industry. DOE did not identify any manufacturer subgroups within the industry other than small manufacturers. DOE will consider the possibility of small businesses being affected by the promulgation of amended energy conservation standards for residential refrigeration products. DOE identified a handful of small businesses within the industry in chapter 3 of the preliminary TSD. During the manufacturer interview process conducted as part of the NOPR, DOE will discuss the potential subgroups and subgroup members it has identified for the analysis. DOE will encourage the manufacturers to recommend subgroups or characteristics that are appropriate for the subgroup analysis. For more detail on the manufacturer subgroup analysis, see chapter 12 of the preliminary TSD.

2.10.3 Competitive Impacts Assessment

DOE must also consider whether a new standard is likely to reduce industry competition, and the Attorney General must determine the impacts, if any, of any reduced competition. DOE will make a determined effort to gather and report firm-specific financial information and impacts. The competitive impacts assessment will focus on assessing the impacts on smaller manufacturers. DOE will base this assessment on manufacturing cost data and information collected from interviews with manufacturers. The manufacturer interviews will focus on gathering information to help assess asymmetrical cost increases to some manufacturers, increased proportion of fixed costs potentially increasing business risks, and potential barriers to market entry (e.g., proprietary technologies). The NOPR will be submitted to the Attorney General for a review of the impacts of standards on competition. The Attorney General's comments on the proposed rule will be considered in preparing the final rule.

2.10.4 Cumulative Regulatory Burden

DOE recognizes and seeks to mitigate the overlapping effects on manufacturers of new or revised DOE standards and other regulatory actions affecting the same equipment. DOE will analyze and consider the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified several regulations relevant to residential refrigeration products, including potential climate change and greenhouse gas legislation.

DOE outlined the cumulative regulatory burden process in the framework document and sought comment from interested parties on any additional regulations facing the residential refrigeration products industry. In response to the cumulative regulatory burden discussion in the framework document, AHAM, Whirlpool, and GE all commented that DOE should consider the effect of potential climate change regulation. (AHAM, Public Meeting Transcript, No. 7 at pp. 116-117 and pp. 182-183, No. 11 at p. 9; Whirlpool, No. 17 at pp. 11-12; GE, No. 15 at pp. 1-2)

As stated in section 2.3.2, DOE cannot consider in its cumulative regulatory burden analysis any legislation that has not yet been enacted or any new rules that have not been finalized. However, DOE recognizes the impact that such legislation or rules could have to DOE's rulemaking schedule and the challenge it presents to manufacturers. For these reasons, DOE will consider conducting additional analyses, addressing use of alternative foam-blowing agents, to allow adjustment of the analysis results in the case that such climate change legislation is enacted during the rulemaking process.

DOE identified several other regulations relevant to refrigeration products manufacturers during interviews conducted as part of the manufacturing impact analysis. These issues included regulations from the Consumer Products Safety Commission (CPSC), new DOE test procedures for residential refrigeration products, amended energy conservation standards for other products manufactured by refrigeration products manufacturers, state energy conservation standards, and international energy conservation standards. All of these regulations and the potential climate change legislation are described further in Chapter 12.

2.10.5 Preliminary Results for the Manufacturer Impact Analysis

As part of the preliminary MIA, DOE discussed potential impacts of amended energy conservation standards with manufacturers of residential refrigeration products. These discussions took place during the interviews DOE conducted for the engineering analysis. The interviews provided valuable information that DOE will use to evaluate the impacts of amended energy conservation standards on manufacturers' cash flows, manufacturing capacities, and employment levels in subsequent phases of the MIA. DOE discusses its findings from the preliminary MIA interviews in the executive summary and in chapter 12 of the preliminary TSD.

2.11 UTILITY IMPACT ANALYSIS

The utility impact analysis includes an analysis of the effect of new energy conservation standards on the electric and the gas utility industries. For this analysis, DOE adapted NEMS, which is a large multi-sectoral, partial-equilibrium model of the U.S. energy sector that the EIA has developed throughout the past decade, primarily for preparing EIA's AEO. In previous rulemakings, a variant of NEMS (currently termed NEMS-BT, BT referring to DOE's Building Technologies Program), was developed to better address the specific impacts of an energy conservation standard.

NEMS, which is available in the public domain, produces a widely recognized baseline energy forecast for the United States through the year 2030. The typical NEMS outputs include forecasts of electricity sales, prices, and electric generating capacity. DOE conducts the utility impact analysis as a scenario that departs from the latest AEO reference case. In other words, the energy savings impacts from amended energy conservation standards are modeled using NEMS-BT to generate forecasts that deviate from the AEO reference case.

2.12 ENVIRONMENTAL IMPACT ANALYSIS

The intent of the environmental assessment is to fulfill requirements to properly quantify and consider the environmental effects of all new Federal rules. The primary environmental effects of energy conservation standards for heating products would be reduced power plant emissions resulting from reduced consumption of electricity. DOE will assess these environmental effects by using NEMS-BT to provide key inputs to its analysis. The portion of the environmental assessment that will be produced by NEMS-BT considers carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Hg).

DOE has preliminarily determined that SO_2 emissions from affected Electric Generating Units (EGUs) are subject to nationwide and regional emissions cap and trading programs that create uncertainty about standard's impact on SO_2 emissions. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for all affected EGUs. SO_2 emissions from 28 eastern States and the District of Columbia (D.C.) are also limited under the Clean Air Interstate Rule (CAIR, published in the *Federal Register* on May 12, 2005. 70 FR 25162 (May 12, 2005), which creates an allowance-based trading program that will gradually replace the Title IV program in those States and D.C.. (The recent legal history surrounding CAIR is discussed below.) The attainment of the emissions caps is flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. The standard could lead EGUs to trade allowances and increase SO_2 emissions that offset some or all SO_2 emissions reductions attributable to the standard. DOE is not certain that there will be reduced overall SO_2 emissions from the standards. The NEMS-BT modeling system that DOE plans to use to forecast emissions reductions currently indicates that no physical reductions in power sector emissions would occur for $SO_{2,.}$ However, remaining uncertainty prevents DOE from estimating SO_2 reductions from the standards at this time.

Even though DOE is not certain that there will be reduced overall emissions from the standard, there may be an economic benefit from reduced demand for SO_2 emission allowances. Electricity savings decrease the generation of SO_2 emissions from power production, which can lessen the need to purchase SO_2 emissions allowance credits, and thereby decrease the costs of complying with regulatory caps on emissions.

With regard to NO_x emissions, the U.S. Environmental Protection Agency (EPA) issued the Clean Air Interstate Rule (CAIR) on March 10, 2005. 70 FR 25162 (May 12, 2005). On July 11, 2008, the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) issued its decision in *North Carolina v. Environmental Protection Agency*, in which the court vacated the CAIR and remanded to EPA to promulgate a rule consistent with the court's opinion. 531 F.3d 896 (D.C. Cir. 2008). If left in place, the CAIR would have permanently capped emissions of NO_x in 28 eastern States and the District of Columbia. However, upon consideration of petitions for review, the D.C. Circuit decided on December 23, 2008 to allow CAIR to remain in effect until it is replaced by a rule consistent with the court's earlier opinion. *North Carolina v. EnvironmentalProtection Agency*, 550 F.3d 1176 (D.C. Cir. 2008). Therefore, DOE's Environmental Analysis is based on CAIR, pending revision by EPA. See www.epa.gov/cleanairinterstaterule.

Similarly, for Hg emissions, the EPA issued the Clean Air Mercury Rule (CAMR). 70 FR 28606 (May 18, 2005). CAMR would have permanently capped emissions of mercury for new and existing coal-fired power plants in all States by 2010. However, on February 8, 2008, the D.C. Circuit issued its decision in *New Jersey v. Environmental Protection Agency*, in which the D.C. Circuit, among other actions, vacated the CAMR. 517 F.3d 574 (D.C. Cir. 2008). EPA has decided to develop emissions standards for power plants under the Clean Air Act (Section 112), consistent with the D.C. Circuit's opinion on the Clean Air Mercury Rule (CAMR). See http://www.epa.gov/air/mercuryrule/pdfs/certpetition_withdrawal.pdf. Pending EPA's forthcoming revisions to the rule, DOE is excluding the CAMR from its Environmental Analysis.

Both with and without emissions caps, decreased power production at emitting power plants can have environmental-related economic benefits. When NO_x and Hg emissions are subject to emissions caps, electricity demand reductions may result in incremental changes in the prices of emissions allowances in cap-and-trade emissions markets rather than physical emissions reductions. When there are physical emissions reductions, economic benefits can accrue from the decreased environmental damage from lower emissions. Therefore, both with and without emissions caps, standards can produce an environmental-related economic benefit in the form of lower prices for emissions allowance credits or a monetary value of the economic benefits of lower emissions. Therefore in addition to potential physical emissions reductions, DOE will examine the potential monetary value of NO_x and Hg benefits that may arise from a standard. DOE has used updated estimate(s) of the value of avoided NO_x and Hg emissions in recent DOE efficiency standards rulemakings. These estimates are summarized in the environmental assessment in the preliminary TSD.

The results for the environmental assessment are similar to NEMS results as published in the AEO. These results include power sector emissions for SO_2, NO_x, Hg, and CO_2 in five-year forecasted increments. The outcome of the analysis for each analyzed standard level will be reported as a deviation from the AEO 2009 reference (base) case.

EEI stated that DOE should account for the rise in renewable portfolio standards and the possibility of an upcoming CO_2 cap and trade program, which would reduce the amount of CO_2 produced per kWh generated. (EEI, No. 13 at p. 5) As stated above, DOE utilizes the most recent forecasts from EIA's NEMS to estimate the future mix of power generation sources. EIA accounts for policies that have been enacted at the time of its analysis, including renewable portfolio standards and regional cap and trade programs, and DOE believes that this approach provides the most reliable basis for estimating future power sector emissions.

NRDC stated that since climate change legislation is extremely likely to be enacted by 2014, which would place limits on CO_2 levels, the analyses should monetize the value of avoided

CO_2. (NRDC, No. 7 at p. 118) The Joint Comment agreed, stating that the analyses cannot be considered accurate descriptions of economic justification for standard setting until a realistic value for avoided CO_2 emissions is included. It suggested that DOE utilize carbon values from EIA's analysis of climate legislation proposed in Congress. (Joint Comment, No. 10 at p. 8) Whirlpool argued against using values for avoided CO_2 in DOE's analysis, stating that projected market values are too uncertain. (Whirlpool, No. 17 at p. 13) DOE has used updated estimate(s) of the value of avoided CO_2 emissions in recent efficiency standards rulemakings. These estimates are summarized in the environmental assessment in the preliminary TSD.

EEI stated that the environmental assessment should consider emissions created during equipment production and delivery, taking account of emissions where the appliances are produced. (EEI, No. 13 at p. 5) EPCA directs DOE to consider the projected amount of energy savings likely to result directly from imposition of the standard. (42 U.S.C. 6295(o)(2)(B)(i)) As emissions created during appliance production and delivery are not considered a direct impact of standards, DOE does not plan to include such emissions in its analysis.

For more detail on the environmental assessment, refer to the environmental assessment report in the preliminary TSD.

2.13 EMPLOYMENT IMPACT ANALYSIS

The imposition of standards can affect employment both directly and indirectly. Direct employment impacts are changes, produced by new standards, in the number of employees at plants that produce the covered products and at the affiliated distribution and service companies. DOE evaluated direct employment impacts in the manufacturer impact analysis. Indirect employment impacts that occur because of the imposition of standards may result from consumers shifting expenditures between goods (the substitution effect) and from changes in income and overall expenditure levels (the income effect). DOE will utilize Pacific Northwest National Laboratory's impact of sector energy technologies (ImSET) model to investigate the combined direct and indirect employment impacts. The ImSET model, which was developed for DOE's Office of Planning, Budget, and Analysis, estimates the employment and income effects energy-saving technologies produced in buildings, industry, and transportation. In comparison with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments.

2.14 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE will prepare a regulatory impact analysis (RIA) pursuant to Executive Order 12866, Regulatory Planning and Review, 58 FR 51735, October 4, 1993, which is subject to review under the Executive Order by the Office of Information and Regulatory Affairs at the Office of Management and Budget. The RIA addresses the potential for non-regulatory approaches to supplant or augment energy conservation standards in order to improve the energy efficiency or reduce the energy consumption of the products covered under this rulemaking.

DOE recognizes that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties can substantially affect energy efficiency or reduce energy consumption. DOE will base its assessment on the actual impacts of any such initiatives to date, but also will consider information presented by interested parties regarding the impacts existing initiatives might have in the future.

2.15 DEVELOPMENT OF STANDARDS FOR LOW-VOLUME PRODUCT CLASSES

DOE conducted rigorous analysis of seven key product classes which represent over 90 percent of refrigeration product shipments. This section addresses the treatment of low-volume product classes. As presented in Table 2.15.1 through Table 2.15.3 below, DOE proposes to develop energy conservation standards for these product classes by extrapolating from the results for the seven key product classes. In this specific case of product class 3A, Figure 2.15.1 illustrates that all-refrigerators with automatic defrost of this proposed product class appear to currently have a less stringent standard than refrigerator-freezers with top-mounted freezers—both of these product types currently are part of product class 3. The plot shows that ENERGY STAR models categorized under product class 3 have a distinctly higher energy use than ENERGY STAR models that fall under the proposed product class 3A.

Table 2.15.1 Extrapolation of Standards for Standard-Size Refrigerators and Refrigerator-Freezers

Product Class	Proposed Approach to Development of Energy Conservation Standards	Notes and Comments
1	Reduction of standard if needed so that product class 1 energy use is no higher than energy use of product class 3. Otherwise no change.	The product class 1 energy standard is currently roughly 11% lower than the standard for product class 3. AHAM data show that product classes 1 and 2 accounted for 0.1% of shipments of refrigerators, refrigerator-freezers, and freezers in 2007.
1A	Establish the standard with the same percentage adjustment as for product class 1.	As discussed in section 5.7.4 of the Engineering Analysis (chapter 5), the baseline-efficiency energy use under the proposed test procedure for product class 1A is less than the energy use for product class 1. The future energy standard for product class 1A would likewise be less.
2	Combine this product class with product class 1.	The energy standards for product classes 1 and 2 are currently identical, and shipments of these products are very low.
3A	Establish the standard with the same percentage adjustment as for product class 3.	The baseline-efficiency energy use under the proposed test procedure for product class 3A is less than the energy use for product class 3. The future energy standard for product class 3A would likewise be less. The current product class 3 standard is less stringent for all-refrigerators than for top-mount refrigerator-freezers, as indicated by the availability only of all-refrigerators of this product class with efficiency level higher than 20% in the ENERGY STAR database (see Figure 2.15.1). Hence, all-refrigerators are expected to achieve the same reduction in energy use with no reduction in cost-effectiveness.
4	Establish the standard with the same percentage adjustment as for product class 7, with some consideration of adjustment of the slope of the energy/adjusted volume relationship.	See section 5.4.2.3 of the Engineering Analysis (chapter 5) for a discussion of the investigation of the energy/adjusted volume slope.
5A	Establish the standard with the same percentage adjustment as for product class 5.	
6	Establish the standard with the same percentage adjustment as for product class 3.	

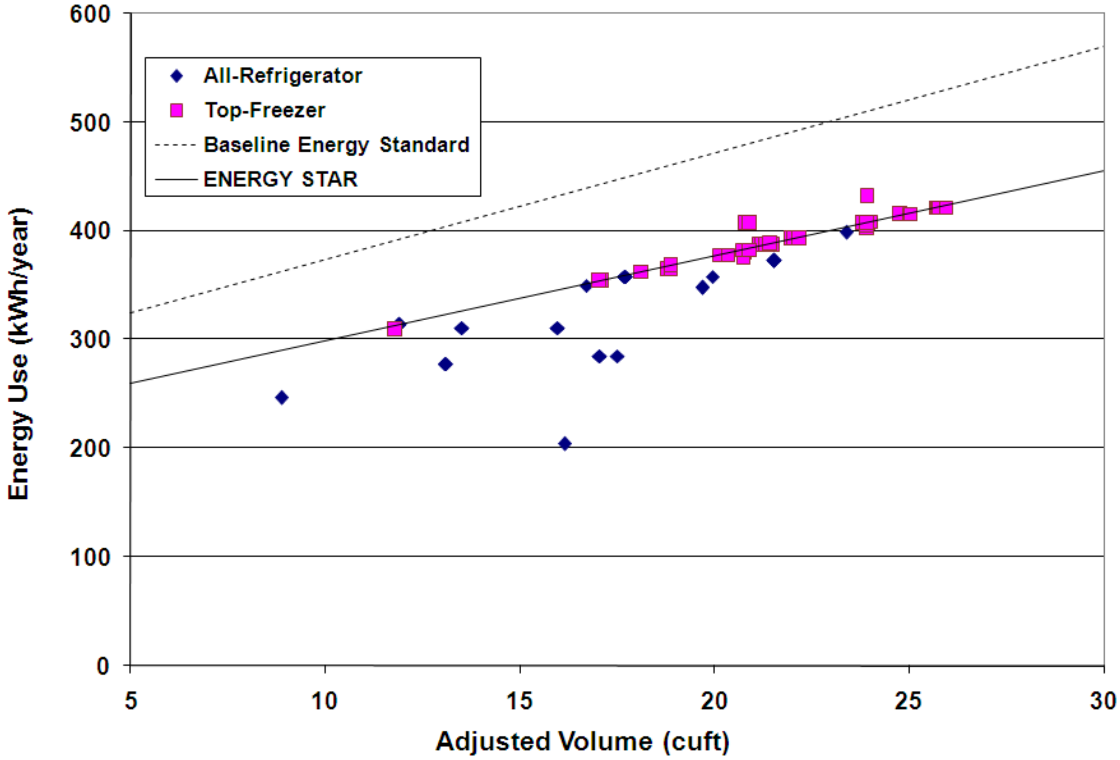

Figure 2.15.1 Current Product Class 3 Products Listed in the ENERGY STAR Database

Table 2.15.2 Extrapolation of Standards for Standard-Size Freezers

Product Class	Proposed Approach to Development of Energy Conservation Standards	Notes and Comments
8	Establish the standard with the same percentage adjustment as for product class 10.	Although product class 8 freezers are upright freezers, they have manual defrost, making them more similar to product class 10 (primarily chest freezers with manual defrost) than product class 9 (upright freezers with automatic defrost). The current energy standard for product class 8 is also is much closer to that of product class 10 than product class 9.
10A	Establish the standard equal to the standard for product class 10 plus the automatic defrost differential of the energy standards for the two types of upright freezers (product class 9 and product class 8).	This is the approach used in the exception granted to Electrolux when the company initially introduced an automatic defrost chest freezer.[d]

[d] *Decision and Order, Electrolux Home Products, Inc.*, Office of Hearings and Appeals, September 13, 2004, (Last accessed July 23, 2009.), www.oha.doe.gov/cases/ee/tee0012.pdf

Table 2.15.3 Extrapolation of Standards for Compact Refrigerators, Refrigerator-Freezers, and Freezers

Product Class	Proposed Approach to Development of Energy Conservation Standards	Notes and Comments
11A	Establish the standard with the same percentage adjustment as for product class 11.	The baseline-efficiency energy use under the proposed test procedure for product class 11A is less than the energy use for product class 11. The future energy standard for product class 11A would likewise be less.
12	Combine this product class with product class 11.	Product class 12 currently has a different energy standard than product class 11 (it is 20 to 25% higher, depending on volume), while for standard-size products, the manual defrost and partial automatic defrost products have the same energy standard (product classes 1 and 2). The only product class 12 products DOE is aware of have energy use about 30% below the standard (i.e. Microfridge MFR-3, Absocold ARD298C), suggesting that the product classes could be combined.
13	Establish the standard with the same percentage adjustment as for product class 18.	Large energy use reductions are not likely cost-effective for these products because they have low production volume, hence the incremental cost relationship of compact freezers is more likely representative than that of product class 11.
13A	Establish the standard with the same percentage adjustment as for product class 13.	Many existing product class 13 products are all-refrigerators with automatic defrost. The Energy Star database has no product class 13 products which are top-mount rather than all-refrigerator. As with product class 3 and 3A, it is expected that achieving efficiency improvement for product class 13A will be no less cost-effective than for product class 13.
14 15	Establish the standard with the same percentage adjustment as for product class 13.	These product classes combined account for only 0.1% of shipments of refrigeration products according to AHAM data.
16 17	Establish the standard with the same percentage adjustment as for product class 18.	

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CHAPTER 3: MARKET AND TECHNOLOGY ASSESSMENT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This report provides a profile of the residential refrigerator and freezer product industries in the United States. The U.S. Department of Energy (DOE) developed the preliminary market and technology assessment presented in this chapter primarily from publicly available information. This assessment identifies the major manufacturers and their product characteristics, which form the basis for the engineering and the life-cycle cost (LCC) analyses. Present and past industry structure and industry financial information help DOE in the process of conducting the manufacturer impact analysis.

3.1.1 Product Definitions

3.1.1.1 Refrigerators, Refrigerator-Freezers, and Freezers

The Code of Federal Regulations (CFR) establishes the product definitions for refrigerators, refrigerator-freezers, and freezers as follows:[1]

- The term *Refrigerator* means an electric refrigerator and the term *Refrigerator-freezer* means an electric refrigerator-freezer.

- *Electric refrigerator* means a cabinet designed for the refrigerated storage of food at temperatures above 32 degrees Fahrenheit (°F) and below 39 °F, configured for general refrigerated food storage, and having a source of refrigeration requiring single phase, alternating current electric energy input only. An electric refrigerator may include a compartment for freezing and storage of food at temperatures below 32 °F, but does not provide a separate low temperature compartment designed for the freezing and storage of food at temperatures below 8 °F.

- *Electric refrigerator-freezer* means a cabinet which consists of two or more compartments with at least one of the compartments designed for the refrigerated storage of food at temperatures above 32 °F. and with at least one of the compartments designed for the freezing and storage of food at temperatures below 8 °F. which may be adjusted by the user to a temperature of 0 °F. or below. The source of refrigeration requires single phase, alternating current electric energy input only.

- *Compact refrigerator, refrigerator-freezer, and freezer* means any refrigerator, refrigerator-freezer or freezer with total volume less than 7.75 ft^3 (220 L) and 36 inches (0.91 meters) or less in height.

- *Freezer* means a cabinet designed as a unit for the freezing and storage of food at temperatures of 0 °F or below, and having a source of refrigeration requiring single phase, alternating current electric energy input only.

3.1.1.2 Wine Coolers

DOE amended the definition of "electric refrigerator", effective December 19, 2001, to include a maximum temperature of the fresh food storage compartment, and to exclude certain appliances whose physical configuration makes them unsuitable for general storage of perishable foods.[2] Because wines coolers maintain storage temperature above 39 ºF, they are exempted from existing refrigerator product classifications and are not required to meet minimum efficiency standards.

3.2 MARKET ASSESSMENT

3.2.1 Product Classes

3.2.1.1 Product Classes Listed in the CFR

The CFR establishes the product classes for refrigerators, refrigerator-freezers, and freezers.[3] As per the CFR, there are 18 product classes. The product classes are based on the following characteristics: type of unit (refrigerator, refrigerator-freezer, or freezer), size of the cabinet (standard or compact), type of defrost system (manual, partial, or automatic), presence or absence of through-the-door (TTD) ice service, and placement of the fresh food and freezer compartments for refrigerator-freezers.

DOE established separate product classes for compact products (<220 L or <7.75 ft^3) because fewer opportunities are available for reducing energy consumption in these products. Space is limited in compact units, so increasing the wall thickness is undesirable. Limited high-efficiency compressor options are available in the capacity ranges appropriate for compact refrigerators. These units typically use natural convection evaporators and condensers and, therefore, cannot employ better fan motors as an energy-saving option.

3.2.1.2 Product Classes Modifications

Table 3.2.1 below shows six proposed new product classes. Two of these new product classes, currently called product class 5A, automatic defrost refrigerator-freezers with bottom-mounted freezer with TTD ice service, and product class 10A, chest freezers with automatic defrost, were identified in the framework document as product classes 19 and 20. DOE proposes to establish these two new product classes pursuant to its decision order to grant exemptions to standards for these specific product categories. DOE will adopt the product class designations for these products which have been adopted by Canada in order to maintain international consistency. The additional new product classes are all-refrigerator products which are proposed to be separated from their current product classes which currently include refrigerators with freezer compartments, refrigerator-freezers, and/or all-refrigerators. The proposed test procedure changes described in section 3.2.2.7 will result in significantly higher energy use for refrigerators with freezer compartments and refrigerator-freezers and somewhat less energy use for all-refrigerators. Hence, maintaining meaningful but fair energy standards requires the separation of all-refrigerators from the other product types.

DOE's Office of Hearings and Appeals granted four exceptions for refrigerator-freezer products with bottom-mounted freezer and TTD ice service, to Maytag Corporation (Maytag), LG Electronics, Inc. (LG), Samsung Electronics, and Electrolux Home Products. DOE granted Maytag its exception on August 11, 2005 (case number TEE-0022), LG's exception on November 9, 2005 (case number TEE-0025), Samsung's exception on July 26, 2007 (case number TEE-0047) and Electrolux's exception on December, 2008 (case number TEE-0056). Before these rulings, there was no appropriately-defined category for this type of product, since the minimum standard for product class 5 (refrigerator-freezers with automatic defrost with bottom-mounted freezer without TTD ice service) was established to cover only products without TTD ice-service at the time of its development. The actual energy consumption of this new product (i.e., with TTD ice-service) is higher than that of product class 5 due to the added heat loss through the door to the fresh-food space, the reduced temperatures of the space reserved in the fresh food compartment for ice storage, which is maintained at lower temperatures than the rest of the fresh food compartment, and the energy consumed by the fan used to cool the space used for ice production and storage.

DOE's Office of Hearings and Appeals granted an exception to Electrolux Home Products (Electrolux) for a specific brand of chest freezer with automatic defrost (case number TEE-0012). The Association of Home Appliance Manufacturers (AHAM) filed a letter supporting this exemption and recommended that DOE use the direct final rule process to establish a new class of chest freezers that would correspond to the minimum efficiency standard for automatic defrost chest freezers. The minimum standard for product class 10 (chest freezers and all other freezers) was established to cover products without automatic defrost at the time of its development. The actual energy consumption of the new product (i.e., with automatic defrost) is higher than that of product class 10 due to the added energy consumption associated with the automatic defrost system.

DOE is considering combining product classes 1 and 2 and also combining product classes 11 and 12. The shipment levels for product classes 1 and 2 are low and the energy conservation standards for these products are currently identical. The shipments for product class 12 are also very low. Although the standard for product classes 12 is currently at a higher energy level than for product class 12, there is no obvious technical basis for this distinction. The key difference between these classes is that product class 12 includes only refrigerator-freezers with partial automatic defrost. These systems have a manual defrost evaporator for the freezer compartment (as do refrigerator-freezers of product class 11), and they also include a second evaporator in the fresh food compartment which undergoes off-cycle defrost, a process which involves no addition of energy to achieve defrost.

Table 3.2.1 Product Classes for Refrigerators, Refrigerator-Freezers, and Freezers

No.	Product Class
Classes listed in the CFR	
1	Refrigerators and refrigerator-freezers with manual defrost
2	Refrigerator-freezers—partial automatic defrost
3	Refrigerator-freezers—automatic defrost with top-mounted freezer without through-the-door ice service
4	Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service
5	Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service
6	Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service
7	Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service
8	Upright freezers with manual defrost
9	Upright freezers with automatic defrost
10	Chest freezers and all other freezers except compact freezers
11	Compact refrigerators and refrigerator-freezers with manual defrost
12	Compact refrigerator-freezers—partial automatic defrost
13	Compact refrigerator-freezers—automatic defrost with top-mounted freezer
14	Compact refrigerator-freezers—automatic defrost with side-mounted freezer
15	Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer
16	Compact upright freezers with manual defrost
17	Compact upright freezers with automatic defrost
18	Compact chest freezers
Product Classes Proposed to be Established During this Rulemaking	
1A	All-refrigerators—manual defrost
3A	All-refrigerators—automatic defrost
5A	Refrigerator-freezers—automatic defrost with bottom-mounted freezer with TTD ice service
10A	Chest freezers with automatic defrost
11A	Compact all-refrigerators—manual defrost
13A	Compact all-refrigerators—automatic defrost

3.2.1.3 Bottom-Drawer Refrigerator-Freezers

Another product type that was recently on the market is a convertible bottom-drawer refrigerator-freezer where the bottom drawer can be used as either a freezer or a fresh food section.[4] This Haier product became active on the ENERGY STAR database in 2007 but is no longer for sale. It was classified as a side-mount refrigerator-freezer with TTD features (product class 7) by the ENERGY STAR program (discussed in section 3.7.1).[5]

3.2.2 Product Test Procedures

The CFR establishes the test procedures for refrigerators, refrigerator-freezers, and freezers. (10 CFR Part 430, Subpart B, Appendices A1 and B1) DOE recently addressed issues pertaining to defrost systems, wine cooling refrigeration products, anti-sweat heaters, chest freezers with automatic defrost, and refrigerator-freezers with bottom-mounted freezers incorporating through-the-door (TTD) features. Additional issues relevant to the test procedures include test result repeatability, references to an older version of the ANSI-AHAM HRF-1 test standard, circumvention, convertible bottom-drawer refrigerator-freezers and other configurations with more than two compartments, standby and off mode energy use, and international test procedure harmonization. The ongoing rulemaking to modify the test procedure addresses many of these issues.

3.2.2.1 New Defrost Systems

DOE published a direct final rule on March 7, 2003 which amended the test procedure for refrigerators and refrigerator-freezers to modify the test period for "long-time" and adaptive automatic defrost refrigerator-freezers. 68 FR 10957. This revision became effective in May 2003. The energy test for such refrigerators consists of two or three parts; the third part applies only to adaptive defrost refrigerators and is optional. The first part measures energy use not including defrost events, and the second measures the energy contribution associated with defrost. The measurement for this second part of the test originally was specified to start as the refrigerator-freezer initiates defrost during a compressor on cycle. The new test procedure allows for a delay between compressor shutdown and defrost initiation, allowing the evaporator to warm up somewhat before initiation of defrost, thus saving a portion of the defrost energy consumption.

3.2.2.2 Control of Anti-Sweat Heaters

DOE granted a test procedure waiver to General Electric Company (GE) for anti-sweat heaters with automatic controls. GE developed a new product line of refrigerator-freezers that have sensors to detect ambient temperature and humidity, allowing the control system to adjust the wattage of anti-sweat heaters to provide only enough heat to evaporate excess moisture. DOE awarded this waiver on February 27, 2008.[6] The waiver provides a method for determining the energy use of an adaptive anti-sweat heater. A similar waiver was granted to Whirlpool Corporation on May 5, 2009.[7] The ongoing test procedure rulemaking proposes a variable anti-sweat heater test procedure to address the GE waiver and the Whirlpool petition for waiver.

3.2.2.3 Testing of Combination Wine Storage--Freezer Products

As discussed in Section 3.1.1.2, DOE has modified the definition of refrigerators to exclude wine storage products. However, DOE has not modified the definition of refrigerator-freezers in a similar fashion to exclude products which combine a freezer compartment with a wine storage compartment. DOE granted a waiver to Liebherr Hausgeräte from the existing DOE test procedure for residential electric refrigerators and refrigerator-freezers, for Liebherr's combination wine storage-freezer line of appliances. According to the current definitions, these products are refrigerator-freezers. In granting the waiver, DOE requires that Liebherr test or rate its combination wine storage-freezer products using a modified procedure proposed by Liebherr in which the wine storage compartment temperature standardized temperature is 55 °F, and the freezer compartment standardized temperature is 5 °F. The wine storage compartment of units tested by this method must not be convertible to any other type of compartment, and must account for 50 percent or more of the total volume.[8] DOE expects to propose revision of the definition of refrigerator-freezer to exclude these products in the ongoing refrigeration product test procedure rulemaking. The establishment of Wine Storage product categories and classes thereof is discussed in Chapter 2.

3.2.2.4 Repeatability Issues for Testing Compact Refrigerators

Because of inconsistencies in test results for compact refrigerators, the National Institute of Standards and Technology (NIST) investigated repeatability issues and published a report entitled "Repeatability of Energy Consumption Test Results for Compact Refrigerators."[9] In addition, NIST participated in a task force formed by AHAM to revise their AHAM HRF-1, *Energy, Performance and Capacity of Household Refrigerators, Refrigerator-Freezers and Freezers* test procedure, which is referenced by the DOE test procedure. The latest version of AHAM's test procedure is now AHAM HRF-1-2008.[10] The existing DOE test procedure still references an older version of the AHAM test procedure, AHAM HRF-1-1979. DOE plans to amend the test procedure to reference the most recent version of AHAM HRF-1.

Recent versions of AHAM HRF-1 clarified that the distance between the rear wall of the test sample and the test room wall or simulated wall should be at the *minimum* distance recommended by the manufacturer's installation instructions. This is one of the issues mentioned in the NIST report. In contrast, the 1979 version of HRF-1 specified that this distance be "in accordance with the manufacturer's instructions." The AHAM HRF-1-2008 addresses, among other issues, simplification of determining cabinet compartment internal volume, another of the issues discussed in the NIST report.

3.2.2.5 Circumvention

Another issue that has been addressed by recent versions of AHAM HRF-1 is the use of controls or features in products that have the effect of circumventing or frustrating the objective of the test procedure. Some refrigerator-freezer models, for example, deactivate certain energy-using components during testing, resulting in a rated performance that is significantly different than actual field performance. EPCA requires that test procedures must be "reasonably designed to produce test results which measure energy efficiency, energy use, water use . . ., or estimated annual operating cost of a covered product during a representative average use cycle or period of use, as determined by the Secretary . . . ." 42 U.S.C. 6293(b)(3). This statutory requirement may be undermined if products are purposefully designed to use controls or features that produce test results that are so unrepresentative of a product's actual energy or water consumption as to provide materially inaccurate comparative data. AHAM incorporated provisions that address circumvention in its 2007 and 2008 test procedure revisions. The ongoing DOE test procedure rulemaking proposes updating DOE's test procedures for refrigerators, refrigerator-freezers, and freezers to reference the latest version of AHAM HRF-1 in order to include by reference language which will more strongly bans circumvention and to provide clarification regarding test sample set-up to help prevent inconsistencies in test results. DOE notes that in its updated ENERGY STAR requirements for refrigerator-freezers in 2008, the ENERGY STAR program has included a provision to prohibit models from meeting the ENERGY STAR criteria through this type of circumvention scheme.[11]

3.2.2.6 Bottom-Drawer Refrigerator-Freezer Models

As discussed above in section 3.3, convertible bottom-drawer refrigerator-freezer models, where the bottom drawer can be used as either a freezer or a fresh food section, have been produced, although it is unclear whether any such products are currently on the market. It appears that the bottom drawer of these product types were tested as a fresh food compartment rather than a freezer. This is inconsistent with the provisions of AHAM HRF-1-1979 as well as AHAM HRF-1-2008, which require control of compartments that are convertible between freezer and fresh food temperature to be tested in the highest energy use position. The ongoing DOE test procedure rulemaking addresses this issue and solicits feedback regarding whether this requirement needs to be reinforced in the DOE test procedure.

3.2.2.7 Harmonizing with International Test Procedures

Working Group 12 of Technical Committee 59 of the International Electrotechnical Commission (IEC) is developing IEC 62552, an international test procedure for refrigerators, refrigerator-freezers, and freezers. One of the goals of this effort is to maximize harmonization among energy test procedures for countries representing key markets for these products. As a result, AHAM has incorporated compartment temperature changes into AHAM HRF-1-2008 which are consistent with the IEC standard. These changes include (1) standard test temperatures of 0 °F rather than 5 °F for the freezer compartment of a refrigerator-freezer and 39 °F rather than 45 °F for the fresh food compartment, (2) standard test temperature of 39 °F rather than 38 °F for an all-refrigerator, and (3) standard test temperature of 39 °F rather than 45 °F for the fresh food compartment of a refrigerator having a freezer compartment. DOE is also revising the DOE energy test procedure to adopt the modified temperatures. The change in temperatures will clearly result in higher test energy use for refrigerator-freezers and refrigerators with freezer compartments and lower test energy use for all-refrigerators, thus necessitating adjustments to kilowatt-hour (kWh)-per-year values for all efficiency levels for these products. As mentioned in section 3.2.1.2, DOE proposes to separate all-refrigerators from product classes which currently combine all-refrigerators with other product types. It is argued that the new temperatures are more consistent with actual temperatures used by consumers use[12,13] and that energy use measured using the new temperatures will also be more representative of actual field energy use. Chapter 5 describes DOE determination of new energy vs. adjusted volume curves for baseline-efficiency products based on the new test procedure.

3.2.2.8 Standby and Off Modes

EISA requires DOE to include consideration of standby mode and off mode energy consumption in future amendments to both its test procedures and energy conservation standards. Specifically, section 310 of EISA amends section 325 of EPCA (42 U.S.C. 6295) by adding the following definitions and other requirements pertaining to standby and off mode energy use:

(gg) STANDBY MODE ENERGY USE.

(1) DEFINITIONS.—

(A) IN GENERAL.—Unless the Secretary determines otherwise pursuant to subparagraph (B), in this subsection:

(i) ACTIVE MODE.—The term "active mode" means the condition in which an energy-using product:—

(I) is connected to a main power source;

(II) has been activated; and

(III) provides 1 or more main functions.

(ii) OFF MODE.—The term "off mode" means the condition in which an energy-using product:—

(I) is connected to a main power source; and

(II) is not providing any standby or active mode function.

(iii) STANDBY MODE.—The term "standby mode" means the condition in which an energy-using product:—

(I) is connected to a main power source; and

(II) offers 1 or more of the following user-oriented or protective functions:

(aa) To facilitate the activation or deactivation of other functions (including active mode) by remote switch (including remote control), internal sensor, or timer.

(bb) Continuous functions, including information or status displays (including clocks) or sensor-based functions.

(B) AMENDED DEFINITIONS.—The Secretary may, by rule, amend the definitions under subparagraph (A), taking into consideration the most current versions of Standards 62301 and 62087 of the International Electrotechnical Commission (IEC).

(2) TEST PROCEDURES.—

(A) IN GENERAL.—Test procedures for all covered products shall be amended pursuant to section 323 to include standby mode and off mode energy consumption, taking into consideration the most current versions of Standards 62301 and 62087 of the International Electrotechnical Commission, with such energy consumption integrated into the overall energy efficiency, energy consumption, or other energy descriptor for each covered product, unless the Secretary determines that:—

(i) the current test procedures for a covered product already fully account for and incorporate the standby mode and off mode energy consumption of the covered product,; or

(ii) such an integrated test procedure is technically infeasible for a particular covered product, in which case the Secretary shall prescribe a separate standby mode and off mode energy use test procedure for the covered product, if technically feasible.

*   *   *   *   *

(3) INCORPORATION INTO STANDARD.—

> (A) IN GENERAL.—Subject to subparagraph (B), based on the test procedures required under paragraph (2), any final rule establishing or revising a standard for a covered product, adopted after July 1, 2010, shall incorporate standby mode and off mode energy use into a single amended or new standard, pursuant to subsection (o), if feasible.
> (B) SEPARATE STANDARDS.—If not feasible, the Secretary shall prescribe within the final rule a separate standard for standby mode and off mode energy consumption, if justified under subsection (o).

For refrigerators, refrigerator-freezers, and freezers, the current test procedure captures standby and off mode energy use. All energy input for the test duration, including during times of compressor off cycle is measured, for a test time period which is at least 3 hours long. Hence, under provision (gg)(2)(A)(i), establishing standby and off modes and test procedures to incorporate them into the overall energy use is not required. Complications potentially arise for refrigerator features not mentioned by the test procedure that might involve some standby energy use during normal consumer use, but that might be disconnected or otherwise turned off during energy testing (*e.g.*, a computer integrated with the refrigerator).

3.2.3 Manufacturer Information

This section provides information on domestic manufacturers of residential refrigerators, refrigerator-freezers, and freezers, including their brand names and products sold in the United States (section 3.2.3.1), estimated market shares (section 3.2.3.2), industry mergers and acquisitions (section 3.2.3.3), and product distribution channels (section 3.2.3.4). The section also discusses manufacturer trade groups (section 3.2.3.5) and manufacturers of compressors (section 3.2.3.6), as this is one of the most important components of residential refrigeration products.

3.2.3.1 Refrigerator, Refrigerator-Freezer, and Freezer Manufacturers

Table 3.2.2 lists refrigerator, refrigerator-freezer, and freezer manufacturers selling products in the United States. The second column indicates whether the manufacturer is a member of AHAM, and the third column indicates whether the manufacturer produces products that are ENERGY STAR compliant. Manufacturers that are a member of AHAM are listed first in the table and generally have the largest U.S. market shares. There are also several smaller manufacturers supplying products to the U.S. Those smaller manufacturers that produce ENERGY STAR-compliant products are listed directly after AHAM member manufacturers.

Table 3.2.2 also indicates the types of products that each manufacturer produces. Product types include: standard-size refrigerator-freezers, freezers, compact units, built-in units, custom units, undercounter units, luxury units, and other types. Other types include: units with more than three doors, units for ‘compact kitchens’ other than compact refrigerators, refrigerated drawers, and commercial-size units.

Table 3.2.2 Refrigerator, Refrigerator-Freezer, and Freezer Manufacturers

Manufacturer Name	**AHAM Member**	**E* Products**	Std Refrig-Freezer	Freezer	Com-pact	Built-In	Custom Door/Inter.	Under Counter	Luxury Unit°°	Other″
Aga Foodservice Group*	Y	-	-	-	-	-	-	-	-	-
Marvel Industries	-	-	Y	Y	-	Y	-	Y	Y (BI,SS,SI)	Y
Northland Corp.	-	-	-	Y	-	-	Y	-	Y (BI,SS,CDD,SI)	-
Bosch Home Appliances Corp.	Y	Y	Y	Y	-	-	Y	-	Y (CDD,SS)	-
Electrolux Home Products**	Y	Y	-	-	-	Y	Y	Y	Y (CDD,SS,BI)	-
Frigidaire	-	Y	Y	Y	-	-	-	-	-	-
Fisher & Paykel Appliances Inc.	Y	-	Y	-	-	-	-	-	Y (SS)	-
GE Appliances***	Y	Y	Y	Y	Y	-	-	-	Y (SS,SI)	-
Hotpoint	-	Y	Y	Y	Y	-	-	-	-	-
Monogram	-	Y	Y	Y	-	Y	-	-	Y (BI,SS,SI)	Y
Haier Group	Y	Y	Y	-	Y	-	-	-	Y (CB,SS,SI)	Y
LG Electronics	Y	Y	Y	-	-	-	-	-	Y (TD,SI, SS)	Y
Liebherr	Y	Y	Y	-	-	Y	-	-	Y (BI,SS)	
Miele Appliances Inc	Y	Y	Y	Y	-	Y	-	-	Y (BI, SS)	-
Samsung Electronics America	Y	Y	Y	-	-	-	-	-	-	-
Sanyo North America Corp.	Y	Y	Y	Y	Y	-	-	Y	-	Y
Sub-Zero Freezer Company	Y	Y	-	Y	-	Y	Y	Y	Y (BI,CDD)	Y
Viking Range Corporation	Y	Y	-	Y	-	Y	Y	-	Y (BI,CDD,SS)	-
W. C. Wood Co. †	Y	Y	Y	Y	Y	-	-	-	-	Y
Vencold	-	-	-	Y	-	-	-	-	-	-
Whirlpool††	Y	Y	Y	-	-	-	-	-	-	-
Amana Appliances	-	Y	Y	Y	-	-	-	-	Y (SS)	Y
Maytag	-	Y	Y	Y	-	-	-	-	Y (SI,SS)	-
Estate Appliances	-	-	Y	-	-	-	-	-	-	-
Magic Chef & Ewave	-	-	Y	Y	Y	-	-	-	-	-
Gladiator Garage Works	-	Y	Y	-	-	-	-	-	-	-
Ikea	-	Y	Y	-	-	-	-	-	-	-
Inglis Home Appliances	-	Y	Y	-	-	-	-	-	-	-
Jenn-Air	-	Y	Y	-	-	Y	Y	-	Y (SS,SI,PI,CDD,BI)	-
Kitchen Aid	-	Y	Y	-	-	Y	-	Y	Y (BI,SS,PI)	Y
Roper Appliances	-	-	Y	-	-	-	-	-	-	-
Absocold Corporation	-	Y	Y	-	Y	-	-	Y	-	Y
Avanti Products †††	-	Y	Y	Y	Y	-	-	Y	-	Y
Crosley Corporation	-	Y	Y	Y	-	-	-	-	Y (SS)	-
Daewoo Electronics Co.	-	Y	-	-	Y	-	-	-	-	-
Danby Products Inc.	-	Y	Y	Y	Y	Y	-	-	Y (BI)	-
Diversified Refrigeration Inc.	-	Y	-	-	-	-	-	-	Y (SI)	Y

Manufacturer Name	AHAM Member	E* Products	Std Refrig-Freezer	Freezer	Com-pact	Built-In	Custom Door/Inter.	Under Counter	Luxury Unit[°°]	Other[″]
Equator Appliances	-	Y	Y	Y	Y	-	-	-	-	-
Galaxy Mfg. Company of C.N.Y.	-	Y	NA	NA	NA	NA	NA	NA	NA	NA
Gorenje USA, Inc.	-	Y	NA	NA	NA	NA	NA	NA	NA	NA
Jetson TV & Appliance Centers	-	Y	Y	Y	Y	Y	-	Y	Y	Y
MicroFridge	-	Y	-	-	Y	-	-	-	-	Y
Organizacion Mabe[#]	-	Y	Y	-	Y	-	-	-	-	-
Camco Inc.	-	Y	Y	Y	Y	-	-	-	Y (SI,SS,PI)	-
Moffat	-	Y	Y	-	-	-	-	-	-	-
Petters Consumer Brands LLC	-	Y	NA	NA	NA	NA	NA	NA	NA	NA
Summit Appliances	-	Y	Y	Y	Y	-	-	Y	-	Y
Sun Frost	-	Y	-	-	-	-	-	-	Y (CD)	Y
U-Line Corporation	-	Y	-	Y	Y	-	-	Y	-	Y
Ultra 8 International LLC	-	Y	-	-	-	-	-	-	-	Y
ACME Kitchenettes Corp.	-	-	-	-	Y	-	-	-	-	-
Atlas Eléctrica[##]	-	-	NA	NA	NA	NA	NA	NA	NA	NA
Bauer Appliances	-	-	Y	Y	-	-	-	-	Y (SI,SS)	Y
Broich Enterprises[†††]	-	Y	Y	Y	-	-	-	-	-	Y
Distinctive Appliances[†††]	-	Y	-	-	-	Y	Y	-	Y (SI,SS,CDD)	-
Euroquip S.A.de C.V.	-	-	-	-	-	-	-	-	-	Y
Jade	-	-	Y	-	-	-	-	-	Y (SS,SI)	-
Indesit Company[###]	-	-	Y	-	-	-	-	Y	-	-
Scottsman	-	-	Y	-	-	-	-	-	-	-
Sunbeam[^]	-	-	Y	-	Y	-	-	-	-	-
Thermador	-	Y	Y	Y	-	-	Y	-	Y (SS,SI,CDD)	
WiniaMando Inc.	-	-	-	-	-	-	-	-	-	Kimchi
Kenmore[^^]	-	Y	Y	Y	Y	-	-	-	-	-
Mastercool[^^]	-	-	NA	NA	NA	NA	NA	NA	NA	NA
United Refrigeration Inc.[^^^]	-	-	-	Y	-	-	-	Y	-	-

* Owns Marvel Industries and Northland Corp.
** Includes Frigidaire and White Westinghouse brands.
*** Includes Hotpoint and Monogram brands.
† Includes Vencold brand.
†† Includes the following brands: Amana Appliances, Maytag, Estate Appliances, Magic Chef & Ewave, Gladiator Garage Works, Ikea, Inglis Home Appliances, Jenn-Air, Kitchen Aid, Roper Appliances.
# 48 percent owned by GE. Includes Moffat brand. Owns Camco Inc.
20 percent owned by Electrolux.
Includes Aritson brand.
^ An affiliate of Petters Group Worldwide, LLC.
^^ Brand names that are produced by more than one mfg.
^^^ Could be a distributor or brand name under another mfg.
°° SS=Stainless Steel; BI=Built-In; CDD=Customized Designed Door; TD=TV in Door; SI=Size; CB=Convertible; PI=Price
″ Units included: units with more than three doors, units for 'compact kitchens'; refrigerated drawers; commercial-size units

3.2.3.2 Refrigerator, Refrigerator-Freezer, and Freezer Manufacturer Market Shares

Appliance magazine provides market share data for the most significant manufacturers (*i.e.*, manufacturers with the greatest sales) for the following four product types: (1) standard-size refrigerators and refrigerator-freezers, (2) compact refrigerators, (3) built-in/undercounter refrigerators, and (4) freezers.[14] Table 3.2.3 through Table 3.2.6 show how market shares have changed over at least a ten-year period. Market shares among the largest manufacturers of standard-size refrigerator-freezers have remained relatively stable. Whirlpool Corporation (Whirlpool)'s 2006 acquisition of Maytag Corporation (Maytag) (discussed below) now gives Whirlpool the largest U.S. market share. Also, Haier America Trading, LLC (Haier), a relatively recent entrant to the market, captured three percent of the market in 2006.

Table 3.2.3 Standard-Size Refrigerator-Freezer Manufacturer Market Shares

Company	Market Share						
	2007	**2006**	**2005**	**2004**	**2002**	**2000**	**1995**
GE	29%	29%	29%	29%	36%	34%	35%
Electrolux	25%	25%	25%	25%	26%	21%	17%
Whirlpool	25%	25%	25%	25%	23%	24%	27%
Maytag	10%	10%	11%	11%	13%	14%	10%
Goodman/Raytheon (Amana)	NA	0%	0%	0%	0%	5%	10%
Haier	4%	3%	2%	2%	2%	0%	0%
W.C. Wood	1%	1%	1%	0%	0%	0%	0%
Other	6%	7%	7%	8%	0%	2%	1%

Source: *Appliance* magazine

The market for compact refrigerators has seen a dramatic shift since 1993 (Table 3.2.4). SANYO North America Corporation (Sanyo) had the largest market share by far in 1993, but now accounts for only seven percent of the market. Haier now has the largest compact refrigerator market share, followed by the joint venture between GE and Mexican appliance company Grupo P.I. Mabe S.A. (Mabe).

Table 3.2.4 Compact Refrigerator Manufacturer Market Shares

Company	Market Share						
	2007	**2006**	**2005**	**2004**	**2002**	**1997**	**1993**
Haier	22%	21%	20.1%	20%	NA	15%	0%
GE/Mabe	16%	16%	16.7%	17%	NA	18%	17%
Sanyo	7%	7%	7.3%	8%	NA	58%	61%
U-Line	5%	5%	4.8%	0%	NA	0%	0%
Danby	3%	3%	2.9%	3%	NA	0%	0%
Avanti	1%	2%	2.5%	0%	NA	0%	0%
Whirlpool/Consul	1%	2%	1.9%	0%	NA	2%	2%
Marvel	2%	2%	1.6%	0%	NA	0%	0%
Wanbao	NA	0%	0%	0%	NA	5%	12%
Others	43%	42%	42.2%	52%	NA	2%	8%

Source: *Appliance* magazine

The reported market for built-in undercounter units has remained relatively stable over the past ten years (Table 3.2.5). The data show that U-Line Corporation (U-Line) has the greatest market share. Note that this market share distribution does not include full-size built-in products.

Table 3.2.5 Built-In Undercounter Refrigerator Manufacturer Market Shares

Company	Market Share						
	2007	**2006**	**2005**	**2004**	**2002**	**2000**	**1995***
U-Line	69%	70%	69%	67%	65%	75%	58%
Marvel	21%	21%	21%	22%	25%	14%	27%
Sub-Zero	6%	6%	6%	7%	6%	10%	12%
Others	4%	3%	4%	4%	4%	1%	3%

Source: *Appliance* magazine; * 1995 data includes compact refrigerators.

Market share data for full-size built-in refrigerators and refrigerator-freezers is not publicly available. Key manufacturers in this product category include Sub-Zero, General Electric's Monagram line, Whirlpool's Kitchenaid line, Viking, and Northland. Manufacturers providing imported products for this market include Liebherr, Bosch, and Miele. AHAM has recently begun collecting shipment data on built-in products. The percentage of overall shipments represented by built-in products has fluctuated between 2005 and 2007 between 1.6% and 2.2%. This includes both full-size and compact (undercounter) built-in products. This data was provided by AHAM as part of the pre-NOPR phase of this rulemaking.

For chest and upright freezers, Electrolux has retained the largest market share for ten years (Table 3.2.6). Haier, which was not in the market in 1995, now captures 13 percent of the market.

Table 3.2.6 Chest/Upright Freezer Manufacturer Market Shares

Company	Market Share						
	2007	**2006**	**2005**	**2004**	**2002**	**2000**	**1995**
Electrolux (Frigidaire)	66%	66%	67%	68%	68%	69%	67%
W.C. Wood	20%	21%	21%	22%	21%	27%	30%
Haier	13%	12%	11%	9%	9%	3%	0%
Sanyo	1%	1%	1%	1%	2%	1%	1%
Whirlpool	NA	0%	0%	0%	0%	0%	1%
Others	NA	0%	0%	0%	0%	0%	1%

Source: *Appliance* magazine

3.2.3.3 Mergers and Acquisitions

The appliance manufacturing industry has had a continuous history of consolidation. Maytag acquired Jenn-Air Corporation (Jenn-Air) in 1982, Magic Chef, Inc. (Magic Chef) in 1986, and Amana Appliances (Amana) in 2001. Whirlpool acquired the KitchenAid division of Hobart Corporation (KitchenAid) in 1986. White Consolidated Industries (WCI) acquired Frigidaire in 1979, and AB Electrolux acquired WCI (including Frigidaire) in 1986.

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

On August 22, 2005, Whirlpool and Maytag announced plans to merge in a deal worth \$2.7 billion.[15] Maytag shareholders approved the merger on December 22, 2005. The U.S. Department of Justice (DOJ) Antitrust Division initiated an investigation into the effects of the merger, including potential lessening of competition or the creation of a monopoly. Opponents of the merger asserted that the combined companies would control as much as 70 percent of the residential laundry market and as much as 50 percent of the residential dishwasher market.[16] Whirlpool claimed that its large potential residential laundry market share was skewed because the company produces washing machines for Sears, which sells them under its Kenmore in-house brand. Whirlpool further stated that it must periodically bid with other manufacturers to keep the Kenmore contract and that Sears controls the pricing of the Kenmore units.[17]

In early January 2006, U.S. Senator Tom Harkin and U.S. Representative Leonard Boswell called on the DOJ to block the merger, claiming it would give Whirlpool an unfair advantage in the home appliance industry. On March 29, 2006, DOJ closed its investigation and approved the merger. DOJ stated that “the proposed transaction is not likely to reduce competition substantially. The combination of strong rival suppliers with the ability to expand sales significantly and large cost savings and other efficiencies that Whirlpool appears likely to achieve indicates that this transaction is not likely to harm consumer welfare.”[18]

The DOJ Antitrust Division focused its investigation on residential laundry, although it considered impacts across all products offered by the two companies. DOJ determined that the merger would not give Whirlpool market power in the sale of its products and that any attempt to raise prices would likely be unsuccessful. To support this claim, DOJ provided reasons including: (1) other U.S. brands, including Kenmore, GE, and Frigidaire, are well established; (2) foreign manufacturers, including LG and Samsung, are gaining market share; (3) existing U.S. manufacturers are below production capacity; (4) the large home appliance retailers have alternatives available to resist price increase attempts; and (5) Whirlpool and Maytag substantiated large cost savings and other efficiencies to benefit consumers.[18]

Whirlpool and Maytag completed the merger on March 31, 2006.

3.2.3.4 Distribution Channels

Most residential refrigerators and freezers move directly from manufacturers to retail outlets. Table 3.2.7 identifies the types of retail stores through which major appliances, including refrigerators and freezers, are sold based on data from AHAM *2005 Fact Book*.[19]

Table 3.2.7 Major Appliance Sales by Channel

Type of Store	Percentage of Appliance Purchases
Department Store (such as Sears or Kohls)	34.7%
Appliance Store or Consumer Electronics Store	30.9%
Home Improvement Store (such as Lowe's or Home Depot)	23.8%
Discount Store (such as Wal-Mart or K-Mart)	2.0%
Membership Warehouse Club/Store (such as Sam's or Costco)	1.8%
Another type of store	6.8%

Source: AHAM *Fact Book*

A certain share of shipments is purchased through channels other than retail outlets, *e.g.*, by multi-family home builders for installation in new homes. The Consortium for Energy Efficiency (CEE) estimates that 20 to 30 percent of home appliance sales are commercial sales, *i.e.*, sales to single/multi-family builders, contractors, government, public housing, and multi-family property managers.[20] Because single-family builders typically do not include refrigerator-freezers as part of a home sale, the 20 to 30 percent estimate by CEE is probably too high for the refrigerator market.

3.2.3.5 Manufacturer Trade Groups

AHAM is the primary manufacturer trade group representing most manufactures of refrigerators, refrigerator-freezers, and freezers. AHAM provides services to its members including government relations; certification programs for room air conditioners, dehumidifiers, and room air cleaners; an active communications program; and technical services and research. In addition, AHAM conducts other market and consumer research studies and publishes a biennial *Major Appliance Fact Book*. AHAM also develops and maintains technical test procedures for various appliances to provide uniform, repeatable procedures for measuring specific product characteristics and performance features.

3.2.3.6 Compressor Manufacturers and Market Shares

Because the compressor is a key energy-using component of refrigerators, it is important to determine which compressor manufacturers are supplying the U.S. refrigerator market. According to three sources, Embraco is the compressor manufacturer with the largest global market share, although several other manufacturers have significant global market share as well.[21, 22] For the U.S. refrigerator market, based on data from Embraco, it has by far the largest market share.[23] Besides Embraco, there are five other major compressor manufacturers supplying the world refrigerator and freezer market: Appliances Components Companies (ACC), Tecumseh Compressor Company (Tecumseh), Danfoss Compressors GmbH, Matsushita Electric Industrial Co., Ltd. (Matsushita), and LG Electronics, Inc. (LG). Table 3.2.8 lists the compressor manufacturers and their estimated global and U.S. market shares.

Table 3.2.8 Compressor Manufacturers and World and U.S. Market Shares

Manufacturer	World Market Share			U.S. Market Share
	2005*	Year not specified**	2006***	2001†
Embraco	19.5%	~23%	25%	56%
ACC	15.0%	~20%	NA	NA
Tecumseh	13.5%	~8%	NA	NA
Matsushita	12.9%	~9%	18%	NA
LG	10.8%	~8%	NA	NA
Danfoss	8.9%	~9%	15%	<1%
Others	19.4%	~23%	NA	NA

Sources: *Universidade Federal de Santa Catarina, 2006; **Institute for Materials Science, Welding and Forming; ***Unable to cite source; †Embraco, 2001.

3.2.4 Regulatory Programs

The following section details current regulatory programs mandating energy conservation standards for refrigerator/freezers. It covers U.S. Federal energy conservation standards, State standards, standards in Canada and Mexico (which may impact the companies servicing the North American market), and international standards.

3.2.4.1 Federal Energy Conservation Standards

The National Appliance Energy Conservation Act of 1987 (NAECA) (42 U.S.C. 6291–6309) established efficiency standards for refrigerators and refrigerator-freezers with a total refrigerated volume of less than 1104 L (39 ft^3) and for freezers with a total refrigerated volume of less than 850 L (30 ft^3). Compact refrigerators and freezers represent separate product classes and have a volume less than 220 L (7.75 ft^3) *and* a height of 0.91 meters (36 inches) or less. The minimum efficiency levels depend on product class and adjusted volume. The adjusted volume is equal to the fresh food internal volume plus an adjustment factor which depends on the product type times the freezer internal volume. The adjustment factor is 1.63 for refrigerator-freezers, 1.44 for refrigerators with freezer compartments, 1.00 for all-refrigerators (which may have a freezer compartment with less than 0.5 ft^3 volume), and 1.73 for freezers. Maximum annual energy use is expressed as kilowatt-hours (kWh) per year (yr)

NAECA initially established energy conservation standards for refrigerator-freezers that became effective in 1990. DOE amended NAECA with new standards that went into effect in 1993, followed by the current amended standards that became effective in July 2001. Refrigerator-freezers manufactured to meet the 2001 standard typically consume about 30 percent less energy than required under the 1993 efficiency regulations. The 1993 and 2001 standards are summarized in Table 3.2.9 below.

As discussed in section 3.2.1, there are two additional product classes that DOE proposes to establish due to exemptions it granted in recent years for products not adhering to existing product class definitions: (1) automatic defrost refrigerator-freezers with bottom-mounted freezer and TTD ice service, and (2) automatic defrost chest freezers. These proposed product classes are listed as 5A and 10A in Table 3.2.9.

Table 3.2.9 Federal Energy Efficiency Standards for Refrigerators, Refrigerator-Freezers, and Freezers

Product Class	Energy Standard Equations for Maximum Energy Use (kWh/yr)	
	Effective January 1, 1993	Effective July 1, 2001
1. Refrigerators and refrigerator-freezers with manual defrost.	13.5AV+299 0.48av+299	8.82AV+248.4 0.31av+248.4
2. Refrigerator-freezer—partial automatic defrost.	10.4AV+398 0.37av+398	8.82AV+248.4 0.31av+248.4
3. Refrigerator-freezer—automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerator—automatic defrost.	16.0AV+355 0.57av+355	9.80AV+276.0 0.35av+276.0
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service.	11.8AV+501 0.42av+501	4.91AV+507.5 0.17av+507.5
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service.	16.5AV+367 0.58av+367	4.60AV+459.0 0.16av+459.0
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.	17.6AV+391 0.62av+391	10.20AV+356.0 0.36av+356.0
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.	16.3AV+527 0.58av+527	10.10AV+406.0 0.36av+406.0
8. Upright freezers with manual defrost.	10.3AV+264 0.36av+264	7.55AV+258.3 0.27av+258.3
9. Upright freezers with automatic defrost.	14.9AV+391 0.53av+391	12.43AV+326.1 0.44av+326.1
10. Chest freezers and all other freezers except compact freezers.	11.0AV+160 0.39av+160	9.88AV+143.7 0.35av+143.7
11. Compact refrigerators and refrigerator-freezers with manual defrost.	13.5AV+299* 0.48av+299*	10.70AV+299.0 0.38av+299.0
12. Compact refrigerator-freezer—partial automatic defrost.	10.4AV+398* 0.37av+398*	7.00AV+398.0 0.25av+398.0
13. Compact refrigerator-freezers—automatic defrost with top-mounted freezer and compact all-refrigerator—automatic defrost.	16.0AV+355* 0.57av+355*	12.70AV+355.0 0.45av+355.0
14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.	11.8AV+501* 0.42**+501*	7.60AV+501.0 0.27av+501.0
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.	16.5AV+367* 0.58av+367*	13.10AV+367.0 0.46av+367.0
16. Compact upright freezers with manual defrost.	10.3AV+264* 0.36av+264*	9.78AV+250.8 0.35av+250.8
17. Compact upright freezers with automatic defrost.	14.9AV+391* 0.53av+391*	11.40AV+391.0 0.40av+391.0
18. Compact chest freezers.	11.0AV+160* 0.39av+160*	10.45AV+152.0 0.37av+152.0
5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.	NA	5.0AV+539.0 0.18av+539.0
10A. Chest freezers with automatic defrost.	NA	14.76AV+211.5 0.52av+211.5

AV: Adjusted Volume in ft^3; av: Adjusted Volume in L

* Applicable standards for compact refrigerator products manufactured before July 1, 2001. Compact refrigerator products are not separate product categories under the standards effective January 1, 1993.

The Energy Independence and Security Act of 2007 (EISA) (P.L. 110-140), requires that DOE publish a final rule no later than December 31, 2010 to determine whether to amend the standards in effect for refrigerators, refrigerator-freezers, and freezers manufactured on or after January 1, 2014.

3.2.4.2 State Energy Conservation Standards

As part of its Title 20 Appliance Efficiency Regulations, the California Energy Commission (CEC) has established standards for consumer refrigeration products that are not covered by Federal standards. CEC set standards for wine chillers (Table 3.2.10) and freezers that have a total refrigerated volume greater than 850 L (30 ft^3) (Table 3.2.11).[24] The standards for freezers with volume greater than 30 ft^3 are numerically identical to the federal standards for smaller freezers—the California standards simply extend the federal standards beyond the federal size limitation.

Table 3.2.10 California Standards for Wine Chillers

Appliance	Maximum Annual Energy Consumption (kWh)
Wine chillers with manual defrost	13.7V + 267
Wine chillers with automatic defrost	17.4V + 344

V = volume in ft^3.

Table 3.2.11 California Standards for Freezers with Volume Greater than 30 cubic feet

Appliance	Maximum Annual Energy Consumption (kWh)
Upright Freezers with manual defrost	7.55AV + 258.3
Upright Freezers with automatic defrost	12.43AV + 326.1
Chest Freezers	9.88AV + 143.7

AV = adjusted total volume, expressed in ft^3, which is 1.73 times freezer volume (in ft^3).

3.2.4.3 Canadian Energy Conservation Standards

Refrigerators and freezers are regulated products in Canada under the Canadian Energy Efficiency Regulations. The regulations reference Canadian Standards Association (CSA) CAN/CSA-C300-00, *Energy Performance and Capacity of Household Refrigerators, Refrigerator-Freezers, and Freezers,* for the testing procedure and for maximum annual energy consumption (MAEC) limits for residential refrigerators, refrigerator-freezers, and freezers. The product classes and MAEC limits in the Canadian regulations are the same as in the U.S. Federal standards.

In November 2006, Canada added two new product types to its Regulations (Amendment 9) to harmonize with recent U.S. rulings with respect to these products.[25] These product types are refrigerator-freezers with automatic defrost and with a bottom-mounted freezer with TTD ice service and chest freezers with automatic defrost system. The maximum energy use regulations, listed in Table 3.2.12 below, are identical to the energy standards that DOE's Office of Hearings and Appeals assigned to these classes.

Table 3.2.12 Canadian Energy Standards for Added Refrigerator and Freezer Product Classes

Appliance	Maximum Annual Energy Consumption (kWh)
Product Class 5A: refrigerator-freezers with automatic defrost and with bottom-mounted freezers with TTD ice service	0.18av+539
Product Class 10A: chest freezers with automatic defrost system	0.52av + 211.5

av = adjusted volume in liters

Natural Resources Canada (NRCan)'s Office of Energy Efficiency (OEE) amended Canada's Energy Efficiency Regulations to add energy performance standards for residential wine chillers (or wine coolers).[26] The proposed standard includes a test procedure and minimum energy performance standard levels for wine chillers harmonized with those in effect in California. Table 3.2.13 below shows the maximum annual energy consumption limits (in kWh) for residential wine chillers.

Table 3.2.13 Canadian Standards for Wine Chillers

Appliance	Maximum Annual Energy Consumption (kWh)
Wine chillers with manual defrost	0.48av + 267
Wine chillers with automatic defrost	0.61av + 344

av = adjusted volume in L.

3.2.4.4 Mexican Energy Conservation Standards

The Mexican Official Standard establishes the maximum energy consumption limits for household refrigerators and freezers using hermetic motor-driven compressors, specifies the test methods for determining such energy consumption and the total refrigerated volume, and provides energy consumption label requirements. This standard applies to household refrigerators up to 1,104 cubic decimeters (39 ft^3) and household freezers of up to 850 cubic decimeters (30 ft^3) using hermetic motor-driven compressors.[27] The new standard levels (NOM-015-ENER-2002) became effective in May 2003.

3.2.4.5 Efficiency Standards Outside North America

According to the Collaborative Labeling and Appliance Standards Program (CLASP) database, all 15 original European Union (EU) member countries, plus 16 other countries outside North America, have mandatory energy efficiency standards for refrigerator-freezers.[28] The countries other than the original EU member countries are: Algeria, Australia, Bahrain, Chile, China, Chinese Taipei, Costa Rica, Hungary, Indonesia, Iran, Israel, New Zealand, Philippines, Republic of Korea, Thailand, and Viet Nam.

In 2005, the European Parliament adopted a Commission proposal for a directive on establishing a framework for setting eco-design requirements (such as energy efficiency requirements) for all energy-using products in the residential, tertiary (services), and industrial sectors.[29] EU-wide rules for eco-design are intended to ensure that disparities among national regulations do not become obstacles to intra-EU trade. The directive does not directly introduce binding requirements for specific products, but does define conditions and criteria for setting requirements regarding environmentally relevant product characteristics (such as energy consumption), and allows these requirements to be improved quickly and efficiently. The directive will be followed by implementing measures that will establish the eco-design requirements.

It is difficult to compare the standards in other countries with those in the U.S. due to differences in test procedures. The development of an international test procedure under the auspices of the International Electrotechnical Commission has international test procedure harmonization as a key objective. Establishment of Standard IEC 62552, which is currently under development, should make it easier in future to compare international refrigeration product energy standard levels.

3.2.5 Voluntary and other Federal and State Programs

In addition to mandatory standards, there are voluntary programs—*e.g.*, the Federal Energy Management Program (FEMP) and CEE—as well as other Federal and State policies that affect the efficiency of new refrigerators and freezers.

3.2.5.1 ENERGY STAR

Historical ENERGY STAR Requirements

ENERGY STAR is a voluntary program administered by the U.S. government to promote energy efficient consumer products. Table 3.2.14 below shows the history of ENERGY STAR energy use criteria for each of the three covered product categories.

Table 3.2.14 History of ENERGY STAR Energy Use Criteria for Residential Refrigerators and Freezers

	1997 Initial Criteria	2001 Revision #1	2003 Addition of Freezers and Compacts	2004 Revision #2	2008 Revision #3
Standard-size Refrigerators & Refrigerator-Freezers	20% below 1993 Federal Standard	10% below 2001 Federal Standard	10% below 2001 Federal Standard	15% below 2001 Federal Standard	20% below 2001 Federal Standard
Standard-size Freezers	--------	--------	10% below 2001 Federal Standard	10% below 2001 Federal Standard	10% below 2001 Federal Standard
Compact Refrigerators & Freezers	--------	--------	20% below 2001 Federal Standard	20% below 2001 Federal Standard	20% below 2001 Federal Standard

As of 2006, the market share of ENERGY STAR-compliant full-size refrigerators and refrigerator-freezers was just under 30%.[30] Within this category, approximately 20 percent of top- and bottom-mount and 50 percent of side-mount refrigerator-freezer units sold in the U.S. were ENERGY STAR compliant. Some States (*i.e.*, Massachusetts, Michigan) have waived state sales tax for purchase of appliances that meet ENERGY STAR levels.

New ENERGY STAR requirements effective in 2008

The current ENERGY STAR criteria, drafted with input from stakeholders and two rounds of public comments, went into effect on April 28, 2008. To support the change, ENERGY STAR released a market analysis[30] and a final report on proposed program requirements.[31] Table 3.2.15 shows the number of models that met the current Federal standard for refrigerators and available models with efficiencies 15 percent, 20 percent, and 25 percent higher than the Federal standard, as of April 2007 (prior to the 2008 revision). ENERGY STAR program staff deemed the number of models offered to consumers at the higher efficiencies to be sufficient to warrant changing the labeling criteria.

Table 3.2.15 Efficiency of Standard Refrigerators and Refrigerator-Freezers on the Market Relative to Current Federal Standard

Efficiency Level	Number of Available Models (prior to 2008 criteria revision)	Percent of Available Models (prior to 2008 criteria revision)
Current Federal Standard (effective July 2001)	2,524	100%
2004 ENERGY STAR Criteria (15% better than Federal Standard)	1,441	57%
2008 ENERGY STAR Criteria (20% better than Federal Standard)	121	4.8%
25% better than Federal Standard	14	0.6%

Source: ENERGY STAR, April 27, 2007[30]

3.2.5.2 Federal Energy Management Program

DOE's FEMP[a] works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites. FEMP helps Federal buyers identify and purchase energy-efficient equipment, including residential refrigerators and freezers.

Federal agencies are required by the Energy Policy Act of 2005 (EPACT 2005, P.L. 109-58) and Federal Acquisition Regulations (FAR) Subpart 23.2 to specify and buy ENERGY STAR-qualified products or, in categories with no ENERGY STAR label, FEMP-designated products which are among the highest 25 percent of equivalent products for energy efficiency. Table 3.2.16 below shows refrigerator and freezer performance requirements for Federal purchases.

[a] For more information, please visit www.eere.energy.gov/femp.

Table 3.2.16 Performance Requirement for Federal Purchases of Refrigerators and Freezers

Product Class	Total Volume* (ft^3)	Product Class Number(s)***	Annual Energy Use**
Single–Door Manual Defrost	≤2.4	11	255 kWh/year or less
Single–Door Manual Defrost	2.5 to 4.4	11	275 kWh/year or less
Single–Door Manual Defrost	4.5 to 6.4	11	295 kWh/year or less
Single–Door Manual Defrost	≥6.5	1 or 11	315 kWh/year or less
Single–Door Automatic Defrost	≤2.4	13	305 kWh/year or less
Single–Door Automatic Defrost	2.5 to 4.4	13	325 kWh/year or less
Single–Door Automatic Defrost	4.5 to 6.4	13	345 kWh/year or less
Single–Door Automatic Defrost	≥6.5	3 or 13	365 kWh/year or less
Bottom–Mount Freezer	≤18.4	5, 5A, or 15	475 kWh/year or less
Bottom–Mount Freezer	18.5 to 20.4	5 or 5A	485 kWh/year or less
Bottom–Mount Freezer	≥20.4	5 or 5A	495 kWh/year or less
Top–Mount Freezer	≤10.4	3, 6, or 13	340 kWh/year or less
Top–Mount Freezer	10.5 to 12.4	3 or 6	360 kWh/year or less
Top–Mount Freezer	12.5 to 14.4	3 or 6	380 kWh/year or less
Top–Mount Freezer	14.5 to 16.4	3 or 6	400 kWh/year or less
Top–Mount Freezer	16.5 to 18.4	3 or 6	420 kWh/year or less
Top–Mount Freezer	18.5 to 20.4	3 or 6	440 kWh/year or less
Top–Mount Freezer	20.5 to 22.4	3 or 6	460 kWh/year or less
Top–Mount Freezer	22.5 to 24.4	3 or 6	480 kWh/year or less
Top–Mount Freezer	≥24.5	3 or 6	500 kWh/year or less
Side-mount Freezer	≤20.4	4, 7, or 14	560 kWh/year or less
Side-mount Freezer	20.5 to 22.4	4 or 7	580 kWh/year or less
Side-mount Freezer	22.5 to 24.4	4 or 7	600 kWh/year or less
Side-mount Freezer	≥25.5	4 or 7	620 kWh/year or less

* Total volume is the sum of the refrigerator and freezer volumes.

** Annual Energy Use is based on DOE test procedure (10 CFR 430, Sub-Part B, Appendix E).

*** Possible Product Class numbers based on Product Class Descriptions

3.2.5.3 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is a nonprofit corporation that promotes the manufacture and purchase of energy-efficient products and services. CEE promotes energy-efficient refrigerators that use significantly less electricity than the Federal standard. These energy-efficient refrigerators represent the upper end of the ENERGY STAR efficiency levels. Effective January 1, 2007, CEE identifies three tiers for “super-efficient” refrigerators and refrigerator-freezers. Table 3.2.17 below provides the specifications for the CEE.

Table 3.2.17 CEE Tier Levels Refrigerators and Refrigerator-Freezers

Efficiency level	Percent Energy Use below Federal Standard	
	Standard Refrigerators	Compact Refrigerators
CEE Tier 1 (Current ENERGY STAR)	20	20
CEE Tier 2	25	25
CEE Tier 3	30	30

3.2.5.4 ENERGY STAR, FEMP, CEE Summary

Table 3.2.18 below presents maximum unit energy consumption (UEC) values for the current Federal standard and the ENERGY STAR and CEE voluntary standards for (1) a top-mount refrigerator-freezer with automatic defrost with no TTD ice features and 21.4 ft^3 adjusted volume, and (2) a side-mount refrigerator freezer with TTD features and 26.2 ft^3 adjusted volume.

Table 3.2.18 Annual Energy Consumption for Refrigerator-Freezers with Different Specifications

Efficiency Level	Top Mount*	Side-Mount**
2001 Federal Standard	486	671
Former ENERGY STAR (15% below standard)	413	570
CEE Tier 1, current ENERGY STAR (20% below standard)	389	537
CEE Tier 2 (25% below standard)	364	503
CEE Tier 3 (30% below standard)	340	469

* Auto defrost, no TTD features, 18.2 ft^3 total volume, and 21.4 ft^3 adjusted volume.
** Auto defrost, TTD features, 21.7 ft^3 total volume, and 26.2 ft^3 adjusted volume.
Source: DOE FY-2005 Priority Setting TSD; based on ENERGY STAR (2004),[32] FEMP (2005)[33] CEE (2004)[34]

3.2.5.5 Manufacturer Tax Credits for Energy-Efficient Appliances

EPACT 2005 provided tax credits to manufacturers for the production of energy-efficient residential refrigerators. These credits were intended to help manufacturers meet the costs of producing appliances that exceed the Federal standards. The credit program was modified by the Emergency Economic Stabilization Act of 2008 (EESA 2008) and extended through 2010.[35] The credit for residential refrigerators is a per-product credit (see Table 3.2.19).

Table 3.2.19 Manufacturer Tax Credits for Energy-Efficient Appliances in EESA 2008

Savings relative to 2001 Federal Standard	Applicable Credit Amount	Applicable Years
20% to 22.9%	$50	2008
23% to 24.9%	$75	2008, 2009
25% to 29.9%	$100	2008, 2009, 2010
30% or more	$200	

Notes: 'Refrigerators' refers to residential automatic defrost refrigerator-freezers with an internal volume of at least 16.5 ft^3.

3.2.5.6 Rebates for Highly Energy-Efficient Products

Electric utilities and other organizations promote the purchase of highly energy-efficient refrigerators through consumer rebates. Typically, these programs offer rebates for products meeting existing ENERGY STAR efficiency levels. Table 3.2.20 below lists some rebates that were offered in 2006. Some utilities also offer incentives to retire old and inefficient appliances.

Many utilities also offer rebates and disposal services for recycling old units in order to encourage consumers to purchase new, more efficient units and to ensure the safe disposal of hazardous waste.

Table 3.2.20 Rebates Offered for Highly Energy-Efficient Refrigerators in 2006

Utility/Organization*	Rebate Level
Efficiency Vermont	$25 (ENERGY STAR), $40 (CEE Tier 2 & 3)
Los Angeles Dept. of Water and Power	$65
PacifiCorp	$20
Sacramento Municipal Utility District	$50
San Diego Gas and Electric	$50
Southern California Edison	Unspecified (while supplies last)

* The table includes those programs listed as providing rebates for ENERGY STAR refrigerators in the publication "Residential Appliance Programs National Summary," by CEE, September 2006. Additional programs may exist.

3.2.5.7 State Tax Incentives for Highly Energy-Efficient Products

According to the State Energy Efficiency Index compiled by the Alliance to Save Energy, Oregon is the only State that offers tax credits for premium-efficiency refrigerators.[36] The tax credit is based on the amount of energy saved above models that meet the Federal standard.

3.2.6 Historical Shipments and Efficiencies

3.2.6.1 Historical Shipments

Two public sources of information provide historical shipments data on residential refrigerators, refrigerator-freezers, and freezers: *Appliance* magazine[37] and the AHAM *Fact Book.*[19] *Appliance* magazine breaks down refrigerator and refrigerator-freezer shipments into three groups: (1) standard-size units, (2) built-in units, and (3) compact units. Both sources break down freezer shipments into chest and upright units. Unfortunately, neither source provides any further level of disaggregation. As discussed below, standard-size shipments can be broken down into two broad groups: (1) top- and bottom-mount refrigerators and refrigerator-freezers, and (2) side-mount units.

Figure 3.2.1 shows historical shipments of refrigerators and refrigerator-freezers. Figure 3.2.2 shows historical shipments of freezers. In the past decade, annual shipments of standard refrigerator-freezers have grown from 8 million to 11 million, although shipments have dropped off significantly in 2007 and 2008 in response to poor economic conditions. Annual shipments of compact refrigerators grew from one million to roughly 3 million, but shipments dropped starting in 2006. Note that the data for refrigerators include products used in non-residential settings (e.g., hotels and offices), but the size of this market segment is unknown.

Shipments of chest and upright freezers have grown less rapidly than those of standard refrigerator-freezers. These shipments rose from 1.5 million in 1997 to 2.5 million in 2002, but shipments dropped starting in 2005 and are now at 2 million annually. Shipments of compact freezers are roughly 0.5 million.

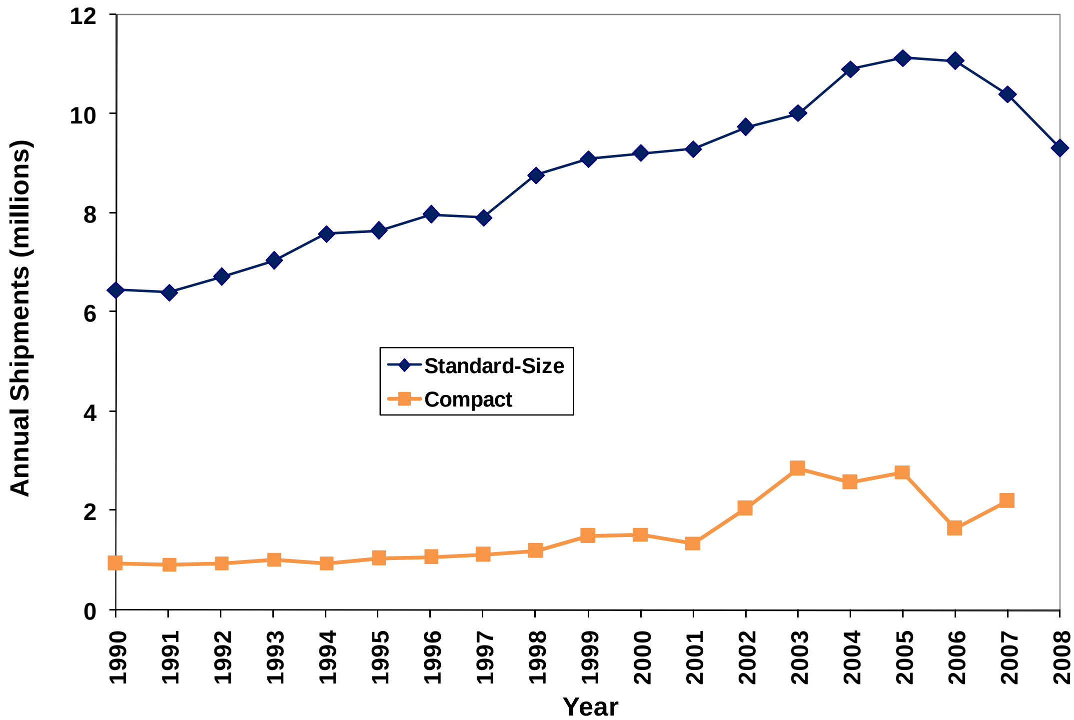


Figure 3.2.1 Annual Shipments of Refrigerators and Refrigerator-Freezers

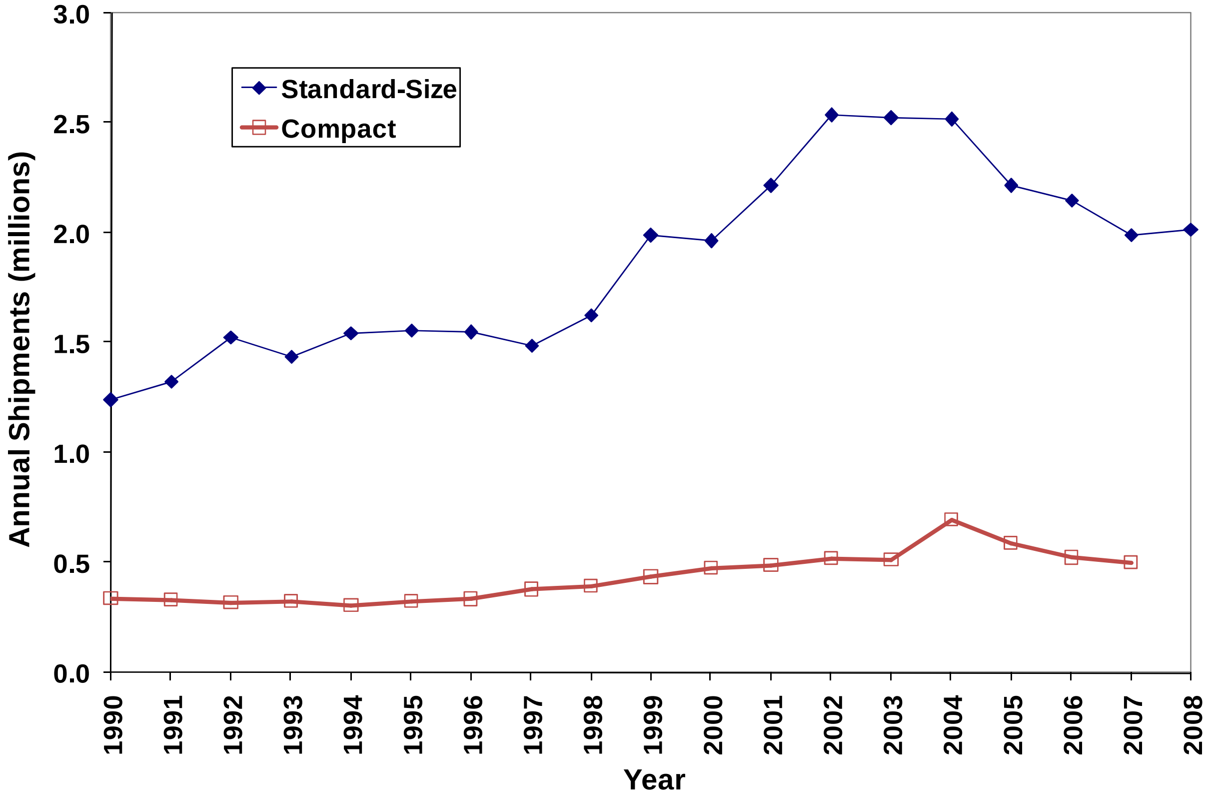


Figure 3.2.2 Annual Shipments of Freezers

For DOE's 2005 technical analysis of amended energy conservation standards for residential refrigerator-freezers, AHAM provided historical shipments data for the time period 1998–2004, broken down into three broad groups: (1) top- and bottom-mount refrigerator-freezers, (2) side-mount units, and (3) single-door units.[38] Table 3.2.21 below shows market share data for only two of the above three groups—top- or bottom-mount refrigerator-freezers and side-mount refrigerator-freezers. According to DOE's 2005 technical analysis, these two product groupings account for over 99 percent of standard-size refrigerator-freezer shipments. Data provided by AHAM as part of the pre-NOPR phase shows that in recent years single-door units accounted for 0.2% or less of shipments of standard-size refrigerators and refrigerator-freezers. This data also shows a strong shift towards bottom-mount refrigerator-freezers in the last few years, coinciding with reduction in market share of both side-mount and top-mount refrigerator-freezers.

Table 3.2.21 Market Shares of Standard Refrigerator-Freezer Product Classes

Year	Top- Mount Refrigerator- Freezer (percent)	Bottom- Mount Refrigerator- Freezer (percent)	Side-Mount Refrigerator-Freezer (percent)
1998	69.3		29.9
1999	68.8		30.8
2000	68.3		31.3
2001	67.5		32.1
2002	66.6		32.8
2003	63.7		34.5
2004	63.4		35.1
2005	62.5	2.0	35.2
2006	54.5	10.6	34.6
2007	53.9	13.6	32.4

Source: AHAM

Based on data from The NPD Group for 2004,[39] DOE estimated that (1) top-mount refrigerator-freezers without TTD ice service in the size category range of 14 to 21 ft^3 [b] comprise 81 percent of total top- and bottom-mount refrigerators, and (2) side-mount refrigerator-freezers with TTD ice service in the size category range of 21 to 30 ft^3 comprise 98 percent of total side-mount refrigerator-freezer shipments.

3.2.6.2 Historical Efficiencies

The average efficiency of new refrigerators and freezers has increased greatly since the 1980s. Figure 3.2.3 below (which shows annual electricity consumption) indicates the changes in efficiency resulting from the Federal standards that took effect in 1990, 1993, and 2001. Note that the average efficiency trends shown in the chart reflect changes in product size and features as well as changes in the efficiency within specific types of products. In particular, the growing market share of side-mount refrigerator-freezers placed upward pressure on the average annual electricity use of new refrigerator-freezers.

[b] Size category is based on ft^3 of total refrigerated volume (fresh food volume plus freezer volume).

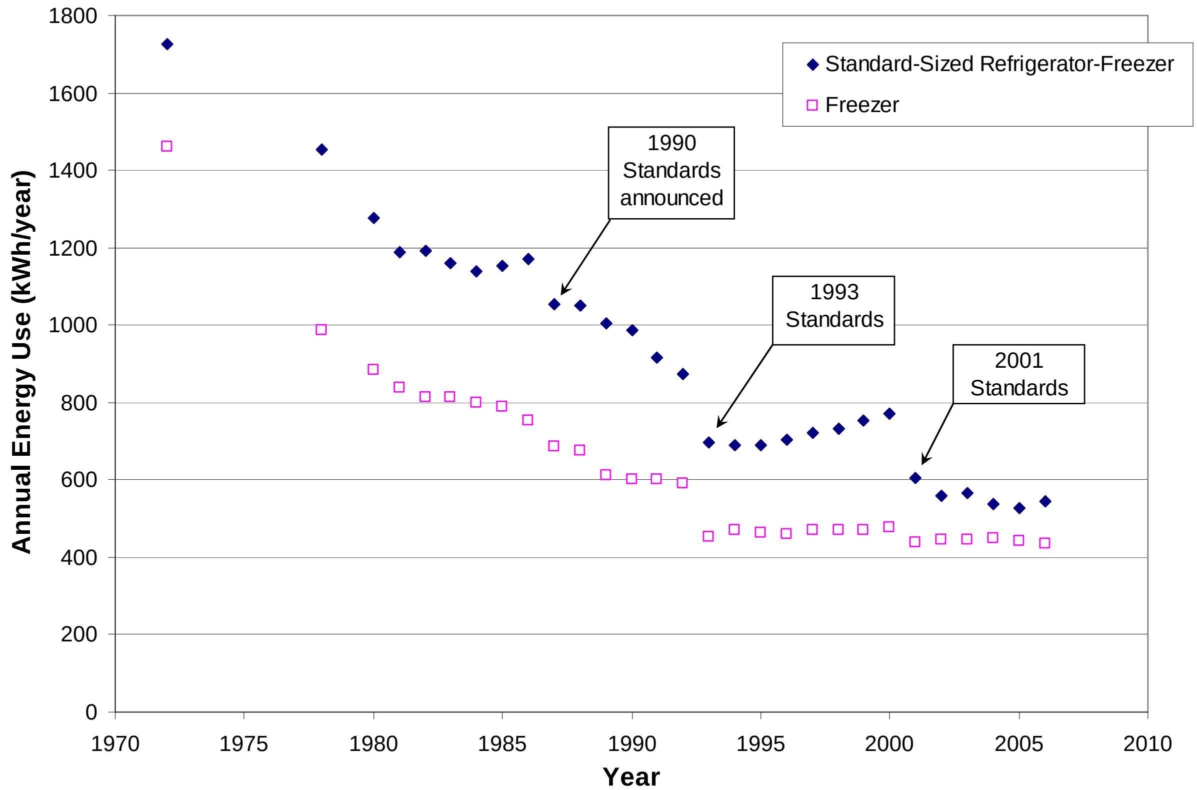


Figure 3.2.3 Average Annual Electricity Use of New Refrigerator-Freezers and Freezers
Source: AHAM

ENERGY STAR sales data are an indicator of the demand for very energy-efficient products. The market share of ENERGY STAR labeled refrigerator-freezers grew from 17 percent in 2001 to 33 percent in 2004 (Table 3.2.22) and held steady in the low 30 percent range in the following two years.[40]

Table 3.2.22 Sales of ENERGY STAR Labeled Refrigerator-Freezers

Year	Energy Star Criteria	Percent of Total
1998	20% below 1993 Standard	19%
1999		24%
2000		27%
2001	10% below 2001 Standard	17%
2002		20%
2003		26%
2004	15% below 2001 Standard	33%
2005		33%
2006		31%

Source: ENERGY STAR

3.2.6.3 Imports and Exports

The share of domestic shipments of refrigerators and freezers accounted for by imports grew significantly in the 1994-2004 period. Refrigerator imports totaled nearly six million units in 2004. Over one-third of the imports came from Mexico. Freezer imports totaled around one million units in 2004.[19]

Annual refrigerator exports—mostly to Canada—were in the 1.0 to 1.1 million units range in the 1994-2004 period, while annual freezer exports ranged between 200,000 and 250,000 units. [19]

3.2.7 Saturation in U.S. Homes

Saturation refers to the percentage of homes with a given product. DOE used four primary sources of information on the saturation and ownership of refrigerators, refrigerator-freezers, and freezers in U.S. homes: (1) a 2001 report prepared for AHAM by NFO Research, Inc.,[41] (2) *Appliance* magazine, (3) the Energy Information Administration (EIA)'s Residential Energy Consumption Survey (RECS),[42,43,44] and (4) a 2005 AHAM report entitled *Major Appliance Saturation & Marketing Factors Study*.[45] Only RECS provides market saturations for recently-built housing; this information is useful for forecasting future shipments to new housing.

The saturation of standard refrigerators has been close to 100 percent for two decades (Table 3.2.23). The RECS data show that the share of households with two or more refrigerators grew from 13 percent in 1993 to 15 percent in 2001 and to 19 percent in 2005 (the current percentage with two or more is likely even higher).

Table 3.2.23 Standard Refrigerator Saturation in U.S. Homes in 1987–2005 Period

Year	Refrigerators, Standard				
	Appliance Magazine	NFO 2001	RECS		
			All	1 unit	2 or more
1987	99.9%				
1988					
1989					
1990		96.7%			
1991					
1992	99.0%				
1993	99.3%		98.6%	85.8%	12.8%
1994	99.5%				
1995	99.7%				
1996	99.8%	93.9%			
1997	99.8%		98.9%	85.8%	13.2%
1998	99.8%				
1999	99.8%				
2000	99.9%				
2001	99.0%	93.1%	99.3%	82.9%	14.6%
2002	99.0%				
2003	99.0%				
2004	99.0%				
2005	99.0%		99.9%	77.7%	19.2%

The data on saturation of compact refrigerators vary greatly (Table 3.2.24). The estimates for 2005 vary from a low of 3.7 percent (RECS) to a high of 17.0 percent (*Appliance* magazine). Comparatively, NFO's estimate for 2001 is 5.6 percent.

Table 3.2.24 Compact Refrigerator Saturation in U.S. Homes in 1987–2005 Period

Year	Refrigerators, Compact				
	Appliance Magazine	NFO 2001	RECS		
			All	1 unit	2 or more
1987					
1988					
1989					
1990		7.4%			
1991					
1992	7.4%				
1993	8.7%		3.2%	3.2%	0.0%
1994	9.2%				
1995	9.7%				
1996	11.2%	5.8%			
1997	12.1%		2.8%	2.8%	0.1%
1998	12.6%				
1999	14.5%				
2000	16.0%				
2001	16.5%	5.6%	3.1%	3.0%	0.1%
2002	16.5%				
2003	16.5%				
2004	17.0%				
2005	17.0%		3.7%	3.1%	0.6%

The data on freezer saturation are also somewhat varied (Table 3.2.25). *Appliance* magazine reports that freezer saturation has risen from 40 percent in 1993 to 45 percent in 2005, but the NFO study reports that the 2001 level (41 percent) was lower than in 1990 (45 percent). RECS shows a much lower freezer saturation in 2001 (32 percent) than the other sources, and also shows a declining trend.

Table 3.2.25 Freezer Saturation in U.S. Homes in 1987-2005 Period

	Freezers				
	Appliance Magazine	NFO 2001	RECS		
Year			All	1 unit	2 or more
1987	40.7%				
1988					
1989					
1990		45.4%			
1991					
1992	38.2%				
1993	40.0%		34.5%	30.5%	4.0%
1994	40.0%				
1995	41.2%				
1996	42.5%	42.4%			
1997	42.4%		33.2%	30.2%	2.9%
1998	42.8%				
1999	42.9%				
2000	44.0%				
2001	47.0%	41.0%	32.0%	28.8%	3.2%
2002	47.5%				
2003	47.5%				
2004	47.0%				
2005	45.0%		31.6%	29.0%	2.6%

As shown in Table 3.2.26, RECS data indicate that in new housing (1) the saturation of freezers is lower, and (2) the share of households with two or more refrigerators is higher in recently-built homes than in the total population of homes. For freezers, this result is in accordance with the declining saturation of freezers in the total population seen in Table 3.2.25.

Table 3.2.26 Refrigerator and Freezer Saturation in New U.S. Homes

Year	Standard Refrigerators			Freezers		
	New Homes*			New Homes*		
	All	1 unit	2 or more	All	1 unit	2 or more
1993	99.7%	90.4%	9.2%	30.3%	27.8%	2.5%
1994						
1995						
1996						
1997	99.6%	85.8%	13.8%	35.9%	33.1%	2.6%
1998						
1999						
2000						
2001	100%	82.5%	15.6%	28.4%	26.3%	2.1%
2002						
2003						
2004						
2005	100%	75.0%	26.1%	27.2%	23.9%	3.3%

Source: RECS surveys; * "New homes" refers to homes built in the 1988-1993 period for the 1993 RECS, the 1992-1997 period for the 1997 RECS, and the 1996-2001 period for the 2001 RECS, and the 2001-2005 period for the 2005 RECS.

3.2.8 Product Retail Prices

3.2.8.1 Historical Retail Prices

AHAM has reported average consumer retail prices for refrigerator-freezers and freezers in past Fact Books. Table 3.2.27 lists the prices for eight years spanning 1980–2002. The real price of refrigerator-freezers and freezers (expressed in 2008 $) declined during the 1980s and 1990s. However, in 2002, the prices of both types of products increased relative to the year 1998.

Table 3.2.27 Refrigerator-Freezer and Freezer Average Retail Prices

Product	Price	Year							
		1980	1985	1986	1991	1993	1994	1998	2002
Refrigerator-Freezers	nominal $	$598	$702	$684	$732	$692	$713	$657	$788
	2008 $	$1,563	$1,405	$1,344	$1,157	$1,031	$1,036	$868	$943
Freezers	nominal $	$426	$479	$449	$434	$334	$344	$315	$405
	2008 $	$1,113	$958	$882	$686	$498	$500	$416	$485

Source: AHAM Fact Books.

3.2.8.2 Refrigerator-Freezer 2004 Retail Prices

DOE's most recent technical analysis of amended energy conservation standards for residential refrigerator-freezers published in October 2005 provided the retail price of the two largest product classes of refrigerator-freezers: top-mount refrigerator-freezers without TTD features and side-mount refrigerator-freezers with TTD features.[38] The analysis also established the retail price of products meeting existing ENERGY STAR levels.

Baseline Retail Prices

DOE determined the retail price of baseline-efficiency top-mount refrigerator-freezers without TTD features and side-mount refrigerator-freezers with TTD features from data purchased from NPD Group. The NPD Group dataset included information about the average price of more than 2000 refrigerator models sold in 2004 in the United States.[c] Table 3.2.28 below summarizes the retail price data for three capacity sizes for each of the product types. The retail prices correspond to baseline-efficiency products, *i.e.*, products that just meet the existing energy conservation standards.

Table 3.2.28 Baseline Unit Retail Prices from 2005 DOE Report (2004$)

Product Type	**14-17 ft^3**	**18-20 ft^3**	**21-22 ft^3**
Top-Mount without TTD	$329	$386	$457
	21-23 ft^3	**24-26 ft^3**	**27-30 ft^3**
Side-Mount with TTD	$702	$789	$926

Source: The NPD Group/NPD Houseworld – POS.

Price of ENERGY STAR

DOE's October 2005 report also provided incremental retail price estimates of ENERGY STAR products relative to baseline products. At the time, ENERGY STAR levels specified 15 percent lower energy consumption than the federal energy standard level. DOE used two approaches to estimate the retail prices: (1) the application of manufacturer and retailer markups to manufacturer costs, and (2) a retail price analysis of ENERGY STAR compliant products based on data from the NPD Group. Table 3.2.29 below summarizes the retail price increments associated with meeting ENERGY STAR relative to baseline models of several different capacity sizes. Note that the two approaches yield roughly the same average retail price increment of meeting ENERGY STAR with the exception of the 27–30 ft^3 side-mount refrigerator.

Table 3.2.29 Average Retail Price Increment of ENERGY STAR from 2005 DOE Report (2004$)

Product Type	**Approach**	**14-17 ft^3**	**18-20 ft^3**	**21-22 ft^3**
Top-Mount without TTD	Markups	$38	$35	$42
	Retail Prices	$28	$49	$63
Product Type	**Approach**	**21-23 ft^3**	**24-26 ft^3**	**27-30 ft^3**
Side-Mount with TTD	Markups	$54	$35	$183
	Retail Prices	$47	$66	$88

Source: DOE, 2005.

[c] The data also included information about the refrigerator brand, manufacturer, attributes (e.g., total refrigerated volume, number and type of shelves), and sales, and whether each model has an Energy Star rating. The data cost $25,000 to purchase.

3.2.8.3 2007 Manufacturer-Suggested Retail Prices

DOE collected retail price data for several refrigerator-freezer and freezer models from five manufacturers' Internet web sites: General Electric, Whirlpool, Frigidaire, Maytag, and LG Electronics. The price data reflect manufacturer-suggested retail prices and, therefore, may not reflect actual sales prices. Even so, DOE conducted a statistical analysis of the data to determine the effect of certain attributes, including the impact of meeting existing ENERGY STAR levels.

DOE collected data on 1,268 refrigerator-freezer and freezer models. The collected data set included information about the retail price and model number of refrigerator-freezers and freezers sold in 2007 in the U.S., coupled with information about the brand, attributes (*i.e.*, color, stainless steel, built-in, French doors), and whether the product met existing ENERGY STAR levels. DOE sorted the data into the following product types: (1) side-mount refrigerator-freezers consisting of 523 models, (2) top-mount refrigerator-freezers consisting of 340 models, (3) bottom-mount refrigerator-freezers consisting of 281 models, (4) chest freezers consisting of 46 models, and (5) upright freezers consisting of 54 models.

Figure 3.2.4 through Figure 3.2.8 present price distributions for each product type, showing variation in price of products which do not meet ENERGY STAR criteria as well as variation in price for products with comply with ENERGY STAR. The price distributions of side-mount and top-mount refrigerator-freezers in Figure 3.2.4 and Figure 3.2.5 indicate that ENERGY STAR generally increases the price and that there is a wider price variation for ENERGY STAR products. Also, both refrigerator-freezer types exhibit skewed price distributions, *i.e.*, more models are low-priced with relatively few high-priced models (as an example, fewer than 10 models were priced above $1,300 for top-mounts). The price distributions for bottom-mount refrigerator-freezers, Figure 3.2.6 below, show that French-door configurations are more of a factor in contributing to high price than ENERGY STAR efficiency levels. Most bottom-mount models already meet ENERGY STAR, and those models configured with French doors are distinctly more expensive. The price distributions for upright freezers show that ENERGY STAR models are generally more expensive (Figure 3.2.7). For chest freezers, there are several models with and without ENERGY STAR that are priced similarly, but there are no low-priced models that qualify for ENERGY STAR (Figure 3.2.8).

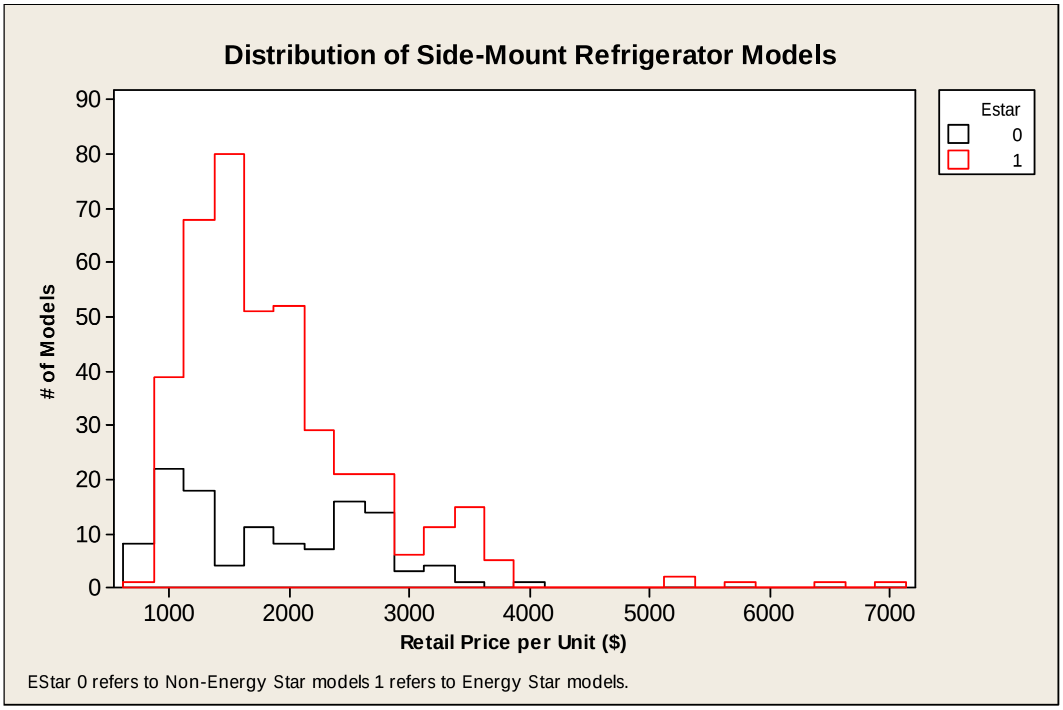


Figure 3.2.4 2007 Manufacturer-Suggested Retail Price Distribution of Side-Mount Refrigerator-Freezers with and without ENERGY STAR (2007$)

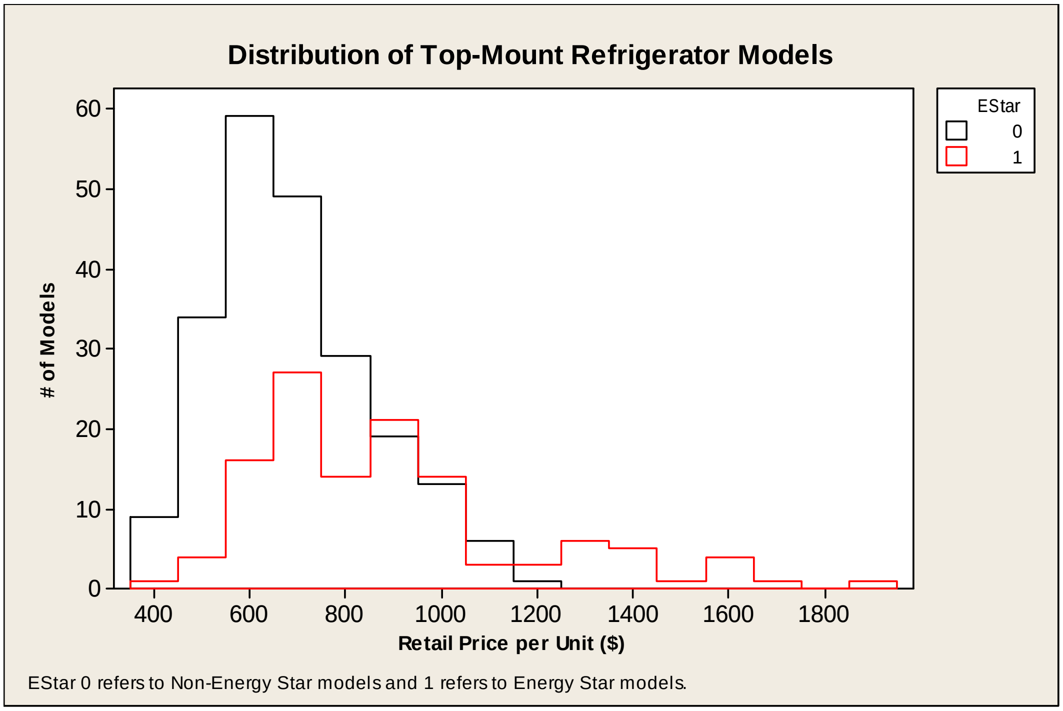


Figure 3.2.5 2007 Manufacturer-Suggested Retail Price Distribution of Top-Mount Refrigerator-Freezers with and without ENERGY STAR (2007$)

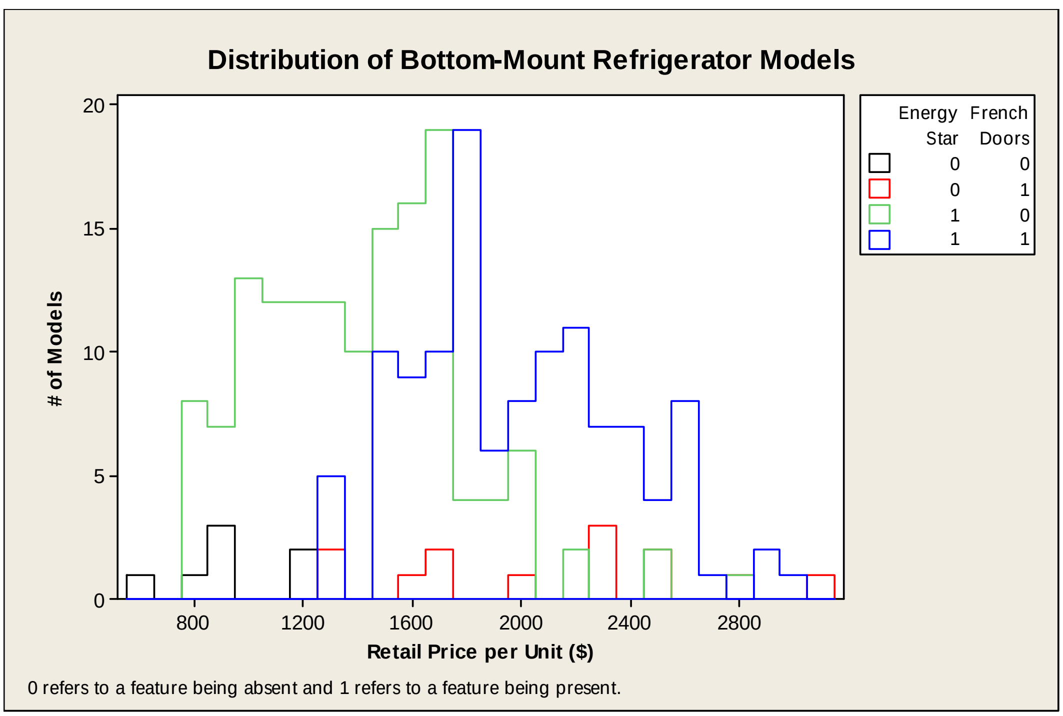


Figure 3.2.6 2007 Manufacturer-Suggested Retail Price Distribution of Bottom-Mount Refrigerator-Freezers with and without ENERGY STAR (2007$)

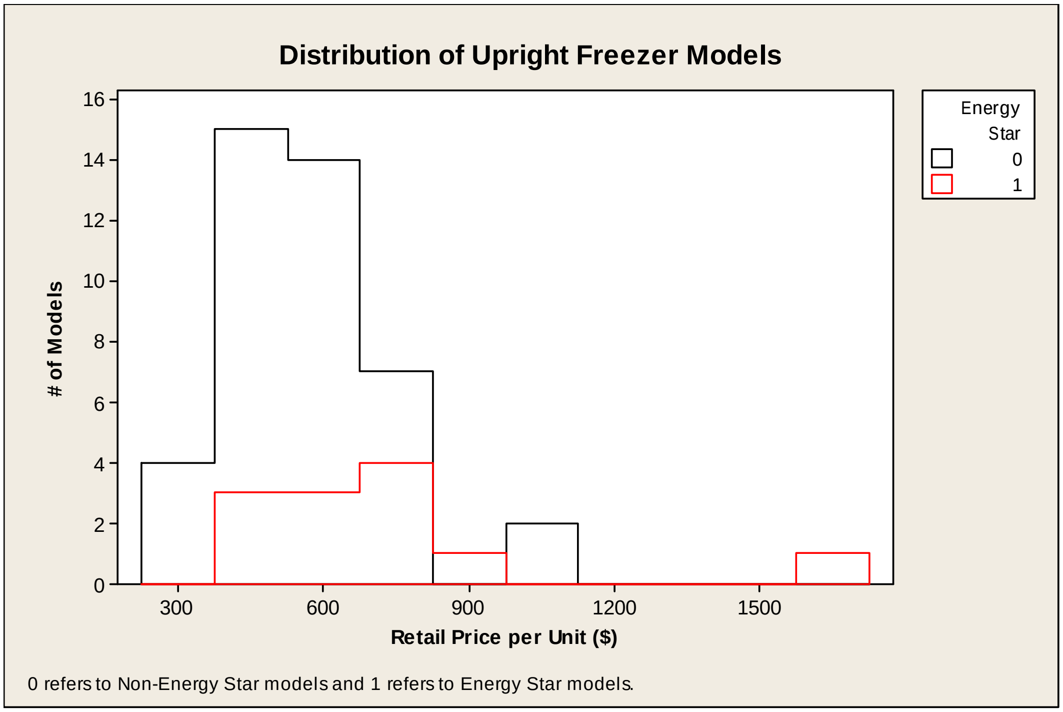


Figure 3.2.7 2007 Manufacturer-Suggested Retail Price Distribution of Upright Freezers with and without ENERGY STAR (2007$)

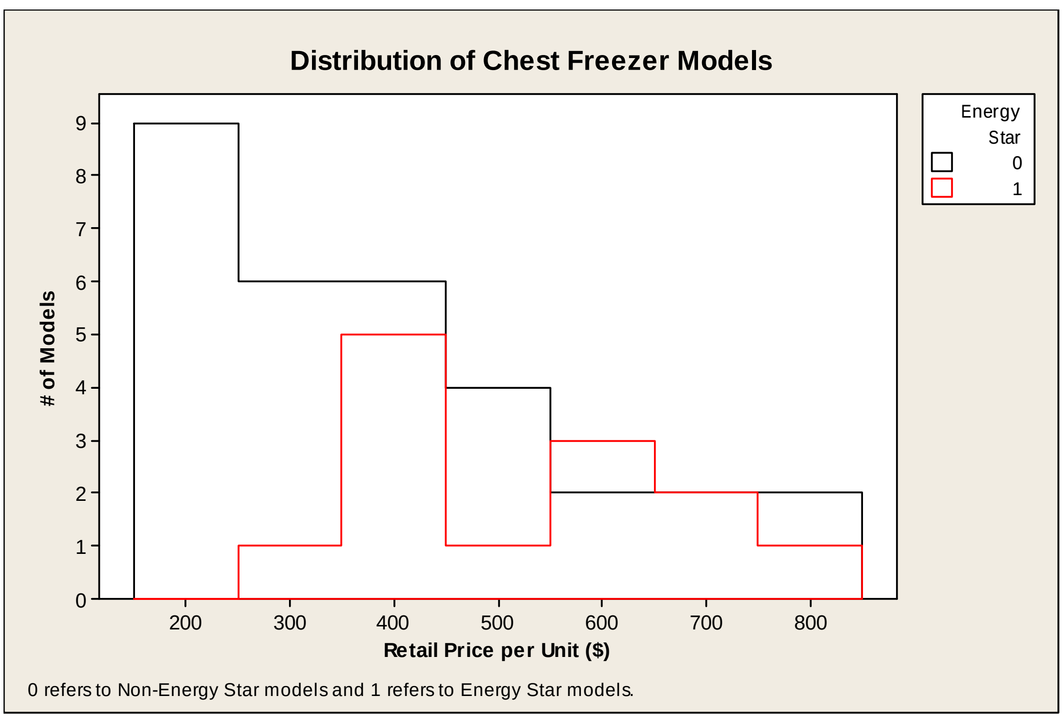


Figure 3.2.8 2007 Manufacturer-Suggested Retail Price Distribution of Chest Freezers with and without ENERGY STAR (2007$)

DOE also performed regression analysis on each of the five product types to estimate the incremental price of the different attributes. For the regression analysis, DOE confined the sample to models with prices within two standard deviations of the mean value. DOE did this to remove outliers from the sample. Removing the outliers lowered the sample size to 92 to 95 percent of the original size, depending on the product type. Specifically, the side-mount refrigerator-freezer sample was reduced from 523 to 502, the top-mount refrigerator-freezer sample was reduced from 340 to 321, the bottom-mount refrigerator-freezer sample was reduced from 281 to 272, the upright freezer sample was reduced from 54 to 53, and the chest freezer sample was reduced from 46 to 43. DOE performed the regression analysis with two types of regression equations that it formulated to determine the price increment due to each attribute: (1) a 'basic' equation where price is a function of only ENERGY STAR qualifying levels (the focus variable); and (2) a 'complete variable' equation where price is a function of ENERGY STAR (the focus variable), product attributes (stainless steel, built-in, French doors), and the brand.

Table 3.2.30 presents the summary results of the regression analysis. The first column in the table indicates the product type and the second column presents the 'constant' price (i.e., the price without any of the attributes under consideration, also referred to as a baseline model) for each product type. The 'coefficients' represent the price adder for a product with a specific attribute (*i.e.*, ENERGY STAR, French doors for bottom-mount products, stainless steel cabinet, and brand). If the value is positive, than the 'coefficient' for the attribute is added to the 'constant' price. If the value is negative, than the 'coefficient' for the attribute is subtracted from the 'constant' price. For example, for side-mount refrigerator-freezers, the 'coefficient' for ENERGY STAR is \$208. Therefore, the added retail price of an ENERGY STAR side-mount refrigerator-freezer is \$208, raising the baseline price from \$1128 to \$1336. Also presented in Table 3.2.30 are the adjusted R-squared value and the number in the sample. In a multiple linear regression model, adjusted R square measures the proportion of the variation in the dependent variable (retail price) accounted for by the explanatory variables.[d]

DOE found that the incremental price effect of meeting ENERGY STAR levels is significant at a 95 percent confidence level for all product types with the exception of bottom-mount refrigerator-freezers. In the case of side-mount refrigerator-freezers, qualifying for ENERGY STAR adds \$208 to the price of the baseline model, while for top-mount refrigerator-freezers it adds \$63. These price increments are significantly higher than those from DOE's October 2005 technical report (see Table 3.2.29 above). Because the analysis conducted for the 2005 technical report was more rigorous (for example, DOE conducted the 2005 retail price analysis using sales-weighted point-of-sale data), the price increments for meeting ENERGY STAR based on the 2007 manufacturer suggested retail price data are likely not as accurate a price indication of meeting ENERGY STAR. Rather, the analysis based on the 2007 prices simply confirms that ENERGY STAR products are more expensive than baseline products. In the case of upright and chest freezers, the analysis shows that the price increase associated with meeting ENERGY STAR is \$107 and \$121, respectively.

For bottom-mount refrigerator-freezers, meeting ENERGY STAR levels is not a significant factor at a 95 percent confidence level. The French door attribute is significant and

[d] Unlike R squared, adjusted R squared allows for the degrees of freedom associated with the sums of the squares in its calculation. Therefore, even though the residual sum of squares decreases or remains the same as new explanatory variables are added, the residual variance does not. For this reason, adjusted R square is generally considered to be a more accurate goodness-of-fit measure than R square.

adds over $330 to the price of a baseline unit. This is consistent with the price distributions of bottom-mount models presented in Figure 3.2.6 above.

The analysis suggests that stainless steel plays a significant role in the price of side-mount, top-mount, and bottom-mount refrigerator-freezers and upright freezers. The 'coefficient' of brand suggests an effect similar to stainless steel. Brand is significant for the three refrigerator-freezer product types but is not significant in the case of freezers.

Table 3.2.30 Regression Analysis of the Incremental Price of ENERGY STAR and other Attributes based on 2007 Manufacturer-Suggested Retail Prices (2007$)

Product Type	Constant (Baseline)	Coefficients (Price Adder)								Adj R^2	Number in Sample
		Energy Star	French Door	Stain-less	Brand						
					Frigidaire	GE	Whirlpool	Maytag	LG		
Side-Mount	$1128	$208	NA	$156	-245	$375	-$231	-$252	$431	0.65	502
Top-Mount	$660	$63	NA	$97	-$54	$80	$28	$49	NA	0.40	321
Bottom-Mount	$1285	-$31*	$332	$143	NA	$283	-$83	$70	-$212	0.58	272
Upright Freezer	$495	$107	NA	$215	$56*	$40*	-$41*	-$40*	NA	0.35	53
Chest Freezer	$352	$121	NA	NA	$116*	$116*	-$100*	-$99*	NA	0.17	43

* Although numerical values are provided, the regression analysis indicated that these attributes were not significant factors in determining the incremental product price at a 95 percent confidence interval.

3.2.8.4 Refrigerator-Freezer and Freezer 2008 Retail Prices

To determine retail prices for the year 2008, DOE drew upon proprietary retail price data collected by The NPD Group.[46] These data reflect prices and sales at many retail outlets in the United States, representing more than 50 percent of retail sales nationwide. The data include model number, refrigerated volume, configuration of doors and ice-making, and whether the unit is an ENERGY STAR product. Based on these data DOE developed a sales-weighted price distribution for non-ENERGY STAR appliances for seven of the 20 product classes.[e] Additional details about this price data are provided in Chapter 8 of this TSD. The average baseline retail prices before sales tax for each of the seven product classes are shown in Table 3.2.31. With the exception of product class 3 (top-mount refrigerator-freezers), the retail prices in Table 3.2.31 are relatively close to the manufacturer-suggested retail prices in Table 3.2.30.

[e] DOE assumed that prices for non-ENERGY STAR models are a reasonable approximation of prices for the baseline models.

Table 3.2.31 Residential Refrigeration Products: Average Baseline Retail Price

Product Class	Baseline Retail Price *2008$*
Product class 3: Top-mount refrigerator-freezer	1,005
Product class 5: Bottom-mount refrigerator-freezer	1,313
Product class 7: Side-by-side refrigerator-freezer with TTD*	1,333
Product class 9: Upright freezer	469
Product class 10: Chest freezer	483
Product class 11: Compact refrigerator	151
Product class 18: Compact freezer	193

* Through-the-door ice service.

3.3 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for refrigerators, refrigerator-freezers, and freezers. Contained in this technology assessment are details about product operations and components (section 3.3.1), an examination of possible technological improvements for each product (section 3.3.2), and a characterization of the product efficiency levels currently commercially available (section 3.3.3).

3.3.1 Product Operation and Components

This section provides a brief description of the components and operation of refrigerators, refrigerator-freezers, and freezers. These descriptions provide a basis for understanding the technologies used to improve product efficiency.

3.3.1.1 Product Operation

Refrigerators, refrigerator-freezers, and freezers are household appliances designed for the refrigerated storage of food products. Definitions for these product types and their operating temperature ranges are discussed in section 3.2.1.

Figure 3.3.1 shows a schematic representation of a typical refrigeration circuit used in residential refrigeration products. As described by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Refrigeration Handbook*,[47] the refrigeration process consists of the following steps:

1. Electrical energy is supplied to a motor that drives a compressor, which draws cold, low-pressure refrigerant vapor for the evaporator and compresses it.
2. The resulting high-pressure, high-temperature discharge gas then passes through the condenser, where it is cooled to saturation condition, condensed to a liquid, and possibly subcooled while heat is rejected to the ambient air.
3. Liquid refrigerant passes through a metering (pressure-reducing) capillary tube to the evaporator, which is at low pressure.

4. The low-pressure, low-temperature liquid in the evaporator absorbs heat from its surroundings, evaporating to a gas, which is again withdrawn by the compressor.

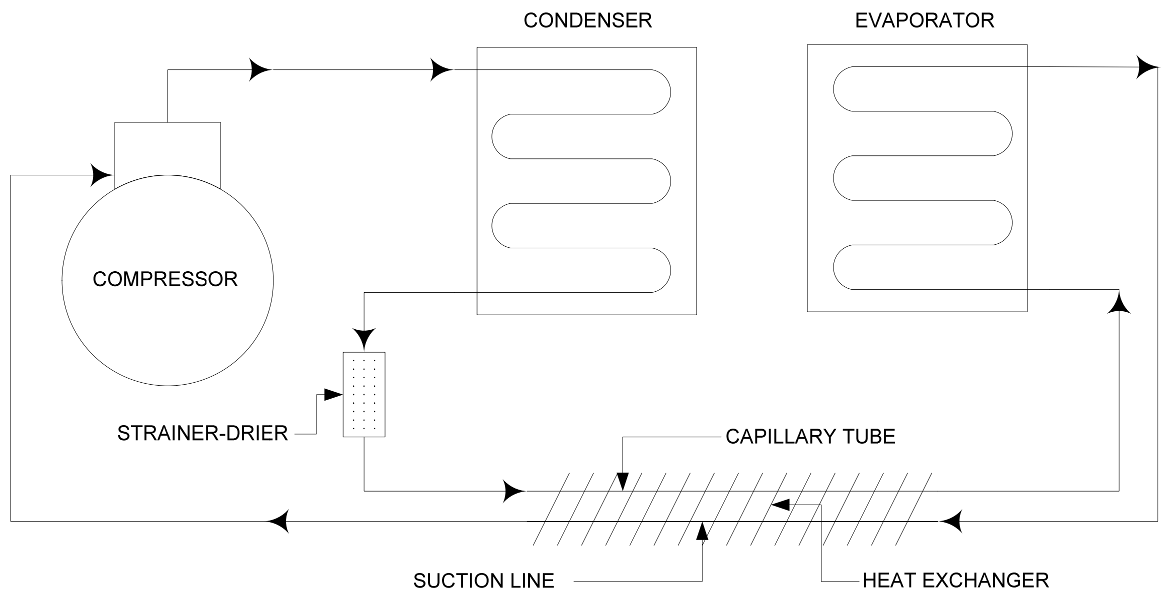
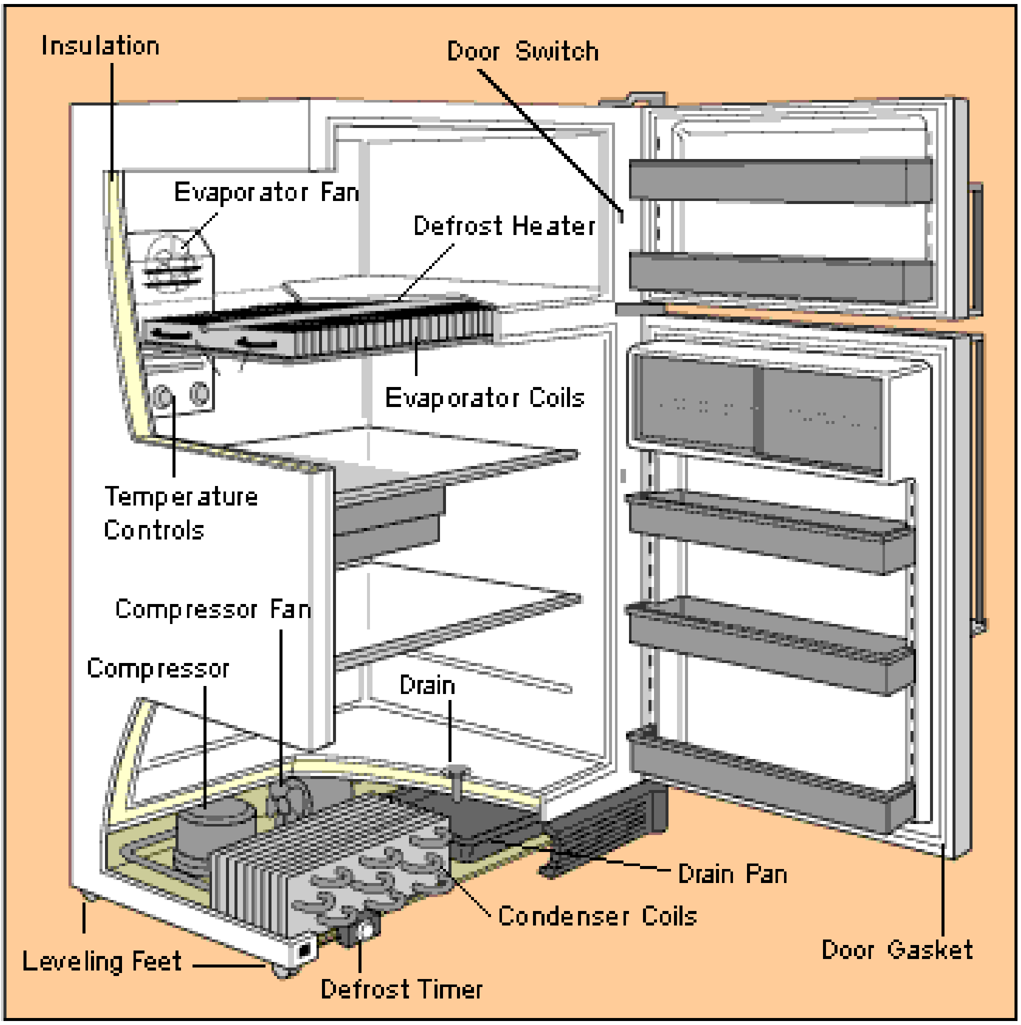


Figure 3.3.1 Refrigeration Circuit

In Figure 3.3.1 above, the metering or flow control device pictured is a non-adiabatic capillary tube. In this configuration, the capillary tube is soldered to the suction line to evaporate the residual liquid in the suction line and warm the vapor. This suction line heat exchanger (or the non-adiabatic capillary) increases the refrigeration capacity of the system by the amount of heat being transferred from the capillary to the suction side. Non-adiabatic capillary tubes are the most common type of metering device in refrigerator-freezers. The other type of metering device, an adiabatic capillary tube, is used in some refrigeration products. In this configuration, the capillary tube does not exchange heat with the suction line and the refrigerant expands from the high pressure to the low pressure adiabatically.

3.3.1.2 Primary Components

The illustration in Figure 3.3.2 (from RemodelGuide.com[48]) shows the components and layout of a typical top-mount refrigerator-freezer. The components and layout are similar in side-mount and bottom-mount refrigerator-freezers. Freezers also have a similar layout and components, but are slightly less complicated due to the fact that they have no fresh food compartment. The text that follows describes the following operations or components: automatic defrost, cooling, temperature control, lighting, ice maker, ice and water dispenser, and door seals and hinges.



Source: RemodelGuide.com

Figure 3.3.2 Top-Mount Refrigerator-Freezer Components

Automatic defrost

Almost all standard-size refrigerator-freezers are self-defrosting. Manual defrost is still used in chest freezers, some upright freezers, and in compact refrigerators and freezers. Self-defrosting refrigerator-freezers and freezers automatically melt frost that accumulates in the freezer compartment. The typical automatic defrost system has three functional components: a defrost timer, a defrost heater, and a defrost thermostat.

- *Defrost timer:* The timer is a clock that is energized with the compressor. The timer initiates defrost after a set interval of compressor operation, typically twelve hours.

- *Defrost heater:* The defrost heater is an electric resistance heating element. It is located just beneath or on the side of the evaporator coil, which is concealed behind a panel in the freezer compartment. The heater melts any ice or frost that builds up. A heater is typically also energized in the drip pan to prevent freeze of melted condensate and clogging of the drip pan drain.

- As the frost and ice melt, the resulting water drips into a drip pan. The pan is connected to a tube that drains the water into a shallow pan at the bottom of the refrigerator-freezer or freezer. The water is then evaporated by air which is drawn by a fan through the condenser and over the compressor shell. In some products which do not use forced convection condensers, particularly freezers, a special pan is mounted on top of the compressor shell and the water is evaporated using heat from the compressor.

- *Defrost thermostat:* The process ends when the defrost thermostat mounted on the evaporator tubing senses that a sufficiently high temperature has been attained.

Cooling

All residential refrigerators, refrigerator-freezers, and freezers work by removing heat from the air in the cabinet. They all have the key components shown in Figure 3.3.1: a compressor, a condenser, a metering or flow control device (usually a capillary tube), and an evaporator.

- *Compressor:* The compressor compresses refrigerant, providing the energy input necessary to drive the cycle. In most residential refrigeration products, the compressor is located at the bottom rear of the unit. In built-in refrigerator-freezers the compressor is often located on top of the refrigerator behind a grill or grate. The compressor runs whenever the refrigerator thermostat calls for cooling.

- *Condenser:* The condenser is a heat exchanger located on the outside of the unit. The three most prevalent condenser configurations are as follows:
  – Forced-convention condensers use fans to move air through them to provide cooling. These condensers are usually located under the unit near the compressor. They can be fabricated of steel tubes with steel wire fins or copper tubes with aluminum fins.
  – Natural convection “static” condensers which don’t use fans are mounted to the back of the unit. They generally have steel tubes and steel wire fins.
  – Hot wall condensers are integrated into the outer shell of the unit. A serpentine of tubing is attached to the inside of the shell and provided with good thermal contact to the shell. This is the common configuration in freezers and it is common in compact refrigerators.

- *Metering or Flow Control Device (Capillary Tube):* The metering device in most household refrigerator-freezers is a capillary tube. As discussed above in section 3.3.1.1, there are two common types of capillary tubes—adiabatic and non-adiabatic, although non-adiabatic are the most common. The capillary tube controls the pressure and flow of the refrigerant as it enters the evaporator.

- *Evaporator:* The evaporator is a heat exchanger located inside the unit. Similar to the condenser, there are three main configurations for evaporators:
  – Forced convection evaporators use fans to move air through them to provide cooling. They are constructed of aluminum tubes and aluminum fins or copper tubes and aluminum fins. They are generally located on the rear wall of the freezer

compartment behind a panel. They can also be located in the mullion separating the freezer and fresh food compartments, as shown in Figure 3.3.2. The evaporator fan circulates air through the evaporator and into both the freezer and fresh food compartments. Because the evaporator absorbs heat, it is very cold, thereby causing any water vapor in the air to freeze on it as frost. Most refrigerator-freezers using this type of evaporator employ automatic defrost.

– Roll bond evaporators fabricated from layers of aluminum sheet primarily use natural convection cooling. The refrigerant passages are formed into the evaporator walls. They are used in single-door refrigerators and are configured either as a flat plate at the rear of the cabinet or a rectangular box. In the latter configuration, the interior of the box is the freezer compartment. While these evaporators generally use natural convection and do not use an evaporator fan, some products with rear-mounted flat roll bond evaporators use fans for performance enhancement. Manual defrosting is required to defrost these evaporators.
– Cold wall evaporators are integrated within the walls of the freezer. This configuration is used in nearly all chest freezers and in many upright freezers. The evaporator consists of tube serpentines attached to the insulation side of the cabinet interior liner. These evaporators use natural convection heat transfer.

Temperature control

All refrigerators, refrigerator-freezers, and freezers have a thermostat or electronic temperature control to maintain the proper temperature. Thermostats are mechanical devices which interrupt the electricity connection to the compressor when the temperature is sufficiently low. Electronic control systems generally use thermistors as temperature sensors, using relays mounted on the circuit boards to activate the compressor and other components such as the evaporator and condenser fans.

Lighting

Refrigerators, refrigerator-freezers, and freezers with internal lighting normally have only one functional lighting component—the switch—which is usually a white push-button mounted to be depressed by operation of the door. Closing the door turns off the light. Refrigerators generally use standard appliance incandescent light bulbs.

Ice maker

Many standard-size refrigerator-freezers come equipped with an ice maker, and nearly all are convertible to installation of an ice maker. The ice maker is a located within the freezer compartment. Ice maker systems have two basic functional components: the icemaker itself, and the water fill valve. The most common ice makers operate as follows:

- The ice maker sends a signal to the water fill valve (normally located on the outside back of the refrigerator, near the bottom) to open and let water into the ice maker tray (or mold). Water fill control is usually by timed opening of the valve (usually 7-10 seconds).

- When the ice has frozen and reached a sufficiently low temperature (10 to 15 °F), sensed with a thermostat located in thermal connection with the ice tray, the ice maker begins to harvest (eject) the cubes.
- To harvest the cubes, the ice maker first turns on a small heater beneath the tray. The heater warms the tray, to help release the ice cubes. Then a sweep fork rotates and pushes the cubes up and out of the tray.
- While the ice maker is dumping the cubes into a the ice storage bin, a metal wire similar to a coat hanger swings up to let the cubes drop below it. When the cubes have dropped, the wire rotates back down. If the holding bin is full of ice, the wire rotate far enough, which stops further production of ice. If the sensing wire can rotate down fully, the ice maker refills with water and repeats the process.

Ice and water dispenser

Many standard-size refrigerator-freezers have a through-the-door (TTD) ice and/or water dispenser. There are several different systems for delivering ice and water through the refrigerator door. What follows is an explanation of the common attributes of all of the systems.

- *Ice dispenser:* For a refrigerator-freezer to provide ice through the door, the ice maker first dumps the ice it produces into a large bin, as discussed above. To request ice at the door, the user presses a lever that activates a switch. The switch turns on a motor that rotates an auger which pushes ice out of the bin, through a chute to the user. Some dispensers also have blades which chop the ice to allow delivery of crushed ice.
- *Water dispenser:* The water dispenser is activated much like the ice dispenser. To request water at the door, the user presses a lever on the front of the refrigerator that activates a switch. The switch turns on an electric water valve at the back of the refrigerator-freezer. Water flows through the valve into a tube, then flows into a reservoir located in the fresh food compartment in which the water is chilled. As new water enters the reservoir, the water that is displaced flows through a separate tube through the dispenser.

Door Seals

All refrigerator, refrigerator-freezer, and freezer doors have a seal—a vinyl gasket attached to the door(s). The seal prevents infiltration of warm ambient air into the cabinet. The seal is lined with a magnet which helps to hold the door closed and create a tight seal. The magnetic portion of the gasket is aligned to face the steel extension of the cabinet's external shell which wraps partially around the front face of the cabinet. Some gasket systems use opposing magnets on the cabinet side to improve door sealing force.

3.3.2 Technology Options

Table 3.3.1 lists the technology options for improving the efficiency of residential refrigeration products. The technology options are categorized by their associated component or system. Each technology option category and the options available for improving the component or system category are discussed below.

Table 3.3.1 Technology Options for Refrigerators, Refrigerator-Freezers, and Freezers

Insulation	**Expansion Valve**
Improved resistivity of insulation	Improved expansion valves
Increased insulation thickness	**Cycling Losses**
Vacuum-insulated panels	Fluid control or solenoid valve
Gas-filled panels	**Defrost System**
Gasket and Door Design	Reduced energy for automatic defrost
Improved gaskets	Adaptive defrost
Double door gaskets	
Improved door face frame	Condenser hot gas
Reduced heat load for TTD feature	**Control System**
Anti-Sweat Heater	Temperature control
Condenser hot gas	Air-distribution control
Electric heater sizing	**Other Technologies**
Electric heater controls	Alternative refrigerants
Compressor	Component location
Improved compressor efficiency	
Variable-speed compressors	**Alternative Refrigeration Cycles**
Linear compressors	Lorenz-Meutzner cycle
Evaporator	Dual-loop system
Increased surface area	Two-stage system
Improved heat exchange	Control valve system
Condenser	Ejector refrigerator
Increased surface area	Tandem system
Improved heat exchange	**Alternative Refrigeration Systems**
Force convection condenser	Stirling cycle
Fans and Fan Motor	Thermoelectric
Evaporator fan and fan motor improvements	Thermoacoustic
Condenser fan and fan motor improvements	

3.3.2.1 Insulation

The primary thermal load on a refrigerator or freezer is the heat transfer through the walls and doors into the cabinet. In one study of an 18.6 ft^3 top-mount refrigerator-freezer, the wall and door heat loads were estimated to account for almost 60 percent of the total thermal load.[49]

Nearly all residential refrigeration products use polyurethane (PU) foam insulation for both the cabinets and the doors. Through the 1980s, CFC-11, a chlorofluorocarbon (CFC), was used as a blowing agent in almost all PU foam insulation. However, under the Montreal Protocol, all CFCs were banned from use by the mid 1990s due to their high ozone depletion potential (ODP). In the 1990s, most manufacturers adopted use of HCFC-141b, a hydrochlorofluorocarbon (HCFC), which has significantly less ODP. However, because HCFC-141b has non-zero ODP, it was banned from production in the U.S. after January 1, 2003. In response to the phase-out of HCFC-141b, AHAM's Appliance Research Consortium (ARC) investigated several alternatives, including two hydrofluorocarbons (HFCs), HFC-134a and HFC-245fa, and cyclopentane, a hydrocarbon (HC). HFCs and HCs both have zero ODP. HCs have a much lower global warming potential (GWP) than HFCs, but they are flammable. ARC, DOE, and EPA sponsored research at Oak Ridge National Laboratory (ORNL) to determine the thermal conductivities of the three alternatives and of HCFC-141b. Based on thermal conductivity, ORNL identified HFC-245fa as the most attractive substance because it had the lowest energy penalty relative to HCFC-141b (see Table 3.3.2).[50] In addition, accelerated lifetime performance tests conducted by ORNL indicated that the thermal conductivity of HFC-245fa foam insulation increases by a smaller percentage than either HFC-134a or cyclopentane foams. Finally, despite the fact that HCs are used in Europe, flammability and volatile organic compound concerns led ARC to determine that HFCs were a more suitable replacement blowing agent.[51] As a result, many manufacturers are currently using HFC-245fa blowing agent for PU foam insulation. However, refrigerators and freezers sold in the U.S. also are using HFC-134a, cyclopentane, and HCFC-141b blowing agent. The HCFC blowing agent is still allowed for refrigerators imported into the U.S.

Table 3.3.2 Thermal Conductivity of Freshly-Sliced Foam Specimens at 75 ºF (23.9 ºC)

	Slice Thickness			
	0.4 inch (1.0 cm)		**1.5 in (3.8 cm)**	
Blowing Agent	*Btu-in/hr-ft²-ºF*	*mW/m-K*	*Btu-in/hr-ft²-ºF*	*mW/m-K*
HCFC-141b	0.132	19.0	0.128	18.4
HFC-245fa	0.138	19.9	0.132	19.0
Cyclopentane	0.150	21.6	0.145	20.9
HFC-134a	0.160	23.1	0.155	22.3

Source: ORNL, 2003.[50]

Improved Resistivity of Insulation

Past research has investigated improving the resistivity of PU foam insulation through the use of additives in the foam.

Research conducted in 1996 demonstrated that adding carbon black provides a means of improving the thermal insulation properties of PU foam. The research showed that PU foam systems using carbon black in conjunction with either HCFC-141b or cyclopentane was able to lower *k*-factors by six to nine percent in panels and in cabinets.[52]

Increased Insulation Thickness

Based on DOE's 1995 technical support document (TSD) for refrigerators, refrigerator-freezers, and freezers, the insulation thickness range for refrigerator-freezers in the mid-1990s was 1.5 to 2.75 inches (3.81 to 7.0 cm) in the doors and 1.5 to 3 inches (3.81 to 7.62 cm) in the cabinet walls. Walls of freezers and freezer compartments tended to be near the higher end while walls of refrigerators and fresh food compartments were nearer the lower end.[53]

Also based on the DOE 1995 TSD, adding 0.5 to 1 inch (1.27 to 2.54 cm) more insulation increases the overall efficiency of the product. Energy reductions associated with these wall thickness increases range from a few percent to over 10 percent. Therefore, DOE considered the addition of more insulation as a technology option to improve efficiency. Although the technology to implement this change is readily available, manufacturers indicated during the rulemaking leading to the April 27, 1997 final rule establishing the current minimum efficiency levels that adding insulation would not be the first technology option they would choose to improve efficiency. Significant investments would be required in foaming systems, tooling, and molding to accommodate thicker insulation. Increased packaging and shipping costs must also be considered. Greater insulation thickness results in either decreased interior volumes, increased exterior dimensions, or some combination of both. Since kitchen dimensions and designed spaces for refrigerator-freezers are limited, there are restrictions on increasing the exterior size of the product. Reducing interior volume is considered undesirable because it impacts consumer utility.

Vacuum-Insulated Panels

Vacuum-insulated panel (VIPs) technology is based on the reduction in conductivity which occurs in a low vacuum, the same concept which is used to reduce heat leakage in thermos bottles. VIPs used in refrigeration products consist of a sealed package with a fill material which provides support to prevent the panel from collapsing and interferes with molecular mean free path as the intermolecular spacing increases at lower vacuum levels. VIPs can be foamed in place between the cabinet liner and wrapper to decrease the heat leakage and energy required to maintain the cabinet at low temperature. Different configurations are commercially available through advances in manufacturing technologies. As a result, VIPs are available in a variety of geometries (*e.g.*, flat, curved, cylindrical) with added features (*e.g.*, holes, cut-outs).[54] Typical VIPs generally consist of a core material and an airtight envelope. Some VIPs also include absorber to absorb gas which leaks through the envelope.

Several core materials have been used in the manufacture of VIPs including polystyrene, open-cell PU, silica powder, and glass fiber. Research sponsored by the European Commission has evaluated these core materials based on their cost and characteristics, including density and manufacturing time. Table 3.3.3 below summarizes the VIP characteristics manufactured with the above core materials.[55] Each of the core materials has associated advantages and disadvantages that dictate their acceptability for an appliance application.

Table 3.3.3 Comparison of Various VIP Core Materials

Property		**Polystyrene**	**Open-cell PU**	**Silica Powder**	**Glass Fiber**
Thermal Conductivity at 10 Pascals (Pa) abs. (0.1 millibar (mbar))	(*mW/m-K*)	4.8 – 5.8	9.7	5.8	2.4
	(*Btu-in/hr-ft^2-ºF*)	0.033 – 0.040	0.067	0.040	0.017
Manufacturing Time		Fast	Medium	Medium	Long
Density (*kilogram(kg)/cubic meter (m^3)*)		80 – 144	64	192	128
Drying Need		No	Yes	Yes	No
Thermal Stability		Low	Medium	Good	Very Good
Recyclability		Yes	Difficult	Yes	NA
Cost		Low	Medium	High	Very High

Source: European Commission, 2000.[55]

ORNL also has evaluated the performance of three types of VIPs: a silica powder filler encapsulated in a polymer barrier film; a fibrous glass insulation filler encapsulated in a stainless steel barrier; and an undisclosed insulation filler encapsulated in a stainless steel barrier.[56] Table 3.3.4 summarizes the center-of-panel thermal conductivities of the panels. For the silica powder and glass fiber filled VIPs, the thermal conductivities in Table 3.3.4 are comparable to those in Table 3.3.3.

Table 3.3.4 Center-of-Panel Thermal Conductivity of VIPs

Property		Silica Powder	Glass Fiber	Unknown
Thermal Conductivity*	(*mW/m-K*)	5.2 – 5.4	2.0 – 2.6	2.7 – 3.1
	(*Btu-in/hr-ft²-ºF*)	0.034 – 0.038	0.014 – 0.018	0.019 – 0.022

* For each filler, the reported thermal conductivities are a range of values from nine separate VIPs.
Source: Vineyard et al, 1998.[56]

ORNL also determined the thermal performance of the VIPs it studied as part of a composite panel. The composite panel consisted of a one-inch VIP surrounded by PU foam insulation to form a two-inch-thick panel. The PU foam insulation was blown with a variety of bowing agents, but, due to the age of the study (from the mid-1990s), ORNL considered neither HFC- nor HC-based blowing agents. For the three VIPs presented in Table 3.3.4, silica power, glass fiber, and unknown, the average composite panel thermal resistances were 21.5, 20.7, and 20.9 hr-ft^2-ºF/Btu, respectively.[56] The lower thermal conductivities reported in Table 3.3.4 for the glass fiber and unknown filled VIPs relative to the silica powder VIP were offset by the heat conduction through their stainless steel encapsulation material.

Of significant concern for VIPs is their long-term thermal conductivity integrity. VIP thermal conductivity increases dramatically as the pressure within the VIP exceeds 100 Pa abs. (1 mbar). The pressure increase in the VIP over time is related to several factors, including: residual gases in the VIP after vacuum, degassing from the VIP core material, and gas diffusion through the envelope pores. Improved envelopes and absorbers have been developed to prevent pressure increases from occurring in VIPs. For example, for the three composite VIPs that it analyzed, ORNL measured only a five-percent reduction in overall thermal resistance over a three-year period. ORNL demonstrated that this reduction in thermal resistance was less than the corresponding reduction for a panel without any VIPs, *i.e.*, panels consisting only of PU foam insulation.[56]

Recent announcements regarding VIPs include the following. Matsushita's VIP technology (trade name of "U-Vacua") was awarded the Minister of Economy, Trade and Industry Prize at the 17th Energy Conservation Awards sponsored by the Energy Conservation Center of Japan in January, 2007.[57] Matsushita claims that its VIP technology has achieved the world's highest level of insulation efficiency with a thermal conductivity of 1.2 mW/m-K (0.008 Btu-in/hr-ft^2-ºF) at 24 ºC (75.2 ºF).[58] Electrolux announced in 2003 the use of VIP technology in a freezer that they claimed reduced energy use by 35 percent relative to PU foam insulation.[59] Va-Q-tek has recently introduced its va-Q-plus VIP technology.[60]

Gas-Filled Panels

Gas-filled panels (GFPs) use thin polymer films and low-conductivity gas to create a device with excellent thermal insulation properties. GFPs are essentially hermetic plastic bags that can take on a variety of shapes and sizes. Inside the outer barrier is a cellular structure called a baffle which is filled with the low-conductivity gas.

Research conducted at LBNL in the mid-1990s has demonstrated the effectiveness of GFPs based on the use of different gases, including xenon and krypton. Table 3.3.5 below summarizes the thermal performance characteristics of different GFPs, based on their center-of-panel and whole-panel performance.[61] LBNL has also conducted research to demonstrate that GFPs, when used in refrigerator-freezers, can reduce energy consumption by approximately eight percent relative to PU foam insulation.[62]

Table 3.3.5 Comparison of Various Gas-Filled Panel Core Materials

Gas Fill	Center of Panel Performance		Whole Panel Performance					
	Thermal Conductivity		Panel Thickness		Mean Temp.		Thermal Conductivity	
	mW/m-K	*Btu-in/hr-ft²-ºF*	*mm*	*inches*	*ºC*	*ºF*	*mW/m-K*	*Btu-in/hr-ft²-ºF*
Xenon	7.4	0.051	24.1	0.95	6.8	44.2	7.4	0.051
Krypton	11.6	0.080	25.2	0.99	11.9	53.4	10.77	0.074
			49.8	1.96	12.3	54.1	1.17	0.008
Argon	19.9	0.138	NA	NA	NA	NA	NA	NA
Air	28.1	0.195	NA	NA	NA	NA	NA	NA

Source: LBNL[61]

In addition, ORNL determined the thermal conductivity of an insulation panel containing radiation baffles within a polymer barrier film and filled with krypton gas at atmospheric pressure. The range of thermal conductivities of nine of these GFPs ranged from 0.088 to 0.092 Btu-in/hr-ft^2-ºF (12.6 to 13.2 mW/m-K). ORNL also analyzed the GFPs as part of a composite assembly consisting of a one-inch panel surrounded by PU foam insulation to form a two-inch-thick panel. The average composite panel thermal resistance was determined to be 18.2 hr-ft^2-ºF/Btu. Finally, ORNL measured only a five-percent reduction in overall thermal resistance over a three-year period, which was less than the reduction observed in a panel consisting only of PU foam insulation.[56]

Although research has demonstrated that GFPs have better thermal performance than PU foam insulation, no known refrigeration products are using the technology. A significant problem in using GFPs is their lack of structural integrity in the resulting product.

3.3.2.2 Gasket and Door Design

A significant portion of the heat gain to refrigerators and freezers occurs around the edges of the doors and through the gaskets on the door edges. An analysis of thermal loads on an 18.6 ft^3 top-mount refrigerator-freezer revealed that over 28 percent of the total heat load into the cabinet came from 'edge' loads, *i.e.*, loads due to heat transfer into the food compartments via paths around the perimeter of the cabinet aperture.[49] Table 3.3.6 summarizes the various 'edge' loads as well as the heat loads through the walls and doors and other sources. If the 'edge' effect losses can be reduced, the efficiency of the refrigerator can be increased. This section only addresses the 'edge' effect loads from the wall and door flanges and the door gasket. Heat loads from the anti-sweat heaters are discussed in the following section (section 3.11.2.3).

Table 3.3.6 Overall Cabinet Loads

Component	**Percent of Total**
'Edge' Effect Loads	**28.5%**
Heat gain due to conduction along the wall steel flange	5.3%
Heat input due to conduction along the door steel flange	7.1%
Heat conduction directly through the door gasket or seal	2.7%
Heat input due to conduction in the mullion region	1.7%
Heat input due to mullion region anti-sweat heater	7.7%
Heat input due to cabinet anti-sweat condenser tube	4.0%
Wall and Door Loads	**59.1%**
Miscellaneous Loads (heat inputs due to evap fan, defrost heaters, and compressor)	**12.4%**

Source: Boughton et al, 1996.[49]

Improved Gaskets

Design of door gaskets is a balance between improving the thermal-efficiency performance of the gasket and ensuring that the door is not difficult to open. If the gasket magnet force is too strong, it becomes difficult to open the door. Based on a European Commission study, door handles have been designed specifically to facilitate door openings by providing leverage and relieving the pressure differential which can build up by freeing a small section of the gasket before the door is opened.[55] Although materials and designs for improving the air tightness of door gaskets exist, apparently no general criteria have been established to enable different designs to be classified.

An EPA report from 1992 describes theoretical modeling and experimental research on gasket heat loads and concludes that replacing about half of either the metal door flange or cabinet flange with plastic can reduce the heat flow through the gasket region by 25 percent.[63] However, this study did not address the impacts on the convection on the cabinet side of the gasket associated with different geometries of the "throat" region between the door dikes and the cabinet wedge or with different evaporator air flow rates. Based on DOE's 1995 TSD, improvements in gasket design can reduce refrigerator-freezer annual energy consumption by one to three percent.[53] Due to the age of both the EPA and DOE research, it is uncertain how much further gaskets can be improved.

Double Door Gaskets

A double door gasket is an additional inner door seal gasket that is added to the gasket design. This further reduces heat leakage and infiltration into the refrigerator and freezer.

Based on information drawn from DOE's 1995 TSD, manufacturers did not introduce double door gaskets in the mid-1990s because of performance problems and cost. Ice can form between the gaskets, greatly reducing their effectiveness. In addition, the gaskets are visually unattractive and they increase the difficulty of meeting safety regulations for minimum door-opening force.

Improved Door Face Frame

As discussed above, cabinet heat loads stem not only from conduction though the refrigerator walls but also from conduction along the external metal casing. The metal shell provides the structural integrity; however, its presence means that heat loads are transferred along the metal shell into the cabinet. This heat transfer into the cabinet is also referred to as the 'edge effect.'

Using a plastic cover on the internal flange can reduce the 'edge effect' heat losses by approximately 50 percent.[49] It is expected that the use of low-conductivity plastics to reduce conduction losses in this area are already being employed in most current U.S. refrigerator-freezer designs.

Reduced Heat Load for TTD Feature

Through-the-door features that provide ice and/or water service displace insulation in the door. These features can make it difficult to apply foam in the doors. This technology option, which is applicable only to those product classes that include TTD ice service, utilizes improved design methods to reduce the heat load of TTD features.

Based on the DOE 1995 TSD, door-design improvements that reduce the heat load from TTD features can reduce refrigerator-freezer annual energy consumption from two to four percent.[53] The TSD provided little explanation of the details of these design changes, citing only "foam insulation" and "improved design methods".

3.3.2.3 Anti-Sweat Heater

Anti-sweat heaters are commonly used in standard-size refrigerator-freezers. In general, compact refrigerators, compact refrigerator-freezers, and compact freezers do not use anti-sweat heat. These heaters apply heat to external surfaces near door gaskets, including the mullion region between the freezer and fresh food compartments and along the perimeter of the cabinet. If electric resistance heaters are used for this purpose, the heaters contribute to energy consumption both with their wattage input and with the heat load they generate that enters the cabinet. Most modern refrigerator-freezers use refrigerant tubes inserted in the cabinets in close proximity to the regions requiring heat. Both hot discharge gas from the compressor and warm liquid leaving the condenser are used to provide this heat, although a majority of products use warm liquid. As reported above in section 3.11.2.2, the heat loads from both electric and refrigerant type anti-sweat heaters can be significant. For the example illustrated in Table 3.3.6, the contribution of the mullion anti-sweat heater represents 7.7 percent of the total cabinet heat load. However, the load associated with the anti-sweat heater of modern designs may be lower due to evolution of design practices to reduce such loads.

Hot Gas or Warm Liquid

The direct electricity consumption of the anti-sweat heaters can be eliminated by using a hot gas or warm liquid refrigerant loop to warm external surfaces to eliminate moisture buildup. This approach is used extensively in residential refrigerator-freezers to reduce energy use—the technology is already part of all or nearly all standard-size refrigerator-freezers.

Electric Heater Sizing

For those products using electric resistance anti-sweat heaters, unnecessarily high-wattage heaters may be used. Therefore, energy use can be decreased by reducing the heater wattage. For those products that still use electric resistance anti-sweat heaters, DOE is unaware to what extent the wattage of the heater is excessive.

Electric Heater Controls including Variable Antisweat

For those products using electric resistance anti-sweat heaters, control schemes can be used to limit the amount of energy used. One option, which is included on some current refrigerator-freezer models, is to use an on-off switch that allows the user to turn off the heater if "sweating" is not an issue. The DOE Energy test procedure calls for testing with the switch in the on position in order to measure annual energy use.[64] However, DOE understands that most manufacturers measure annual energy use as an average of a test with the heater on and a test with the heater off.

Another option is to control the anti-sweat heater based on temperature and humidity conditions. As discussed in section 3.2.2.2, DOE is considering incorporating into the test procedure for refrigerators and refrigerator-freezers an adaptation of a test procedure for which a waiver was granted to GE. The waiver provides a method for calculating the annual energy use contribution of electric anti-sweat heaters which are controlled to operate only as much as needed to avoid moisture accumulation, based on the input of ambient temperature and/or humidity sensors.[6]

3.3.2.4 Compressor

The compressor is the primary energy-consuming component in a refrigerator, refrigerator-freezer, or freezer. Therefore, technologies that can advance compressor efficiency have a significant effect on overall product efficiency.

Residential refrigeration products use positive-displacement compressors in which the entire motor-compressor is hermetically sealed in the welded steel shell. Two types of compressors have been used in residential refrigeration products over the years—reciprocating and rotary. However, predominantly reciprocating compressors are now used in U.S. products.

Almost all compressors are directly driven by two-pole squirrel-cage induction motors running at approximately 3,000 rpm on 60 Hz power. Three types of induction motors have been used in refrigerator compressors: resistance start/induction run (RSIR), capacitor start/induction run (CSIR), and resistance start/capacitor run (RSCR). Of the three motor types, the RSIR motor is the least efficient. As a result of the U.S. energy efficiency standards that took effect in 1993 and 2001, the vast majority of compressor motors now use the RSCR type.

Refrigerator compressor capacities range from as low as 125 Btu/hr (for compact refrigerators) to as high as 2,000 Btu/hr, although maximum capacities are more typically 950 Btu/hr for U.S. residential refrigerator-freezers. Two organizations have established conditions for rating the performance of refrigerator compressors: ASHRAE and Comité Européen des

Constructeurs de Matériel Frigorifique (CECOMAF).[f] Table 3.3.7 below shows the rating conditions of these two organizations. The rating conditions are almost identical, except for the liquid temperature—this is the temperature leaving the condenser or any subcooling loop such as an anti-sweat heating loop. Because the CECOMAF liquid temperature is higher, compressor capacities and efficiencies under ASHRAE rating conditions are approximately 30 percent higher than for CECOMAF conditions. The actual operating conditions for compressors in residential refrigeration products under DOE energy test conditions can be significantly different than these rating conditions. Most notably, the condensing temperatures are generally significantly lower than 130 ˚F.

Table 3.3.7 Compressor Rating Conditions

Rating Condition	**ASHRAE**	**CECOMAF**
Evaporator	-10 ºF (-23.3 ºC)	-10 ºF (-23.3 ºC)
Condenser	130 ºF (54.4 ºC)	131 ºF (55 ºC)
Ambient	90 ºF (32.2ºC)	89.6 ºF (32 ºC)
Suction Gas	90 ºF (32.2ºC)	89.6 ºF (32 ºC)
Liquid	90 ºF (32.2 ºC)	131 ºF (55 ºC)

Compressor efficiency is also a function of refrigeration capacity. Based on data from DOE's 1995 TSD, maximum expected compressor efficiencies for the year 1998 demonstrated that efficiency drops off with decreasing cooling capacity.[53] The expected maximum compressor efficiencies for the year 1998 as reported in the 1995 TSD are shown below in Table 3.3.8 below. A year 2000 European Commission study to support energy standards of domestic refrigeration appliances also noted the drop in efficiency as capacity drops.[55] The reduced efficiency for lower-capacity compressors has been attributed to optimization of performance for higher-capacity compressors[65] and to the higher importance of mechanical losses and losses associated with re-expansion of gases left in the clearance volume as the swept volume of the reciprocating piston decreases.

[f] CECOMAF is a European appliance manufacturer trade association formed in 1958. It merged with EUROVENT in 1996 to become EUROVENT/CECOMAF. This organization is now called EUROVENT.

Table 3.3.8 Estimated 1998 Maximum Compressor Efficiencies

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

Source: DOE, 1995 TSD.
* Performance based on ASHRAE rating conditions. Performance based on the use of refrigerant R-134a.

More recent compressor performance data was collected as part of the engineering analysis, and the results of this investigation is presented in Chapter 5. The highest efficiency single-speed compressors available for standard-size refrigerator-freezers have EER near 6.25 Btu/hr-W.

Improved Compressor Efficiency

Conversion to high-efficiency compressors is fairly straightforward for manufacturers to implement as long as the appropriate compressors are available. As indicated above, maximum efficiencies for compressors that are utilized in the most common types of U.S. refrigerator-freezers range to near 6.25 Btu/hr-W.

Variable-Speed Compressors

Variable-speed compressors allow efficiency improvement as compared to single-speed compressors since they can provide a better match of thermal loads during the vast majority of hours when the loads are low. Most of the time, the compressor would operate at low speed with a high percentage of on-time. This would lower energy consumption by reducing off-cycle losses and by allowing the heat exchangers to operate with lower mass flow, thus boosting their effectiveness. However, careful consideration must be given to how variable speed compressors are implemented, because increased fan run times could negate compressor energy savings.

Electronics are used by variable-speed compressors to vary the speed. They use either inverter-driven induction motors or permanent magnet motors. Most U.S. residential refrigeration products do not currently use variable-speed compressors, but the use of these compressors is becoming more common.

Various past studies have illustrated a range of energy savings achievable through use of variable speed compressors. Arthur D. Little reported savings of approximately 25 percent compared to single-speed motor systems in 1999.[66] Research conducted by Tecumseh Products Company demonstrated that energy savings of 15 percent as well as reduction of sound and vibration levels.[67] Simulation analyses conducted at the University of Illinois demonstrated that steady-energy savings ranging from four to 14 percent could be realized through the use of a two-speed compressor in concert with multiple-speed evaporator and condenser fans. The research also demonstrated that an additional 0.5 to four percent in energy consumption could be saved through the reduction of cycling frequency, i.e. the number of starts.[68]

Embraco has developed its third generation variable-speed compressor that utilizes a permanent magnet motor controlled by a programmable electronic unit.[69] Table 3.3.9 presents the rated performance of some of Embraco's variable-speed compressors. The rated efficiencies of these variable-speed compressors are not necessarily higher than the best efficiencies of single-speed compressors--evaluation of the benefits of variable-speed compressors requires consideration of the system performance rather than just rated performance.

Table 3.3.9 Efficiencies of Some of Embraco's Variable-Speed Compressor Models

Model	**Capacity Range***		**Efficiency***	
	W	*Btu/hr*	*COP*	*EER*
VEGY6H (1600-4500 revolutions per minute (rpm))	98 – 281	676 – 959	Up to 1.78	Up to 6.07
VEGY7H (1600-4500 rpm)	111 – 314	379 – 1071	Up to 1.81	Up to 6.18
VEGY8C (1600-4000 rpm)	132 – 319	450 – 1088	Up to 1.79	Up to 6.11

Source: Embraco, 2006.
* Performance based on ASHRAE rating conditions. Models utilize refrigerant R-134a.

Linear Compressors

Linear compressors employ a different design than either reciprocating or rotary compressors and are reportedly more efficient than either. These compressors use a linear rather than rotary motor, thus eliminating the crankshaft and linkage which converts the rotary motion to the linear motion of the piston of a reciprocating compressor. Elimination of the mechanical linkage reduces friction and side-forces. The linear motor requires power electronics and a controller to assure proper piston throw. Most linear compressor designs use a free piston arrangement and can be controlled for a range of capacities through adjustment of piston displacement. Early work on the concept suggested that the compressors can operate without requiring oil, which could provide additional energy benefit by improving heat transfer in the evaporator. Refrigerator noise levels can also be reduced by utilizing linear compressors in the same way that this can be done with variable-speed compressors, by operating most of the time at low capacity.[70]

An early version of the linear compressor design was developed by Sunpower for integration into refrigerators for the European market using isobutene (R-600a) as a refrigerant.[71] LG has developed a linear compressor for household refrigerators which does require use of oil. LG claims that its line of linear compressors is up to 20 percent more efficient than reciprocating designs.[72] Table 3.3.10 presents the rated efficiencies of LG's linear compressors.[73] LG reports the efficiency of its linear compressors only at "LG Reference Conditions," which are significantly different than the ASHRAE rating conditions. Under ASHRAE conditions, compressors are rated with evaporating and condensing temperatures of -10ºF (-23.3ºC) and 130ºF (54.4ºC), respectively, while the "LG Reference Conditions" are based on evaporating and condensing temperatures of -14.8ºF (-26ºC) and 100.4ºF (38ºC), respectively. It is not clear what the liquid and suction vapor temperatures for the LG conditions are—these temperatures also impact capacity and power input. At the same evaporating and condensing temperatures and with liquid and suction vapor conditions consistent with the ASHRAE test conditions, a high efficiency rotating-shaft reciprocating compressor such as the Embraco EGX70HLC would have an operating EER of about 6.9 Btu/hr-W. Hence, the LG linear compressor may be about 9% more efficient than the best current-technology rotating-shaft reciprocating compressors.

Table 3.3.10 Efficiencies of LG's Current Linear Compressor Models

Model	Capacity Range*		Efficiency*	
	W	*Btu/hr*	*COP*	*EER*
DLF81LACT	310	1058	2.14	7.3
FA81LACT	293	1000	2.20	7.5
FA72LACT	276	941	2.20	7.5
FA63LACT	241	823	2.20	7.5
FA54LACT	207	706	2.20	7.5

Source: LG, 2007.
* Performance based on 'LG Reference' rating conditions. Models utilize refrigerant R-134a.

In the trade press, LG has expressed willingness to license the linear compressor technology to competitors.[74] However, because the LG design is proprietary, the widespread use of linear compressors is uncertain.

3.3.2.5 Evaporator

The evaporator is a key component of the refrigeration system. As discussed earlier in section 3.11.2, there are three basic evaporator designs depending on the refrigeration product: standard-size refrigerator-freezers and upright freezers with automatic defrost typically use a forced-convection finned-tube design; compact refrigerators and refrigerator-freezers and small-size standard refrigerator-freezers generally use a roll-bond design; and chest freezers and upright freezers with manual defrost typically use a coil design that is integrated within the walls of the unit. Some manual defrost freezers also use evaporators which are integrated with the wire shelving. In the case of the finned-tube designs used in standard-size refrigerator-freezers, design, modeling, and experimental studies have been conducted to evaluate their heat transfer performance.[75, 76] Evaporator performance can be enhanced by increasing the heat exchanger surface area or improving the heat exchange performance.

Increased Surface Area

Increasing the heat exchanger surface area can be achieved by increasing the face area of the evaporator or adding more tube rows. These measures are limited by the geometry of the refrigeration product. There is a tradeoff between increasing the volume occupied by the heat exchanger and reducing the interior volume of the refrigerator.

In its 1995 TSD, DOE considered increasing the evaporator surface area for most of the product classes analyzed; this resulted in an estimated one to two percent reduction in annual energy consumption.[53] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the evaporator surface area was increased. Therefore, it is uncertain to what extent design efforts to increase the evaporator surface area have been employed in current U.S. refrigerator-freezer designs.

Improved Heat Exchange

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally-grooved surfaces are used to enhance the tubing. In its 1995 TSD, DOE considered enhancing the evaporator's heat exchange performance for many of the product classes analyzed; this resulted in an estimated one to two percent reduction in annual energy consumption.[53] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the evaporator heat exchange performance was enhanced. Therefore, it is uncertain to what extent design efforts to enhance the evaporator heat exchange performance have been employed in current U.S. refrigerator, refrigerator-freezer, and freezer designs.

Heat exchanger technologies that could potentially improve evaporator performance are microchannel heat exchangers, electrohydrodynamic enhancement, and the adoption of phase-change materials. In the case of microchannel heat exchangers, past research has demonstrated that the use of such heat exchangers in domestic refrigerators can provide system efficiencies comparable to current technologies while reducing refrigerant charge.[77] Electrohydrodynamic enhancement employs high-voltage fields to improve the heat exchange performance. However, safety issues involved in using such high voltages in domestic appliances have not yet been resolved. In addition, no prototypes are available to test and evaluate this technology for domestic refrigerators and freezers. Finally, with regard to phase-change materials, Thomson (a French manufacturer) has integrated into its heat exchangers a phase-change material that enables higher average evaporation temperatures than conventional designs, thereby yielding energy savings.[55] It is unclear for any of these technologies whether they will ever achieve widespread use in refrigerator-freezers.

Research has also been conducted on the use of a ground-source heat exchanger as a means of rejecting heat from the cabinet and improving the efficiency of a refrigerator-freezer. Although the use of such a design reduced energy consumption considerably, it is likely not practical for most domestic refrigeration products.[78]

3.3.2.6 Condenser

The condenser, like the evaporator, is a key component of the refrigeration system and is located on the outside of the unit. As discussed in section 11.1.2, there are three basic condenser designs depending on the refrigeration product: Standard-size refrigerator-freezers typically use a forced-convection finned-tube design; compact refrigerators and refrigerator-freezers generally use a wire-and-tube "static" design which uses natural convection cooling; and freezers typically use a hot wall condenser that is integrated within the shell of the unit. In the case of the static condensers used in compact units, modeling studies have been conducted to evaluate their heat transfer performance.[79] Modeling studies have also been performed on hot-wall condensers.[80, 81] Condenser performance can be enhanced by increasing the heat exchanger surface area or improving the heat exchange performance.

Increased Surface Area

Increasing the heat exchanger surface area can be achieved by increasing the face area of the condenser or adding more tube rows. These measures can be limited by the geometry of the refrigeration product. There may be a tradeoff between increasing the volume occupied be by the heat exchanger and reducing the interior volume of the refrigerator.

In its 1995 TSD, DOE considered increasing the condenser surface area for many of the product classes analyzed; this resulted in an estimated one to two percent reduction in annual energy consumption.[53] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the condenser surface area was increased. Therefore, it is uncertain to what extent design efforts to increase the condenser surface area have been employed in current U.S. refrigerator-freezer designs.

Improved Heat Exchange

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally grooved surfaces are used to enhance the tubing. In its 1995 TSD, DOE considered enhancing the condenser's heat exchange performance for some freezer and compact unit product classes; this resulted in approximately a two percent estimated reduction in annual energy consumption.[53] In the 1995 TSD, DOE based cost and efficiency improvements for this technology on estimates by manufacturers. No details were provided on how exactly the condenser heat exchange performance was enhanced. Therefore, it is uncertain to what extent design efforts to enhance the condenser heat exchange performance have been employed in current U.S. refrigerator, refrigerator-freezer, and freezer designs.

As with evaporators, other heat exchanger technologies could be employed to improve condenser performance. Microchannel heat exchangers, electrohydrodynamic enhancement, and the adoption of phase-change materials are all applicable to condensers, although phase-change materials have only been used in evaporators. It is unclear for any of these technologies whether they will ever achieve widespread use in refrigerator-freezers.

The same research that investigated the use of ground-source heat exchangers as means of rejecting heat for the cabinet also examined its application for rejecting heat from the condenser. The technology was demonstrated to be effective at reducing the energy use of a refrigerator-freezer, but is likely not practical for most domestic refrigeration products.[55]

Forced-Convection Condenser

Most standard-size refrigerator-freezers use forced-convection condensers. In contrast, most standard-size freezers use hot wall condensers. The forced convection configuration can provide higher heat transfer effectiveness. However, space for housing a forced convection condenser and its associated fan is not always available. The consideration of conversion to forced-convection condensers will depend on whether a particular product class is designed in a way that allows housing of the condenser and fan in a suitable location.

3.3.2.7 Fan and Fan Motor

Fans are used to increase evaporator and condenser heat transfer. Because most refrigerator-freezers use forced-convection condensers which rely on fans for air movement, fan and fan-motor technology options for the condenser are applicable. However, many manual-defrost refrigerators and freezers—specifically chest freezers and small, under-counter-type refrigerators—use static condensers and/or natural convection evaporators and, as a result, do not use fans and fan motors.

For those refrigeration products that do utilize fans, refrigerator manufacturers purchase fans and fan motors from outside vendors. Therefore, conversion to more-efficient fan motors can be accomplished relatively easily when more-efficient fans and fan motors are available.

Fan and Fan Motor Improvements

Evaporator can condenser fans are typically of axial design. Evaporator fan blades are typically either 100mm or 110mm in diameter. Because the evaporator fan and fan motor are located within the refrigerated cabinet and the electric energy input adds to the refrigeration load, more-efficient evaporator fan or evaporator fan motor designs contribute to efficiency improvements in two ways: (1) reducing the power consumption of the fan motor and (2) reducing the power consumption of the compressor due to decreased heat losses into the cabinet from the fan motor.

One source of inefficiency for axial fans lies in their tendency to throw air outward. The Pax Group™ has developed a fan (PAX fan) that employs streamlined blades with patented geometrical shapes which reportedly provide better airflow direction and improved efficiency. Tests performed with the PAX fan have demonstrated a reduction in fan-motor power of 23 percent and an overall reduction in refrigerator energy consumption of 3.9 percent relative to a refrigerator with a typical axial fan blade design.[82] However, because the PAX fan is proprietary, the widespread use of the design is highly uncertain.

Before the 1993 U.S. energy efficiency standards took effect, most evaporator and condenser fan motors were shaded pole induction designs, with efficiencies between 10 and 15 percent and power input of about 15 Watts (W). Higher-efficiency motor designs include permanent split capacitor motors (PSC) induction motors with 20 to 30 percent efficiency, and brushless DC motors, with near 65 percent efficiency.

3.3.2.8 Expansion Valve

The metering device in most household refrigerator-freezers is a capillary tube. As discussed above in section 11.1.1, there are two common types of capillary tubes—adiabatic and non-adiabatic. In the non-adiabatic configuration, the capillary tube is soldered to the suction line to evaporate the residual liquid in the suction line and to warm the vapor to near-ambient temperature. The suction line heat exchanger (or the non-adiabatic capillary) improves efficiency because it increases the refrigeration capacity of the system by the amount of heat being transferred from the capillary to the suction side. Non-adiabatic capillary tubes are the most common type of metering device in refrigerator-freezers. The other type of metering device, an adiabatic capillary tube, is used in some refrigeration products. In this configuration, the capillary tube does not exchange heat with the suction line and the refrigerant expands from the high pressure to the low pressure adiabatically. Research has been conducted to develop models to study the performance of both types of capillary tubes.[83, 84]

Improved Expansion Valve

Automatic, adjustable thermostatic or electronic expansion valves may provide improved performance. The technology for this design option is available; however, a modification in system design is required. DOE has not be able to identify any data demonstrating that improved expansion valves will save energy in domestic refrigerators.

3.3.2.9 Cycling Losses

Off-cycle refrigerant migration reduces a refrigeration product’s efficiency by transferring heat from outside the cabinet into the evaporator. Changes in refrigerator design that reduce this aspect of cycling losses can increase the unit’s efficiency.

Fluid Control or Solenoid Valve

A fluid control or solenoid valve installed after the condenser to effectively isolate the evaporator from the condenser during the off-cycle can be used to prevent any refrigerant migration. Research has demonstrated that solenoid valves can yield substantial energy savings.[85] However, there are drawbacks to using solenoid valves. First, refrigeration migration allows the system pressure to equalize, reducing the required starting torque of the compressor motor. A solenoid valve would increase the required starting torque of the compressor motor. Second, adding such a valve could negatively affect system reliability.

3.3.2.10 Defrost System

Section 3.11.1.2 provides a description of typical automatic defrost systems for refrigerator-freezers. Most units use electric heaters to defrost the ice buildup on the evaporator located in the freezer section of a refrigerator-freezer. Energy use associated with defrost includes the energy input for the heater and also the refrigeration system energy used to remove the defrost heat from the cabinet.

Reduced Energy for Automatic Defrost

In some cases, the defrost heat supplied is more than required. Thus, energy savings can be achieved by reducing the defrost heat by either using a smaller heater, reducing the heater on-time, reducing the frequency of defrost, or a combination of these.

In its 1995 TSD, DOE found that most manufacturers had already significantly reduced the electric heat for auto defrost in order to comply with the energy efficiency standards that became effective in 1993.[53] There may be limited additional energy savings possible through optimization of automatic defrost.

Adaptive Defrost

To reduce the energy used for defrost, adaptive defrost can be used. An adaptive defrost system can control both the defrost time and the amount of defrost heat. Adaptive defrost systems make use of controls to adjust the time between defrost cycles to the appropriate amount for the door opening frequency, ambient conditions, and other consumer usage patterns which affect the introduction of moisture into the cabinet. In a typical automatic defrost system, a mechanical timer initiates defrost after a specified time period, usually 10 to 12 hours of compressor on-time. By allowing adjustment of the time between defrosts, energy use can be reduced. The DOE energy test procedure includes modified test procedures for evaluating the energy use of products with adaptive defrost. In its 1995 TSD, DOE estimated that energy consumption can be reduced by three to four percent with adaptive defrost.[53] It is unclear what percentage of the refrigerator market currently uses adaptive defrost.

Condenser Hot Gas

Another method of reducing the energy required for defrost is to eliminate the need for electric heaters by substituting condenser hot gas in their place. In a condenser hot gas defrost system, the compressor continues to run and a valve opens allowing hot compressed refrigerant to flow to the evaporator. Many frost-free refrigerator-freezers in the 1960s and 1970s used such a defrost system.

3.3.2.11 Control System

The control systems discussed here pertain to those controlling the temperature and air-distribution within the refrigeration product.

Temperature Control

Conventional thermostats are thermomechanical devices that are not very accurate. The inaccuracy of these devices may produce large temperature fluctuations within the cabinet and, in turn, thermodynamic inefficiencies. Electronic thermostats are available that can provide more precise and repeatable temperature control than conventional thermostats. This can result in improved efficiency. Electronic thermostat systems can also account for more parameters than just the cabinet temperature, such as the room temperature, to better regulate product operation and reduce compressor run times.

Air-Distribution Control

For refrigerator-freezers, better air distribution between the freezer and fresh food compartments can improve temperature control and reduce energy consumption. Improving the distribution of cold air within the refrigerator-freezer allows the temperature difference between the air and foodstuffs to be minimized, enabling the evaporation temperature to be raised and, thereby, reducing energy consumption. It is uncertain to what degree the air distribution control in current refrigerator-freezer models can be improved. However, the fact that several patents have been issued in the U.S. since 1995 regarding air distribution implies that improvements in air distribution control are possible.[55]

3.3.2.12 Other Technologies

Alternative refrigerants and changing the location of refrigeration components can also improve the efficiency of refrigeration products. These two technology options are discussed below.

Alternative Refrigerants

Through the 1980s, CFC-12, a chlorofluorocarbon, was used as the refrigerant in almost all refrigerators, refrigerator-freezers, and freezers. However, under the Montreal Protocol, all CFCs were banned from use by the mid-1990s due to their high ozone depletion potential (ODP). In the early 1990s, many alternative refrigerants were evaluated as a replacement for CFC-12. Of the alternatives considered, the industry settled on HFC-134a as the replacement for CFC-12. Although initial research demonstrated that HFC-134a as a drop-in replacement yielded efficiencies which were four to 10 percent less than CFC-12, further work showed that with the appropriate superheat and subcooling taken into consideration, HFC-134a could yield essentially equivalent system efficiencies as CFC-12.[86]

Because HFC-134a exhibits some global warming potential (GWP), research continued to find an alternative refrigerant with less or no GWP. For example, R-152a has a lower GWP than HFC-134a but, primarily due to flammability concerns and the potential liability issues it posed to refrigerator manufacturers, it was dismissed as a potential alternative.

Naturally occurring substances such as carbon dioxide, ammonia, and hydrocarbons are all considered to be environmentally safe refrigerants with very low GWP. Hydrocarbons in particular are attractive due to their similar thermodynamic properties to CFC-12. Much research has been conducted showing the efficiency benefits of hydrocarbons. For example, the performance of propane/isobutane and propane/butane mixtures in domestic refrigerators has been shown to be equal to or better than products using CFC-12.[87, 88] Hydrocarbon flammability has been pointed out as a significant drawback and has prevented their adoption in U.S. products. In contrast, European refrigerator manufacturers started manufacturing products with isobutane in the 1990s. However, recently the General Electric Company announced the intention to introduce this refrigerant in the U.S.[89]

Component Location

In its 1995 TSD, DOE saw energy savings potential in more optimal placement of certain components. For example, if the compressor and condenser are located on the top of the refrigerator-freezer, DOE determined that they can operate more efficiently because heat is more readily convected away from the system and, in addition, the condenser fan can be eliminated. As described previously, traditionally, the compressor and condenser are located at the bottom rather than the top of the refrigerator-freezer so the user can have easy access to the food compartments, to key center of gravity low, and to provide air flow and a heat source near the tray which collects defrost water to assure quick re-evaporation of water. Locating the condenser and compressor at the top of the unit would require modification of traditional practice and consumer preference. It would also require product redesign, which could potentially increase manufacturing costs.

Another option is to locate the evaporator fan motor outside the cabinet to reduce internal loads from the heat loss of the motor. However, it is difficult to prevent air leakage where the motor shaft penetrates the cabinet wall. The 1995 TSD concluded that the lack of experimental data prevented the evaluation of component relocation.[53]

3.3.2.13 Alternative Refrigeration Cycles

Alternative refrigeration cycles may have the potential to improve system efficiency. Several alternative refrigeration cycles for refrigerator-freezers are described below. Dual-loop refrigerator-freezers using two independent refrigeration cycles (one for the fresh food compartment and the other for the freezer compartment) are available on the market. Also, dual-evaporator units likely utilizing a control valve system are also being marketed. The other alternatives listed below have been demonstrated in prototypes to reduce energy consumption but it is uncertain as to whether they can be mass produced as a practical alternative to today's current conventional refrigeration systems.

Lorenz-Meutzner Cycle

In a conventional refrigerator-freezer, the temperature of the freezer and fresh food compartments are around 5ºF (-15ºC) and 38ºF (3.3ºC), respectively. This suggests that the fresh food compartment with a smaller temperature lift (i.e., the temperature difference between the evaporator and condenser) can operate with a higher efficiency than that of the freezer. By using zeotropic[g] refrigerant mixtures, the Lorenz-Meutzner cycle exploits the inherent thermodynamic advantages of the temperature glide exhibited during evaporation or condensation of the refrigerant mixture. By choosing a refrigerant mixture with very wide temperature glide, the refrigerant mixture can pass sequentially through the freezer and fresh food compartment evaporators, providing refrigeration at the two evaporating temperature levels using a single compressor. As compared to a conventional refrigerator-freezer, the hardware differences include a high-temperature evaporator for the fresh food compartment and a low-temperature heat exchanger between the fresh food and freezer evaporators. Lorenz and Meutzner in their research determined that their cycle using an R-22/R-11 refrigerant mixture (50 percent of each) achieved up to 20 percent energy savings compared to a conventional refrigerator-freezer using R-12 only.[90]

Subsequent research validated Lorenz and Meutzner's findings and demonstrated the viability of the cycle based on the use of different zeotropic refrigerant mixtures, including mixtures composed of hydrocarbons. For example, as compared to a conventional refrigerator-freezer, experimentation on an 18 ft^3 top-mount refrigerator-freezer demonstrated that a modified

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[g] A zeotropic mixture consists of two or more refrigerant components. Zeotropic mixtures have what is referred to as a temperature glide when they boil and condense: at a fixed pressure, the temperature is higher for higher quality (i.e. vapor fraction). Unlike zeotropes, azeotropic mixtures consist of two or more refrigerant components that behave like a single refrigerant, exhibiting no temperature glide.

Lorenz-Meutzner cycle yielded 16.6 percent, 14.6 percent, and 16.7 percent energy savings with binary mixtures of R-22/R-123, propane/n-pentane, and propane/n-butane, respectively.[91]

Because the industry settled on the use of HFC-134a to replace CFC-12, interest in the Lorenz-Meutzner cycle as an alternative to conventional refrigeration cycles declined.

Dual-Loop System

One of the best methods to reduce the thermodynamic irreversibilities resulting from the operation with a single evaporator in a refrigerator-freezer is to employ two separate refrigeration cycles. This system, referred to as a dual-loop system, has two completely separate refrigeration cycles which provide cooling for the freezer and fresh food compartments independently. In practice, the theoretical benefits of such a cycle are not achieved due to the use of two compressors that are smaller and less efficient than the original single compressor. Also, dual-loop systems are physically larger and would either increase the product's external dimensions or decrease the usable refrigerator volume.

Research has demonstrated that the energy savings due to a dual-loop system are a function of the cabinet load ratio (defined as the ratio of the fresh food to the freezer cabinet loads) and the ratio of the freezer and refrigerator cycle efficiencies. Depending on these two parameters, a dual-loop system using HFC-134a can reduce energy consumption by up to 30 percent compared to a conventional refrigerator-freezer.[92]

There are numerous products currently on the market that incorporate dual-compressor systems, including Bosch's Integra line of bottom-mount refrigerator-freezers,[93] Sun Frost's RF19 model,[94] Northland's 48-inch side-mount refrigerator-freezer,[95] Sub-Zero's built-in line of refrigerator-freezers,[96] Liebherr refrigerators,[97] etc.

Two-Stage System

The two-stage system employs one condenser, two evaporators, two compressors, and at least one suction-line heat exchanger. The increased efficiency of this system over a conventional system is obtained due to a smaller work requirement that results from the low-pressure ratio for each of the two compressors.[98] The two-stage system offers the advantage of having one fewer component (a condenser) than the dual-loop system, but has many of the same disadvantages (e.g., either increased external dimensions or decreased internal volume).

Control Valve System

The control valve system has two evaporators, one for the fresh food compartment and one for the freezer compartment, but only one compressor and one condenser. Two different length capillary tubes and a control valve are installed between the fresh food and freezer evaporator inlets and the condenser outlet. The valve directs the flow of the refrigerant through one of the evaporators at a time. That is, only one of the two compartments is cooled at any given time. With this configuration, the fresh food compartment is cooled at a higher evaporator temperature than the freezer compartment. Experimental research conducted on this system configuration indicated that the energy efficiency can be improved by 8.5 percent over that of a conventional refrigerator-freezer.[99]

GE offers a refrigerator-freezer system called the ClimateKeeper2™ system that uses two evaporators.[100] Also, KitchenAid and Jenn-Air both offer under-counter compact refrigerator-freezers that use dual evaporators.[101] [102] The system details of none of these products is clearly described in the product literature.

Ejector Refrigerator

One of the intrinsic losses in a conventional refrigeration cycle is the throttling of the refrigerant in the capillary tube. Throttling is an isenthalpic process in which work that could be extracted in the expansion process is not captured. In the ejector refrigerator, some of this work can be captured and used to raise the pressure of refrigerant entering the compressor above that of the evaporator. Simulation research has been conducted on an ejector refrigerator that consists of one compressor, one condenser, two capillary tubes, two evaporators (one for the fresh food compartment and the other for the freezer compartment), and an ejector. In this refrigerator, saturated liquid refrigerant exits the condenser and expands in the capillary tube to the fresh food evaporator. In the fresh-food compartment, the refrigerant is partially evaporated. At the outlet of the evaporator, the liquid refrigerant is separated from the vapor in a separator. The vapor flows to the ejector, where it is accelerated to high velocity. The liquid expands in a second capillary tube to the freezer evaporator, where it evaporates entirely. The vapor leaving the freezer evaporator is entrained in the high-velocity flow of the vapor which left the fresh food evaporator. The mixed flow is decelerated to increase its pressure. The mixed flow higher pressure flow passes to the compressor suction port to be compressed. This particular ejector refrigerator was shown to have an efficiency which is 12.4 percent higher than a conventional refrigerator-freezer.[103]

Tandem System

Like the control valve system and the ejector refrigerator, the tandem system uses two evaporators (one for the fresh food compartment and another for the freezer compartment), one condenser, and one compressor. Refrigerant flows in series first through the fresh food evaporator, then the freezer evaporator, and it passes a second time through the fresh food evaporator. The warm liquid refrigerant leaves the condenser and flows to fresh food evaporator without a first expansion. In the fresh food evaporator the refrigerant liquid undergoes heat exchange with the evaporating refrigerant which has passed through the freezer evaporator. The temperature of the liquid is reduced by this heat exchange. The liquid then passes through the capillary tube where its pressure is reduced. The two-phase refrigerant then passes through the freezer evaporator and absorbs heat from the freezer compartment. This vaporization process only occurs when the freezer evaporator fan is turned on by the freezer thermostat. The refrigerant then passes back through the fresh food evaporator. Here, if the refrigerant has not already been vaporized (i.e., the freezer compartment does not require cooling), it vaporizes as a result of absorbing heat from the fresh food compartment and the warm liquid. The superheated refrigerant then flows to the compressor suction port. At the beginning of the compressor run, the fresh-food compartment fan is turned on first. Thus, the fresh food compartment is cooled before the system reaches steady state. As a result, the system uses the pull-down period of each cycle, which is generally not suitable for cooling the freezer, to cool the fresh food compartment. This particular tandem system was shown to reduce energy use by 18 percent compared to a conventional refrigerator-freezer.[104]

3.3.2.14 Alternative Refrigeration Systems

Alternative refrigeration systems do not use vapor compression to provide refrigeration. Three alternative refrigeration systems are discussed below: the Stirling cycle, thermoelectric cooling, and thermoacoustic cooling. Although research and development has been conducted on each of these systems, and thermoelectric compact refrigerators and wine coolers are currently being marketed, none are a viable alternative for standard-size refrigerators, refrigerator-freezers, and freezers.

Stirling Cycle

A Stirling-cycle machine is a device that operates on a closed regenerative thermodynamic cycle, with cyclic compression and expansion of the working fluid at different temperature levels, and where the flow is controlled by volume changes, so that there is a net conversion of heat to work or vice versa. ‘Regenerative’ refers to the use of an internal heat exchanger, the regenerator, which is an essential part of the Stirling cycle. A Stirling refrigeration cycle compresses and expands an inert gas in a single cylinder. Heat is rejected at one end of the cylinder and absorbed at the opposite end. In the absence of all thermodynamic losses, the efficiency could be higher than for vapor compression systems, but there are various technical difficulties that have so far limited the use of Stirling-cycle cooling to small prototype domestic refrigerators. There is no circulating refrigerant fluid and the hot and cold heat areas are relatively small, which creates heat exchange challenges for any but the lowest-capacity systems.

Thermoelectric

Thermoelectric cooling occurs when a current is passed across the junction of two dissimilar metals. One side of the device becomes hot and the other cold. Materials (semiconductors) have relatively recently been developed that have allowed for the use of this type of cooling in some applications. Thermoelectric cooling devices have no moving parts, do not age, and have extremely long lifetimes. There are several compact refrigerators and wine coolers using thermoelectric cooling that are being marketed, including several models offered by Avanti Products.[105] However, they have very low efficiency and are not yet suitable for standard-size domestic refrigerator-freezers.

Thermoacoustic

Acoustic cooling uses a sound generator inside a closed tube to vibrate a gas and cause alternate compression and expansion and therefore heating and cooling. The efficiency of prototypes have not been as high as vapor compression systems and the devices have been physically large for the amount of cooling produced.

3.3.3 Energy Efficiency

DOE gathered data on the energy efficiency of residential refrigerators, refrigerator-freezers, and freezers currently available in the marketplace. DOE created a database of the current models by surveying manufacturers’ websites. The data provide an overview of the energy efficiency of each product class covered by this rulemaking.

For the models in the DOE database, Figure 3.3.3 through Figure 3.3.22 present by product class the relationship between rated annual energy use and adjusted volume. In each figure, lines representing the maximum allowable energy consumption (i.e., the current minimum efficiency standard) and the current ENERGY STAR level (that took effect in April 2008 for standard-size refrigerators and refrigerator-freezers), are provided. This allows for a quick visual inspection of the number of models that met the ENERGY STAR level.

The data representing all-refrigerators are highlighted in the figures for product classes 1, 3, 11, and 13. For product classes 1 and 11, the products which are not all-refrigerators could be either basic refrigerators or manual defrost refrigerator-freezers. For product classes 3 and 13, the products which are not all-refrigerators are refrigerator-freezers. The percentage of all-refrigerators is high for product class 11 and very high for product class 13.

The DOE survey found no current models in product class 6, top-mount refrigerator-freezers with through the door ice and with automatic defrost. DOE still provides a figure for this class (Figure 3.3.9) to show the maximum allowable energy consumption for this product class. Many of the other product classes also have few products.

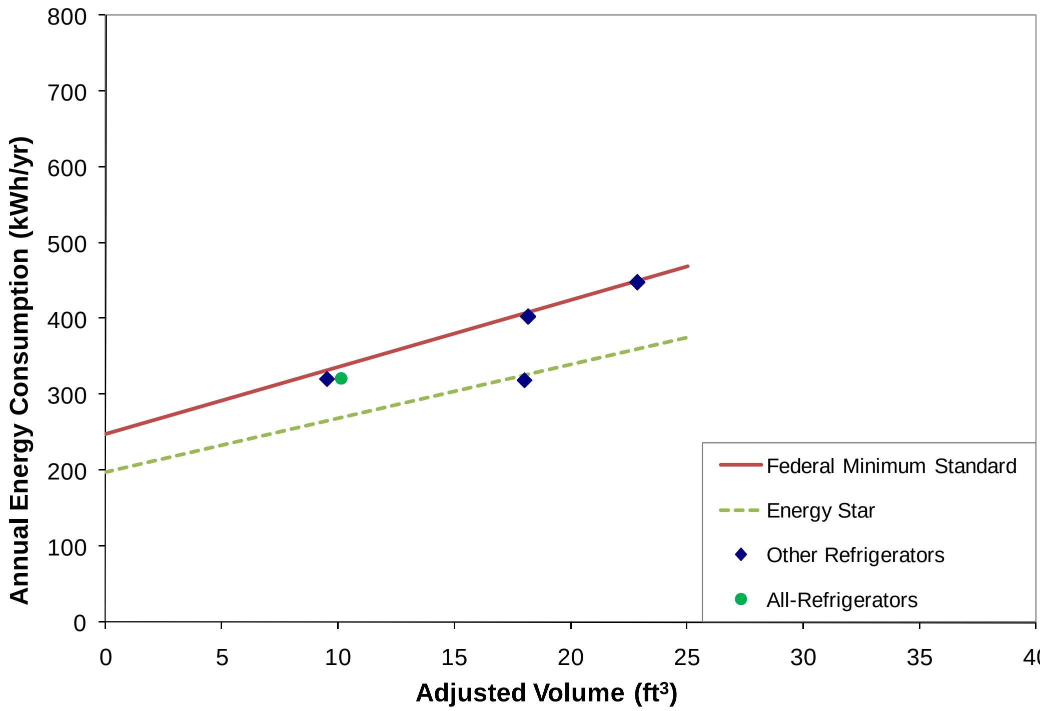

Figure 3.3.3 Annual Energy Consumption for Refrigerators and Refrigerator-Freezers with Manual Defrost (Product Class #1)

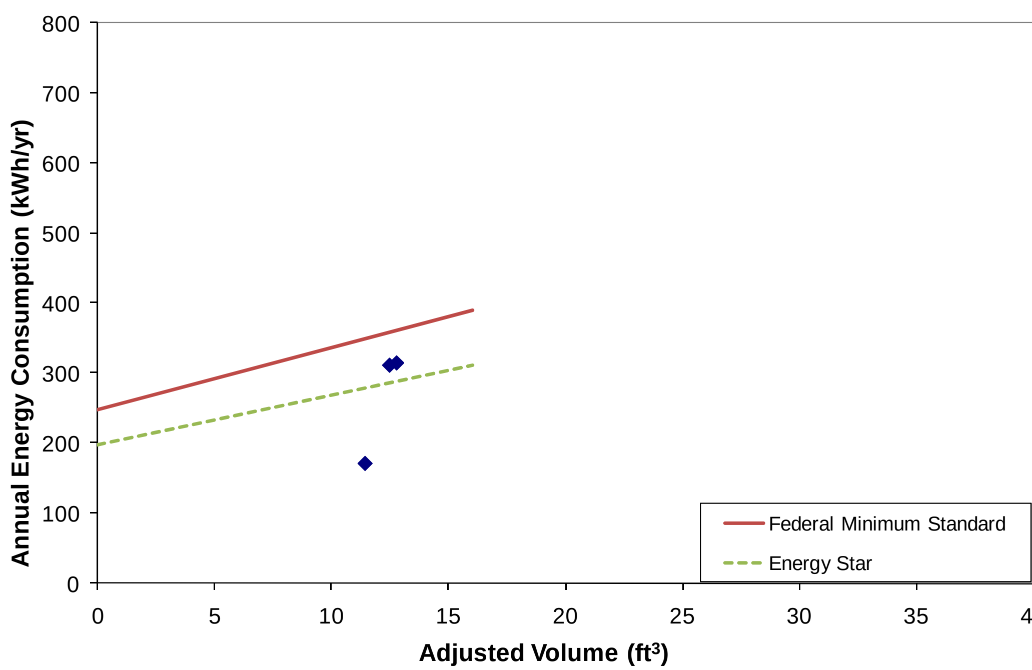

Figure 3.3.4 Annual Energy Consumption for Refrigerator-Freezers with Partial Automatic Defrost (Product Class #2)

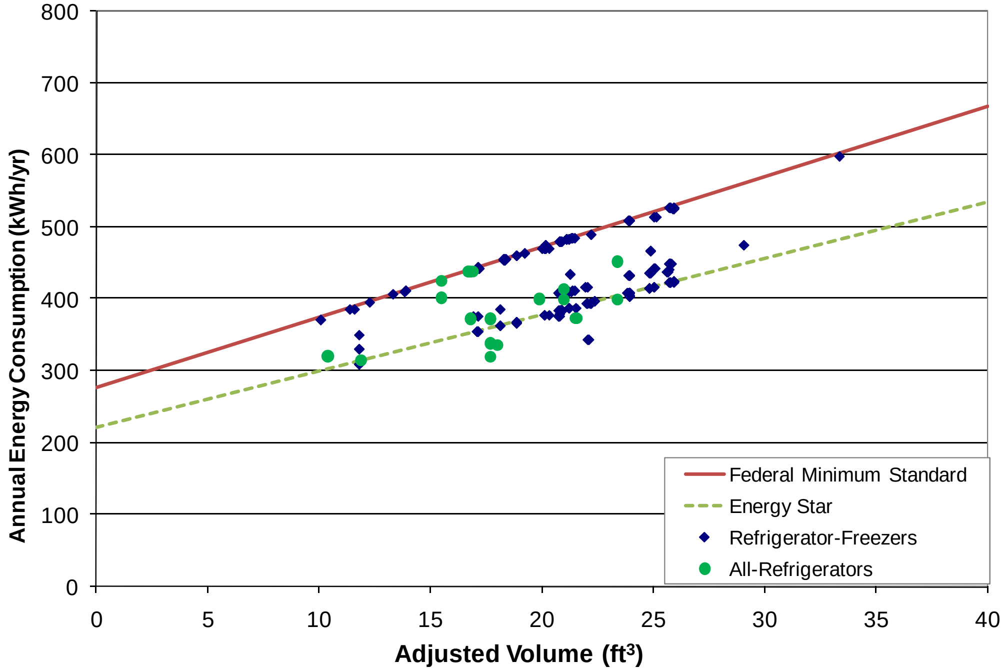

Figure 3.3.5 Annual Energy Consumption for Top-Mount Refrigerator-Freezers with Automatic Defrost without TTD Ice Service and All-Refrigerators with Automatic Defrost (Product Class #3)

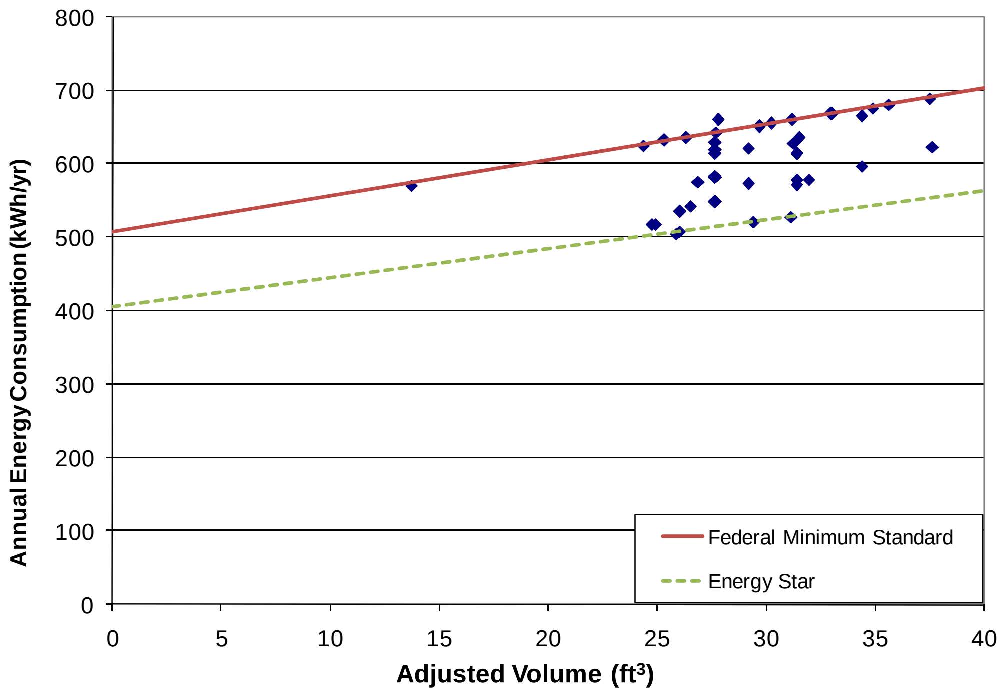

Figure 3.3.6 Annual Energy Consumption for Side-Mount Refrigerator-Freezers with Automatic Defrost without TTD Ice Service (Product Class #4)

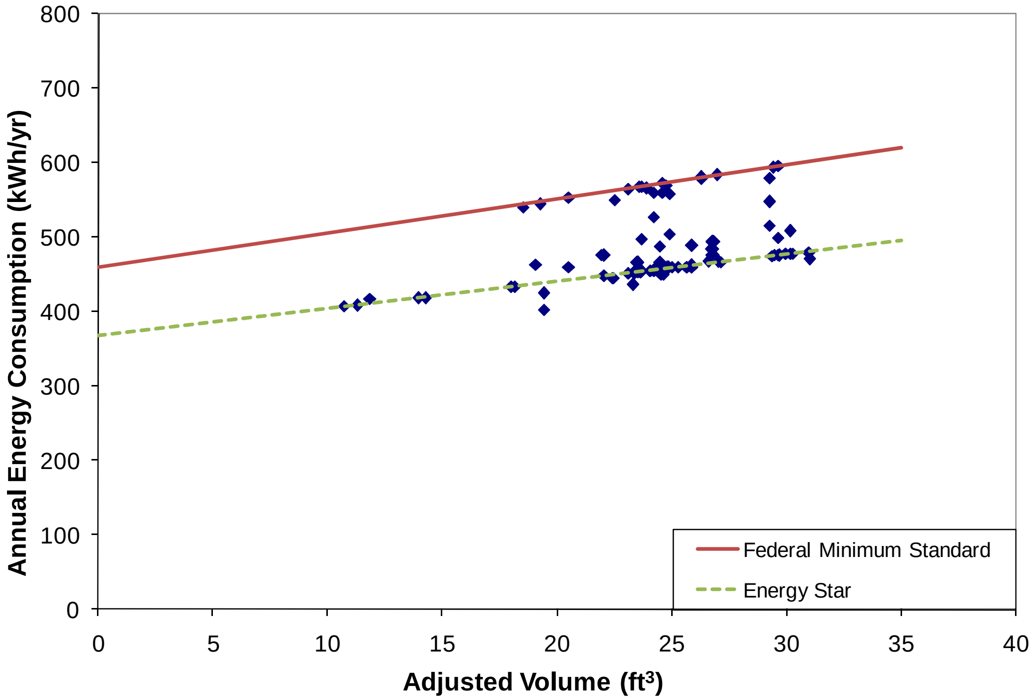

Figure 3.3.7 Annual Energy Consumption for Bottom-Mount Refrigerator-Freezers with Automatic Defrost without TTD Ice Service (Product Class #5)

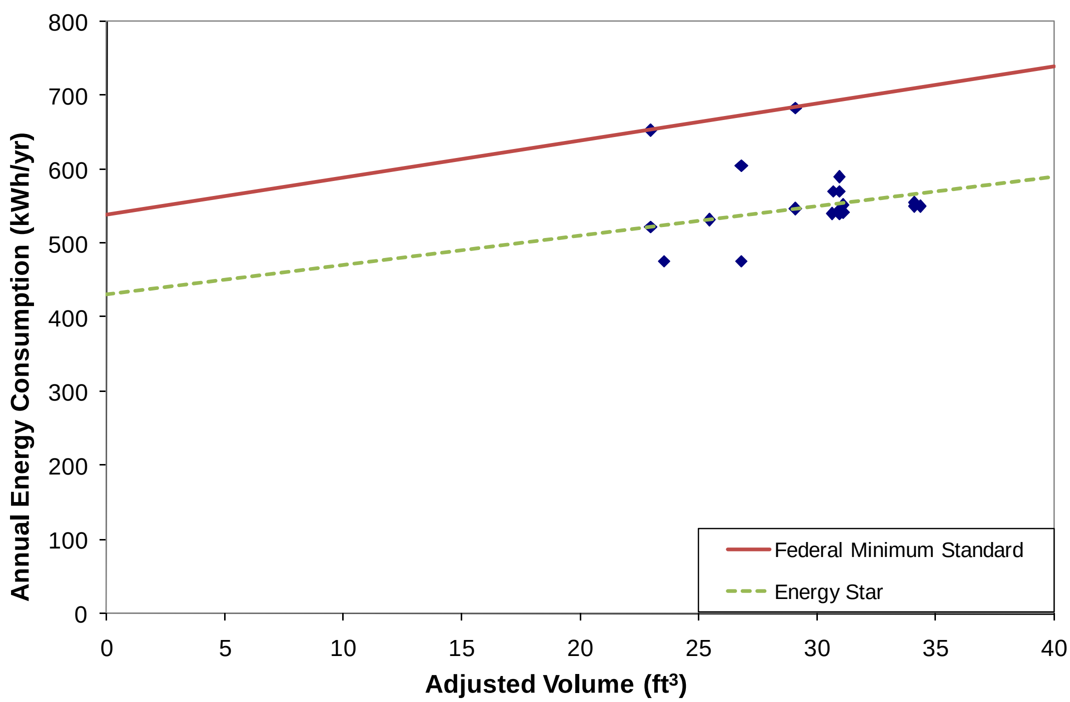

Figure 3.3.8 Annual Energy Consumption for Bottom-Mount Refrigerator-Freezers with Automatic Defrost with TTD Ice Service (Product Class 5A)

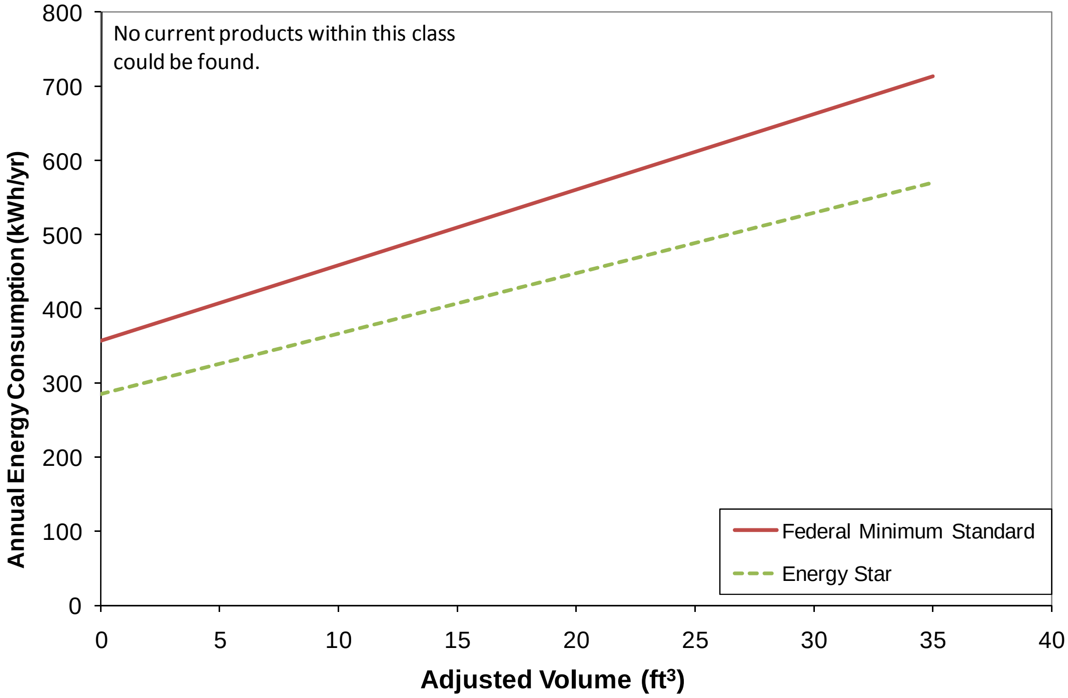

Figure 3.3.9 Annual Energy Consumption for Top-Mount Refrigerator-Freezers with Automatic Defrost with TTD Ice Service (Product Class #6)

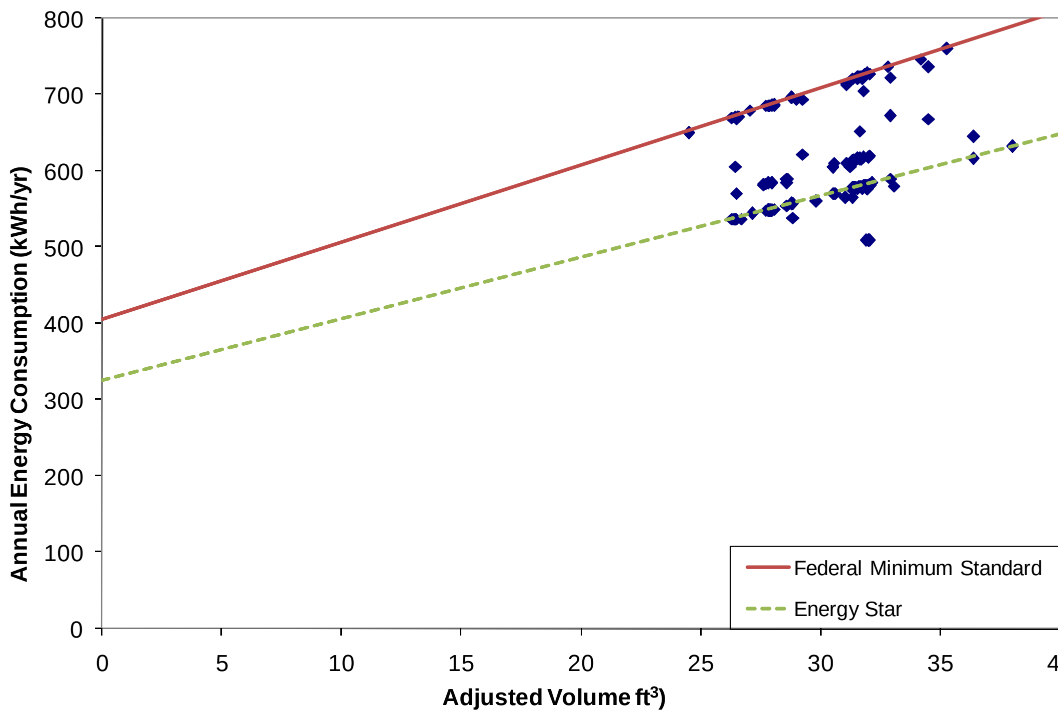

Figure 3.3.10 Annual Energy Consumption for Side-Mount Refrigerator-Freezers with Automatic Defrost with Through-the-Door Ice Service (Product Class #7)

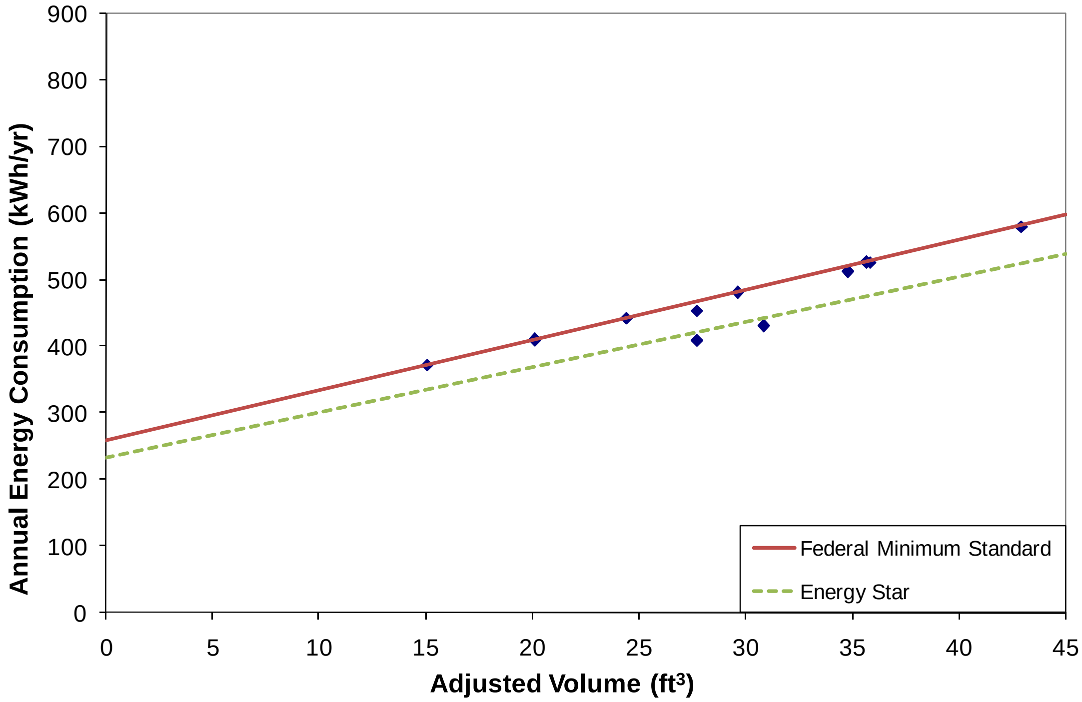

Figure 3.3.11 Annual Energy Consumption for Upright Freezers with Manual Defrost (Product Class #8)

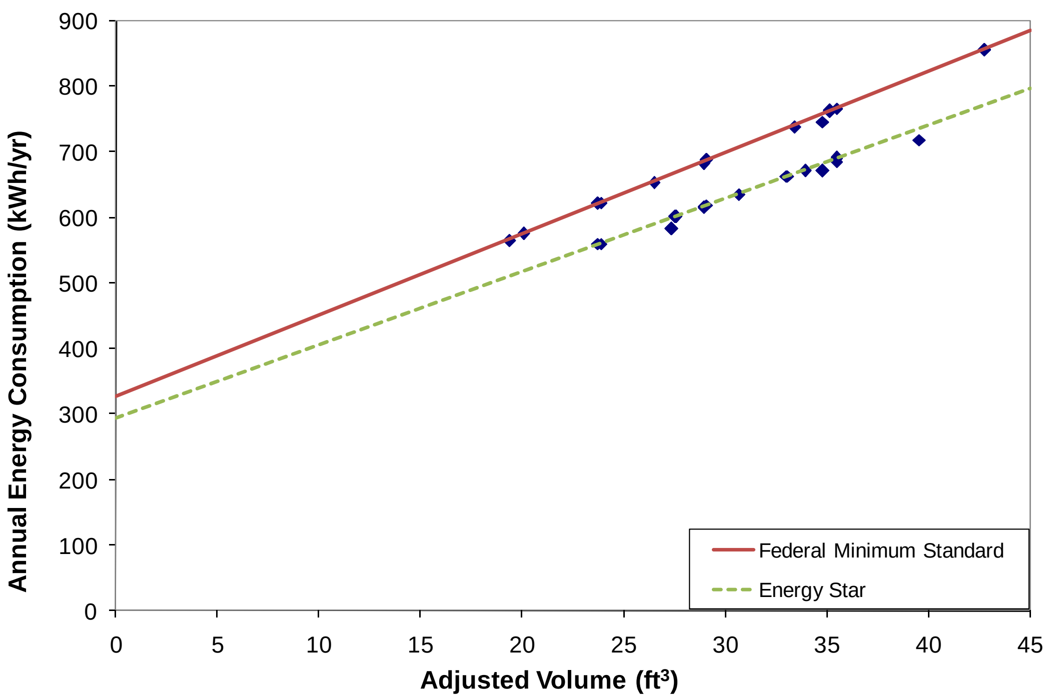

Figure 3.3.12 Annual Energy Consumption for Upright Freezers with Automatic Defrost (Product Class #9)

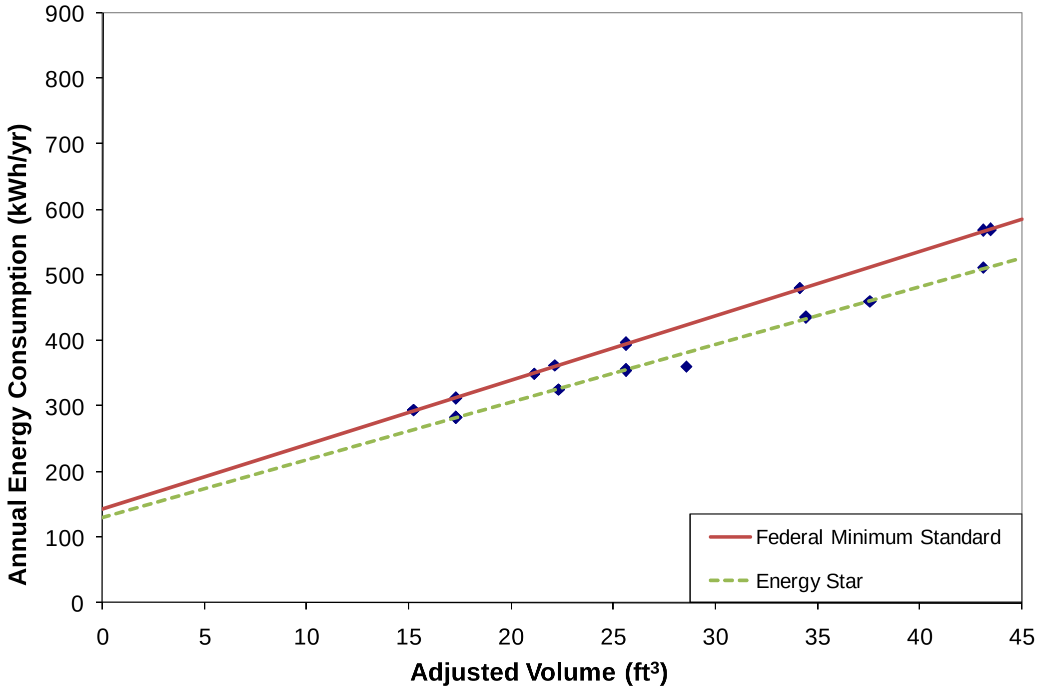

Figure 3.3.13 Annual Energy Consumption for Chest Freezers and all other Freezers except Compact Freezers (Product Class #10)

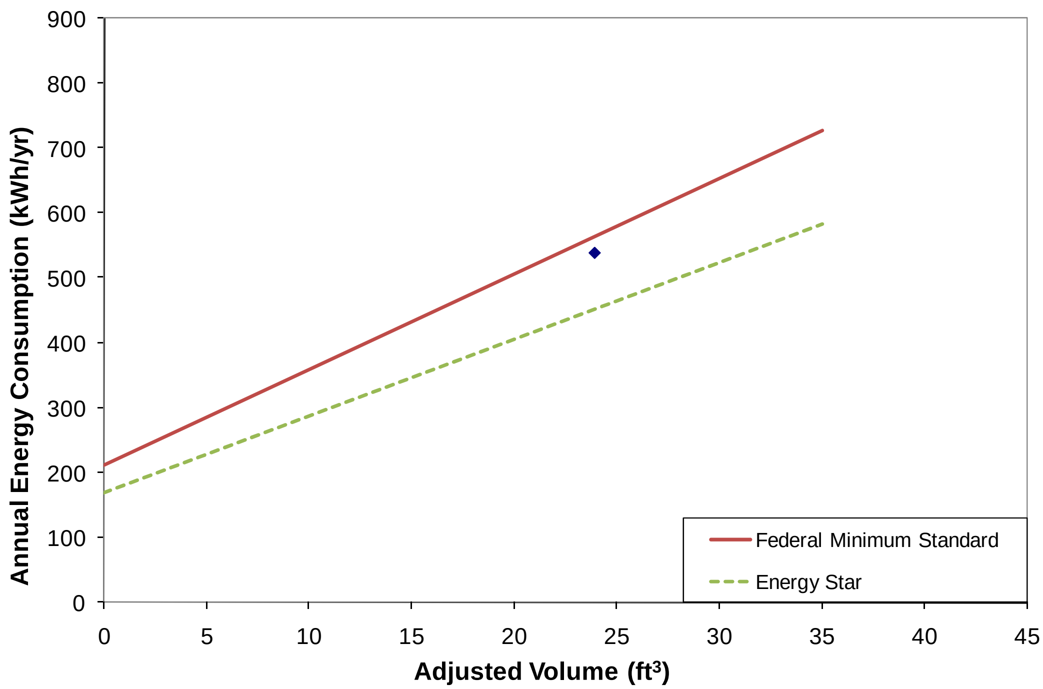

Figure 3.3.14 Annual Energy Consumption for Chest Freezers with Automatic Defrost (Product Class #10A)

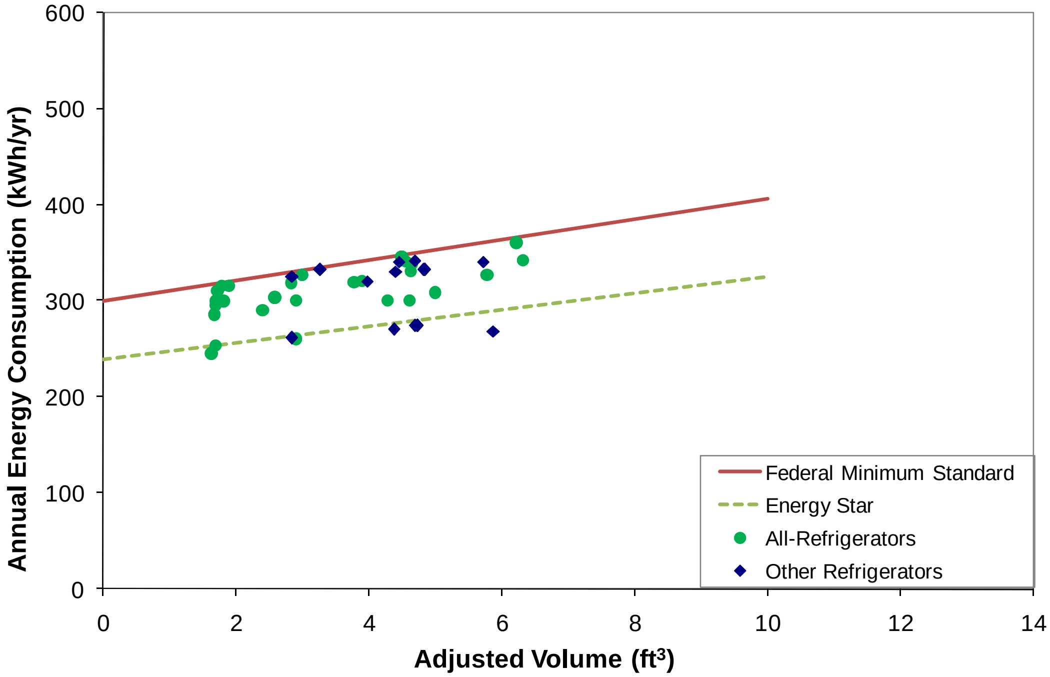

Figure 3.3.15 Annual Energy Consumption for Compact Refrigerators and Refrigerator-Freezers with Manual Defrost (Product Class #11)

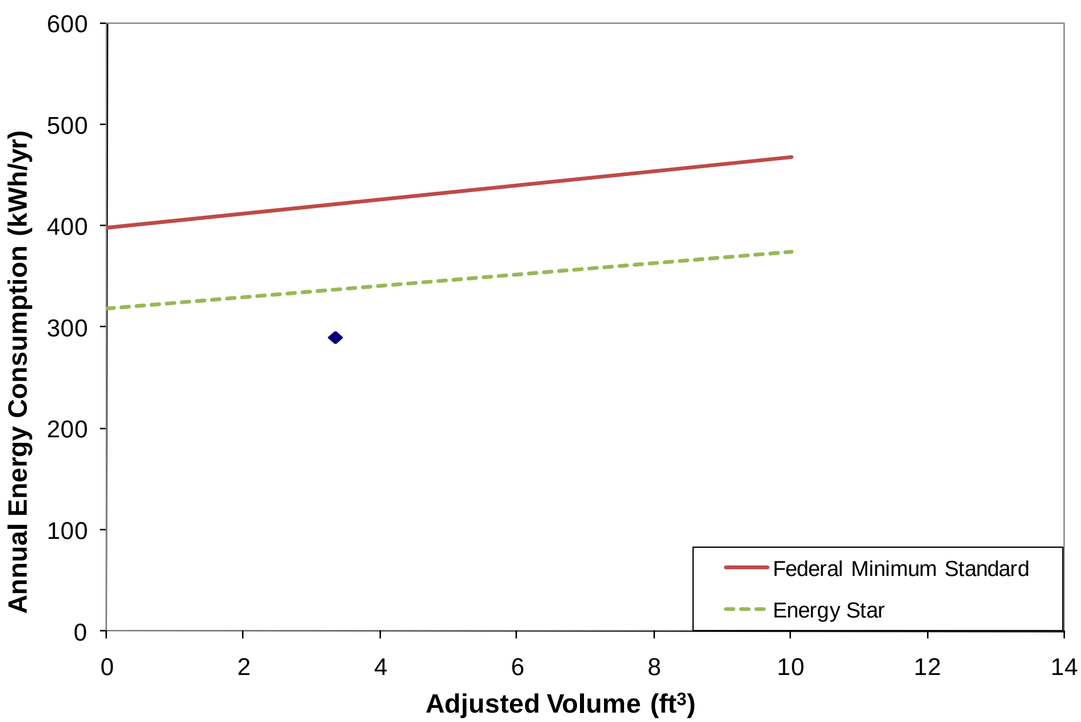

Figure 3.3.16 Annual Energy Consumption for Compact Refrigerator-Freezers with Partial Automatic Defrost (Product Class #12)

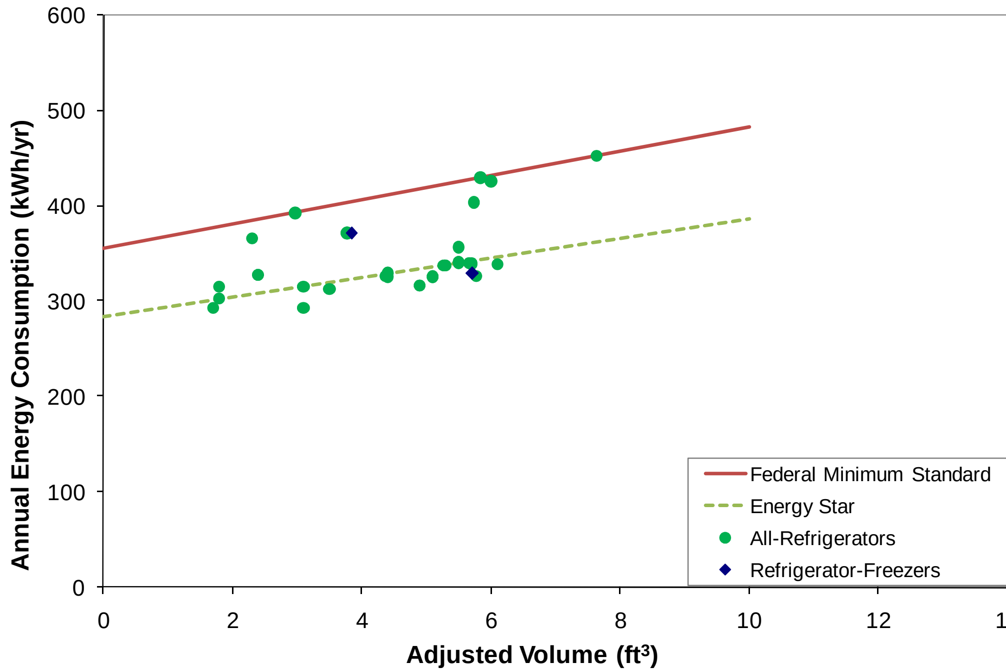

Figure 3.3.17 Annual Energy Consumption for Compact Top-Mount Refrigerator-Freezers with Automatic Defrost and All-Refrigerators with Automatic Defrost (Product Class #13)

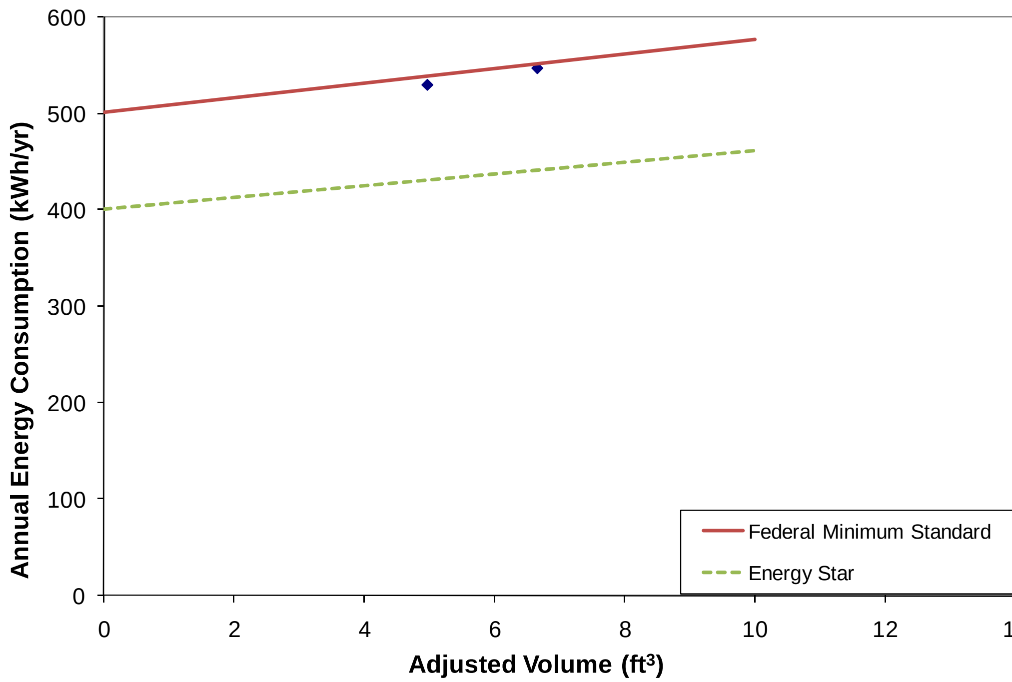

Figure 3.3.18 Annual Energy Consumption for Compact Side-Mount Refrigerator-Freezers with Automatic Defrost (Product Class #14)

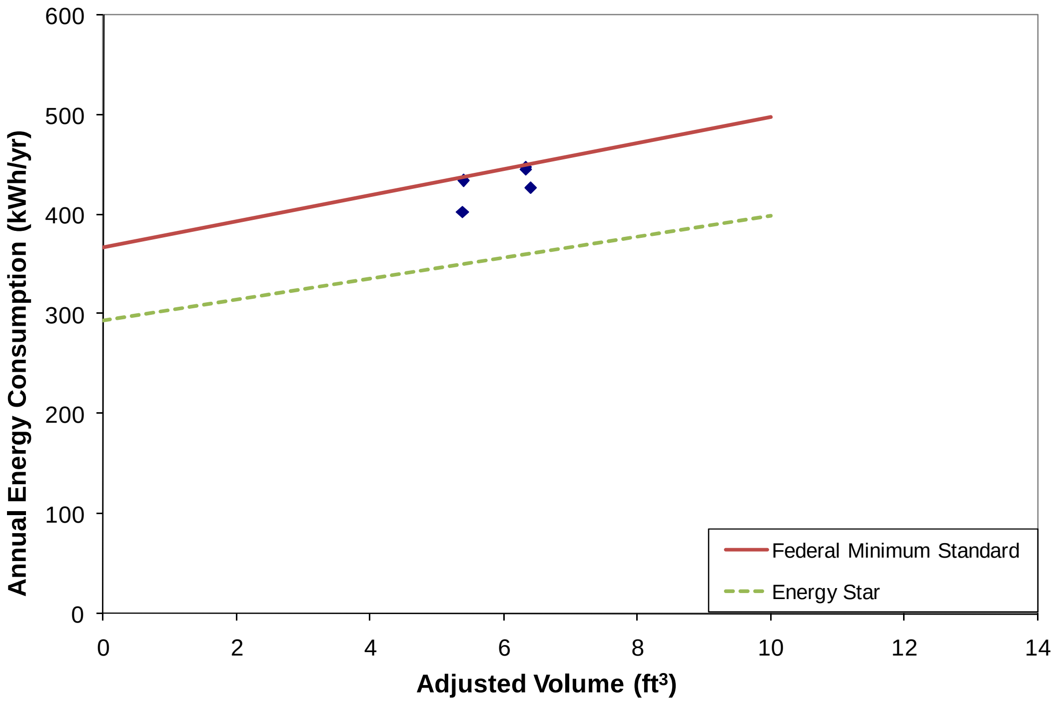

Figure 3.3.19 Annual Energy Consumption for Compact Bottom-Mount Refrigerator-Freezers with Automatic Defrost (Product Class #15)

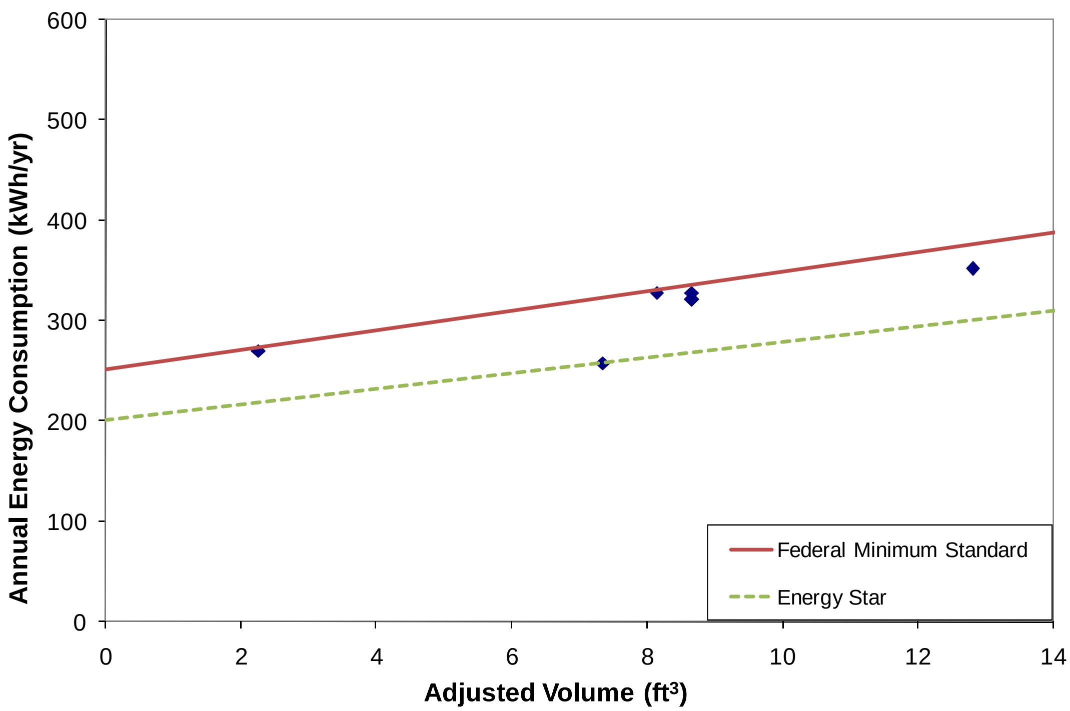

Figure 3.3.20 Annual Energy Consumption for Compact Upright Freezers with Manual Defrost (Product Class #16)

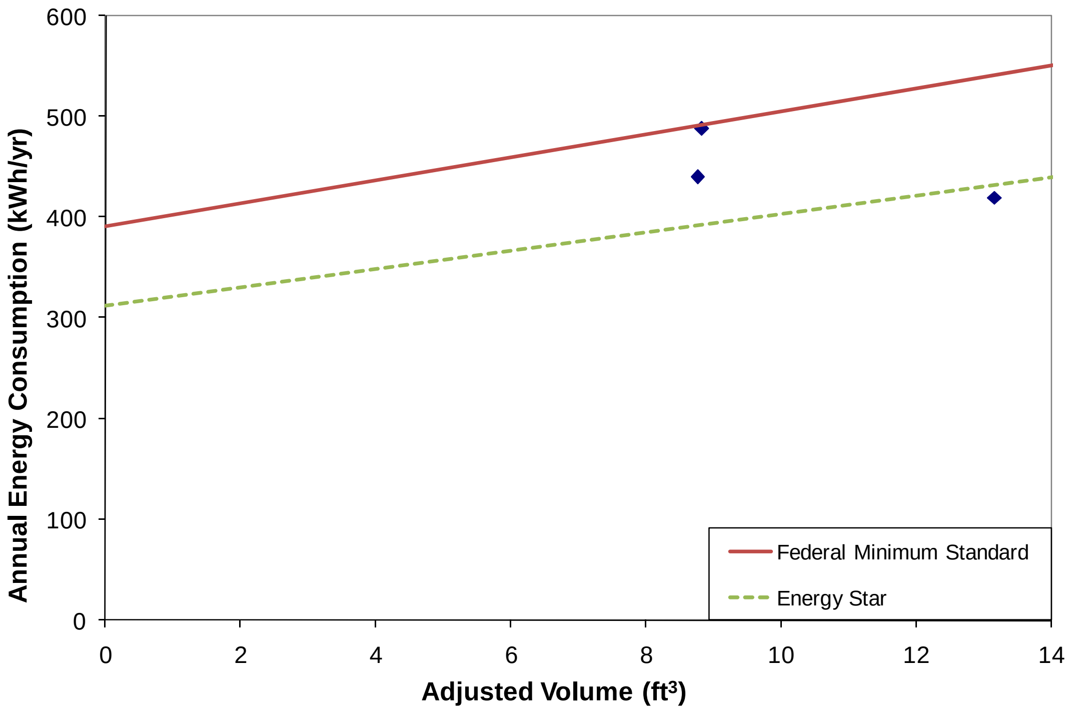

Figure 3.3.21 Annual Energy Consumption for Compact Upright Freezers with Automatic Defrost (Product Class #17)

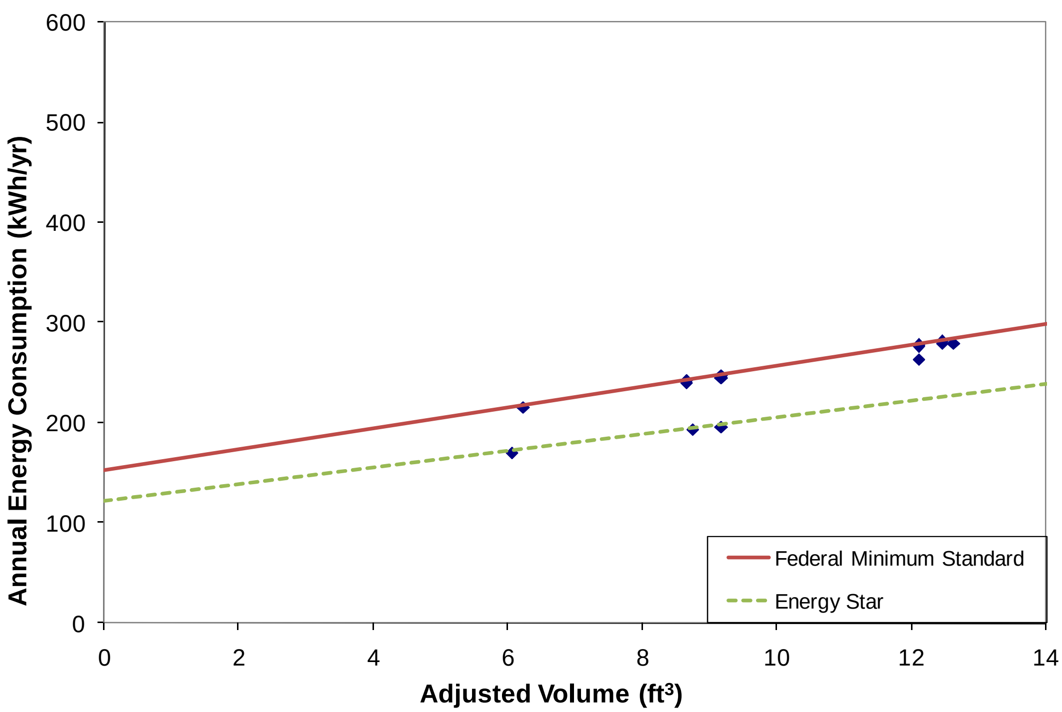

Figure 3.3.22 Annual Energy Consumption for Compact Chest Freezers (Product Class #18)

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CHAPTER 4: SCREENING ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter details the screening analysis that the U.S. Department of Energy (DOE) conducted in support of the ongoing energy conservation standards rulemakings for refrigerators, refrigerator-freezers, and freezers.

In chapter 3, the market and technology assessment (MTA), DOE presented an initial list of technologies that can improve the energy efficiency of residential refrigeration products. The purpose of the screening analysis is to evaluate the technologies that improve equipment efficiency to determine which technologies to consider further and which to screen out. DOE consulted with a range of parties, including industry, technical experts, and others to develop a list of technologies for consideration. DOE evaluated the technologies pursuant to the criteria set out in the Energy Policy and Conservation Act (EPCA), as amended. (42 U.S.C. 6311-6317)

Section 325(o) EPCA establishes criteria for prescribing new or amended standards designed to achieve the maximum improvement in energy efficiency. Further, EPCA directs the Secretary of Energy to determine whether a standard is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A), as directed by 42 U.S.C. 6316(a)(1)-(3)). EPCA also establishes guidelines for determining whether a standard is economically justified. (42 U.S.C. 6295(o)(2)(B)) Appendix A to subpart C of Title 10, Code of Federal Regulations, Part 430 (10 CFR Part 430), "Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products" (the Process Rule), sets forth procedures to guide DOE in its consideration and promulgation of new or revised equipment energy conservation standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy efficiency standard. In particular sections 4(b)(4) and 5(b) of the Process Rule guide DOE in determining whether to eliminate from consideration any technology that presents unacceptable problems with respect to the following criteria:

Technological feasibility. Technologies incorporated in commercial equipment or in working prototypes will be considered technologically feasible.

Practicability to manufacture, install, and service. If mass production of a technology in commercial equipment and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then that technology will be considered practicable to manufacture, install, and service.

Impacts on equipment utility or equipment availability. If a technology is determined to have significant adverse impact on the utility of the equipment to significant subgroups of customers, or result in the unavailability of any covered equipment type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as equipment generally available in the United States at the time, it will not be considered further.

Adverse impacts on health or safety. If it is determined that a technology will have significant adverse impacts on health or safety, it will not be considered further.

In sum, if DOE determines that a technology, or a combination of technologies, has unacceptable impacts on the policies stated in section 5(b) of the Process Rule, it will be eliminated from consideration. If a particular technology fails to meet one or more of the four criteria, it will be screened out. Section 4.2 documents the reasons for eliminating any technology.

4.2 SCREENED-OUT TECHNOLGIES

This section describes the technologies that DOE eliminated for failure to meet one of the following four factors: (1) technological feasibility; (2) practicability to manufacture, install, and service; (3) impacts on equipment utility or equipment availability; and (4) adverse impacts on health or safety.

4.2.1 Improved Resistivity of Insulation

Past research has demonstrated that the resistivity of polyurethane (PU) foam insulation can be improved through the use of additives that reduce the thermal conductivity of the foam.

Research conducted in 1996 demonstrated that adding carbon black provides a means of improving the thermal insulation properties of PU foam using both HCFC-141b or cyclopentane blowing agents.[1] However, DOE is not aware that this process has been adopted by any supplier of PU foam insulation or any refrigerator manufacturer. Manufacturers have reported that it darkens the interior of a refrigerator lined with white plastic, and it stains anything it contacts.

Discussion with PU foam insulation vendors indicates that there is work ongoing which may lead to improvement in insulation performance but that any such technology would not likely be ready for introduction to the market by 2014. Discussion with manufacturers has confirmed that there are no available options for improvement in PU foam insulation performance (other than reverting to use of banned blowing agents). Due to the lack of available information and predictions that there is no significant benefit to be expected from PU foam improvements, DOE has eliminated this option from consideration in the engineering analysis.

4.2.2 Gas-Filled Panels

Investigation of the status of gas-filled panels suggests that there has been some evaluation of this technology by manufacturers of residential refrigeration equipment, but that no manufacturers are using it in their products. The costs are reported to be as high as for vacuum insulation panels (VIPs), with less reduction in thermal load. DOE has not been able to identify a credible supplier that would provide gas filled panel products to the refrigeration industry. DOE has eliminated this technology from further consideration.

4.2.3 Improved Gaskets, Double Gaskets, Improved Door Face Frame

Past investigation on reduction of heat load in the gasket and door face frame area has focused on (1) limiting the conduction of heat through metal casing material passing underneath the gasket magnet on the cabinet side or in the region of the gasket clip on the door side into the cabinet interior, (2) using a gasket which provides additional cover of frame surfaces towards the interior of the magnet to prevent cold air from reaching the high-conductivity metal casing near the gasket magnet, and (3) providing a long thin “throat” area between the gasket and the interior to limit convection heat transfer. Most current designs are effective in addressing these issues.

Limited information is publicly available which would allow quantification of additional improvement potential for the door frame/gasket area of refrigerators. Some manufacturers use extra-strong gasket magnets to limit infiltration and thermal loss, but it is unclear whether significant thermal improvement is possible with such systems. Manufacturers indicated during pre-NOPR discussions that properly designed and installed gasket systems provide a tight seal and that there isn’t any further reduction in air leakage that could be achieved with improvements in the gasket system such as increasing the magnetic force. In addition, consumer safety laws preclude use of excessive door sealing force.

Based on information drawn from DOE’s 1995 TSD, double door gaskets were not adopted by many manufacturers in the mid-1990s because of performance problems and cost. Ice has a tendency to form between the gaskets, greatly reducing their effectiveness. In addition, the gaskets tend to be visually unattractive and they make it more difficult to meet the consumer safety regulations for minimum door-opening force.

It is expected that incremental improvement may be possible for some products, however, the lack of good quantified information on general improvement potential in this area makes this technology option unsuitable for consideration as a design option.

4.2.4 Reduced Heat Load for TTD Feature

During Pre-NOPR analysis discussions, manufacturers indicated that there is little or no reduction in load which can be achieved through redesign of TTD features. DOE inspected the TTD system of a side-by-side refrigerator and concluded that the load impact of this feature is modest. The door insulation thickness is maintained behind the recess except within an inch or two of the chute opening, and low-conductivity plastic is used on all surfaces. The chute door closes reliably. A calculation of the thermal load suggests that it is on the order of 3W (10 Btu/hr). The reverse engineering of this feature shows that a 2W electric anti-sweat heater is used to prevent condensation of the exterior surfaces nearest the ice chute opening. Manufacturers indicated that these load levels are typical for TTD features. Even if the chute door was insulated with ½-inch of insulation (which would likely interfere with chute door operation), the load impact would be minimal, due to the very low surface area of this door. Based on the very low potential for improvement, DOE has eliminated reduced heat load TTD features as an option for further analysis.

4.2.5 Warm Liquid or Hot Gas Refrigerant Anti-Sweat Heating

Although some refrigerators do still use electric anti-sweat heating, the typical anti-sweat heater for baseline units, according to the reverse engineering work and discussion with manufacturers, is warm liquid refrigerant. A possible exception is French door refrigerators. In these products, providing heat to the gasket surfaces which seal between the French doors (or to the flip-mullion used in some designs for sealing in this region) is not possible using warm refrigerant liquid or hot gas. French door refrigerators may use electric anti-sweat heaters in this region, but for these products conversion to refrigerant line anti-sweat is impractical. Due to the current use of refrigerant-line anti-sweat in situations where it can be used, DOE has eliminated this option from further consideration.

4.2.6 Electric Anti-Sweat Heater Sizing

Because the baseline products considered in the engineering analysis predominantly use warm liquid anti-sweat, the consideration of adjustment of the sizing of electric anti-sweat heaters is not relevant.

4.2.7 Linear Compressors

While promising potential has been reported for linear compressors, there is very little information available for commercialized linear compressors that allows confident prediction of performance and cost impacts of this technology. Information for some LG linear compressors has been reported at “LG Reference Conditions,” which are significantly different than the standard ASHRAE rating conditions. Under ASHRAE conditions, compressors are rated at -10 ºF (-23.3 ºC) evaporating temperature and 130 ºF (54.4 ºC) condensing temperature. The “LG Reference Conditions” are based on -14.8 ºF (-26 ºC) evaporating and 100.4 ºF (38 ºC) condensing temperatures. It is not clear what the liquid and suction vapor temperatures for the LG conditions are—these temperatures also impact capacity and power input. The performance of some of LG’s linear compressors at the LG conditions is presented in Table 4.2.1 below. At the same evaporating and condensing temperatures and with liquid and suction vapor conditions consistent with the ASHRAE test conditions, a high efficiency rotating-shaft reciprocating compressor such as the Embraco EGX70HLC would have an operating EER of about 6.9 Btu/hr-W. Hence, the LG linear compressor may be about 9% more efficient than the best current-technology rotating-shaft reciprocating compressors.

Table 4.2.1 LG Linear Compressor Performance Data

Model	Capacity Range*		Efficiency*	
	W	*Btu/hr*	*COP*	*EER*
DLF81LACT	310	1058	2.14	7.3
FA81LACT	293	1000	2.20	7.5
FA72LACT	276	941	2.20	7.5
FA63LACT	241	823	2.20	7.5
FA54LACT	207	706	2.20	7.5

Source: LG, 2007.

* Performance based on ‘LG Reference’ rating conditions. Models utilize refrigerant R-134a.

In the trade press, LG has expressed willingness to license the linear compressor technology to competitors.[2] However, because the LG design is proprietary, the widespread use of linear compressors is highly uncertain. Use of linear compressors in LG refrigerators is less explicit in LG product data than it was a few years ago, so it is unclear how many products are actually using these compressors. Other compressor manufacturers who have indicated that they have investigated linear technology have stated that linear compressor technology does not provide a clear path to improved efficiency, and some have indicated that they are no longer actively pursuing this technology. Hence, availability of linear compressor technology as an option for improved efficiency is uncertain. Further, DOE was not able to obtain cost estimates for linear compressors. For these reasons, DOE has eliminated linear compressors from further consideration in the analyses.

4.2.8 Improved Evaporator Heat Exchange

Improving heat exchanger performance can be achieved through the use of enhanced fins and/or tubes. These types of fin and tube enhancements are common in air-conditioning applications where slit and louvered designs are used to enhance the fin surface and different types of internally-grooved surfaces are used to enhance the tubing. Application of similar enhancements in refrigerator evaporators is complicated by frost accumulation on the evaporators. Effectiveness of the fine slit and louver features for refrigerator evaporators is dubious because they would be blocked quickly with frost. In order to avoid the energy use associated with frequent defrost, fin spacing in refrigerator evaporators is comparatively sparse. This allows the evaporator to work effectively without blocking airflow with a considerable accumulation of frost. During defrost, the typical flat fin design of these evaporators assures that the frost slides rapidly off the fins and doesn't get stuck on fin enhancement features. During discussions with manufacturers, little indication was provided that efficiency could significantly be enhanced through the use of fin or tube enhancements. DOE has eliminated this option from consideration in subsequent analysis.

4.2.9 Improved Condenser Heat Exchange

Use of heat exchanger enhancements for the condenser are complicated by the need for adequate performance when the heat exchanger has not been cleaned. Most refrigerator condensers (other than hot wall condensers integrated into the outer shells of the products) are made of steel tubes and steel wire fins. These condensers have a very open construction which allows dust to flow through easily and which reduces blockage of air flow if dust does collect on the condenser surfaces. Flat fin condensers used in refrigerators are known to require more careful attention to cleaning. Use of high fin densities is more accepted in air-conditioning applications because periodic maintenance is expected and because size would get enormous if aggressive fin spacing wasn't employed, whereas cleaning of refrigerator condensers occurs infrequently or never, and the loads are small enough so that maximizing use of space is not critical. DOE has eliminated this option from consideration in subsequent analysis.

4.2.10 Fan Blade Improvements

Refrigerator fan blades use an axial design. They are typically injection molded plastic with a three-dimensional shape for improved performance as compared with older stamped sheet metal designs. One source of inefficiency for axial fans lies in their tendency to throw air outward, necessitating a shroud to collect and redirect airflow along the axis as intended. The Pax Group™ has developed a fan (PAX fan) that employs streamlined blades with patented geometrical shapes derived from a naturalistic design approach, providing better airflow direction and improved efficiency. Tests performed when replacing existing motor combinations with A.O.Smith motors and PAX fan blades show power input reductions in the range of roughly 10% to 35%.[3] It is impossible to tell how much of this benefit is associated with the fan blade and how much with the motor. Also, because the PAX fan is proprietary, the widespread use of the design is highly uncertain. There is in general little data available to quantify the energy benefit possible with improvement in fan blade design in today's refrigeration products. Fan performance is highly dependent on details of integration with the system: orifice geometry, tolerance of blade/orifice gap, match of system flow impedence to fan performance, etc. Hence, making credible estimates of energy savings potential through fan blade replacement requires testing fan blade swaps in baseline products. The cost of fabrication of improved fan blade geometries should be low, so most of the cost increase associated with this technology option would be associated with paying for the blade development and/or licensing fees. It is very difficult to predict what these costs would be unless specific vendors of high efficiency fan blades can be identified who provide complete information. During discussions with manufacturers, no information was provided which would allow credible calculation of savings and costs associated with improved fan blades. Hence, DOE has eliminated this option from further consideration.

4.2.11 Improved Expansion Valve

Residential refrigeration products exclusively use capillary tubes for refrigerant flow metering. These tubes are inexpensive and they lend themselves easily to low-cost fabrication of suction line heat exchangers by brazing the capillary to the suction line. Automatic, adjustable thermostatic or electronic expansion valves are available, but they generally are oversized for residential refrigeration. Furthermore, it is unclear whether there is any potential for energy savings using alternative expansion devices. The DOE Energy test is conducted with a single set of standardized temperatures for the ambient air (90 °F) and for the compartments. A capillary tube can be designed to provide optimized performance for this set of temperatures. Systems are generally designed to operate with evaporator exit conditions having little or no superheat during energy testing, thus maximizing use of the evaporator. In the lower ambient temperature typical in homes, the pressure available to move refrigerant through the capillary tube is lower, thus possibly leading to increased superheat and less than optimum performance. An automatic valve could provide optimum performance for a wider range of operating conditions, but such improvement is not reflected in current energy testing. DOE has eliminated this option from further consideration.

4.2.12 Off-Cycle Valve

Off-cycle refrigerant migration reduces a refrigeration product's efficiency by allowing warm and/or vapor-phase refrigerant to pass into the cabinet. A fluid control or solenoid valve installed after the condenser to effectively isolate the evaporator from the condenser during the off-cycle can be used to prevent refrigerant migration. Research has demonstrated that solenoid valves can yield substantial energy savings.[4] Such a solenoid valve represents a possible reliability issue, although many wine storage products use similar solenoid valves to allow control of multiple compartments with a single compressor. Also, operation with an off-cycle valve requires that the compressor motor can start up against a substantial pressure difference. The starting windings of compressors that can do this reliably over the life of a refrigerator draw more power and hence reduce the compressor's steady-state efficiency. The different efficiency levels of commercial refrigeration compressors designed for instant restart versus restart after pressure equalization have EER ratings which differ by 10% or more. Such a difference would be expected for residential compressors operating with an off cycle valve, and this difference would more than neutralize any benefit accrued from using the off-cycle valve. Hence, DOE has eliminated this option from further consideration.

4.2.13 Reduced Energy for Automatic Defrost

In some cases, the defrost heat supplied is more than required. Thus, energy savings can be achieved by reducing the defrost heat by either using smaller heaters, reducing the heater on-time, reducing the frequency of defrost, or a combination of these. In its 1995 TSD, DOE found that most manufacturers had already significantly reduced the electric heat for auto defrost in order to comply with the energy efficiency standards that became effective in 1993.[5] The percent of energy represented by defrost for the refrigerator-freezers tested as part of this rulemaking ranged from 4% to 5% for products without adaptive defrost and from 1% to 5% for products with adaptive defrost. It is unlikely that significant energy savings are achievable by further reducing the energy for automatic defrost without compromising defrost performance, except through use of adaptive defrost.

4.2.14 Condenser Hot Gas Defrost

Another method of reducing the energy required for defrost is to eliminate the need for electric heaters by substituting condenser hot gas in their place. In a condenser hot gas defrost system, the compressor continues to run and a valve opens allowing hot compressed refrigerant to flow to the evaporator. Many frost-free refrigerator-freezers in the 1960s and 1970s used a condenser hot gas defrost system. In its 1995 TSD, DOE was not able to identify data that demonstrated that the condenser hot gas method was more cost-effective than adaptive defrost. Therefore, DOE dropped the condenser gas defrost as a technology option in favor of adaptive defrost. [6] Hot gas defrost would potentially save energy because a large portion of the heat for defrost could be provided by heat generated by the compressor motor during the on-cycle rather than from new electricity use. The compressor is at an elevated temperature with respect to ambient during the on-cycle and is certainly much warmer than freezing temperature. The heat would be transported to the evaporator with circulating refrigerant during the defrost cycle. However, in spite of this potential reduction in use of electricity to provide defrost heat, the energy savings potential is not well documented. Also, there are concerns regarding reliability of the required valve.

4.2.15 Electronic Temperature Control

DOE has not identified any relevant information showing the energy benefit of electronic temperature control. Potential benefits of electronic control when operating with single-speed compressors are fine-tuning of the run times and fine-tuning of the cut-in and cut-out temperatures. While there may be potential for incremental improvement associated with such fine-tuning, the lack of data supporting claims for energy savings make it difficult to properly analyze this option.

4.2.16 Air-Distribution Control

Air temperature distribution in refrigeration products with fan-forced evaporator air flow is generally good, in contrast with some products with cold wall or roll bond evaporators. Hence, it is not clear that improvements in air distribution will provide significant reduction in energy use. Redirection of air flows in a cabinet could potentially provide a false indication of efficient operation, for instance if the coldest air from the evaporator discharge is directed at the locations used for the energy test thermocouples. It is conceivable that valid reduction in energy use could occur if the air flow distribution keeps cold air away from the walls of the cabinet. However, there is insufficient information regarding the designs of air flow distribution systems to quantify potential energy savings.

4.2.17 Alternative Refrigerants

R-600a (isobutane) is the most logical alternative to the HFC-134a refrigerant used exclusively in U.S. residential refrigeration products. Isobutane is a hydrocarbon refrigerant which has been used for many years in refrigeration products in Europe and other foreign countries. The theoretical efficiency of isobutane is higher than that of HFC-134a, however, the U.S. refrigeration industry has not adopted hydrocarbon refrigerants (likewise for the U.S. air conditioning industry) due to concerns regarding flammability. Recent shifts in this viewpoint are the result of pressures regarding the direct global warming impact of the refrigerant rather than the energy use impacts. Comments from manufacturers regarding the potential for efficiency improvement using isobutane are mixed. In any case, it is not expected that U.S. manufacturers will switch to isobutane to reduce energy use and that there will be limited conversion unless legislation is enacted which mandates phaseouts for global warming substances such as HFC refrigerants. In the case of such legislation, the potential improvement in energy use associated with isobutane will be balanced by a potential increase in energy use associated with reduced resistivity of PU foam insulation made with cyclopentane blowing agent, the most likely replacement for currently-used HFC blowing agents. DOE will consider the impacts of switch to hydrocarbon refrigerants and blowing agents if such legislation is enacted, but DOE will not consider use of isobutane as a design option to improve efficiency in the absence of such legislation.

4.2.18 Component Location

Locating the compressor at the top of the refrigerator was noted as a potential technology option. However, this change would increase structural requirement for the refrigerator cabinet, increase risk of product tip-over, and provide much less practical use of space from the consumer perspective. It also makes design for re-evaporation of defrost water more challenging. It is unlikely that the savings would justify all of these drawbacks.

Another option is to locate the evaporator fan motor outside the cabinet to reduce internal loads from the heat loss of the motor. Evaporator fan motor input wattages are now in the range 3W to 7W, with fan blade efficiency in the range 20% to 30% and motor efficiency in the range 20% to 50%. Hence, load reduction, associated with moving the motor loss outside the cabinet, is only in the range 1W to 5W for the typically less than 50% of the time that the evaporator fan is in operation. The loss associated with the added infiltration and conduction is likely to be comparable to this level. Additional issues with this approach include reliability, reduced design flexibility, and the fact that reduction of motor losses (by using more efficient fan motors) may be a more effective approach to reducing the impact of the fan motor power input.

No options for relocation of components have been identified which merit further consideration in the engineering analysis.

4.2.19 Lorenz-Meutzner Cycle

Research on Lorenz-Meutzner cycles reported in the literature involve binary mixtures HCFC-22/CFC-11, HCFC-22/HCFC-123, propane/n-pentane, and propane/n-butane. These systems achieved efficiency levels from 15 to 20 percent better than the baseline systems with which they were compared.[7,8] Because the industry settled on the use of HFC-134a to replace CFC-12, interest in the Lorenz-Meutzner cycle as an alternative to conventional refrigeration cycles declined. All of the refrigerant combinations discussed above have specific problems, the first two with phaseout of constituent refrigerants CFC-11 and HCFC-22, and the last two with flammability of the hydrocarbon blends involved. While it is possible that HFC mixtures could be developed to create a viable Lorenz-Meutzner cycle refrigerator, DOE is not aware that such a prototype has been built and tested successfully. Hence, DOE has not considered this technology in the engineering analysis.

4.2.20 Dual-Loop System

Dual-loop systems have difficulty achieving their theoretical improvement potential due to the significantly reduced efficiency for smaller-capacity compressors. If the two compressors of a dual-loop system serving a refrigerator-freezer were sized appropriately for their respective loads, the freezer compressor capacity would nominally be roughly half that of a single-system compressor. A fresh food compressor typically operates at a capacity significantly higher than its nominal capacity because of the higher evaporating temperature when cooling just the fresh food compartment. Hence, the nominal capacity of a fresh food compartment compressor serving a dual-loop system is generally 30 to 40 percent that of the single-system compressor. Even with the efficiency improvement associated with higher evaporating temperature operation of the fresh food compartment compressor, this compressor still would not operate at an efficiency level better than that of the single-system compressor for freezer conditions. Hence, with the efficiency characteristics of available compressors, it is not clear that the dual-loop architecture will provide any energy savings. Hence, DOE has not considered this technology in the engineering analysis.

4.2.21 Two-Stage System

In practice, a two-stage system would suffer the same disadvantages associated with a dual-loop system. Furthermore, it is not clear that a suitable compressor is available for the lower stage of such a system. DOE is not aware of any prototypes of such a system using compressors which their manufacturers would warrantee for such a product. Hence, DOE has not considered this technology in the engineering analysis.

4.2.22 Control Valve System and Tandem System

There are many patents covering dual-evaporator refrigerator designs. It is not clear how many of these were developed to improve system efficiency, since one of the benefits of using dual evaporators is avoiding excessively low humidity levels in the fresh food compartment. While there is research involving laboratory testing which shows that these technology options can save energy, DOE is not aware of any commercialized refrigerators using either of these approaches. In discussions with manufacturers none identified these options as being interesting approaches for energy use reduction. Further, due to the extensive patent literature discussing dual-evaporator systems, it is likely that products requiring dual evaporator designs would be restricted to the patentholders. Hence, DOE has not considered this technology in the engineering analysis.

4.2.23 Ejector Refrigerator

Energy savings have been reported for use of an ejector system in laboratory testing. In discussions with manufacturers there was limited familiarity with this concept and no acknowledgement that it has been proven through prototype testing and/or that it is an interesting concept for improving efficiency. Hence, DOE has not considered this technology in the engineering analysis.

4.2.24 Stirling Cycle

In principle, the efficiency of Stirling cycles could be higher than for vapor compression systems, but there are various technical difficulties that have so far limited the use of Stirling-cycle cooling to small prototype domestic refrigerators. There is no circulating refrigerant fluid and the hot and cold end areas are very small, which creates heat exchange difficulties. Heat pipes may be required to transfer heat to and from the system. A comparison of the performance of Stirling cycle with vapor compression compressors is shown in Figure 4.2.1 below. The Stirling cycle data was obtained from the Global Cooling website[9] and from data presented at the Purdue Refrigeration Conference in 2002.[10] The figure shows that Stirling technology is not currently ready to improve upon the efficiency of conventional technology. Hence, DOE has not considered this technology in the engineering analysis.

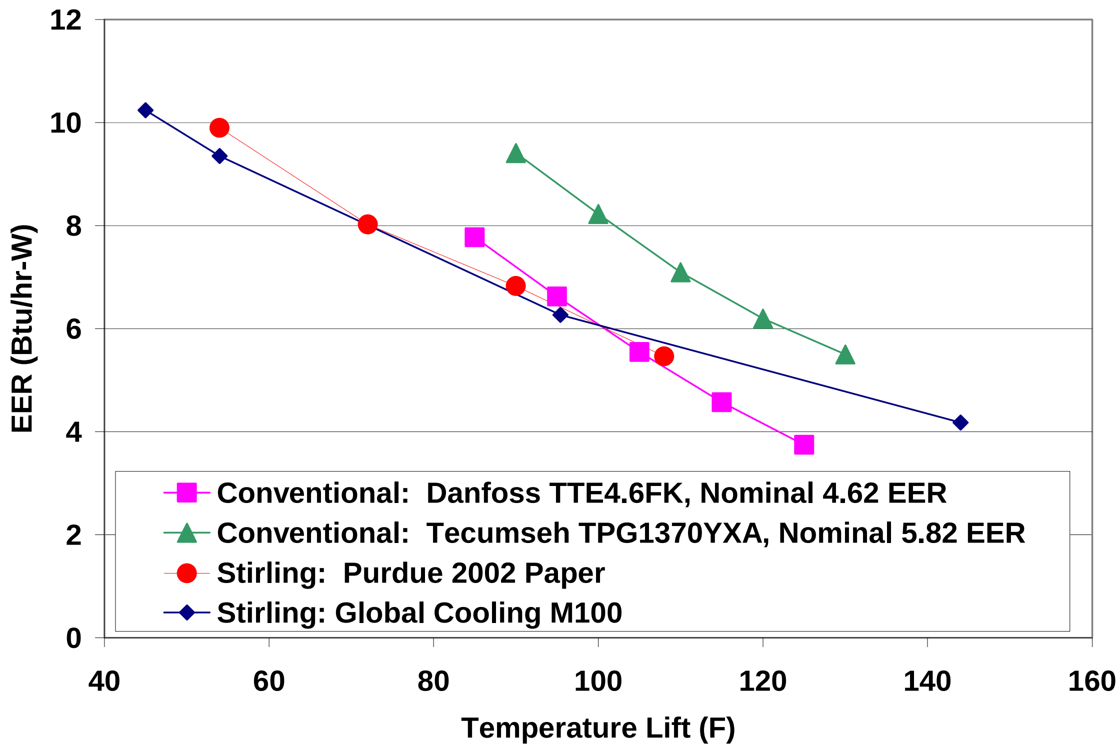

Figure 4.2.1 Comparison of Stirling and Vapor Compression Technologies

4.2.25 Thermoelectric

Thermoelectric cooling technologies currently do not achieve efficiency levels which make them attractive as a design option for improving residential refrigeration energy efficiency. As an example, DOE tested a thermoelectric refrigerator as part of the reverse engineering effort of this rulemaking. This refrigerator was a Haier model HRT02WNC, a 1.7 cuft all-refrigerator. In an 80 °F ambient with the system operating at full power, this unit was able to cool the interior to 47 °F while drawing 50W total. The fans serving the inside and outside heat sinks of the thermoelectric unit are rated at a voltage of 12 Volts and currents of 0.13 Amps and 0.16 Amps respectively, and a control board power input of 1W is assumed. The thermal load for the cabinet was estimated as 12 W. Hence the thermoelectric module EER was 0.9 at a temperature lift of at most 33 °F, an order of magnitude less than is achieved by conventional technology. Hence, DOE has not considered this technology in the engineering analysis.

4.2.26 Thermoacoustic

While research suggests that thermoacoustic cooling systems could achieve respectable efficiencies, the technology has not reached a level of maturity sufficient for serious consideration as the basis for efficiency improvement in residential refrigeration products. Hence, DOE has not considered this technology in the engineering analysis.

4.3 REMAINING TECHNOLOGIES

After eliminating those technologies that have no effect or do not increase EER and screening out those technologies that that do not meet the requirements of sections 4(a)(4) and 5(b) of the Process Rule, DOE is considering the technologies in the following list.

- Increased Insulation Thickness
- Vacuum Insulation Panels (VIPs)
- Variable Anti-sweat Heating
- Improved Compressor Efficiency
- Variable Speed Compressors
- Increased heat exchanger area (extension of surface area or addition of coil rows).
- Use of forced convection condenser (for upright freezers)
- Improved efficiency fan motors (brushless DC)
- Adaptive Defrost

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CHAPTER 5: ENGINEERING ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis establishes the relationship between manufacturer production cost and energy consumption for the refrigerators, refrigerator-freezers, and freezers covered in this rulemaking. The "cost-efficiency" relationship serves as the basis for cost-benefit calculations in terms of individual customers, manufacturers, and the Nation, from which the most economically-justified, technically feasible standard level is ultimately determined.

The inputs into the engineering analysis include baseline characteristics for each product class addressed in the market and technology assessment (chapter 3), the design options from the screening analysis (chapter 4), as well as cost and energy use data collected from manufacturers, component vendors, reverse-engineering, and energy testing. The output of the engineering analysis is the cost-efficiency relationship for each product class independent of cabinet volume, which will be used in the life-cycle and payback period analyses (chapter 8).

This chapter covers the product classes DOE analyzed, and the methodology used by DOE to develop manufacturing costs, energy consumption, and extend the analysis to low-volume product classes, as well as the results of these analyses.

5.2 PRODUCT CLASSES ANALYZED

In the engineering analysis for the preliminary notice of proposed rulemaking (Pre-NOPR), DOE analyzed the seven product classes listed in Table 5.2.1. DOE considers these classes to be representative of products currently shipped by the residential refrigerator, freezer, and refrigerator-freezer industry based on total shipments. These product classes represent close to 90% of the shipments of refrigerators, refrigerator-freezers, and freezers. DOE did not directly analyze all covered product classes in order to carry out the analysis as efficiently as possible. DOE proposes extrapolation of energy standards to the remaining product classes as described in section 2.15 of chapter 2.

Table 5.2.1 Product Classes Analyzed in Engineering Analysis

Product Class	Equipment Description
3	Refrigerator-freezers—automatic defrost with top-mounted freezer without TTD ice service
5	Refrigerator-freezers—automatic defrost with bottom-mounted freezer without TTD ice service
7	Refrigerator-freezers—automatic defrost with side-mounted freezer with TTD ice service
9	Upright freezers with automatic defrost
10	Chest freezers and all other freezers except compact freezers
11	Compact refrigerators and refrigerator-freezers with manual defrost
18	Compact chest freezers

5.3 METHODOLOGY OVERVIEW

This section describes the analytical methodology DOE used in the engineering analysis. In this rulemaking, DOE has adopted a combined efficiency level, design option approach to developing cost-efficiency curves. DOE established efficiency levels defined on percent energy use lower than that of baseline efficiency products in order to allow comparison of information developed from different sources. However, DOE's analysis is based on the efficiency improvements associated with groups of design options.

Figure 5.3.1 presents the steps in the analysis and illustrates how they contribute to developing the cost-efficiency curves. The process begins with data collection and ends with the incremental cost curve results.

As input to the analysis, DOE requested incremental cost-efficiency data from the industry. The Association of Home Appliance Manufacturers (AHAM) provided aggregated incremental cost data for a number of the product classes under analysis. This information was supplemented by analytically-derived cost-efficiency curves for the seven product classes listed in Table 5.2.1.

To develop the analytically-derived cost-efficiency curves, DOE collected information from various sources on the manufacturing cost and energy use reduction characteristics of each of the design options. DOE reviewed product literature, conducted reverse-engineering of current products, and interviewed component vendors of compressors, fan motors, insulation, and heat exchangers. DOE also conducted interviews with manufacturers, using an engineering questionnaire which is reproduced in appendix 5-A.

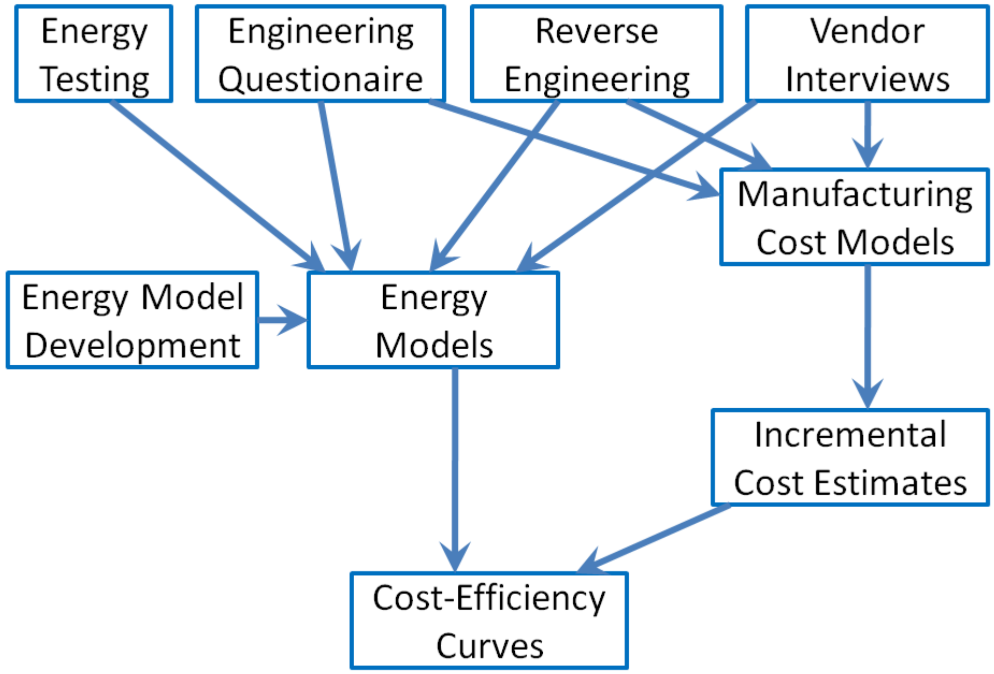

Figure 5.3.1 Flow Diagram of Engineering Analysis Methodology

Cost information from the vendor interviews and engineering questionnaires provided input to the manufacturing cost model. Incremental costs associated with specific design options were calculated using the cost model. Energy use reduction was modeled with a modified version of the established EPA Refrigerator Analysis (ERA) program which was used in the previous refrigerator rulemaking. The reverse engineering, vendor interviews, and manufacturer interviews provided input for the energy analysis. The incremental cost estimates and the energy modeling results together constitute the energy efficiency curves presented in this chapter.

5.4 EFFICIENCY LEVELS

5.4.1 Baseline Units based on the Current Test Procedure

DOE selected baseline units as reference points for all of the product classes, against which DOE determined changes resulting from use of energy saving design options. The baseline unit in each product class represents the basic characteristics of equipment in that class. A baseline unit is a unit that just meets current required energy conservation standards and provides basic consumer utility.

As discussed in chapter 3, DOE has initiated a rulemaking to revise the energy test procedure for refrigerators, refrigerator-freezers, and freezers. Some of the anticipated changes to the test procedure such as changes in compartment temperatures will result in changes in the measured energy consumption. The test procedure change will also affect the measured size of the refrigerators, expressed as adjusted volume.

Since the maximum energy use for residential refrigeration products is expressed as a function of adjusted volume, the change in adjusted volume also affects the definition of baseline products. This section discusses definitions of baseline units for the engineering analysis based on the current test procedure, while the next section discusses modified definitions for baseline refrigeration products based on the expected revised test procedure.

For this rulemaking, DOE established baseline efficiency levels as the current federal energy conservation standards, expressed as maximum annual energy consumption as a function of the product's adjusted volume, as shown in Table 5.4.1. These definitions are based on testing according to the current energy test procedure.

Table 5.4.1 Refrigerator, Refrigerator-Freezer, and Freezer Energy Conservation Standards and Proposed Baseline Model Efficiencies

Product Class	Equations for Maximum Energy Use (kWh/yr)
1. Refrigerators and refrigerator-freezers with manual defrost.	8.82AV + 248.4 0.31av + 248.4
2. Refrigerator-freezer—partial automatic defrost.	8.82AV + 248.4 0.31av + 248.4
3. Refrigerator-freezer—automatic defrost with top-mounted freezer without TTD ice service and all-refrigerator—automatic defrost.	9.80AV + 276.0 0.35av + 276.0
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without TTD ice service.	4.91AV + 507.5 0.17av + 507.5
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without TTD ice service.	4.60AV + 459.0 0.16av + 459.0
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with TTD ice service.	10.20AV + 356.0 0.36av + 356.0
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with TTD ice service.	10.10AV + 406.0 0.36av + 406.0
8. Upright freezers with manual defrost.	7.55AV + 258.3 0.27av + 258.3
9. Upright freezers with automatic defrost.	12.43AV + 326.1 0.44av + 326.1
10. Chest freezers and all other freezers except compact freezers.	9.88AV + 143.7 0.35av + 143.7
11.Compact refrigerators and refrigerator-freezers with manual defrost.	10.70AV + 299.0 0.38av + 299.0
12. Compact refrigerator-freezer—partial automatic defrost.	7.00AV + 398.0 0.25av + 398.0
13. Compact refrigerator-freezers—automatic defrost with top-mounted freezer and compact all-refrigerator—automatic defrost.	12.70AV + 355.0 0.45av + 355.0
14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.	7.60AV + 501.0 0.27av + 501.0
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.	13.10AV + 367.0 0.46av + 367.0
16. Compact upright freezers with manual defrost.	9.78AV + 250.8 0.35av + 250.8
17. Compact upright freezers with automatic defrost.	11.40AV + 391.0 0.40av + 391.0
18. Compact chest freezers.	10.45AV + 152.0 0.37av + 152.0
5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with TTD ice service.	5.0AV + 539.0 0.18av + 539.0
10A. Chest freezers with automatic defrost.	14.76AV + 211.5 0.52av + 211.5

AV= adjusted volume in cubic feet; av = adjusted volume in liters;
Refrigerator-Freezers: AV = fresh food internal volume + 1.63 * freezer internal volume
Freezers: AV = 1.73 * freezer internal volume
Refrigerators (single-door): AV = fresh food internal volume + 1.44 * freezer internal volume
All-Refrigerators: AV = internal volume

5.4.2 Baseline Efficiency Definitions Based on the Expected Test Procedure

As discussed in chapter 3, DOE expects to propose revisions in the energy test procedure to harmonize with expected test temperatures under consideration for IEC test procedure 62552 and to simplify calculation of refrigerated volumes. The expected test temperature changes are summarized in Table 5.4.2 below.

Table 5.4.2 Expected Cabinet Temperature Changes for the DOE Test Procedure

Equipment Type	Fresh Food Compartment Temperature °F		Freezer Compartment Temperature °F	
	Current	Expected	Current	Expected
Refrigerator-Freezer	45	39	5	0
All-Refrigerator	38	39	Not Applicable	
Refrigerator w/ Freezer Compartment	45	39	15	15 (No Change)
Freezer	Not Applicable		0	0 (No Change)

The temperature changes also impact the volume adjustment factor used to determine the adjusted volume. This factor is multiplied by the freezer compartment volume in the adjusted volume calculation. Current and expected volume adjustment factors are summarized in Table 5.4.3 below.

Table 5.4.3 Volume Adjustment Factors

Product	Current Test Procedure	Expected Test Procedure Revisions
Refrigerator-Freezer	1.63	1.76
Basic Refrigerator*	1.44	1.47
Freezer	1.73	1.76
All-Refrigerator**	1.00	1.00

*A basic refrigerator is a single-door refrigerator with a freezer compartment with volume greater than 0.5 ft^3.
**An all-refrigerator can have a freezer compartment with volume less than 0.5 ft^3.

The key changes in the volume measurement calculation between the current test procedure and the expected revised test procedure are summarized in Table 5.4.4 below. Adjusted volume will be impacted both by the change in the volume adjustment factor and the change in the volume measurement.

Table 5.4.4 Compartment Volume Calculation Changes

Item	AHAM HRF-1-1979	AHAM HRF-1-2008	Expected Effect on Volume
Automatic Ice Maker Storage Bin	Included (4.2.1.1a)	Would be included under "removable containers" but dispenser MAY NOT be included	None*
Ice Makers	Included (4.2.1.1a)	No Mention	None*
Water Coolers	Included (4.2.1.1a)	No Mention	None*
Door Shelf Fronts and Bottoms	Included (4.2.1.1b)	Shelves molded into the inner door panel NOT included (4.2.2)	Decrease
Volume between the Deductible Door Dikes and Cabinet Breaker Strips or Adjacent Liner Wall	Not Included (4.2.1.2d)	No mention of exclusion, so probably included.	Increase
Shelf Hangers & Shelf and Pan Rails	Not included for fixed projections if collective volume is >0.05 ft^3 (4.2.1.2e)	Could be interpreted as part of shelving and would thus be included.	Increase

*Although AHAM HRF-1-2008 either doesn't mention this item or is not fully clear regarding its treatment for the volume calculation, it is expected that manufacturers would use the AHAM HRF-1-1979 approach.

5.4.2.1 Data Illustrating the Impact of Test Procedure Changes

The different compartment temperatures of the expected revised energy test procedure will change test energy use for refrigerators and refrigerator-freezers. In addition, both the impact of the modified temperatures on the adjusted volume and the modified volume calculation method will change adjusted volumes. For these reasons, it is necessary to establish modified relationships between energy use and adjusted volume to define baseline products. AHAM provided data for a number of the product classes, presented in Table 5.4.5 through Table 5.4.7 below (this is referred to as the AHAM TP Change data).

The AHAM TP Change data for product classes 11 and 13 both show energy use reductions, indicating that the products represented by these data are primarily all-refrigerators. AHAM was not able to separately provide data for the all-refrigerators of these product classes, because insufficient data was provided by manufacturers for aggregation.

Additional data sources which provide indication of the impacts of the test temperature changes for standard-size refrigerator-freezers include (1) energy test measurements for the refrigerator-freezers tested as part of this rulemaking, and (2) calculation of the energy impacts using ERA, the energy modeling tool used for this rulemaking. The energy use impacts indicated by these sources are shown in Table 5.4.8. DOE conducted these energy tests and calculations for three products of each of the seven analyzed product classes (see Section 5.5.3.1 for discussion on selection of products for reverse engineering and energy testing).

Table 5.4.5 Compartment Temperature and Adjusted Volume Change Data provided by AHAM—Current Test

Product Class		Fresh Food Volume	Freezer Volume	Adjusted Volume	Energy Use
3 (R-F)	Average	12.82	5.02	20.92	420
	Standard Deviation	3.54	1.82	6.53	55
	Number of Samples	19	19	19	19
3A (AR)	Average	19.26		19.26	374
	Standard Deviation	3.4		3.4	54
	Number of Samples	11		11	11
5	Average	14.21	5.15	22.62	493
	Standard Deviation	1.85	1.02	3	55
	Number of Samples	18	18	18	18
7	Average	15.77	9.32	30.95	617
	Standard Deviation	1.61	0.87	2.53	68
	Number of Samples	24	24	24	24
9	Average		16.85	29.14	603
	Standard Deviation		4.88	8.45	136
	Number of Samples		18	18	18
11	Average	4.38		4.65	334
	Standard Deviation	1.38		1.38	44
	Number of Samples	13		13	13
13	Average	4.75		4.77	296
	Standard Deviation	1.18		1.15	77
	Number of Samples	12		12	12

Note: **R-F** refers to refrigerator-freezers; **AR** refers to all-refrigerators.

Table 5.4.6 Compartment Temperature and Adjusted Volume Change Data provided by AHAM--Proposed Test

Product Class		Fresh Food Volume	Freezer Volume	Adjusted Volume	Energy Use
3 (R-F)	Average	12.79	4.96	21.44	472
	Standard Deviation	3.51	1.78	6.59	53
	Number of Samples	19	19	19	18
3A (AR)	Average	19.51		19.51	364
	Standard Deviation	3.51		3.51	53
	Number of Samples	11		11	11
5	Average	14.42	5.25	23.12	582
	Standard Deviation	1.88	1	3.01	68
	Number of Samples	18	18	18	18
7	Average	15.95	9.01	31.45	702
	Standard Deviation	1.79	0.75	2.49	82
	Number of Samples	24	24	24	24
9	Average		16.84	29.47	603
	Standard Deviation		5.04	8.73	136
	Number of Samples		18	18	18
11	Average	4.34		4.61	324
	Standard Deviation	1.36		1.36	48
	Number of Samples	13		13	13
13	Average	4.8		4.83	285
	Standard Deviation	1.23		1.2	73
	Number of Samples	12		12	12

Note: **R-F** refers to refrigerator-freezers; **AR** refers to all-refrigerators.

Table 5.4.7 Compartment Temperature and Adjusted Volume Change Data provided by AHAM—Impact

Product Class		Fresh Food Volume	Freezer Volume	Adjusted Volume	Energy Use
3 (R-F)	Average	-0.1%	-1.1%	2.8%	12.4%
	Standard Deviation	0.6%	0.9%	2.3%	6.9%
	Number of Samples	19	19	19	18
3A (AR)	Average	1.2%		1.2%	-2.6%
	Standard Deviation	1.0%		1.0%	1.1%
	Number of Samples	11		11	11
5	Average	1.5%	2.2%	2.2%	18.2%
	Standard Deviation	1.2%	2.2%	1.2%	3.7%
	Number of Samples	18	18	18	18
7	Average	1.0%	-3.1%	1.6%	14.0%
	Standard Deviation	2.0%	4.6%	2.0%	6.7%
	Number of Samples	24	24	24	24
9	Average		-0.4%	0.9%	0.0%
	Standard Deviation		2.5%	2.2%	0.0%
	Number of Samples		18	18	18
11	Average	-0.7%		-0.6%	-3.1%
	Standard Deviation	1.9%		1.6%	1.4%
	Number of Samples	13		13	13
13	Average	0.9%		1.0%	-3.6%
	Standard Deviation	1.6%		1.4%	0.8%
	Number of Samples	12		12	12

Note: **R-F** refers to refrigerator-freezers; **AR** refers to all-refrigerators.

Table 5.4.8 Energy Use Impact of Compartment Temperature Changes: Data Developed by DOE

Product Class	Product Description	Impact based on energy measurements	Impact based on ERA modeling
3	16 ft^3 Top-Mount R-F	19.1%	14.2%
	21 ft^3 Top-Mount R-F	27.7%	16.0%
	21 ft^3 E* Top-Mount R-F	26.6%	14.1%
5	18.5 ft^3 E* Bottom-Mount R-F	12.5%	22.1%
	25 ft^3 E* Bottom-Mount R-F 1	27.6%	13.8%
	25 ft^3 E* Bottom-Mount R-F 2	17.3%	14.4%
4	22 ft^3 Side-Mount R-F†	17.7%	12.5%
7	26 ft^3 Side-Mount R-F	24.5%	12.4%
	26 ft^3 E* Side-Mount R-F	25.0%	12.2%
11	1.7 ft^3 Compact Refrigerator	-4.5%	-2.4%
	4.0 ft^3 Compact Refrigerator	Not Tested	13.4%

†This product was thought to be product class 7 when purchased.

The AHAM TP Change data shows reasonable agreement with the DOE modeled energy use impacts. However, the DOE energy measurements indicate a higher sensitivity to the temperature change of the new test procedure. The AHAM data shows that there can be significant variation in the sensitivity of different refrigerator-freezer products to the test temperature changes, particularly for product classes 3 and 7. The two compact refrigerators of Table 5.4.8 exhibit different responses to the compartment temperature change because the 1.7 ft^3 refrigerator has a freezer compartment smaller than 0.5 ft^3 and is tested as an all-refrigerator, while the 4.0 ft^3 refrigerator has a freezer compartment just larger than 0.5 ft^3, requiring that it be tested as a basic refrigerator.

5.4.2.2 Establishment of Baseline Energy—Adjusted Volume Relationships Based on the New Test Procedure

The available data to inform the establishment of baseline energy versus adjusted volume relationships based on the expected revised test procedure is discussed in Section 5.4.2.1. While this data does not address every product class, DOE proposes to use it as the basis for establishing the baseline relationships. The approach DOE used to develop these relationships for all the product classes is summarized in Table 5.4.9 below. Note that product classes 1, 3, 11, and 13 are split because, while the all-refrigerators have reduced energy use with the new test procedure, the products which include freezers have significantly higher energy use. This applies to product class 11, since many of these units have freezer compartments smaller than 0.5 ft^3, which allows them to be classified and tested as all-refrigerators rather than basic refrigerators. The test procedure impact of this classification is that the refrigerator compartment temperature will be raised for all-refrigerators, while it will be reduced for basic refrigerators under the proposed test procedure.

Table 5.4.9 Approach for Establishing Baseline Energy--Adjusted Volume Relationships

Product Class	Approach
1	Use modeling with ERA for temperature, assume negligible adjusted volume impact based on AHAM data for PC11.
1A (All-Refrigerators)	Use AHAM TP Change aggregated data of product class 3 all-refrigerators.
2	Trend consistent with PC1.
3 (Refrigerator-Freezers)	Use AHAM TP Change aggregated data.
3A (All-Refrigerators)	Use AHAM TP Change aggregated data.
4	Use AHAM TP Change aggregated data of product class 7.
5	Use AHAM TP Change aggregated data.
5A	Use AHAM TP Change aggregated data of product class 5.
6	Use AHAM TP Change aggregated data of product class 3 refrigerator-freezers.
7	Use AHAM TP Change aggregated data.
8 (volume only)	Assume negligible volume impact due to simplicity of manual defrost freezer interior.
9 (volume only)	Use AHAM TP Change aggregated data.
10 (volume only)	Assume negligible impact due to simplicity of manual defrost freezer interior.
10A (volume only)	Use AHAM TP Change aggregated data for PC9.
11	Use modeling with ERA for temperature, assume negligible adjusted volume impact based on AHAM data.*
11A (All-Refrigerators)	Use modeling with ERA for temperature, assume negligible adjusted volume impact based on AHAM data.*
12	Trend consistent with PC11.
13 (Refrigerator-Freezers)	Use AHAM TP Change aggregated data of product class 3 refrigerator-freezers.*
13A (All-Refrigerators)	Use AHAM TP Change aggregated data of product class 3 all-refrigerators.*
14	Use AHAM TP Change aggregated data of product class 7.
15	Use AHAM TP Change aggregated data of product class 5.
16 (volume only)	Assume negligible volume impact due to simplicity of manual defrost freezer interior.
17 (volume only)	Use AHAM TP Change aggregated data for PC9.
18 (volume only)	Assume negligible volume impact due to simplicity of manual defrost freezer interior.

*The AHAM energy use increase data cannot be used for this product class, because it is not known how many of these products are all-refrigerators.

Note: For product classes 8, 10, 16, and 18, while the volume impact is assumed to be negligible, the adjusted volume increases according to the increase in the volume adjustment factor.

The methodology for determining new baseline energy—adjusted volume curves given the data indicating the impacts on the energy use and adjusted volume for a given product class is as follows. The proposed energy use and the current energy use for a product are represented as being proportional using an Energy Standard Adjustment Factor (ESAF).

$$BEC_{NEWTP} = ESAF \times BEC_{CURTP}$$ **Equation 5.4.1**

Where:
BEC_{NEWTP} = Baseline energy consumption using the new test procedure;
BEC_{CURTP} = Baseline energy consumption using the current test procedure.

The ESAF is considered to be a function only of product class. Dependence on adjusted volume or efficiency level cannot be determined based on the available data.

Similarly, the adjusted volume for a product under the proposed test procedure is related to the adjusted volume under the current test procedure using a Volume Calculation Adjustment Factor (VCAF).

$$AV_{NEWTP} = VCAF \times AV_{CURTP}$$ **Equation 5.4.2**

Where:
AV_{NEWTP} = Adjusted Volume using the new test procedure;
AV_{CURTP} = Adjusted Volume using the current test procedure.

The VCAF, like the ESAF, is considered to be a function only of product class. Baseline energy use for the current test procedure is expressed as follows, where the constants A and B are a function of product class.

$$BEC_{CURTP} = A \times AV_{CURTP} + B$$ **Equation 5.4.3**

Combining Equations 5.4.1 through 5.4.3 gives the following relationship for the baseline energy consumption based on the new test procedure.

$$BEC_{NEWTP} = ESAF \times \left(A \times \frac{AV_{NEWTP}}{VCAF} + B \right) = \left(\frac{ESAF}{VCAF} \times A \right) \times AV_{NEWTP} + (ESAF \times B)$$

Hence, the baseline energy consumption for the product class for the new test procedure can be represented as a straight-line relationship based on new constants A_{NEW} and B_{NEW}, where the new constants are related to the current constants as follows.

$$A_{NEW} = \left(\frac{ESAF}{VCAF} \right) \times A; \quad B_{NEW} = ESAF \times B$$

The baseline energy use based on the expected revised test procedure is presented in Table 5.4.10 below for each of the product classes.

Table 5.4.10 New Baseline Energy Consumption based on Proposed Test Procedure

Product Class	ESAF	VCAF	Current Baseline Energy Use (kWh/year)	Expected Test Procedure Baseline Energy Use (kWh/year)
1	1.132	1	8.82 AV + 248.4	9.98 AV + 281.2
1A	0.974	1.012	8.82 AV + 248.4	8.49 AV + 241.9
2	1.132	1	8.82 AV + 248.4	9.98 AV + 281.2
3	1.124	1.028	9.8 AV + 276	10.72 AV + 310.2
3A	0.974	1.012	9.8 AV + 276	9.43 AV + 268.8
4	1.14	1.016	4.91 AV + 507.5	5.51 AV + 578.6
5	1.182	1.022	4.6 AV + 459	5.32 AV + 542.5
5A	1.182	1.022	5 AV + 539	5.78 AV + 637.1
6	1.124	1.028	10.2 AV + 356	11.15 AV + 400.1
7	1.14	1.016	10.1 AV + 406	11.33 AV + 462.8
8	1	1.017	7.55 AV + 258.3	7.42 AV + 258.3
9	1	1.009	12.43 AV + 326.1	12.32 AV + 326.1
10	1	1.017	9.88 AV + 143.7	9.71 AV + 143.7
10A	1	1.009	14.76 AV + 211.5	14.63 AV + 211.5
11	1.125	1	10.7 AV + 299	12.04 AV + 336.4
11A	0.977	1	10.7 AV + 299	10.45 AV + 292.1
12	1.125	1	7 AV + 398	7.88 AV + 447.8
13	1.124	1.028	12.7 AV + 355	13.89 AV + 399.0
13A	0.974	1.012	12.7 AV + 355	12.22 AV + 345.8
14	1.14	1.016	7.6 AV + 501	8.53 AV + 571.1
15	1.182	1.022	13.1 AV + 367	15.15 AV + 433.8
16	1	1.017	9.78 AV + 250.8	9.61 AV + 250.8
17	1	1.009	11.4 AV + 391	11.3 AV + 391
18	1	1.017	10.45 AV + 152	10.27 AV + 152

Note: In the "Current Baseline" equations, AV is calculated using the current volume calculation method and adjustment factor, while in the "Proposed" equations, AV is calculated using the proposed volume calculation method and adjustment factor (see Table 5.4.3)

5.4.2.3 Investigation of the Slope of the Energy Use Curve

DOE carried out analysis to confirm whether the slopes of the baseline energy use—adjusted volume curves for the product classes analyzed in depth as part of the engineering analysis are representative of the energy use of typical products. DOE conducted these analyses based on the expected revised test procedure. The analysis started with an energy model of a minimally-compliant product and examined the trend in calculated energy use as the product size changes with constant insulation thickness. For the analysis of compact refrigerators, DOE considered the change in efficiency of typically available compressors sized appropriately for the product. For standard-size products the DOE used a constant compressor efficiency in the analysis, based on observation that compressor efficiency does not vary significantly in the capacity range suitable for most standard-size products (this is discussed in greater detail in section 5.8.3). The energy—adjusted volume slopes calculated in this analysis are presented in Table 5.4.11 below. The table also shows the slopes of the proposed baseline energy use—adjusted volume relationships of Table 5.4.10 above. The comparison provides an indication of whether adjustment might be required to the proposed baseline energy use relationships, which are based on the current energy conservation standards and the expected impacts of the expected revised test procedure. The comparison shows that consideration may need to be given to whether the slope for the baseline energy use relationships should be adjusted for product classes 5, 11, 11A, and 18. By extension, similar consideration should be given to the slopes for product classes 4 and 5A, which were not directly examined, but the trends for which should be predicted by the analyses for product classes 7 and 5, respectively. The question of whether adjustments should be made to the baseline energy use relationships of Table 5.4.10 is a topic on which DOE requests comment from stakeholders.

Table 5.4.11 DOE Assessment of the Slope of the Energy Use Curve

Product Class	Calculated Energy Curve Slope from ERA Models*	Slope from Proposed Baseline Energy Use Equation (Table 5.4.10)
3	13.3	10.7
5	12.3	5.3
7	11.9	11.3
9	9.4	12.3
10	7.7	9.7
11	16.4	12.0
11A	20 to 35**	10.5
18	4.5	10.3

* Analysis was conducted for both the small and large units analyzed for product classes 3, 5, 7, 9, 10, 18. Values shown are averages of slopes for the two ERA models.
** The energy use—adjusted volume relationship is nonlinear, with higher slope at lower volumes. The slopes indicated are applicable for a range of adjusted volumes from 1.7 to 3.6 ft^3.

5.4.3 Incremental Efficiency Levels

DOE established a series of incremental efficiency levels, for which it has developed incremental cost data and quantified the cost-efficiency relationship for each of the seven analyzed product classes. The incremental efficiency levels are shown in Table 5.4.12 below. Maximum available efficiency levels for the analyzed product classes, which are based on a survey of product databases and manufacturer websites, are tabulated in Table 5.4.13 below. Maximum technology levels, which are based on DOE energy modeling using all applicable design options, are discussed in Section 5.4.4.

Table 5.4.12 Incremental Efficiency Levels (% Energy Use Less than Baseline)

Level	Standard-Size Refrigerator-Freezers (PC 3, 5, 7)	Standard-Size Freezers (PC 9, 10)	Compact Refrigerators and Freezers (PC 11, 18)
1	10%	10% (Current ENERGY STAR)	10%
2	15% (Former ENERGY STAR)	15%	15%
3	20% (Current ENERGY STAR *)	20%	20% (Current ENERGY STAR *)
4	25% (CEE Tier 2)	25%	25% (CEE Tier 2)
5	30% (CEE Tier 3)	30%	30% (CEE Tier 3)
6	35%	35%	35%
7	40%	40%	40%
8	45%**	45%	45%

*Current ENERGY STAR is equivalent to CEE Tier 1 for standard-size refrigerators and refrigerator-freezers and for all compact products.
**The 45% efficiency level was not analyzed for product class 7 because it is beyond maximum technology according to DOE analysis.

Table 5.4.13 Maximum Available Levels (%Energy Use Less than Baseline)

PC	Maximum Available Level**		
	%	Volume (ft^3)	Brand & Model #
3	22%	18	Frigidaire FRT18HS7J
5	26%	19	Sub-Zero BI30US8
7	30%	26	Whirlpool GS5VHA
9	43%	8	Gaggenau RF411700
10	16%	9	W.C.Wood C09
11	26%	6	MicroFridge 5.6MFR
18	21%	5	Haier ESCM050

** Source: ENERGY STAR Database (4/7/2009), CEE Database (3/16/2009), CEC Database (4/1/2009), Manufacturer websites

5.4.4 Maximum Technology Level

DOE defines a maximum technology level to represent the theoretical maximum possible efficiency if all available design options are incorporated. The maximum technology level is not to be confused with the maximum available level, which is the highest efficiency unit currently available on the market. In many cases the maximum technology level is not commercially available because it is not yet economically feasible. Figure 5.4.1 below shows the maximum available efficiency levels, based on the ENERGY STAR database of 4/9/09, with adjustments including deleting products which are no longer for sale based on the CEC database and manufacturers' and retailers' websites. For this chart, the all-refrigerator products of product classes 1, 3, 11, and 13 were not included—some of these have higher efficiency levels than those shown in the chart. The maximum available efficiency product varies significantly among the product classes, from 1% for product class 13 to 51% for product class 2.

As mentioned, the maximum technology level may not represent available products because they may not be economically feasible. DOE determined maximum technology levels using energy modeling. The energy models for the maximum technology levels were based on use of all design options applicable for the specific product classes. While these product configurations have not likely been tested as prototypes, all of the individual design options have been incorporated in available products. The maximum technology efficiency levels for the analyzed product classes are presented in Table 5.4.14 below. These efficiency levels are significantly higher than the maximum available products. The costs of the maximum technology efficiency level designs are also quite high, being based on extensive use of high-cost design options such as vacuum insulating panels as well as all applicable lower-cost design options. Table 5.4.14 indicates which design options were used for each of the product classes.

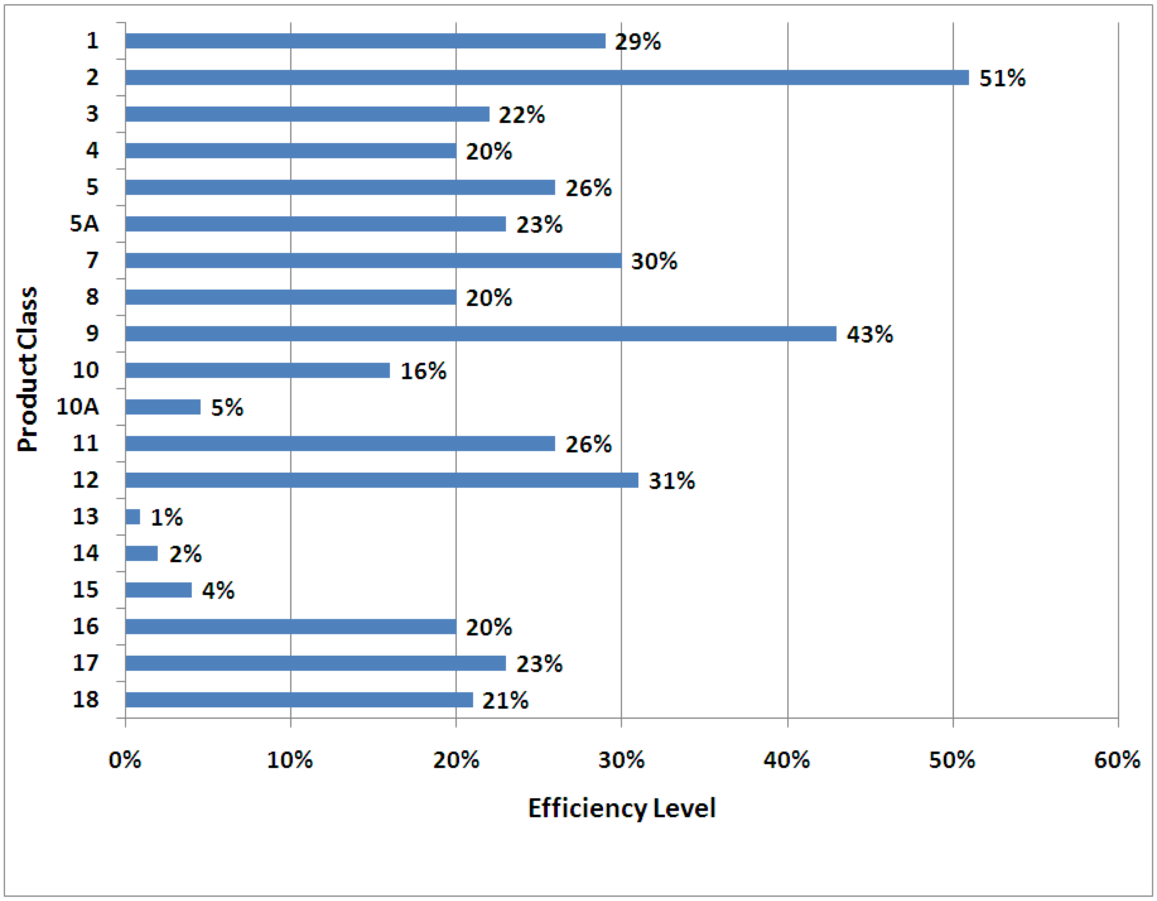

Figure 5.4.1 Maximum Efficiency Levels Available by Product Class

Table 5.4.14 Maximum Technology Levels

Product Class	% Lower Energy	Design Options Used									
		Brushless DC Evaporator Fan	Brushless DC Condenser Fan	Forced Convection Condenser	Larger Evaporator	Larger Condenser	Thicker Insulation	VIPs	Variable Speed Compressor	Adaptive Defrost	Variable Anti-Sweat
3	56%	✓	✓		✓	✓		✓	✓	✓	
5	53%	✓	✓		✓	✓		✓	✓	✓	✓
7	45%	✓	✓		✓	✓		✓	✓	✓	
9	55%	✓	✓	✓	✓		✓	✓	✓	✓	
10	51%				✓	✓	✓	✓	✓		
11	75%				✓	✓	✓	✓	✓		
18	52%						✓	✓	✓		

Note: Levels indicated are the average determined for the two products of each product class analyzed in detail.

5.5 DATA COLLECTION

DOE collected data from a number of sources to support the engineering analysis. The key sources include the following.

- AHAM
- Component Vendors
- Reverse-Engineering of Products
- Manufacturer Interviews
- Energy Tests

The data collection process is described in greater detail in the following sections.

5.5.1 Manufacturer-Submitted Shipment and Cost Data from AHAM

DOE included draft data requests sheets to support the engineering and other DOE analyses in the framework document as Tables A1 through A10 of that document. Some of these tables were revised based on comments received during the framework comment period. For example, incremental cost data was provided for up to 35% efficiency level, and included a 10% efficiency level, which replaced the 15% efficiency level of the draft tables. Other requests DOE made to AHAM in addition to the requests made in the framework document include the following.

- Historical shipment data for Wine Coolers, broken out by key types: manual defrost/auto defrost.
- Historical shipment data for Built-in Refrigerators, disaggregated by product class.
- Recent shipment data for products incorporating a wine cooler compartment with either (1) a fresh food compartment, (2) a freezer compartment, or (3) both a fresh food and a freezer compartment.
- Recent shipment data for French Door refrigerators broken out between products with and without TTD ice service.
- Recent shipment data for convertible-bottom-drawer refrigerators (products with three doors configured as a side-by-side arrangement on top with a single drawer below, and for which the upper compartments are freezer and fresh food compartments and the drawer is convertible).
- Percent of refrigerator-freezers shipped with ice makers for applicable product classes (3, 4, 5, 13, 14, 15), historical data if possible.
- Total shipments of ice makers (any breakdown by (a) installed at factory, (b) installed by dealer, (c) installed by homeowner?), historical data if possible.
- For as many refrigerator, refrigerator-freezer, and freezer models as practical, data on the impact of the proposed changes in compartment temperature and volume calculation method:
    - Compartment Volumes: volumes calculated according to the current procedure and according to the new procedure, with indication of product class.
    - Energy use (for refrigerators and refrigerator-freezers only): Annual energy use measurements for units tested for both temperatures (i.e. not Energy Label data—this should be energy test values calculated based on test data for the old temperatures and the new temperatures for sequential tests of the same unit. This will typically require three tests to make sure that both sets of temperatures are bracketed.
    - It is anticipated that data for product classes 3 and 13 would be separated according to whether the product is a refrigerator-freezer or all-refrigerator.

AHAM supported the rulemaking by supplying much of this data. AHAM supplied DOE with aggregated shipment-weighted average data for many of the submittals in order to avoid divulging data submitted by individual manufacturers. The AHAM incremental cost data included incremental material, labor, and overhead costs as well as conversion capital expenditures and one-time product conversion expenses for each efficiency level. These data are presented in Section 5.9.2, where they can more readily be compared with the results of DOE analysis. Data associated with other AHAM submittals are presented in the relevant chapters and sections most directly related to the data in question.

5.5.2 Component Vendor Data

DOE directly contacted major suppliers of key refrigerator and freezer components to obtain performance and cost data to support its design option analysis. The data received from vendors was compared with information received from manufacturers during the manufacturer interviews in order to develop input values for performance and cost parameters for the energy modeling and manufacturing cost modeling. This vendor solicitation effort consisted of phone interviews, email correspondence, and in-person interviews. Table 5.5.1 lists the vendors contacted.

DOE also obtained from the compressor vendors or their websites complete performance data for compressors used in many of the energy analyses, including analyses for baseline and improved-efficiency configurations.

Table 5.5.1 Component Vendors Contacted by DOE during Engineering Analysis

Component Type	Vendors
Compressors	Embraco Tecumseh Matsushita Danfoss LG Huayi ACC (ZEL) Jiangsu Baixue Electric Appliances Co.,Ltd
Fan Motors	Matsushita
VIPs	va-Q-tec Matsushita
Foam Insulation	BASF Foam Supplies
Heat Exchangers	Brazeway

5.5.3 Reverse Engineering

DOE purchased a number of representative refrigerators and freezers as part of the engineering analysis in order to examine design and fabrication details. This reverse-engineering included detailed measurement of dimensions, system and component-level power measurements, measurement of air flows for products with forced convection heat exchangers, and physical teardowns. The results of the reverse engineering process were used as input to the manufacturing cost modeling and the energy use modeling. This section describes the selection of products for reverse-engineering as well as some of the measurements made to support subsequent modeling. Section 5.6 provides a more thorough description of the physical teardown process used to support manufacturing cost modeling.

5.5.3.1 Selection of Products for Reverse Engineering

DOE performed reverse engineering on units rated at baseline and improved (i.e., ENERGY STAR) energy consumption levels for the seven analyzed product classes. DOE chose at least one representative small-size and one large-size unit to cover the range of volumes within each product class. In order to best examine the design choices associated with efficiency improvements, DOE selected baseline efficiency/ENERGY

STAR product pairs if possible, for which the two products were identical other than the differences necessary for the ENERGY STAR-rated product to achieve higher efficiency. Such product pairs included the 21 ft^3 Top-Mount refrigerator-freezers, the 26 ft^3 Side-Mount refrigerator-freezers, the 20 ft^3 upright freezers, and the 4 ft^3 compact refrigerators. Table 5.5.2 lists descriptions of the selected units and indicates whether energy testing was performed (see Section 5.5.5 for more on energy testing).

Table 5.5.2 Selected Units for Reverse-Engineering and Energy Testing

PC	Product Description	Energy % Less than Baseline	Energy Test	Physical Teardown	Energy Use Model
3	16 ft^3 Top-Mount R-F	0%	✓	✓	✓
	21 ft^3 Top-Mount R-F	0%	✓	✓	✓
	21 ft^3 E* Top-Mount R-F	20%	✓	✓	✓
4	22 ft^3 Side-Mount R-F†	0%	✓	✓	✓
5	18.5 ft^3 E* Bottom-Mount R-F	15%*	✓	✓	✓
	25 ft^3 E* Bottom-Mount R-F 1	20%	✓	✓	
	25 ft^3 E* Bottom-Mount R-F 2	20%	✓	✓	
5A	25 ft^3 French Door E* Bottom-Mount R-F	20%			✓
	26 ft^3 French Door E* Bottom-Mount R-F	20%			
7	26 ft^3 Side-Mount R-F	0%	✓	✓	✓
	26 ft^3 E* Side-Mount R-F	20%	✓	✓	✓
9	14 ft^3 Upright Freezer	0%		✓	✓
	20 ft^3 Upright Freezer	2%	✓	✓	✓
	20 ft^3 E* Upright Freezer 1	12%		✓	✓
	20 ft^3 E* Upright Freezer 2	10%			
10	15 ft^3 Chest Freezer	1%	✓	✓	✓
	15 ft^3 E* Chest Freezer	11%		✓	✓
	20 ft^3 Chest Freezer	0%		✓	✓
11	1.7 ft^3 Compact Refrigerator	7%	✓	✓	✓
	4 ft^3 Compact Refrigerator	2%		✓	✓
	4 ft^3 E* Compact Refrigerator	22%		✓	✓
18	3.4 ft^3 Compact Chest Freezer	0%		✓	✓
	7 ft^3 Compact Chest Freezer 1	1%		✓	✓
	7 ft^3 Compact Chest Freezer 2	1%		✓	✓

*Exact efficiency level is not known because product literature did not include indication of separate compartment volumes.
†This product was thought to be product class 7 when purchased.

5.5.3.2 Collection of Energy Modeling Data

DOE examined each unit prior to teardown to record details to be used as input for the energy modeling. The key measurements are described in this section.

The rated refrigerated volumes for each product's compartments and its rated energy use were based on product literature or the ENERGY GUIDE. In the case of the 3.4 ft^3 chest freezer, the product literature did not provide an indication of energy use, and the product did not arrive with an ENERGY GUIDE. For this product, DOE assumed that energy use was exactly equal to maximum allowable energy use for the product class.

Power input for the product was measured for a period of 24 or more hours. This measurement was not intended to be an energy test, but provided useful information regarding the product controls, including off-cycle wattage, defrost heater on-time, and defrost interval (or indication of variable defrost). The power measurements for the products were made in the reverse engineering test laboratory, whose ambient temperature may have covered a broad range from 65 ˚F to 85 ˚F during the time that these measurements were carried out. Also, careful attention was not paid to the temperature setpoints for this measurement—the setpoints generally were left in the as-shipped positions.

Component-level power measurements were carried out for fans, defrost heaters, and manual defrost controls for the products which had these components. Power was also measured for some products' anti-sweat heaters.

Air flow measurements were made for all forced-convection heat exchangers. These measurements were made with a hot wire anemometer. The location of these measurements varied depending on the heat exchanger type and configuration. The determination of air flows based on these measurements is not very reliable, so this measurement was used as an indication of air flow trends more than exact indication of air flow for the various products.

Details of the cabinet size and insulation thickness were based on direct physical measurements. Most of these measurements were made prior to the teardown, but measurements of some parameters, such as outer shell thickness, inner liner thickness, and insulation thickness, were made during the teardown process. Use of insulation other than polyurethane foam was noted as part of the teardown process. Frame area details including gasket details were observed, and recorded with pictures as part of the teardown process.

Heat exchanger details were recorded, including type, configuration, numbers of tubes and fins, dimensions, etc. For cold wall and hot wall heat exchangers this data was recorded during the product teardown process. The details of anti-sweat heaters were also determined during the teardown process, including the layout for refrigerant anti-sweat loops. The details of suction line heat exchangers were similarly determined during teardown.

Component manufacturer and model data were recorded for key components such as compressors, fans, and controls.

The energy modeling data for the teardown products are presented in detail in appendix 5-A.

5.5.4 Manufacturer Interviews

DOE's contractor discussed engineering issues with manufacturers during the pre-NOPR interviews. The engineering questions were consolidated into an engineering questionnaire, which guided the interview process for all of these discussions. The engineering questionnaire is shown in appendix 5-A. Key technical topics addressed during these discussions include the following:

- Typical characteristics of components and typical design details (i.e. such as insulation thicknesses) used for key product classes.
- Typical design differences between baseline and ENERGY STAR products.
- Differences in design pathways and incremental costs across different product classes
- Viability of technology options, and their typical costs.

All of these interviews were conducted under non-disclosure agreements with the manufacturers. Hence, none of the individual responses can be reported. However, values for many of the parameters and costs used in the engineering analysis were based on aggregated input from these discussions.

5.5.5 Energy testing

DOE conducted energy testing to verify energy use of many of the products obtained for reverse engineering, to provide refrigeration system data to support energy use modeling, and to evaluate the difference in energy use between current energy test compartment temperatures and the new temperatures associated with the expected revised test procedure.

Twelve of the 24 units were tested, as indicated in Table 5.5.2, including all of the refrigerator-freezer models and one each of the upright freezers, chest freezers, and compact refrigerators. No compact chest freezers were tested.

Energy testing was carried out by an independent test lab according to the DOE Energy Test Procedure as described in 10 CFR Part 430 Subpart B, Appendix A1 or B1, with reference to AHAM Standard HRF-1-1979 as applicable. In addition to the standard energy test results, DOE requested specific temperature measurements to be taken in various locations during the test to better understand the refrigeration system operating characteristics. Specifically, low-mass thermocouples were mounted in good thermal contact with the surface of refrigerant tubing, insulated externally from local ambient air. Table 5.5.3 lists the additional measurements.

Table 5.5.3 Additional Thermocouple Locations for Energy Test

Thermocouple Location	Refrigerator-Freezers	Upright Freezer	Chest Freezer	Compact Refrigerator
Discharge 4” from shell	✓	✓	✓	✓
Condenser Inlet	✓			
Condenser Mid	✓			
Condenser Outlet	✓	✓	✓	✓
Evaporator Inlet	✓	✓	✓	
Evaporator Outlet	✓	✓	✓	✓
Suction 4” from shell	✓	✓	✓	✓
Condenser Air Inlet	✓			
Pan Heater In		✓		
Pan Heater Out		✓		
Hot Wall Condenser Surface		✓	✓	✓
Compressor Compartment Air		✓	✓	✓
Cold Wall Evaporator Surface			✓	✓

Two units of the 1.7 ft^3 compact refrigerator were tested because the first of these was not able to hold proper internal temperatures.

5.6 MANUFACTURING COST MODELING

5.6.1 Generation of Bills of Materials

The end result of each teardown is a structured bill of materials (BOM). DOE developed structured BOMs for each of the physical teardowns. Structured BOMs describe each product part and its relationship to the other parts in the estimated order in which manufacturers assembled them. The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed (e.g., presses, drills), the process cycle times, and the labor associated with each manufacturing step. The result is a thorough and explicit model of the production process, which includes space, conveyor, and equipment requirements by planned production level.

The BOMs incorporate all materials, components, and fasteners classified as either raw materials or purchased parts and assemblies. The classifications into raw materials or purchased parts were based on DOE’s previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). DOE also visited manufacturing plants to reinforce its understanding of the industry’s current manufacturing practices for each of the three product categories.

For purchased parts, the purchase price is estimated based on volume-variable price quotations and detailed discussions with manufacturers and component suppliers. For fabricated parts, the prices of "raw" materials (e.g., tube, sheet metal) are estimated on the basis of 5-year averages (see Section 5.6.4.4). The cost of transforming the intermediate materials into finished parts is estimated based on current industry pricing. DOE shared major estimates with manufacturers during the engineering manufacturer interviews to gain feedback on the analysis, its methodology, and preliminary results.

5.6.2 Cost Structure of the Spreadsheet Models

The manufacturing cost assessment methodology used is a detailed, component-focused technique for calculating the manufacturing cost of a product (direct materials, direct labor, and the overhead costs associated with production). The first step in the manufacturing cost assessment was the creation of a complete and structured BOM from the disassembly of the units selected for teardown. The units were dismantled, and each part was characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasters with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interview and plant visits were conducted with manufacturers to add industry experience on the methodology and pricing.

The last step was to convert this information into dollar values. To perform this task, DOE collected information on labor rates, tooling costs, raw material prices, and other factors. DOE assumed values for these parameters using internal expertise and confidential information available to DOE contractors. Although most of the assumptions are manufacturer specific and cannot be revealed, Section 5.6.4.3 provides a discussion of the values used for each assumption.

In summary, DOE assigned costs of labor, materials, and overhead to each part whether purchased or produced in-house. DOE then aggregated single-part costs into major assemblies (e.g., door assembly, heat exchanger assembly, shelving, packaging, controls, bottom components assembly, wiring harnesses, inner/outer wrapper assembly, etc.) and summarized these costs in a worksheet. During engineering interviews with manufacturers, DOE showed key estimates from the cost model and asked for feedback. DOE considered any information manufacturers gave that was relevant to the cost model and incorporated it into the analysis, if appropriate.

5.6.3 Cost Model and Definitions

Once DOE disassembled selected units, gathered information from manufacturer catalogs on additional products, and identified technologies, DOE created an appropriate manufacturing cost model that could translate physical information into manufacturer production costs (MPCs). The cost model is based on production activities and divides factory costs into the following categories:

- Materials: Purchased parts (i.e. compressor, fan motors, control boards, door handles, shelf frames, etc.), raw materials (i.e., cold rolled steel, copper tube, etc.), and indirect materials that are used for processing and fabrication.
- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

5.6.3.1 Cost Definitions

Because there are many different accounting systems and methods to monitor costs, DOE defined the above terms as follows:

- Direct material: Purchased parts (out-sourced) plus manufactured parts (made in-house from raw materials).
- Indirect material: Material used during manufacturing (e.g., welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Indirect labor: Labor costs that scaled with fabrication and assembly labor. This included the cost of technicians, manufacturing engineering support, stocking, etc. that were assigned on a span basis.
- Equipment and plant depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment wears out.
- Tooling depreciation: Cost for initial tooling (including nonrecurring engineering and debugging of the tools) and tooling replacement as it wears out.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.
- Utilities: Electricity, gas, telephones, etc.
- Maintenance: Annual money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function as unit cost.

5.6.4 Cost Model Assumptions Overview

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. Some assumptions were different for specific manufacturers, depending on their market position, manufacturing practices, and size.

In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. DOE used assumptions regarding the manufacturing process parameters (e.g., equipment use, labor rates, tooling depreciation, and cost of purchased raw materials) to determine the value of each component. DOE then summed the values of the components into assembly costs and, finally, the total product cost. The product cost included the material, labor, and overhead costs associated with the manufacturing facility. The material costs included both direct and indirect materials. The labor costs included fabrication, assembly, indirect, direct, and supervisor labor rates, including the associated overhead.

The labor costs included assembly, fabrication, supervisor, and indirect labor. Overhead costs included equipment depreciation, tooling depreciation, building depreciation, utilities, equipment, tooling maintenance, insurance, property, and taxes.

DOE used the information gathered from manufacturer interviews to make updates to the cost model. These changes involved updating component and material pricing.

The next sections discuss specific assumptions about outsourcing, factory parameters, production volumes, and material prices. When the assumptions are manufacturer-specific, they are presented as industry averages to prevent disclosure of confidential information.

5.6.4.1 Fabrication Estimates

DOE characterized parts based on whether manufacturers purchased them from outside suppliers or fabricated them in-house. For purchased parts, DOE estimated the purchase price. For fabricated parts, DOE estimated the price of raw materials (e.g., tube, sheet metal) and the cost of transforming them into finished parts. Whenever possible, DOE obtained price quotes directly from the manufacturers' suppliers.

DOE based the manufacturing operations assumptions on internal expertise, interviews with manufacturers, and manufacturing facilities site visits. The major manufacturer processes identified and developed for the spreadsheet model are listed in Table 5.6.1. Fabrication process cycle times were estimated and entered into the BOM.

Table 5.6.1 Cost Model In-House Manufacturing Operation Assumptions

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing Stamping/Pressing Turret Punch Tube Forming Brake Forming Cutting & Shearing Insulating & Insulation Injection Tube/Wire Bending Brazing Vacuum Forming Blow Molding	Washing Painting Powder Coating De-burring Polishing Refrigerant Charging	Adhesive Bonding Spot Welding Seam Welding Packaging	Inspecting & Testing

5.6.4.2 Production Volumes Assumptions

A manufacturer's production volumes vary depending on several factors, including market share, the type of product produced (i.e., standard- size refrigerator-freezer, compact refrigerator-freezer, etc.), and if the manufacturer produces other similar products. DOE based production volume assumptions for these residential refrigeration products on shipment data, industry knowledge, and engineering manufacturer interviews. The manufacturing plant annual production capacities used for the analyses differ by product class as follows.

- Product Classes 3 and 6: 1.5 million
- Product Classes 5 and 5A: 0.5 million
- Product Classes 4 and 7: 1 million
- Product Class 9: 150,000
- Product Class 10: 100,000
- Product Class 11: 0.5 million
- Product Class 18: 100,000

5.6.4.3 Factory Parameters Assumptions

DOE used information gathered from publicly available literature, manufacturer interviews, and analysis of common industry practices to formulate factory parameters for each type of manufacturer. DOE first made assumptions about a set of preliminary factory parameters before the manufacturer interviews. DOE then revised the assumptions using comments and information gathered during the interviews. Table 5.6.2 lists DOE's assumptions for refrigerator manufacturers.

Table 5.6.2 Refrigerator & Freezer Factory Parameter Assumptions

Parameter	Assumption
Plant Capacity (units/yr)	see section 5.6.4.2
Actual Annual Production Volume (units/yr)	5/6 of plant capacity
Fabrication Labor Wages ($/hr)	16.00
Fringe Benefits Ratio	50%

5.6.4.4 Material Cost Assumptions

DOE determined the cost of raw materials using publicly available information such as the American Metals Market[a], interviews with manufacturers, and direct discussions with material suppliers. Common metals used in the fabrication of residential refrigerator products include plain cold rolled steel (CRS), copper tubing, and aluminum. There have been large fluctuations in metal prices over the last few years. To account for these fluctuations, DOE used a 5-year average of metal prices from the Bureau of Labor

[a] American Metals Market. Last accessed November 2008. <http://www.amm.com>.

Statistics Producer Price Indices (PPIs) spanning 2003 to 2008 with an adjustment to 2008$.[b] DOE used the PPIs for copper rolling, drawing, and extruding and steel mill products, and made the adjustments to 2008$ using the gross domestic product implicit price deflator.[c] Table 5.6.3 shows the 5-year average metal prices DOE used for the analysis.

Table 5.6.3 Five-Year Metal Prices (2003-2008)

Metals	Cost ($/lb) ($2008)
Plain Cold Rolled Steel (CRS)	$0.36
Painted CRS	$0.57
Galvanized CRS	$0.48
Aluminized CRS	$0.54
Textured CRS	$0.61
CRS Tube	$0.74
Stainless Steel	$2.06
Fin Aluminum	$1.64
Plain Copper	$2.13
Copper Tube – Plain	$2.76
Brass	$1.45
Galvanized Wire	$0.60
Standard Aluminum	$1.26
Copper Tube – Rifled	$2.96
Aluminum Tube	$1.89
Hot Rolled Steel	$0.37
Hot Rolled Steel Pipe	$0.47

Between 2003 and 2006, the price of steel rose over 60 percent and the price of copper rose over 140 percent. DOE used a 5-year average in material prices from 2003 to 2008 to normalize these drastic increases to better represent long-term material price averages.

For resins used in the fabrication of these refrigeration products, DOE used current resin prices gathered from industry research, publications such as Plastics News,[d] and interviews with manufacturers. Resin prices are determined by quantity and supplier (i.e., contract specific) and therefore have no true fixed market price. For this analysis, DOE used market resin prices current as of November 2008. The prices of resins have been constantly increasing and closely follow petroleum prices. Table 5.6.4 shows the current resin prices used in the analysis.

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[b] U.S. Department of Labor, Bureau of Labor Statistics, Producer Price Indices. Last accessed November 2008. <http://www.bls.gov/ppi>.
[c] U.S. Department of Commerce, Bureau Economic Analysis, Gross Domestic Product Implicit Price Deflator. Last accessed November 2008. <https://bea.gov/bea/dn/nipaweb/TableView.asp#Mid>.
[d] Plastic News, Resin Pricing. Last accessed March 21, 2008. <http://www.plasticsnews.com/subscriber/headlines.phtml>.

Table 5.6.4 Most Prevalent Resin Prices as of December 2007

Resins	Cost ($/lb) ($2008)
Polystyrene (PS)	$0.66
Polypropylene (PP)	$0.67
Low Density Polyethylene	$0.73
Polyurethane Foam (non-HCFC blowing agent)	$1.29
PVC (Hard)	$0.47

5.6.5 Manufacturing Production Cost

Once the cost estimate for each teardown unit was finalized, a detailed summary was prepared for relevant components, subassemblies, and processes. The BOM thus details all aspects of product costs. DOE totaled the cost of materials, labor, and direct overhead used to manufacture a product in order to calculate the manufacturing production cost.[e] Figure 5.6.1 shows the general breakdown of costs associated with manufacturing a product.

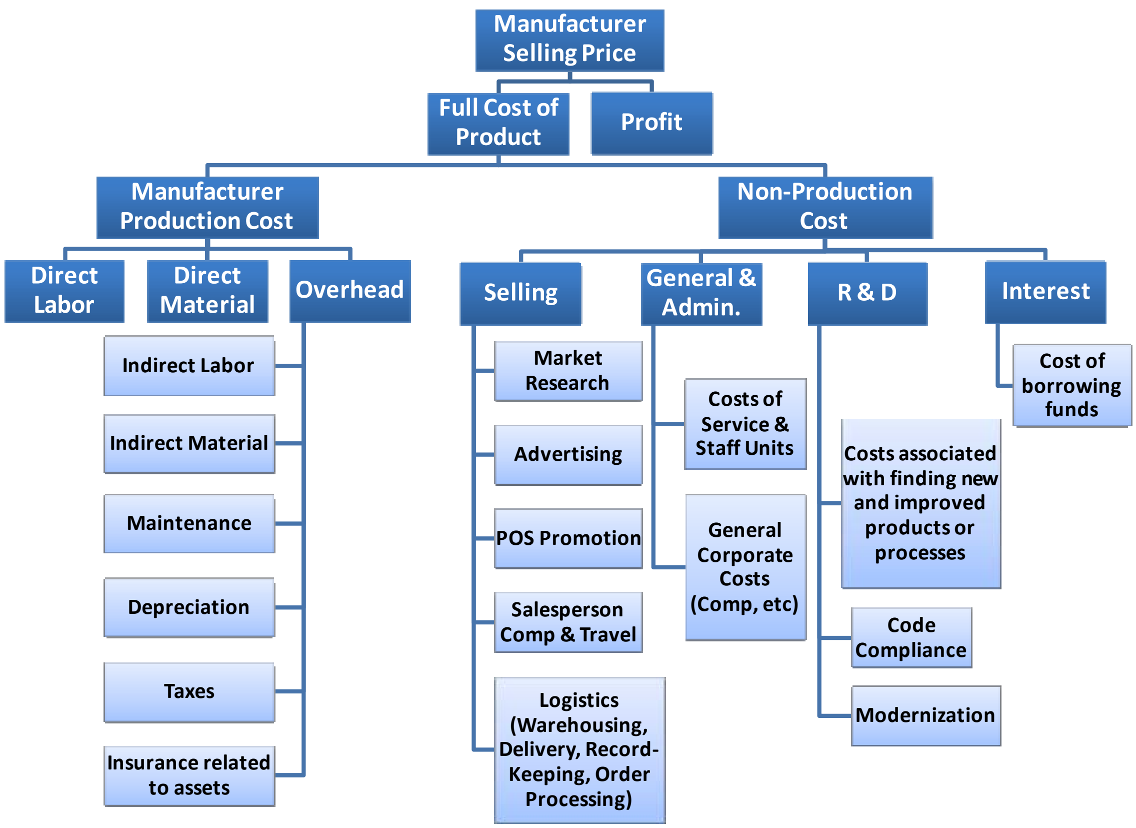

Figure 5.6.1 Full Production Costs

[e] When viewed from the companywide perspective, the sum of all material, labor, and overhead costs equals the company's sales cost, also referred to as the cost of goods sold (COGS).

The full cost of product is broken down into two main costs, the full production cost or MPC, and the non-production cost. The non-production cost is equal to the manufacturer markup minus profits.

Technologies used in the units subject to teardown are noted in the summary sheet of each cost model and are cost-estimated individually. Thus, various implementations of technologies can be accommodated, ranging from assemblies that are entirely purchased to units that are entirely from raw materials. Hybrid assemblies, consisting of purchased parts and parts made on site are thus also accommodated.

5.6.6 Incremental Cost Estimates

Incremental costs were determined for design options applied to the baseline-efficiency refrigerator models. The approach for estimating the incremental costs varied depending on the design option. Details in this calculation which are specific to individual design options are discussed in Section 5.8, which discusses design options. Aspects of the incremental cost calculation which were generally applied to multiple design options are discussed in this section.

Many of the design options involve replacement of a current component with a higher-efficiency component. For these design options, the increased price paid by the OEM for the new component represents the manufacturing cost increase—other elements of product cost such as overhead and capital expenditures would be insignificantly affected by these design changes. The appropriate price increases are discussed in Section 5.8 by design option.

For some design changes, calculating the cost impact of the design change required direct use of the manufacturing cost model to determine changes to a number of parts. The baseline manufacturing cost was subtracted from the manufacturing cost of the modified design to determine the incremental cost of the design option. This approach was used in particular for insulation thickness increases and heat exchanger size increases for cold wall and hot wall heat exchangers.

5.6.6.1 Overhead and Depreciation Costs

Some design options involve costs in addition to the price increase associated with a new component. For such options, there may be overhead and capital expenses which must be added to the direct costs associated with the design option. Estimates of typical additional costs associated with overhead and depreciation for manufacture of refrigeration products were made for the reverse-engineering models, using estimates of these costs provided by the manufacturing cost model. These calculations were carried out based on proposed typical production plant capacities, with actual production volumes estimated to be 5/6 of plant capacities. The annual plant capacities for the product classes used in these calculations are as indicated in section 5.6.4.2.

The additional costs are presented as percentage of direct material and labor costs in Table 5.6.5 below. The averages for the listed product class categories were used to increase direct material and labor costs for some design options for which this adjustment was necessary.

Table 5.6.5 Overhead and Depreciation Cost Ratios

Product Class Group	Product Class	Product	Percent Cost Ratio	Average Percent Cost Ratio for Product Class Group
Standard-Size Refrigerator-Freezers	3	16 ft^3 Top-Mount R-F	31.2%	23.4%
		21 ft^3 Top-Mount R-F	23.2%	
		21 ft^3 E* Top-Mount R-F	23.2%	
	4	22 ft^3 Side-Mount R-F†	22.0%	
	5	19 ft^3 E* Bottom-Mount R-F	23.5%	
		25 ft^3 E* Bottom-Mount R-F 1	20.9%	
		25 ft^3 E* Bottom-Mount R-F 2	23.3%	
	7	26 ft^3 Side-Mount R-F	20.7%	
		26 ft^3 E* Side-Mount R-F	22.5%	
Standard-Size Freezers	9	14 ft^3 Upright Freezer	28.6%	28.5%
		20 ft^3 Upright Freezer	26.2%	
		20 ft^3 E* Upright Freezer 1	25.0%	
	10	15 ft^3 Chest Freezer	35.5%	
		15 ft^3 E* Chest Freezer	33.2%	
		20 ft^3 Chest Freezer	22.5%	
Compact Refrigerators, Refrigerator-Freezers, and Freezers	11	1.7 ft^3 Compact Refrigerator	40.2%	39.2%
		4 ft^3 Compact Refrigerator	35.6%	
		4 ft^3 E* Compact Refrigerator	36.5%	
	18	3.4 ft^3 Compact Chest Freezer	42.3%	
		7 ft^3 Compact Chest Freezer 1	36.6%	
		7 ft^3 Compact Chest Freezer 2	44.2%	

The manufacturing cost model estimates are consistent with overall industry trends. Census data shows that the average value of this cost adder for NAICS code 335222 (Household Refrigerator and Home Freezer Manufacturing) is 27.7%.

5.6.6.2 Depreciation Costs for Insulation Thickness Increases

DOE considered that increases in cabinet wall and door thicknesses would require redesign of the entire refrigerator or freezer platform and lead to building of a new production plant. This conservative approach to the analysis was based on input from manufacturers. For such design changes, the difference in greenfield costs[f] of two designs would not capture the depreciation costs which would be incurred by the manufacturer and which would add to the product cost after such a platform conversion. DOE conservatively used the greenfield depreciation costs per product determined by the

[f] Greenfield costs are defined as the costs associated with building a new manufacturing facility, to be distinguished from the costs required to upgrade or modify a facility.

manufacturing cost model as an additional cost for wall thickness increases. The calculation of manufacturing costs for all of the teardown products based on typical plant capacities described above was used as the basis for the determination of greenfield depreciation costs per product. The results of the calculations are summarized in Table 5.6.6 below. Average depreciation costs were applied in the engineering analyses for product class groups with similar levels of depreciation costs, as indicated in the table.

Table 5.6.6 Greenfield Depreciation Costs per Product

Product Class Group	Product Class	Product	Depreciation Cost	Average Depreciation Cost for Product Class Group
Standard-Size Refrigerator-Freezers	3	16 ft^3 Top-Mount R-F	$29.60	$27.05
		21 ft^3 Top-Mount R-F	$23.55	
		21 ft^3 E* Top-Mount R-F	$23.97	
	4	22 ft^3 Side-Mount R-F†	$28.95	
	5	19 ft^3 E* Bottom-Mount R-F	$27.49	
		25 ft^3 E* Bottom-Mount R-F 1	$27.95	
		25 ft^3 E* Bottom-Mount R-F 2	$39.57	
	7	26 ft^3 Side-Mount R-F	$26.74	
		26 ft^3 E* Side-Mount R-F	$28.14	
Freezers	9	14 ft^3 Upright Freezer	$19.08	$18.26
		20 ft^3 Upright Freezer	$18.21	
		20 ft^3 E* Upright Freezer 1	$18.41	
	10	15 ft^3 Chest Freezer	$18.54	
		15 ft^3 E* Chest Freezer	$19.59	
		20 ft^3 Chest Freezer	$17.31	
	18	3.4 ft^3 Compact Chest Freezer	$21.00	
		7 ft^3 Compact Chest Freezer 1	$16.91	
		7 ft^3 Compact Chest Freezer 2	$15.32	
Compact Refrigerators	11	1.7 ft^3 Compact Refrigerator	$8.35	$8.98
		4 ft^3 Compact Refrigerator	$9.29	
		4 ft^3 E* Compact Refrigerator	$9.29	

5.6.6.3 G&A and Profit

DOE estimated the further addition to the manufacturer selling price associated with G&A and profit for the appliance industry as 26% of manufacturer production cost. This adder was applied to all of the MPC estimates in order to determine manufacturer selling price (MSP) numbers. This markup is described in more detail in chapter 6.

5.7 ENERGY MODELING

DOE carried out detailed energy modeling of representative baseline and ENERGY STAR refrigeration products as one indication of the incremental costs required to achieve higher efficiency levels. The products selected for reverse engineering provided the basis for the energy modeling. Energy model input was determined for these products from the data collected during the reverse engineering work, described in Section 5.5.3. Additional data used both as input and for calibration of individual product energy models was provided by energy testing as described in Section 5.5.5. Energy modeling was also conducted for modified designs using groups of design options to improve efficiency to determine the expected energy savings associated with the design options. Using the energy modeling results and manufacturing cost modeling results for these designs allowed DOE to develop incremental cost estimates for multiple efficiency levels based on each of the baseline products analyzed.

DOE carried out energy modeling during this rulemaking using an improved version of the EPA Refrigerator Analysis (ERA) program, earlier versions of which have been used in previous refrigerator rulemakings. Section 5.7.1 describes the ERA model development briefly. A more detailed description of the program and its recent development is presented in appendix 5-B.

5.7.1 Energy Model development

ERA is a steady-state energy model that calculates heat leakage into a cabinet and determines the energy needed by the refrigeration system to maintain the interior temperatures as specified by the user. Total energy used includes the energy from the compressor, fan motors, defrost heater, electronic control, and anti-sweat heaters, if applicable. See appendix 5-B for a detailed explanation of the ERA model.

The DOS version of ERA was developed initially under EPA-sponsorship during the late 1980s. This was undertaken by the EPA as part of its involvement in the establishment of energy standards for refrigerators, refrigerator-freezers, and freezers under the National Appliance Energy Conservation Act of 1987 (NAECA). A developmental version of the program was used by the DOE as a partial basis for the energy standard established in 1989 (effective in 1993). The work also involved extensive testing of the model against manufacturer-supplied refrigeration appliance design and test data. Based on these comparisons and manufacturer review comments through its industry organization (AHAM), development of the model continued until its release in 1997.[1]

ERA combined an analysis of the refrigeration load requirements of the cabinet with a simulation of the capacity and efficiency of the refrigeration cycle. The cabinet loads module was a modest enhancement of a program developed for the DOE during the late 1970s,[2] including the consideration of door-opening effects on the load and an ability to deal with complex insulation systems. The cycle module was a derivative of the NIST CYCLE 7 program,[3] which used the CSD equation of state to represent the thermodynamic properties of pure and mixed refrigerants,[4] adapting routines for calculating refrigerant properties from REFPROP3.[5] The program, and its User's Manual, were first released to the public in 1993, and for a few years were downloadable from the EPA website.[6] Subsequent to the 1993 final rule, DOE published updated standards for refrigerators, refrigerator-freezers and freezers in 1997, becoming effective in 2001. Analysis carried out in support of the 1997 final rule involved use of the final released EPA version of ERA.[1]

The DOS version of ERA was subsequently modified as described in appendix 5-B, but these revisions were not made available to the public. During the course of this rulemaking, further development of the model was carried out in order to allow use of the model for calculation of energy use of modern residential refrigeration products and to allow a modern version of the program to be made available to stakeholders to validate DOE analysis. Key modifications made include the following.

- Enhancement of the user-interface to a Windows environment
- Employment of the most current refrigerant property routines
- Incorporation of a broad range of evaporator and condenser algorithms that correspond to the technologies now found in modern refrigerators
- Improved compressor modeling, with built-in procedures for validating supplied compressor maps
- Improvements where desirable in the cabinet loads analysis and cycle performance algorithms.
- Preparation of internal documentation of the program through extensive context-sensitive Help files.

Many of the energy model calculations described in this chapter were made using a DOS version of the ERA program prior to the completion of the Windows version.

The development history and capabilities of the program are described in more detail in appendix 5-B.

5.7.2 Supplemental Spreadsheet Models

Spreadsheet analysis tools were developed and used as part of some of the energy model development and calculations in order to (1) calculate airside heat transfer performance of spine fin evaporators, (2) determine appropriate composite insulated wall thermal resistivity when calculating cabinet thermal performance using vacuum panel insulation, and (3) adjusting ERA energy model output results for some product configurations for which ERA did not allow input of separate thermal resistivity for separate walls.

Spine fin evaporator airside heat transfer performance was calculated using a spreadsheet. Equations for the model were based on the work of Holtzapple and Carranza.[7,8] The ERA heat exchanger models (the ERAEVAP program) provided heat transfer coefficients for refrigerant-side heat transfer in the two-phase and superheated regimes. Using these values, the spreadsheet model provided the overall heat transfer coefficients for the two regimes of the evaporator and the effective heat transfer area, which were the inputs for DOS version of ERA.

When modeling use of vacuum insulation panels (VIPs), the cabinet walls or door have two regions of differing thermal resistivity. Average values of resistitivity were calculated and entered into ERA to model these composite insulation systems.

The ERA model structure did not allow separate specification of insulated wall resistivity for the compressor compartment—the program uses the bottom surface resistivity for this region of the cabinet. In some cases, separate spreadsheet calculations were conducted to adjust energy model results to account for the different resistivity that may be used in this region. For this calculation, used when application of VIP to the bottom surface was considered, the compressor compartment thermal load was increased proportional to the ratio in resistivities of the modeled surface and the composite surface including VIP. The compressor energy use was then increased in proportion to the reduction in overall thermal load.

5.7.3 Development and Calibration of ERA Current Energy Test Models

ERA modeling during the engineering analysis involved the following three phases.

- Modeling of existing products based on the current energy test procedure.
- Adjustment of models to represent baseline products tested under the expected revised test procedure.
- Iterative modeling with multiple series of adjustments to calculate the energy savings which can be achieved with different combinations of design options.

This section focuses on the first phase of the ERA modeling work, namely establishing models for the teardown products based on the current energy test procedure. These models were later adjusted to represent baseline energy use under the new test procedures, and these models were used subsequently to calculate energy savings potential. The baseline analysis results were compared with available data to assure that the models provide accurate representation of product energy use. This section discusses the creation and calibration of the ERA energy models, the metrics which were compared, and the adjustments which were made in some cases in order to improve calibration.

Input data for energy modeling was collected during the reverse engineering phase of the project. Collection of this data is discussed in Section 5.5.3.2 above. For products which DOE arranged to have energy tested, additional information was available for certain model parameters, such as defrost heater on times, compressor run time between defrosts, evaporator exit superheat, etc. Performance data was obtained from compressor vendors for the compressors used in the teardown products, as well as for compressors which could be considered as alternative options to reduce energy use.

Initial energy models were created, and the models were subsequently adjusted to provide a best match with available data for product performance. Key sources of information used for calibration of the energy models were the product EnergyGuide labels and data from energy tests carried out for a number of the reverse engineering units (Section 5.5.5). Energy test parameters besides energy use which were examined include compressor running power input, duty cycle, evaporating temperature, and condensing temperature. Since not all ERA input parameters can be determined definitively based on available information, some of the inputs were adjusted within reasonable ranges in order to provide good matches between model results and other performance indicators. It is recognized that energy levels reported in the EnergyGuide can be conservative to provide margin for variation in the production process. Hence, it is expected that ERA results would more likely be lower than the EnergyGuide value than higher.

In some cases the directly modeled energy use was significantly lower than actual product energy use, In some of these cases in which the system operating parameters could be well calibrated based on test data, DOE attributed the high actual duty cycle and energy use to high actual cabinet thermal load. A number of factors could possibly explain such results, including greater impact than expected of thermal short circuits associated with wiring harnesses and other design details, excess gasket region load, and consistently lower insulation thermal performance than expected. A consistently underperforming compressor model could also explain such a discrepancy, but DOE concluded that this explanation is less likely than factors which would increase cabinet thermal load. Hence, for these cases, additional cabinet load was added to result in an energy use and compressor duty cycle which provided reasonable agreement with the available data. The side-mount refrigerator-freezers (product classes 4 and 7) were adjusted using this approach.

In some cases, DOE concluded that ERA was not modeling particular heat exchangers properly. Adjustments were made in which the calculated effective surface area of the heat exchanger was adjusted upwards or downwards to represent heat transfer performance different than modeled. These adjustments were made to achieve more reasonable match of evaporating or condensing temperatures. Similar adjustments were made in some cases to evaporator pressure drop to adjust for an apparent discrepancy between measured evaporator surface temperature and compressor power input.

The ERA analysis results after adjustments of the model input for the seven key product classes analyzed are compared with the EnergyGuide data and Energy test results in Figure 5.7.1 for refrigerator-freezers, in Figure 5.7.2 for standard-size freezers, and in Figure 5.7.3 for compact refrigerators and freezers. Energy testing was performed on a limited group of freezers and compact products: one upright freezer, one chest freezer, and one compact refrigerator. For these figures, the energy use of the freezers has been adjusted consistent with the energy test by applying the 0.85 correction factor for upright freezers and the 0.7 correction factor for chest freezers.

The energy models are within a few percent of the EnergyGuide labeled energy use with one key exception, the 1.7 ft^3 compact refrigerator. For this unit, the roughly 15%

discrepancy with the EnergyGuide energy use was not reconciled. Because the measured energy use also differed significantly from the rated energy use for this product, DOE could not draw firm conclusions regarding system operation in order to assist in the calibration effort. DOE expects that both the cabinet and system for this product are operating less efficiently than modeled.

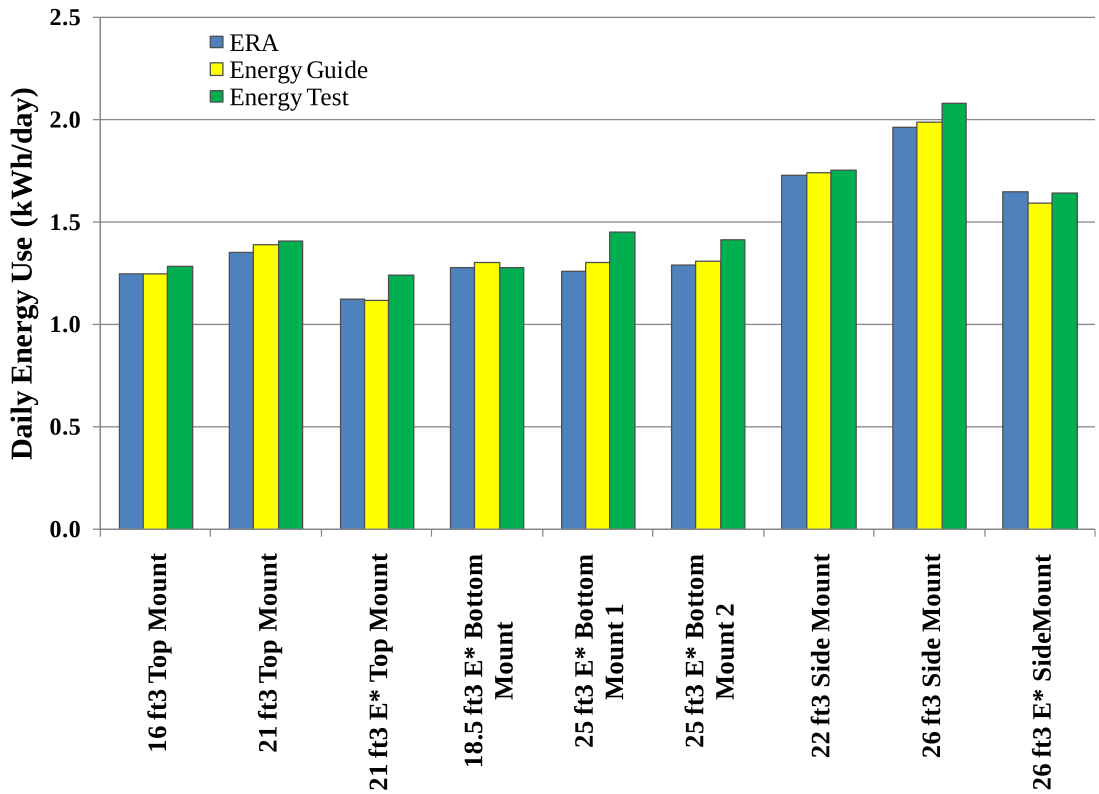

Figure 5.7.1 ERA Analysis for Refrigerator-Freezers Compared with EnergyGuide Labels and Energy Test Measurements

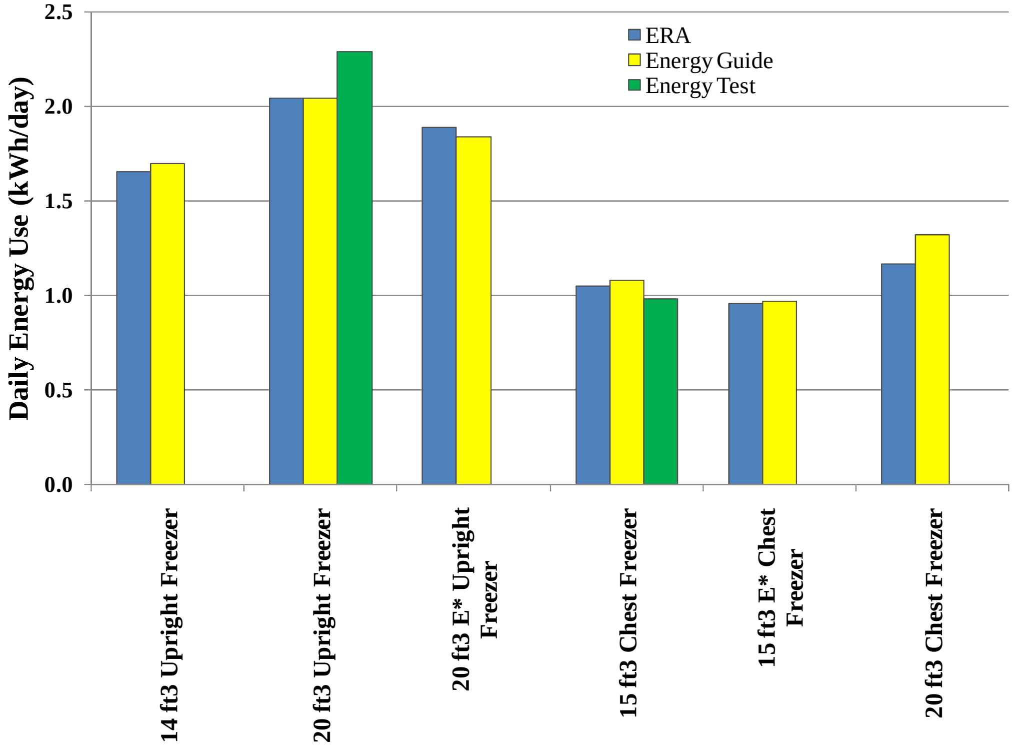

Figure 5.7.2 ERA Analysis for Freezers Compared with EnergyGuide Labels and Energy Test Measurements

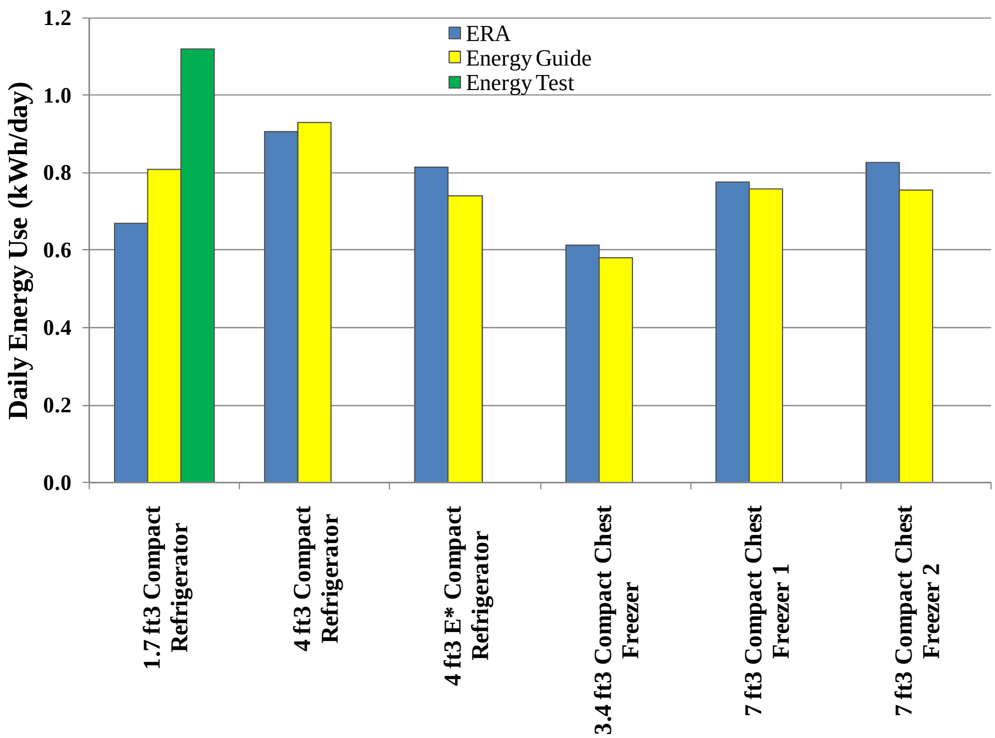

Figure 5.7.3 ERA Analysis for Compact Refrigerators and Freezers Compared with EnergyGuide Labels and Energy Test Measurements

5.7.4 Adjustments to Energy Models to Represent Baseline Products Tested Under the Proposed Test Procedure

This section discusses adjustment of the calibrated baseline ERA models to address two issues: (1) modification of some of the modeled product designs so they represent baseline-efficiency products of the desired product classes, and (2) adjustment for the proposed test procedure changes.

Modifications were made to some of the modeled product designs so that they represent baseline products of the product classes of interest with appropriate typical characteristics. The changes made are discussed in the following paragraphs.

Some of the teardown products purchased were not available as baseline-efficiency products, i.e. products with energy use that is minimally compliant with the current energy standards. This was true primarily for product class 5, refrigerator-freezers with automatic defrost and bottom-mounted freezers without TTD ice service. As indicated above in Table 5.5.2, one of these products had energy use roughly 15% below the maximum allowable energy use (the former ENERGY STAR level), and the others had energy use at 20% below (the current ENERGY STAR level). In order to allow the engineering analysis to examine the cost associated with the efficiency improvement from the 0% to the 15% and 20% efficiency levels, a baseline model was created for a product which would be minimally compliant with the standards. This was done by carrying out the engineering analysis in reverse, removing the less cost-effective design options first, in order to achieve calculated energy levels consistent with the baseline energy standard.

For product class 5, baseline models were established to represent products with French Doors. Comments made at the framework meeting and submitted to DOE as part of the framework comment period addressed this issue, as discussed in chapter 2. Most of the teardown products were purchased prior to the framework meeting, so DOE was not able to consider this issue when selecting these products. The two French Door products (see Table 5.5.2) were purchased later, to allow investigation of the different design details for these products. However, these French Door products are not product class 5, since they have TTD ice service. During the manufacturer interviews, DOE learned that more than half the sales of product class 5 currently have French Doors. As a result, DOE has used a French Door design as the basis for the engineering analysis for this product class. Because neither the products initially purchased for teardown nor the French Door products purchased later strictly fit the intended baseline design configuration, adjustments were made to establish product class 5 French Door designs for the engineering analysis. This was done for the 25 ft^3 product by developing and adjusting an energy model for one of the 25 ft^3 product class 5A reverse engineering units and for the 18.5 ft^3 product by adding French Door design features to the initial baseline model for the 18.5 ft^3 product class 5 reverse engineering unit. Development of the product class 5 French Door models involved the following considerations and steps.

French door refrigerator-freezers generally require electric anti-sweat heaters to prevent condensation of moisture on the gaskets and/or flip-mullions which seal between the French doors, since refrigerant-line anti-sweat heating is not possible in this region. The electric anti-sweat heater power input for the models was set at 6 W total, in spite of information that these heaters can have higher wattage input. The maximum time-averaged heat input for a warm refrigerant liquid anti-sweat heater is typically somewhat lower per length,[g] suggesting that a wattage level of 6 W should be sufficient. DOE did not have adequate information regarding the thermal characteristics of the French Door gasket in order to allow a more refined estimate. DOE developed the baseline product design parameters assuming that the energy use is the average of tests with the anti-sweat heater on during one test and off during another.[h]

Gasket load for the fresh food compartment was increased to account for the additional gasket region length. This was added to the single-door 18.5 ft^3 product class 5 model, but was already part of the baseline for the fresh food compartment doors of the 25 ft^3 product class 5A model. The freezer compartment of the 25 ft^3 product class 5A teardown model had two drawers. Hence, the energy model representing this product as received incorporated an increase in the freezer compartment gasket load to account for the additional gasket length. When establishing the baseline ERA model for subsequent design option analysis, the added gasket load representing the two drawers was removed from the model. DOE took this step in order to establish a baseline model representing a single freezer drawer.

The loads associated with the TTD ice system of the 25 ft^3 product class 5A baseline were eliminated to create the 25 ft^3 product class 5 with French Doors model. This includes the loads of the ice chute penetration, as well as the loads associated with the duct which conveys cold freezer air to the ice maker compartment. Additional loads and energy use associated with heaters in the region of this duct never entered into the model, because DOE understands that the teardown product was tested in a fashion which prevented activation of these heaters.

Different compressor efficiency levels were selected and/or different fan motor types were selected in order to achieve modeled energy use consistent with the energy conservation standard.

DOE obtained the product class 4 teardown unit (refrigerator-freezer with automatic defrost and side-mounted freezer *without* TTD ice service) with the understanding that it had TTD ice service. To address this discrepancy in the energy

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[g] For example, if the liquid flow of an 800 Btu/h nominal capacity compressor is cooled from a condenser exit temperature of 110 ˚F down to an ambient temperature of 90 ˚F, the delivered heat load during compressor operation is 70 Btu/h. Assuming roughly 50% duty cycle and 13 ft of freezer perimeter (the typical location for warm liquid anti-sweat), the heat per linear foot is 10.8 Btu/h-ft, equivalent to 3.2 W/ft.

[h] As discussed in Chapter 3, the DOE energy test procedure calls for calculation of refrigerator energy use based on a test with anti-sweat heater switch in the on position. However, DOE understands that many if not all manufacturers calculate energy use as the average of tests with the switch in the on position and the off position. DOE expects to propose changing the test procedure to allow averaging of the two tests in the ongoing test procedure rulemaking.

modeling work, the initial baseline model for the product was modified to represent product class 7 (refrigerator-freezer with automatic defrost and side-mounted freezer *with* TTD ice service). This was done by adding load and additional electric anti-sweat heat appropriate for the TTD feature.

The engineering analysis has been carried out based on the expected revised energy test procedure, which includes modified cabinet temperatures as discussed in Section 5.4.2. After calibration of the ERA models with EnergyGuide and energy test data according to the current energy test procedure, and after the adjustment to the models to better represent the products under investigation as described above, the ERA models were adjusted to represent operation under the new energy test procedure. This adjustment did not apply to the freezers, since there are no proposed changes to the freezer compartment temperatures. The calculated impact of the compartment temperature changes on the energy use is discussed in Section 5.4.2.1 and is shown in Table 5.4.8 of that section. This calculated impact of the temperature changes is fairly consistent with the results provided by AHAM, although it is less than the impact measured during DOE testing of the teardown products.

5.8 DESIGN OPTIONS

After conducting the screening analysis described in chapter 4, DOE considered the remaining technologies in the design option analysis. Table 5.8.1 lists the design options considered for each product classes. Some design options are only applicable to certain types of equipment. Following the table is a description of how each of the design options was applied during the engineering analysis. See chapter 3 for background descriptions of the technologies.

Table 5.8.1 Design Options by Product Class

Design Option	PC3	PC5	PC7	PC9	PC10	PC11	PC18
Increased Insulation Thickness				✓ 1 in	✓ 1 in	✓ 3/4 in	✓ 3/4 in
Vacuum-Insulated Panels	✓	✓	✓	✓	✓	✓	✓
Improved Compressor Efficiency	✓	✓	✓	✓	✓	✓	✓
Variable-Speed Compressor	✓	✓	✓	✓	✓	✓	✓
Increased Evaporator Surface Area	✓	✓	✓	✓	✓	✓	
Increased Condenser Surface Area	✓	✓	✓		✓	✓	
Forced Convection Condenser				✓			
Brushless DC Evaporator Fan	✓	✓	✓	✓			
Brushless DC Condenser Fan	✓	✓	✓	✓			
Adaptive Defrost	✓	✓	✓	✓			
Variable Anti-Sweat Heater Control		✓					

5.8.1 Increased Insulation Thickness

Manufacturers stated during discussions that the potential for insulation thickness increases is very limited for many product classes. Greater insulation thickness would result in either decreased interior volumes, increased exterior dimensions, or some combination of both. They cited the high percentage of the market associated with replacements and the fixed sizes available for replacement refrigerators in consumers' kitchens. The 1995 TSD supporting the 1997 refrigerator energy conservation standard final rule provided information regarding the reduction in served market associated with exterior size increases.[9] Reduction in internal volume is undesirable because this is a key selling feature. As a result, DOE did not consider insulation thickness increase in the analysis for standard-size refrigerator-freezers.

There is some more flexibility in the potential to increase insulation thickness for freezers, since freezers are less likely to be placed in fixed-dimension spaces in kitchens. DOE did consider insulation thickness increase of up to 1 inch for standard-size freezers.

Compact refrigerators often have limitations on potential for size increase. However, many compact refrigerator products currently have insulation thickness no more than an inch. The potential energy benefit of insulation thickness increases for these products is significant. Hence, DOE considered increases of up to 3/4 inch for these products. DOE considered increase up to ¾ inch also for compact freezers.

While a manufacturer's approach to implementing insulation thickness increase would likely involve a combination of reduced internal volume and increased external dimensions, DOE used just external dimension increase. This was done to assure that the product size (represented by adjusted volume) and the associated baseline energy use for the product did not change as the design options were applied.

Costs associated with insulation thickness increases were calculated using the manufacturing cost model. As discussed in Section 5.6.6, DOE applied a conservative treatment of depreciation costs in which additional cost equal to the greenfield depreciation cost per product was added in order to reflect the likely build of a new production facility. DOE assumed that the depreciation cost would be incurred for any increase in insulation thickness. However, DOE allowed for increases in the door thickness without applying depreciation costs associated with the cabinet, and vice versa.

Initial manufacturing cost model calculations provided the total cost impact of increasing all of the insulation in the product by a single amount. In order to allocate the cost increase to the cabinet and the door, DOE assumed that the cost of increasing the insulation thickness of the door was 5% of the total. This allocation was applied to both direct costs and depreciation costs.

5.8.2 Vacuum-Insulated Panels

Vacuum-insulated panels (VIPs) increase efficiency by significantly increasing the thermal resistivity of the cabinet walls, and therefore decreasing heat penetration into the cabinet. DOE considered the addition of ½-inch thick VIPs to the walls and doors of the cabinet for all product classes, and the remainder of the insulation thickness was filled with PU foam. Data for VIP thermal characteristics and costs were provided by va-Q-tec, a VIP manufacturer. The cost information was confirmed through discussions with manufacturers. In these discussions, manufacturers pointed out that edge effects can result in actual performance significantly less than predicted. However, DOE considers that thermal performance estimates based on the va-Q-tec technology are more accurate than for other VIP options because this technology has a more modest mid-panel thermal resistance and a significantly thinner metallic layer than other options. The mid-panel conductivity of this VIP technology is 3.5 mW/m-C (0.024 Btu-in/sqft-hr-˚F).[10] In contrast, the conductivity of PU foam is in the range 0.13 to 0.14 Btu-in/sqft-hr-˚F.

As discussed in Section 5.7.2, thermal performance of composite walls including VIPs was done using composite wall average thermal resistivities. The composite wall resistivity R_w was calculated as follows.

$$R_w = \frac{\left(R_{VIP}t_{VIP} + R_{PU}t_{PU}\right)}{\left(t_{VIP} + t_{PU}\right)}$$

Where R_{VIP} and R_{PU} are the thermal resistivities of the VIP and the PU foam, and t_{VIP} and t_{PU} are the thicknesses of the VIP and PU foam layers. The thermal resistivities for the materials are the inverses of the conductivities.

DOE analysis of cabinet load reduction achievable through the use of VIPs using this analysis approach is consistent with analysis carried out by va-Q-tec and also consistent with prototype testing using VIP technology. The reduction in cabinet load possible using VIPs for a refrigerator-freezer with typical wall thickness is roughly 30%, which is consistent with results reported by Electrolux for use of vacuum insulation in freezers.[11]

The following cost information, which va-Q-tec provided and/or which DOE developed based on subsequent discussions, formed the basis of the applied costs for VIPs.

- Average panel cost $3.08/ft^2 at 1.2 cm thickness.
- Fill cost as a percent of panel cost 60%.
- Added glue cost for adhering the panel to cabinet surfaces 5% of panel cost.
- Cost savings associated with displaced PU foam 2.5% of panel cost.

In order to allow calculation of costs for other VIP thicknesses, the fill cost is considered proportional to the thickness, while the remaining cost per square foot is constant. In addition, direct labor cost associated with application of the panel to cabinet and door surfaces was calculated based on the $24/hr wage rate (including fringe benefits) discussed in section 5.6, and time for application of 10 minutes for a compartment and 1 minute for a door. The direct material and labor costs associated with use of the VIP must be adjusted to account for capital expenses and overhead associated with incorporation of VIPs into the production process. Because the material cost of VIPs is currently high in relation to the costs of other materials used in the manufacture of refrigerators and freezers, the cost adders for overhead and depreciation discussed in Section 5.6.6.1 and shown in Table 5.6.5 were divided by two in order to provide more reasonable representation of these costs for this technology. Hence, DOE used the following percent additions: 11.7% for standard-size refrigerator-freezers, 14.2% for standard-size freezers, and 19.6% for compact refrigerators.

5.8.3 Improved Compressor Efficiency

DOE considered the substitution of higher efficiency compressors for all product classes. This design option was often applied in two stages if there was a large gap between the baseline energy efficiency ratio (EER) and the maximum available EER for a given compressor capacity. DOE acquired compressor performance data from compressor vendors for use in the energy analysis, including capacity and power input for the applicable range of combinations of suction and discharge pressure conditions. As an example of the potential for improvement, standard-size baseline refrigerator-freezers typically use compressors with a rated EER of 5.0 to 5.5 Btu/h-W. DOE considered improved EERs of 5.75 through 6.25 Btu/h-W.

Currently the highest EER compressor commercially available is rated near 6.25 Btu/h-W for standard- size refrigerator-freezers. The range of available compressor efficiencies is illustrated in Figure 5.8.1 below. The peak available efficiency level does not vary significantly for the range of capacities typical for standard-size refrigerator-freezers (600 to 800 Btu/h). However, efficiency level drops off considerably for smaller capacity compressors that are generally used in compact refrigerators and freezers.

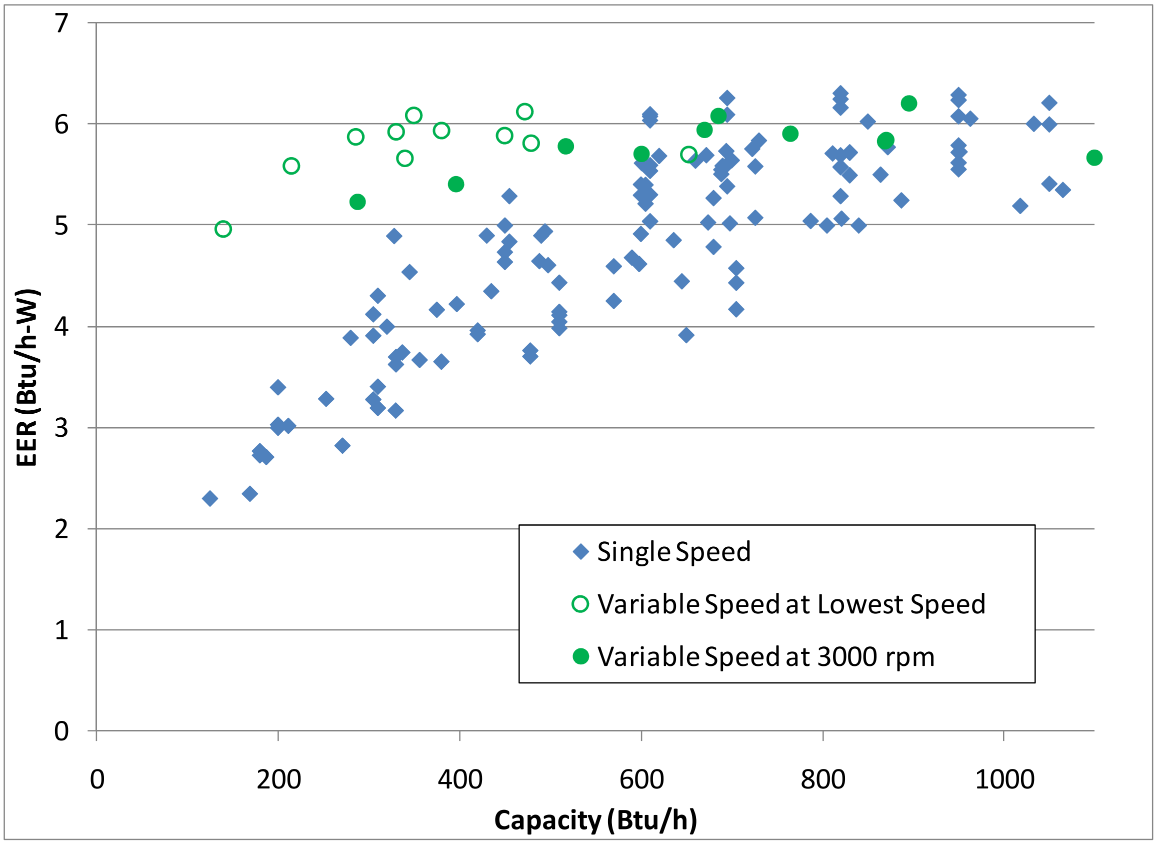

Figure 5.8.1 Compressor Efficiency Data

Estimates for increased cost of higher-efficiency compressors used for standard-size refrigerator-freezers and standard-size freezers were received from compressor vendors. These estimates were also discussed with manufacturers. Based on this information, DOE developed a curve for the cost premium associated with higher efficiency compressors. This curve is shown in Figure 5.8.2 below.

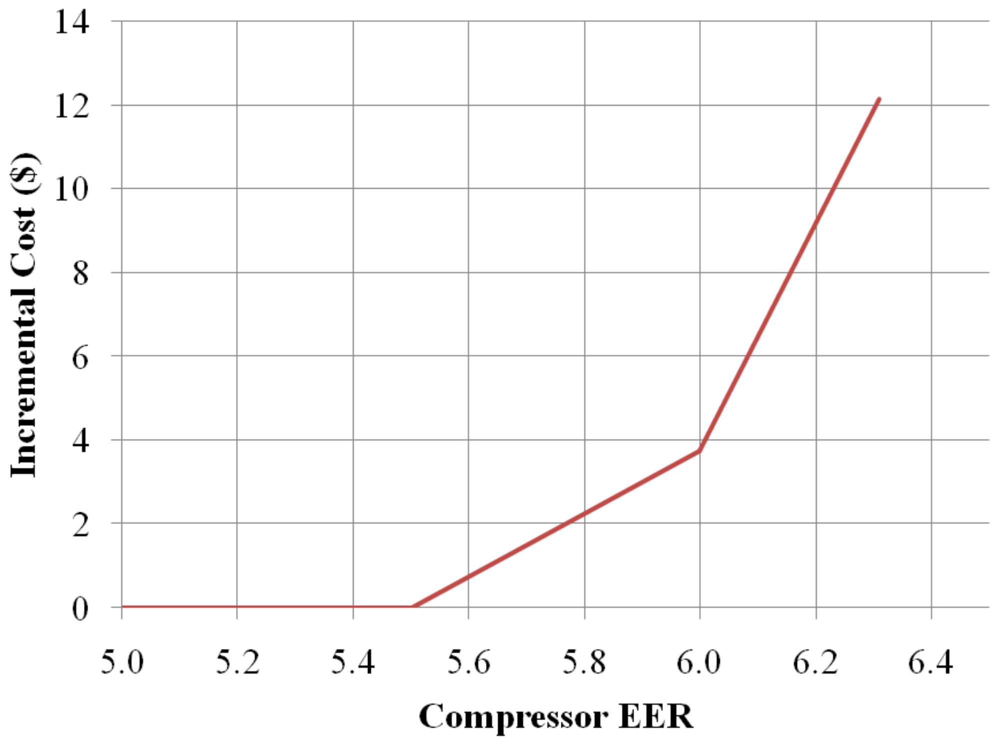

Figure 5.8.2 Incremental Cost for Single-Speed Compressors for Standard-Size Products

When considering compressor efficiency improvement for standard-size products, DOE used the performance data of specific higher-efficiency compressors in the energy analysis. The alternative compressors were selected to have nearly the same capacity as the baseline compressors, in order to assure nearly identical performance except for compressor power input.

In the analysis of compressor efficiency improvements for compact products, an approach was required which addressed the reduction of compressor efficiency as the capacity is reduced. A curve roughly representing the maximum available EER for smaller compressors was developed. This curve is compared in Figure 5.8.3 below with the data for commercially available compressors.

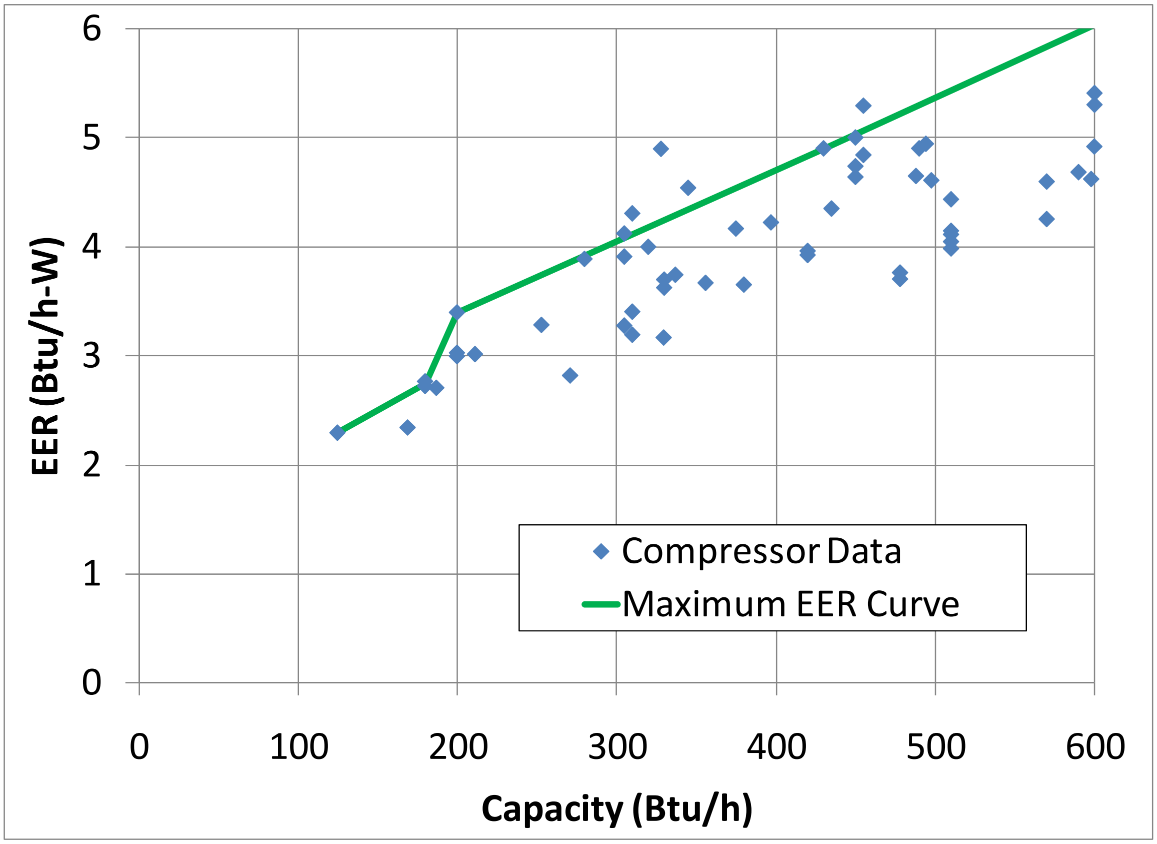

Figure 5.8.3 Efficiency Curve for Low Capacity Compressors

To model energy use of higher efficiency low-capacity compressors, DOE reduced the power input data for the baseline compressor by a selected factor so that the rated EER matches the maximum EER of the above curve. The baseline compressors of the products analyzed had EERs typically 0.5 to 1 Btu/h-W lower than the maximum curve shown in the figure above.

DOE received vendor cost estimates for efficiency improvements for low-capacity compressors. DOE also received information on the typical cost increase during discussions with manufacturers of products which use these compressors. A representative cost estimate of $10 per 1.0 Btu/h-W efficiency improvement was used in the analysis.

5.8.4 Variable-Speed Compressor

Variable speed compressors (VSC) operate at multiple speeds to allow variation of compressor capacity. They also generally use permanent magnet motors, which can be more efficient than induction motors for the power level required for residential refrigerator compressors. They improve efficiency by (1) use of the higher-efficiency motor technology, (2) increasing the operating effectiveness of heat exchangers because there is lower mass flow being cooled or warmed by a fixed-size heat exchanger, and (3) reducing cycling losses by reducing the number of cycles. VSC technology has been available for many years and a number of refrigerator-freezer products currently use the technology. Currently nearly all of these products use Embraco VSCs. DOE obtained compressor performance data for the range of sizes of Embraco VSCs. This information was used in the energy analysis. DOE selected VSC capacities to nearly match those of the replaced single speed compressors at 3000 rpm. The lowest available speed for the Embraco VSCs is 1,600 rpm. The compressor typically cycles at the low speed to maintain internal setpoints for energy test conditions. DOE primarily used the performance data for 1,600 rpm in the energy analyses. The performance of VSC compressors at the lowest speed and at 3,000 rpm is shown in Figure 5.8.1 above.

In order to maximize the energy benefit of VSCs, a design typically needs to address the impact that longer run time at lower capacity has on fan energy use. The increase in fan energy use can negate much of the reduction in compressor energy use. As a result, it is typically necessary to use brushless DC fan motors. In addition, the speed of brushless DC fan motors can be varied, depending on the design configuration. DOE is not aware of brushless DC fan motors designed for 120 VAC power input which allow adjustment of fan speed, although such a design should be viable. Most designs incorporating fan speed control use DC-input power for the fans and require a control system which can provide the DC power and vary it to adjust fan speed. Not all of DOE's analysis involved optimization of fan speed and power with the variable speed compressor system. Some of the analyses involved selection of 50% fan speed, and some of the anlyses involved selection of speed to achieve roughly 50% power input. The cube law for fan power was used to calculate power input, except that at the 1/8 power level associated with the 50% fan speed, this power level was doubled.

Cost estimates for the switch to variable speed compressors were provided by Embraco, and cost estimates were also obtained during discussions with manufacturers. An average of cost estimates provided by the manufacturers weighted by manufacturer market share is very near $50, not including additional changes which might be required to implement a variable speed system. DOE used a $50 cost increase in the analyses. Additional costs associated with conversion of a refrigeration system to variable speed operation are associated with a switch to brushless DC fan motors and the use of a control system sophisticated enough to provide adequate or optimized control. The Embraco VSC design includes a control system which can be used with a conventional mechanical thermostat. This system has been implemented in a commercially available freezer.[12] The Embraco control adjusts speed based on the response of the mechanical thermostat. DOE considers that this approach is suitable for products with manual defrost. For products with automatic defrost and especially adaptive defrost, it is not reasonable to expect that that the Embraco system alone would be suitable. DOE included in cost estimates an additional $25 for addition of an electronic control system for products with automatic defrost. For product classes for which a significant portion of current models already have electronic control (product classes 5 and 7), analysis was conducted for an electronic control unit and a mechanical control unit. The average results for these product classes were weighted averages based on the distribution of electronic control for the product class. The current electronic percentages were selected based on input from manufacturers as 50% for side-mounts and 75% for bottom-mounts. The additional cost associated with conversion to brushless DC fan motors did not generally apply: because brushless DC fan motors are more cost effective than a full conversion to variable speed, the cost of the motors would have already been applied at a lower efficiency levelwhen a change to variable speed is considered.

5.8.5 Increased Evaporator Surface Area

The evaporator is necessary for transferring heat from the cabinet to the refrigerant. Larger surface area allows the heat transfer to occur more efficiently. DOE considered an increase in evaporator surface area for all products analyzed. In some cases the size increase was limited by available space. This was true especially for the chest freezers and compact refrigerators. DOE considered size increases of up to 20%, except for one of the upright freezer models, for which DOE considered an increase of up to 50%. The size increases were implemented in the energy analysis through increase of the effective heat exchanger surface areas and refrigerant pressure drops entered into the ERA model. The pressure drop increases as well as the surface area because the refrigerant tube length would be increased to maintain fin efficiency.

Treatment of the cost of the evaporator size increase depended on the evaporator type. For forced convention and roll bond evaporators, the baseline costs of the evaporators were adjusted upwards by the size increase factor. For cold wall evaporators, the cost increase was directly calculated in the manufacturing cost model by increase of the tube lengths and materials associated with providing good tube/liner thermal contact.

5.8.6 Increased Condenser Surface Area

The condenser transfers heat from the refrigerant to the ambient air. Larger surface area allows the heat transfer to occur more efficiently. DOE considered an increase in condenser surface area for all products analyzed. In some cases the size increase was limited by available space. This was true especially for hot wall or static condensers. DOE considered size increases of up to 20%. The size increases were implemented in the energy analysis through increase of the effective heat exchanger surface areas and refrigerant pressure drops entered into the ERA model. The pressure drop increases as well as the surface area because the refrigerant tube length would be increased to maintain fin efficiency.

Treatment of the cost of the condenser size increase depended on the condenser type. For forced convention and static condensers, the baseline costs of the condensers were adjusted upwards by the size increase factor. For hot wall condensers, the cost increase was directly calculated in the manufacturing cost model by increase of the tube lengths and materials associated with providing good tube/shell thermal contact.

5.8.7 Brushless DC Fan Motors

Brushless DC fan motors are more efficient than the shaded pole motors which are often used in baseline model refrigerators.

In the TSD supporting the 1997 refrigerator energy conservation standard final rule, shaded pole fan motor power input ranging from 8 to 12 W was assumed to be reduced to 4.5 W when switching to brushless DC motors.[9] This is a reduction in power ranging from 44 to 57%. The cost increase of that analysis associated with the switch was $6.50 for an evaporator fan and $4.50 for a condenser fan.

The fan power input measured for the teardown products are summarized in Table 5.8.2 below. For the baseline/ENERGY STAR product pairs, power input is provided for both sets of each applicable fan. The fan motor power reduction associated with the switch to brushless DC motors based on this data is in the range 60% to 65%.

Table 5.8.2 Teardown Product Fan Power Input

Product	Evaporator Fans		Condenser Fans	
	Shaded Pole	Brushless DC	Shaded Pole	Brushless DC
21 ft^3 Top-Mount**	5.7, 6.1	NA	9.4	3.3
26 ft^3 Side-Mount**	5.6, 5.8	NA	8.5	3.4
25 ft^3 Bottom Mount 1	6.5	NA	NA	3.7
18.5 ft^3 Bottom Mount	6.2	NA	NA	3.8
25 ft^3 Bottom Mount 2	NA	3.25*	NA	2.2*
22 ft^3 Side-Mount	NA	3.25*	9.1	NA
20 ft^3 Upright Freezer**	11.5	4.5	NA	NA
14 ft^3 Upright Freezer	7.4	NA	NA	NA

*DC-input fan. The listed wattage is nominal.
**Data provided for a baseline/ENERGY STAR product pair.

DOE also obtained information on typical fan motor power reduction associated with a switch to brushless DC motors during discussions with manufacturers. The responses indicated that the reductions would be more modest than suggested by the 1995 TSD values or the measurements of teardown products. DOE selected a compromise power reduction of 50% when the possible reduction was not already clearly illustrated by the measurements of the baseline/ENERGY STAR teardown product pairs under analysis.

Incremental cost estimates for the switch to brushless DC motor were obtained through discussion with Matsushita, a key vendor supplying these motors, and through discussions with manufacturers. DOE used incremental cost estimates of $3.75 for condenser fans and $3.50 for evaporator fans.

5.8.8 Adaptive Defrost

An adaptive defrost system adjusts the time interval between defrosts based on some indication of the need for defrost. A common indicator is the length of time required to complete the previous defrost. Other indicators could include the number of door openings or a measurement of ambient humidity. DOE considered this design option for product classes which have automatic defrost (product classes 3, 5, 7, and 9). The

ERA model allows input of compressor run time between defrost. To model this option, DOE increased the compressor run time between defrosts to 38 hours, as compared to the typical range for baseline products of 10-15 hours. The 38 hours is the default time interval allowed by the test procedure if the mean time between defrost test is not carried out, assuming default values of the minimum and maximum compressor run intervals of 12 and 84 hours.

Based on discussions with manufacturers, DOE used an incremental cost of $8 in the energy analysis for adaptive defrost. This cost assumes use of a standalone adaptive defrost controller, which could be used if the refrigerator does not already have electronic control. Refrigerators which have electronic control can implement adaptive defrost with programming changes which incur no per-unit cost. For some products for which a significant portion of current shipments already have electronic control, the incremental cost for adaptive defrost was multiplied by the fraction of products of the product class which do not already have electronic control, as was done for the electronic control cost addition for variable speed compressors.

In cases where both adaptive defrost and variable speed compressor design options were analyzed, the cost of the adaptive defrost was eliminated, because the introduction of electronic controls would make use of a standalone adaptive defrost controller unnecessary.

5.8.9 Variable Anti-Sweat Heater Control

Variable anti-sweat heater control adjusts the time-average wattage of an electric anti-sweat heater based on ambient temperature and humidity conditions so that all surfaces are just above the ambient dew point. DOE considered this option for bottom-mount French-door refrigerator-freezers (PC 5). These products must use electric anti-sweat heaters in the region of the seal between the two fresh food doors to control condensation, because warm liquid anti-sweat heating cannot be applied in this region. Most modern refrigeration products use warm liquid anti-sweat heating, thus making electric anti-sweat heaters unnecessary, except in such locations. To model the energy use reduction associated with this design option, DOE established a curve representing the heater power input as a function of ambient humidity. DOE then calculated annual average electric anti-sweat heater wattage based on the frequency distribution of humidity levels established in the GE waiver describing a test procedure for this control scheme.[13] The selected DOE curve is based on power levels of 0W at 65% RH and 9W at 100% RH. The maximum power was increased as compared with the 6W used for the anti-sweat heater for the baseline product analysis (see the discussion in Section 5.7.4), because the variable anti-sweat heater control minimizes the energy use impact of the higher wattage.

Implementation of variable anti-sweat heater control requires use of a humidity sensor and an electronic controller which can adjust the time-average heater wattage appropriately. For products which already have electronic control, DOE used the cost just of a humidity sensor. DOE used a cost of $9.48 for a Honeywell humidity sensor based on high-quantity pricing.[14] No product currently exists which provides standalone variable anti-sweat heater control. However, DOE considers the $8 example of the standalone adaptive defrost controller to be representative of the incremental cost of such a product.

5.8.10 Forced Convection Condenser

A forced convection condenser can be more efficient than a hot wall condenser, because it enables more effective heat transfer from the refrigerant to the ambient air. DOE considered this option for upright freezers only (product class 9). This conversion involves the addition of a typical wire-tube condenser, a fan assembly, wiring to power the fan, and a warm liquid anti-sweat heating loop, and the elimination of hot wall tubing on the insulation side of the outer shell. In the case of the upright freezer products examined for the reverse engineering work, there was ample space underneath the cabinet for the condenser and fan assembly. In addition, these products incorporated hot gas condensate pan heaters. These heaters could be eliminated in a forced-convection arrangement, because the condenser heat and air flow of the forced convection arrangement would be sufficient to evaporate the condensate, as is generally done for refrigerator-freezers. DOE used a net incremental cost of $3 for this conversion—most of the cost of the added components would be saved through elimination of the hot wall condenser. DOE analyzed this design option both with shaded pole and brushless DC condenser fans. The option provided an energy benefit in combined design option analysis only when using the brushless DC fan motor.

5.9 ENGINEERING ANALYSIS RESULTS

This section shows the incremental cost curves developed by DOE and provides comparison to the data provided by AHAM.

5.9.1 DOE Cost-Efficiency Curves

DOE generated cost-efficiency curves for two product volumes in each of the seven analyzed product classes based on combinations of individual design options. The curves were normalized by converting to costs at specific efficiency levels (every 5% energy use reduction from 10% to 45%) for simplified downstream analysis.

Conversion of cost curves to the specified efficiency levels was complicated by the characteristics of the design options required to provide further efficiency improvement. Some design options can be partially applied, while others cannot. For instance, for the 21 ft^3 top-mount refrigerator, the second step in the design option path raises the efficiency level from 9.9% to 16.8% by increasing the compressor EER from 5.54 to 6.08 Btu/h-W. The cost for compressor efficiency improvement, illustrated in Figure 5.8.2, varies as the efficiency varies. Because intermediate efficiency level compressors are generally available, the cost to achieve a fraction of the increase to 16.8% would be a fraction of the cost to achieve the full step to 16.8%. Hence, DOE calculated the cost of raising efficiency to the 10% and 15% levels by calculating the lower cost of partial improvement in compressor EER. In some cases, such as implementation of a variable speed compressor, the design option cannot be partially implemented. For these cases, the entire cost of the design option was applied at the intermediate efficiency level, even though the design might overshoot the efficiency level. This causes some of the incremental cost curves to have slopes which don't increase monotonically.

The DOE incremental MSP costs are presented in Table 5.9.1 below. While DOE analyzed two sizes of each product, it is not clear that differences in the curves can rightly be attributed to the size differences. Other factors likely have greater influence, for instance for product class 3 the 16 ft^3 product had noticeably thinner insulation than the 21 ft^3 product. DOE considers the averages of the MSPs to be representative for each product class. The separate analysis of the slopes of the energy use vs. adjusted volume curves discussed in section 5.4.2.3 addresses the issue of adjustments to more accurately reflect the impact that product size has on energy use.

Table 5.9.1 DOE Incremental Costs

Product Class	Size* (ft^3)	Efficiency Level							
		10%	15%	20%	25%	30%	35%	40%	45%
3	16	$6.52	$11.21	$21	$49	$94	$127	$168	$208
	21	$0.47	$4.16	$11	$20	$31	$81	$145	$208
	Avg	$3.50	$7.68	$16	$35	$62	$104	$156	$208
5	18.5	$7.21	$16.34	$26	$36	$58	$119	$177	$243
	25	$0.00	$2.27	$9.49	$30	$41	$107	$185	$254
	Avg	$1.80	$5.79	$14	$31	$45	$110	$183	$251
7	22	$9.92	$23.45	$76	$139	$203	$264	$359	N/A
	26	$12.44	$14.46	$32	$73	$131	$194	$262	$345
	Avg	$11.18	$18.96	$54	$106	$167	$229	$311	N/A
9	14	$6.38	$6.38	$11	$34	$62	$90	$175	$259
	20	$6.43	$16.51	$17	$21	$31	$64	$73	$135
	Avg	$6.41	$11.45	$14	$28	$47	$77	$124	$197
10	15	$0.00	$2.93	$8.90	$14	$18	$45	$51	$106
	20	$4.70	$9.16	$39	$45	$52	$104	$104	$168
	Avg	$2.35	$6.05	$24	$29	$35	$74	$77	$137
11	1.7	$2.44	$4.70	$7.10	$19	$20	$29	$45	$61
	4	$4.28	$7.94	$10.61	$22	$23	$24	$33	$53
	Avg	$3.36	$6.32	$8.85	$21	$22	$27	$39	$57
18	3.4	$5.42	$8.38	$32.54	$46	$63	$63	$63	$87
	7	$6.68	$10.93	$35.52	$39	$57	$63	$87	$92
	Avg	$6.05	$9.65	$34.03	$43	$60	$63	$75	$90

*These are total product volumes based on the current test procedure, not adjusted volumes.

DOE did not attempt to provide distributions of costs at each efficiency level. While the MSP curves for the two different sizes for each product class provides some indication of the variation of the costs, the full range is very likely much greater. There is insufficient information currently available for DOE to confidently calculate cost distributions at each efficiency level. The average curves for incremental manufacturer selling price are plotted in Figure 5.9.1 through Figure 5.9.3 below.

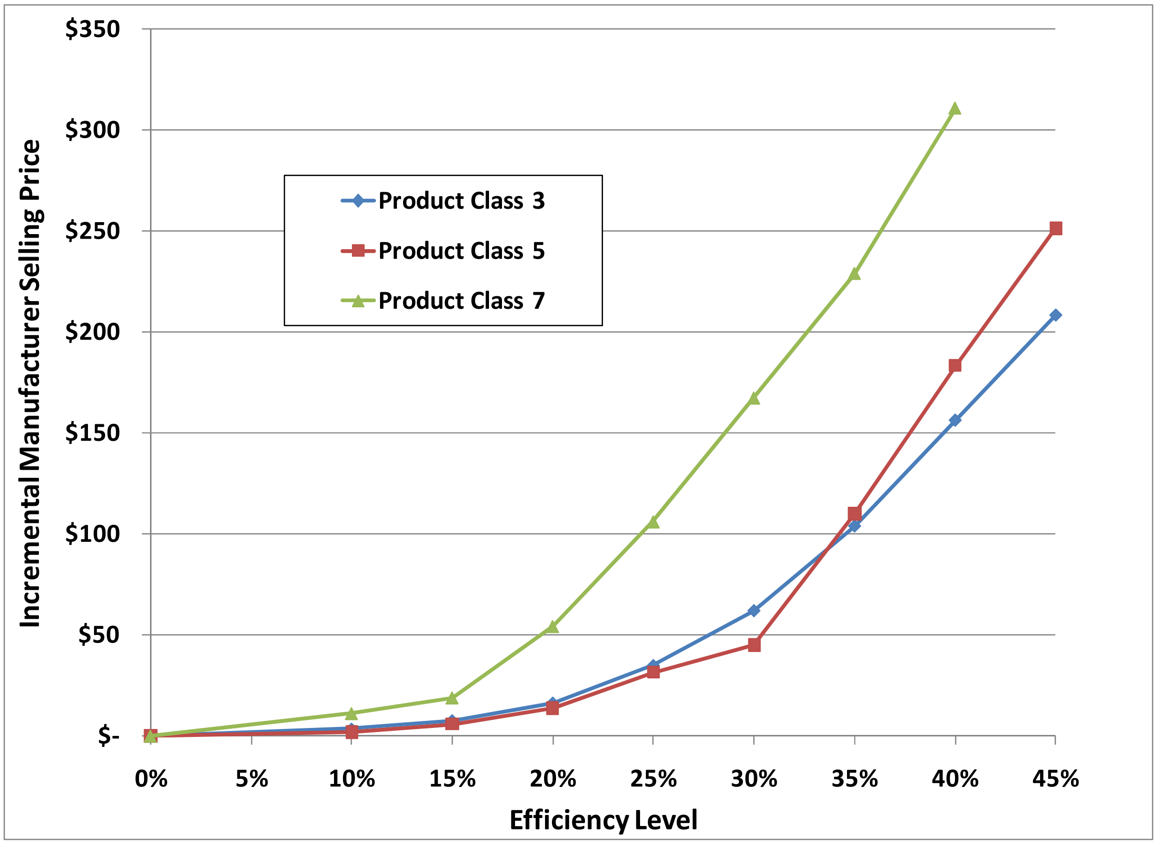

Figure 5.9.1 Incremental Manufacturer Selling Price for Standard-Size Refrigerator-Freezers

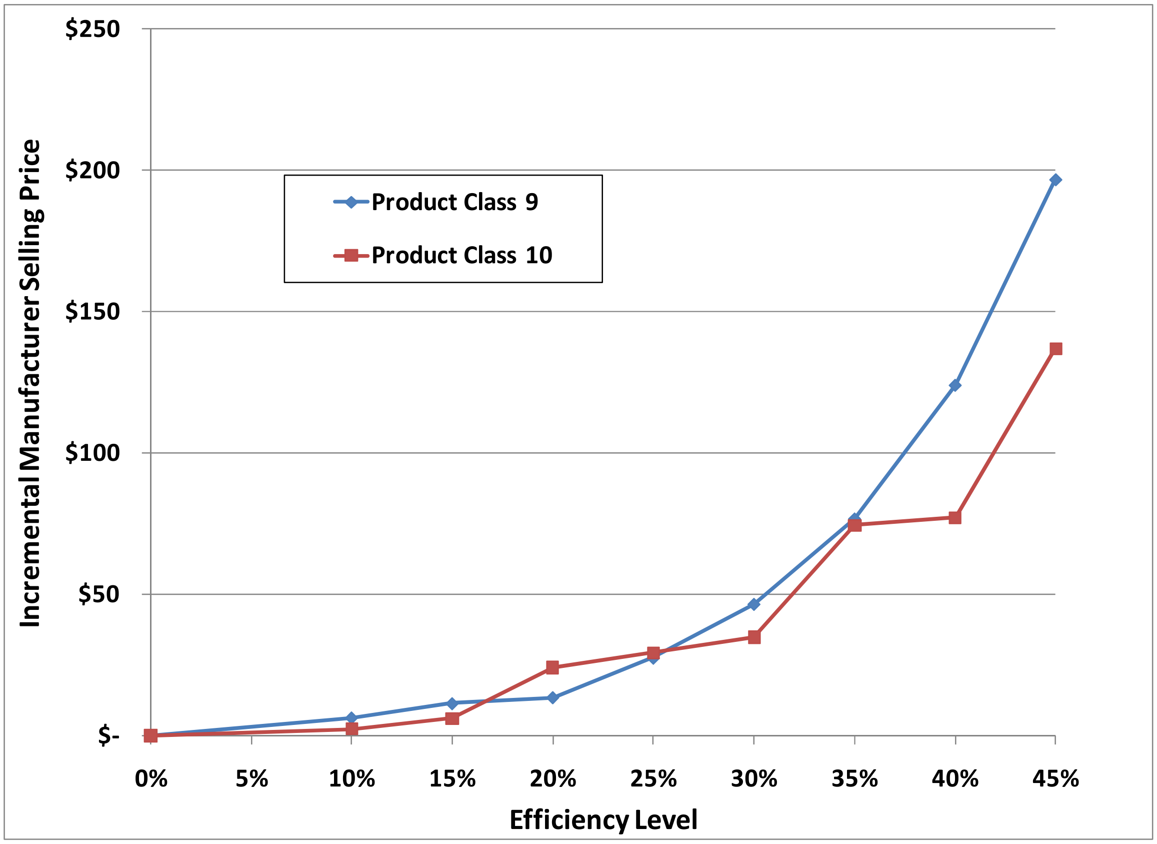

Figure 5.9.2 Incremental Manufacturer Selling Price for Standard-Size Freezers

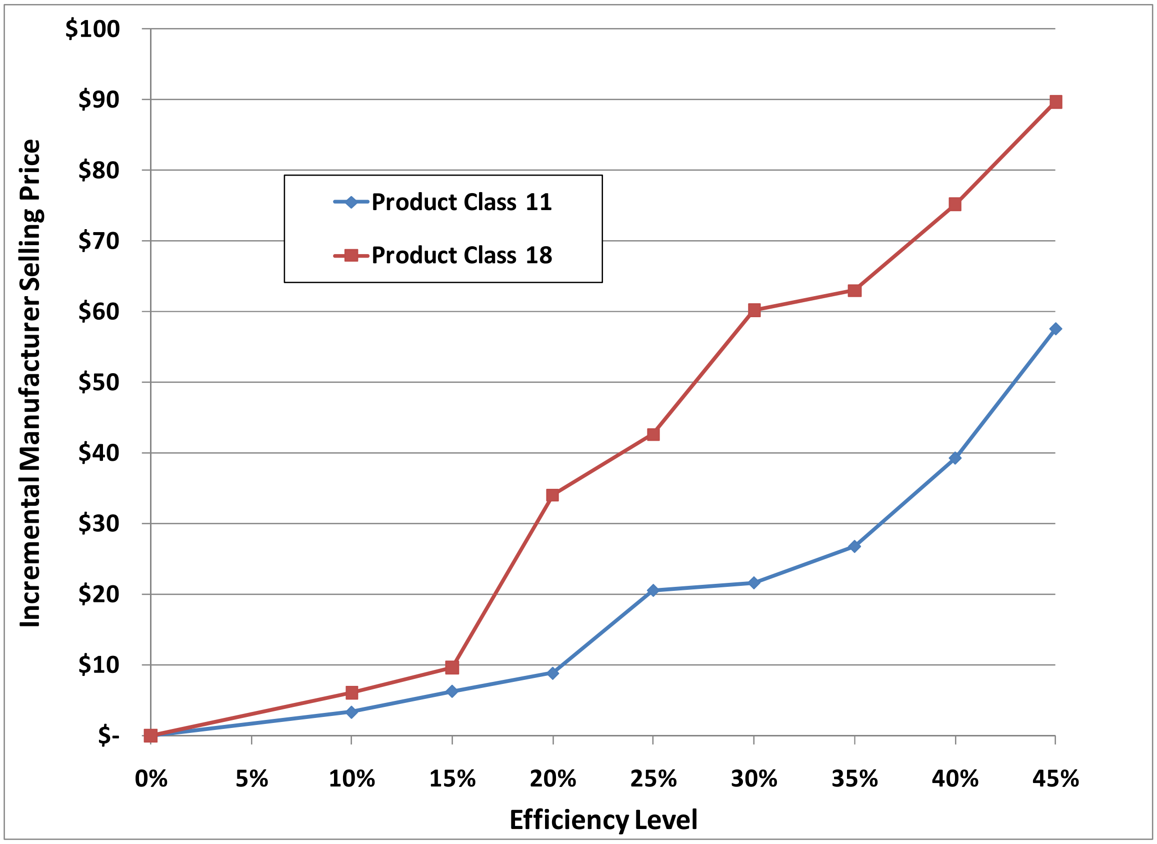

Figure 5.9.3 Incremental Manufacturer Selling Price for Compact Refrigerators and Freezers

5.9.2 AHAM Incremental Cost Data

This section presents the aggregated incremental cost data provided by AHAM and discusses differences between this data and the incremental cost information developed by DOE.

The data request sheets initially provided for the AHAM incremental cost data collection effort are in the framework document as Tables A-7A through A-7F of that document. The data collection effort was later modified to include a 35% efficiency level and to reduce the 15% efficiency level to 10% in order to provide an intermediate first level. Data was submitted to AHAM by manufacturers and this data was aggregated in preparation for submission to DOE, so that no reported data would represent responses from fewer than three manufacturers.

Sufficient data was collected to allow reporting of incremental costs for product classes 3, 5, 7, 9, and 11, although for product classes 5 and 11 the reporting was for only one of the product sizes.

After receipt of the data, DOE posed follow-up questions, some through AHAM and some directly with individual manufacturers, to improve understanding of the results. DOE requested that AHAM provide indication of what percent of shipments within each product class was represented by reported information, so that the results for capital investments and one-time expenditures could more accurately be allocated to individual products. DOE also requested clarification regarding whether the capital investments and one-time expenditures reported for the two sizes of a product class would be added to provide total costs for the product class, or whether any portion of the cost would overlap. AHAM requested clarification on this question from members, and the response was that there is very little overlap in reporting of these costs.

The following sections present the AHAM data and comparisons with DOE results by product class.

5.9.2.1 Product Class 3

Incremental cost data for product class 3 refrigerator-freezers provided by AHAM are summarized in Table 5.9.2 below.

Table 5.9.2 AHAM Incremental Cost Data for Product Class 3

Efficiency Level			10%	20%	25%	30%	35%
Product Class 3—15 ft^3							
Incremental Cost	Average (99%)*	Material	$13.02	$20.32	$90.79	$148.13	$160.19
		Labor	$0	$0	$4.23	$8.72	$9.13
		Overhead	$0	$0	$0	$0.04	$0.07
CCE & OTPCE ($million)	Total Industry	Building CAPX (99%--4)*	$0	$0	$3.5	$4.0	$4.5
		Tooling/Equipment CAPX (99%--4)*	$0	$15.0	$25.2	$120.4	$125.5
		R&D (57%--3)*	$0	$0	$4.5	$4.5	$17.5
		Marketing (57%--3)*	$0	$0	$2.5	$2.5	$2.5
	Shipment-Weighted Average	Building CAPX	$0	$0	$0.14	$0.14	$0.14
		Tooling/Equipment CAPX	$0	$4.58	$6.75	$40.66	$40.69
		R&D	$0	$0	$0.75	$0.75	$4.72
		Marketing	$0	$0	$0.68	$0.68	$0.68
Product Class 3—21 ft^3							
Incremental Cost	Average (99%)*	Material	$8.98	$22.09	$92.55	$150.79	$173.83
		Labor	$0	$0	$4.22	$8.99	$8.99
		Overhead	$0	$0	$0	$0.04	$0.04
	Minimum (57%)*	Material	$0	$8.27	$34.61	$43.60	$68.30
		Labor	$0	$0	$0	$0.54	$0.54
		Overhead	$0	$0	$0	$0.04	$0.04
	Maximum (57%)*	Material	$0.81	$10.18	$36.23	$46.93	Blank
		Labor	$0	$0	$0	$0.55	$0.56
		Overhead	$0	$0	$0	$0.04	$0.04
CCE & OTPCE ($million)	Total Industry	Building CAPX (99%--4)*	$0	$0	$3.0	$3.0	$3.0
		Tooling/Equipment CAPX (99%--4)*	$0	$3.0	$65.5	$125.5	$130.5
		R&D (57%--3)*	$0.5	$0.5	$2.5	$2.5	$12.5
		Marketing (57%--3)*	$2.5	$2.5	$2.5	$2.5	$2.5
	Shipment-Weighted Average	Building CAPX	$0	$0	$0.01	$0.01	$0.01
		Tooling/Equipment CAPX	$0	$0.92	$19.05	$42.27	$42.27
		R&D	$0.14	$0.14	$0.14	$0.14	$3.19
		Marketing	$0.68	$0.68	$0.68	$0.68	$0.68

CCE&OTPCE: Conversion Capital Expenditures and One-Time Product Conversion Expenses. Material, Labor, and Overhead are per unit. Blank entries indicate that there were insufficient responses for AHAM to provide data.
*Percent of Product Class 3 shipments represented by these data and number of manufacturers represented (for capital and one-time expenditures).

The AHAM average incremental cost data for product class 3 refrigerator-freezers are compared with the DOE costs in Figure 5.9.4 below. The DOE costs in these curves have the manufacturer markup taken out so that they can be compared on a consistent basis. The AHAM curves include material, labor, overhead, and depreciation and one-time expenses.

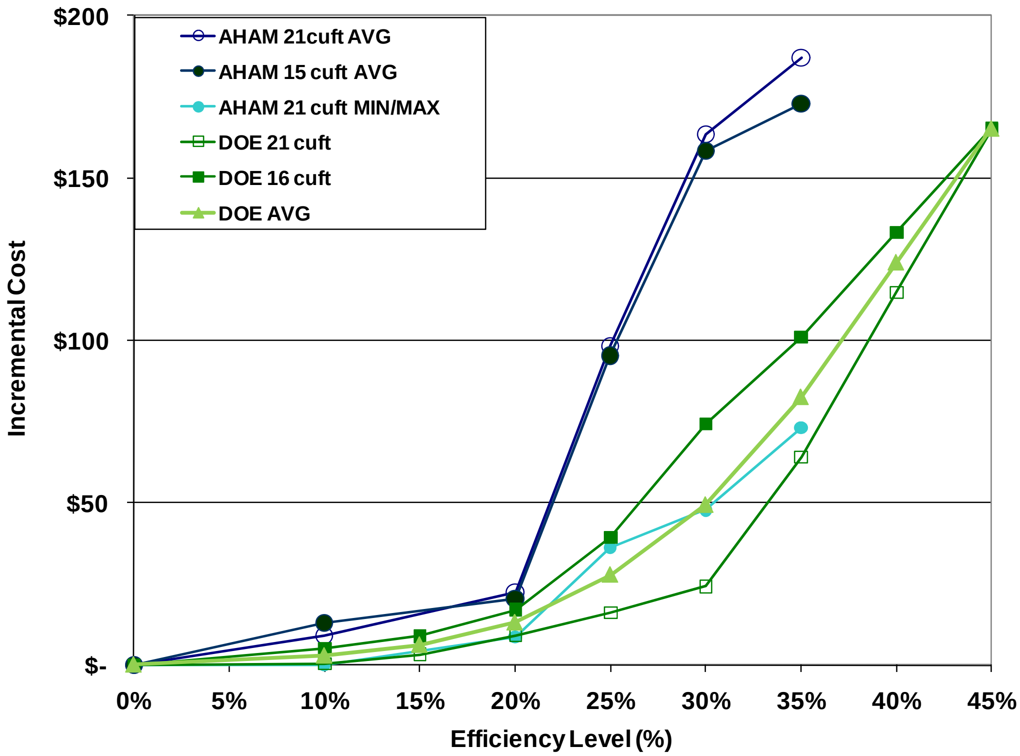

Figure 5.9.4 Incremental Cost Curves for Product Class 3

Per-product incremental cost associated with capital expenditures and one-time expenses have been calculated as follows based on the AHAM data for these cost categories. Total reported industry expenditures for each of the four categories (building, equipment, R&D, marketing) are divided by the percent of shipments represented by the data as reported by AHAM to determine the total industry value of each of these expenditures. These values are then added to obtain the total one-time expenditures for the product class for each of the two product class sizes for which data was provided. The one-time expenditures for the small and large size products are added to obtain total product class one-time expenditures. For product classes for which data were reported for only one of the sizes (product classes 5 and 11), the total for the size is doubled to represent the total one-time expenditures for the entire product class. Allocation of the one-time expenditures is based on the projected shipments for the product class for the first 10 years of the life of the new standard as determined for the NIA. The expenditures are divided by the total of these shipments to determine the impact of one-time expenditures per unit. This value is then added to the incremental costs for the product represented by materials, labor, and overhead.

The data provided for the 21 ft^3 product class 3 refrigerator-freezers includes results for the average, the maximum, and the minimum cost data provided by manufacturers responding to the query for incremental cost data. Different numbers of responses were obtained for the average than for the minimum and maximum, as indicated in Table 5.9.2. The results for minimum and maximum, provided by manufacturers representing 57% of shipments for product class 3, are nearly equal. This suggests that the average cost data provided by these same manufacturers is nearly equal to these minimum and maximum values. The cost curve for these manufacturers, shown in Figure 5.9.4 with adjustments for capital and one-time expenditures, agrees very well with DOE results. The average cost data provided by the manufacturer(s) representing the remaining 42% of the product class shipments must have been quite high.

In spite of the apparently good agreement between the DOE results and the AHAM data for the manufacturers who reported minimum and maximum incremental costs, there still remains a key discrepancy. DOE discussed the data submittals with some manufacturers after AHAM's aggregation of the data, and the manufacturers reported that insulation thickness increases were considered as part of the design options associated with the data. Since DOE's results did not consider insulation thickness increases, it would be expected that the DOE results would indicate higher costs.

5.9.2.2 Product Class 5

Incremental cost data for product class 5 refrigerator-freezers provided by AHAM are summarized in Table 5.9.2 below.

Table 5.9.3 AHAM Incremental Cost Data for Product Class 5

Efficiency Level			10%	20%	25%	30%	35%
Product Class 5—19 ft^3							
Incremental Cost	Average (86%)*	Material	$2.23	$6.54	$48.82	$56.67	$86.17
		Labor	$0.20	$0.25	$0.36	$0.71	$1.00
		Overhead	$0.33	$0.46	$0.49	$0.65	$0.85
	Minimum (82%)*	Material	$1.86	$9.67	$51.24	$56.09	$85.59
		Labor	$0.13	$0.20	$0.21	$0.26	$0.55
		Overhead	$0.41	$0.62	$0.65	$0.82	$1.01
	Maximum (82%)*	Material	$1.86	$9.67	$51.24	$56.09	$85.59
		Labor	$0.13	$0.20	$0.21	$0.26	$0.55
		Overhead	$0.41	$0.62	$0.65	$0.82	$1.01
CCE & OTPCE ($million)	Total Industry	Building CAPX (86%--4)*	$0.1	$0.2	$0.5	$0.8	$1.0
		Tooling/Equipment CAPX (86%--4)*	$0.3	$0.8	$31.0	$31.3	$36.5
		R&D (86%--4)*	$0.9	$1.7	$3.2	$4.0	$12.3
		Marketing (86%--4)*	$0.2	$2.7	$2.8	$2.8	$2.8
	Shipment-Weighted Average	Building CAPX	$0	$0	$0	$0.01	$0.01
		Tooling/Equipment CAPX	$0	$0.01	$7.74	$7.75	$8.00
		R&D	$0.01	$0.52	$0.54	$0.56	$2.52
		Marketing	$0	$1.71	$1.71	$1.71	$1.71

CCE&OTPCE: Conversion Capital Expenditures and One-Time Product Conversion Expenses. Material, Labor, and Overhead are per unit. Blank entries indicate that there were insufficient responses for AHAM to provide data.
*Percent of Product Class 5 shipments represented by these data and number of manufacturers represented (for capital and one-time expenditures).

The AHAM incremental cost data for product class 5 is compared with the calculations carried out by DOE in Figure 5.9.5 below. The DOE costs in these curves have the manufacturer markup taken out so that they can be compared on a consistent basis. The AHAM curves include material, labor, overhead, and depreciation and one-time expenses. The AHAM and DOE data are in good agreement, except at the 25% and 30% efficiency levels. However, as with product class 3, the agreement may not be entirely consistent because the DOE results did not consider insulation thickness increases.

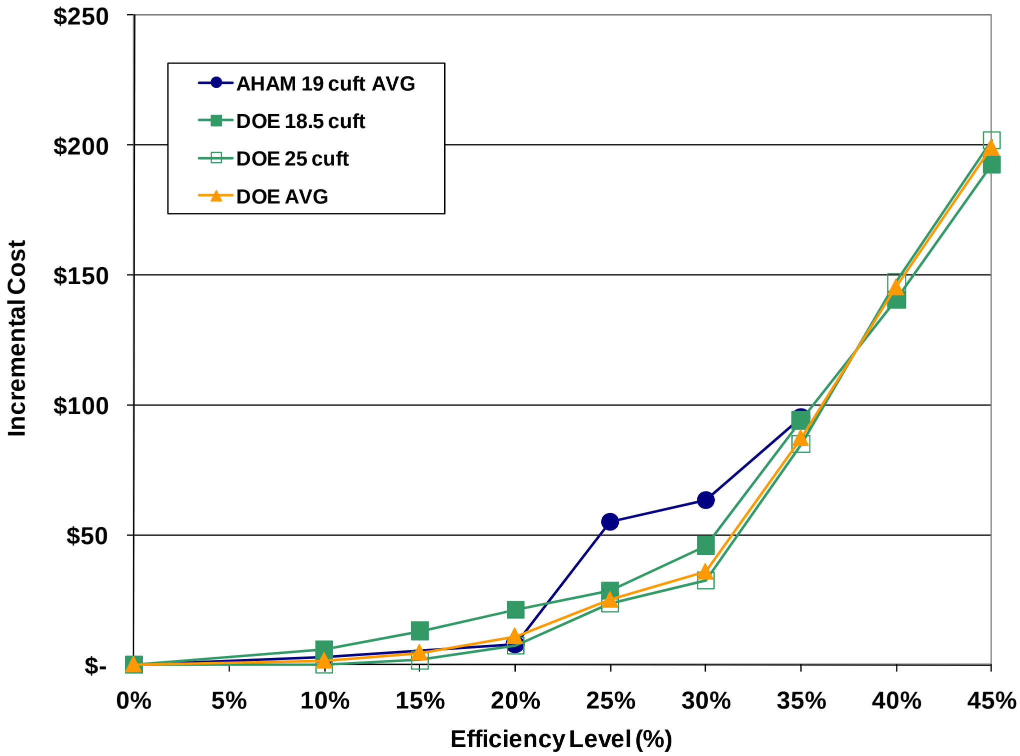

Figure 5.9.5 Incremental Cost Curves for Product Class 5

5.9.2.3 Product Class 7

Incremental cost data for product class 7 refrigerator-freezers provided by AHAM is summarized in Table 5.9.4 below.

Table 5.9.4 AHAM Incremental Cost Data for Product Class 7

Efficiency Level				10%	20%	25%	30%	35%
Product Class 7—22 ft^3								
Incremental Cost		Average (97%)*	Material	$7.83	$52.26	$70.33	$84.58	$109.23
			Labor	$0	$1.78	$3.56	$3.68	$3.80
			Overhead	$0	$0	$0	$0.01	$0.03
CCE & OTPCE ($million)	Total Industry	Building CAPX		Blank	Blank	Blank	Blank	Blank
		Tooling/Equipment CAPX (97%--3)*		$6.0	$6.0	$91.0	$91.0	$91.0
		R&D		Blank	Blank	Blank	Blank	Blank
		Marketing		Blank	Blank	Blank	Blank	Blank
	Shipment-Weighted Average	Building CAPX		Blank	Blank	Blank	Blank	Blank
		Tooling/Equipment CAPX		$1.32	$1.32	$17.48	$17.48	$17.48
		R&D		Blank	Blank	Blank	Blank	Blank
		Marketing		Blank	Blank	Blank	Blank	Blank
Product Class 7—25 ft^3								
Incremental Cost		Average (97%)*	Material	$4.48	$11.60	$50.47	$50.62	$53.08
			Labor	$0.03	$0.06	$1.89	$3.61	$3.65
			Overhead	$0.07	$0.11	$0.12	$0.15	$0.21
		Minimum (80%)*	Material	$0.25	$1.81	$10.01	$3.55	$5.03
			Labor	$0.02	$0.02	$0.02	$0.04	$0.05
			Overhead	$0.05	$0.07	$0.07	$0.11	$0.15
		Maximum (80%)*	Material	$4.39	$37.43	$65.02	$13.94	$15.19
			Labor	$0.03	$0.04	$0.14	$0.06	$0.07
			Overhead	$0.09	$0.14	$0.15	$0.18	$0.22
CCE & OTPCE ($million)	Total Industry	Building CAPX (80%--4)*		$0.1	$0.2	$0.6	$21.0	$21.3
		Tooling/Equipment CAPX (97%--5)*		$24.3	$25.2	$129.5	$242.4	$250.3
		R&D (80%--4)*		$1.9	$2.0	$4.5	$8.0	$9.4
		Marketing (80%--4)*		$2.7	$2.7	$2.8	$2.8	$2.8
	Shipment-Weighted Average	Building CAPX		$0	$0	$0.09	$12.12	$12.16
		Tooling/Equipment CAPX		$5.25	$5.25	$26.70	$66.41	$66.41
		R&D		$0.45	$0.45	$0.46	$1.51	$1.51
		Marketing		$1.50	$1.50	$1.50	$1.50	$1.50

CCE&OTPCE: Conversion Capital Expenditures and One-Time Product Conversion Expenses. Material, Labor, and Overhead are per unit. Blank entries indicate that there were insufficient responses for AHAM to provide data.
*Percent of the Product Class 7 shipments represented by these data and number of manufacturers represented (for capital and one-time expenditures).

The AHAM incremental cost data for product class 7 are compared with the calculations carried out by DOE in Figure 5.9.6.The DOE costs in these curves have the manufacturer markup taken out so that they can be compared on a consistent basis. The AHAM curves include material, labor, overhead, and depreciation and one-time expenses.

For the 22 ft^3 product 7 size, capital and one-time expenditure data was provided only for tooling/equipment costs. To assure that building, R&D, and marketing costs have been considered, the R&D and marketing costs for this product size have been set equal to the equivalent costs for the 26 ft^3 product size. The building capital cost has been assumed to be proportional to tooling/equipment capital cost for product class 7. For product class 7, the DOE cost estimates are higher than the AHAM data at higher efficiency levels. However, the leveling off of the AHAM 25 ft^3 curve is expected to be an anomaly of the reporting and aggregation process—this feature of the curve is not expected to be representative of the actual cost trend for this product.

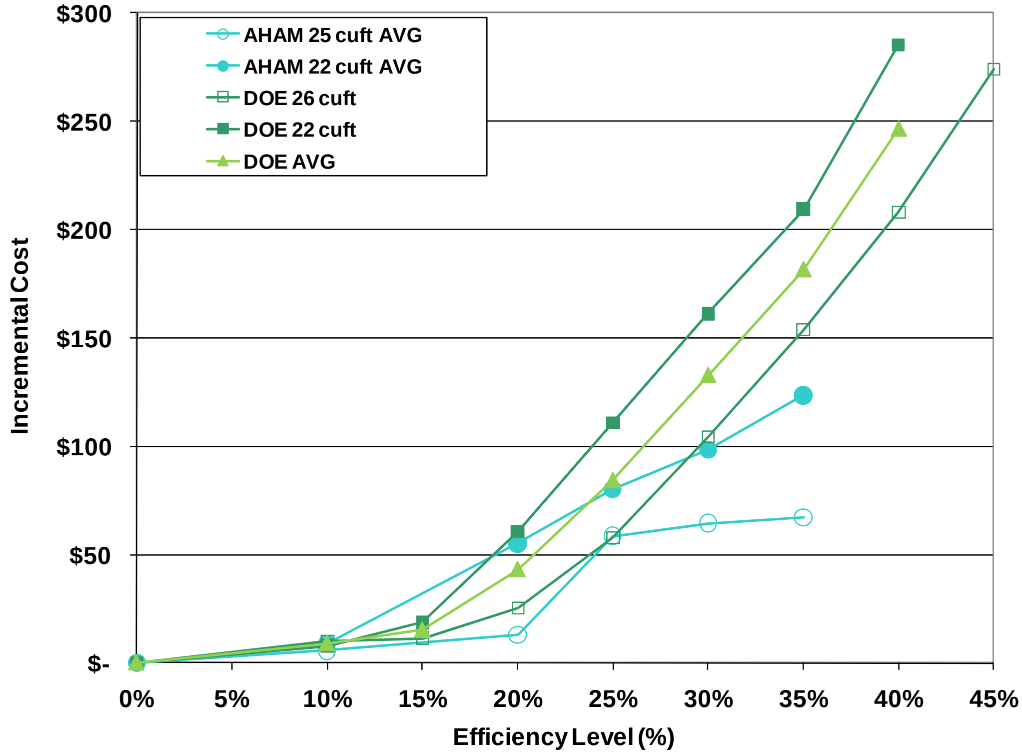

Figure 5.9.6 Incremental Cost Curves for Product Class 7

5.9.2.4 Product Class 9

Incremental cost data for product class 9 refrigerator-freezers provided by AHAM is summarized in Table 5.9.5 below.

Table 5.9.5 AHAM Incremental Cost Data for Product Class 9

Efficiency Level			10%	20%	25%	30%	35%
Product Class 9—14 ft^3							
Incremental Cost	Average (21%)*	Material	$10.86	$33.20	$21.92	$30.94	$40.86
		Labor	$1.03	$3.79	$2.27	$3.07	$4.26
		Overhead	$0.48	$1.28	$1.36	$1.45	$2.16
CCE & OTPCE ($million)	Total Industry	Building CAPX (21%--3)*	$0.1	$0.1	$3.2	$3.3	$3.5
		Tooling/Equipment CAPX (21%--3)*	$0.2	$0.5	$5.6	$10.6	$15.9
		R&D (21%--3)*	$0.3	$0.4	$2.8	$3.1	$3.2
		Marketing (21%--3)*	$0.2	$0.2	$0.3	$0.3	$0.3
	Shipment-Weighted Average	Building CAPX	$0	$0	$1.17	$1.17	$1.17
		Tooling/Equipment CAPX	$0	$0	$1.95	$3.90	$5.88
		R&D	$0	$0	$0.78	$0.79	$0.79
		Marketing	$0	$0	$0	$0	$0
Product Class 9—20 ft^3							
Incremental Cost	Average (21%)*	Material	$9.72	$32.90	$21.45	$31.55	$40.60
		Labor	$0.78	$3.55	$2.40	$3.20	$4.21
		Overhead	$0	$0.80	$1.50	$1.58	$1.98
CCE & OTPCE ($million)	Total Industry	Building CAPX (21%--3)*	$0	$0.2	$3.2	$3.4	$4.2
		Tooling/Equipment CAPX (21%--3)*	$0	$0.5	$8.2	$15.7	$23.4
		R&D (21%--3)*	$0	$0.3	$3.3	$3.7	$3.9
		Marketing (21%--3)*	$0	$0.2	$0.3	$0.3	$0.3
	Shipment-Weighted Average	Building CAPX	$0	$0	$1.17	$1.17	$1.18
		Tooling/Equipment CAPX	$0	$0	$2.96	$5.84	$8.76
		R&D	$0	$0	$1.17	$1.17	$1.17
		Marketing	$0	$0	$0	$0	$0

CCE&OTPCE: Conversion Capital Expenditures and One-Time Product Conversion Expenses. Material, Labor, and Overhead are per unit. Blank entries indicate that there were insufficient responses for AHAM to provide data.
*Percent of the Product Class 9 shipments represented by these data and number of manufacturers represented (for capital and one-time expenditures).

The AHAM incremental cost data for product class 9 are compared with the calculations carried out by DOE in Figure 5.9.7 below. The DOE costs in these curves have the manufacturer markup taken out so that they can be compared on a consistent basis. The AHAM curves include material, labor, overhead, and depreciation and one-time expenses. The DOE costs are lower than the AHAM data, especially at the 20% efficiency level, however the discrepancy diminishes at higher efficiency levels.

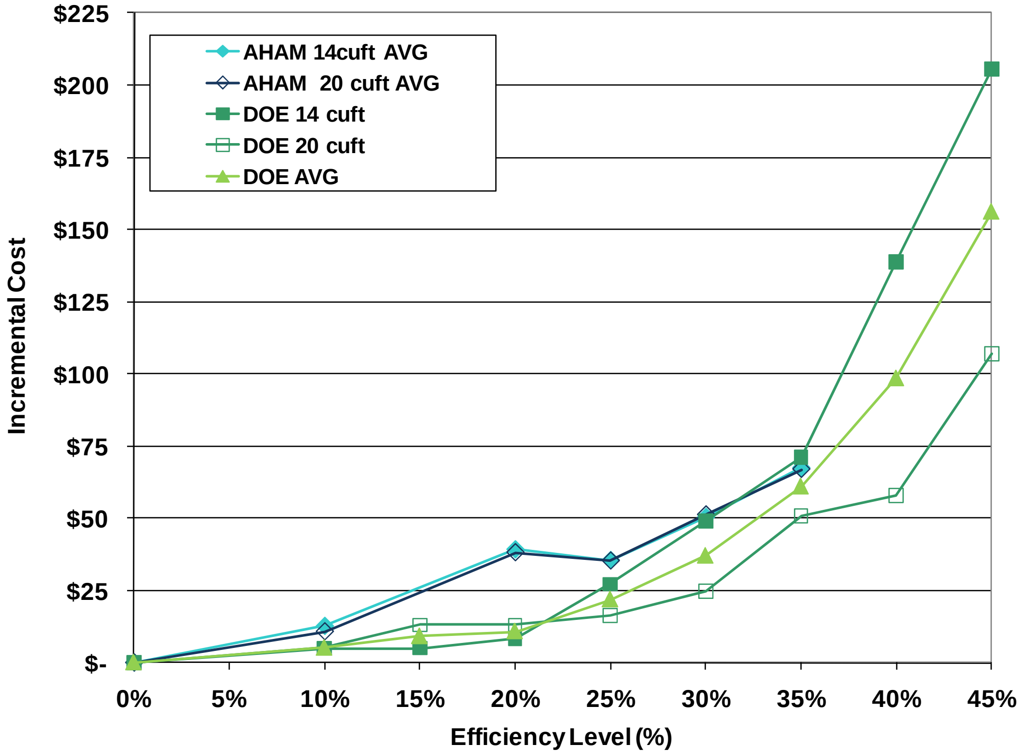

Figure 5.9.7 Incremental Cost Curves for Product Class 9

5.9.2.5 Product Class 11

Incremental cost data for product class 11 (compact refrigerators and refrigerator-freezers with manual defrost) provided by AHAM is summarized in Table 1 below.

Table 5.9.6 AHAM Incremental Cost Data for Product Class 11

Efficiency Level			10%	20%	25%	30%	35%
Product Class 11—5.5 ft^3							
Incremental Cost	Average (54%)*	Material	$16.53	$71.17	$120.81	$130.12	$135.40
		Labor	$0	$3.78	$7.55	$7.55	$7.55
		Overhead	$0	$0	$0	$0	$0
CCE & OTPCE ($million)	Total Industry	Building CAPX	Blank	Blank	Blank	Blank	Blank
		Tooling/Equipment CAPX (54%--3)*	$0	$1.1	$1.1	$5.3	$5.5
		R&D	Blank	Blank	Blank	Blank	Blank
		Marketing	Blank	Blank	Blank	Blank	Blank
	Shipment-Weighted Average	Building CAPX	Blank	Blank	Blank	Blank	Blank
		Tooling/Equipment CAPX	$0	$0.41	$0.44	$2.04	$2.20
		R&D	Blank	Blank	Blank	Blank	Blank
		Marketing	Blank	Blank	Blank	Blank	Blank
CCE&OTPCE: Conversion Capital Expenditures and One-Time Product Conversion Expenses. Material, Labor, and Overhead are per unit. Blank entries indicate that there were insufficient responses for AHAM to provide data. *Percent of the Product Class 11 shipments represented by these data and number of manufacturers represented (for capital and one-time expenditures).							

The AHAM incremental cost data for product class 11 are compared with the calculations carried out by DOE in Figure 5.9.8 below. The DOE costs in these curves have the manufacturer markup taken out so that they can be compared on a consistent basis. The AHAM curves include material, labor, overhead, and depreciation and one-time expenses. The discrepancy between the curves is very large. The high AHAM estimate for the 20% efficiency level is puzzling, because this is the ENERGY STAR level. DOE considers it unlikely that ENERGY STAR products of this product class could have $75 higher production cost than baseline efficiency products. Such products listed in the ENERGY STAR database are shown in Figure 5.9.9 below. The differences between the baseline and ENERGY STAR 4 ft^3 refrigerators of the reverse engineering work include a larger evaporator, a different compressor, and slightly thicker walls, differences that would incur an order of magnitude less than $75 in additional production cost. The design option analysis uses a slightly different combination to achieve the 20% efficiency level: thicker wall, higher compressor efficiency, and a larger condenser.

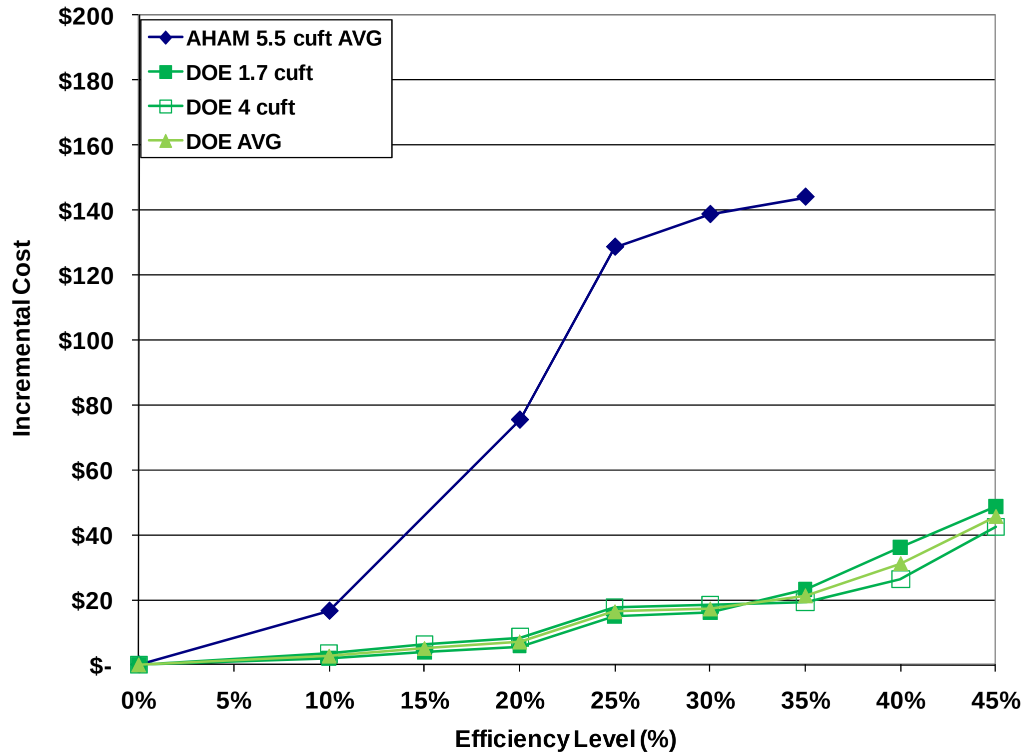

Figure 5.9.8 Incremental Cost Curves for Product Class 11

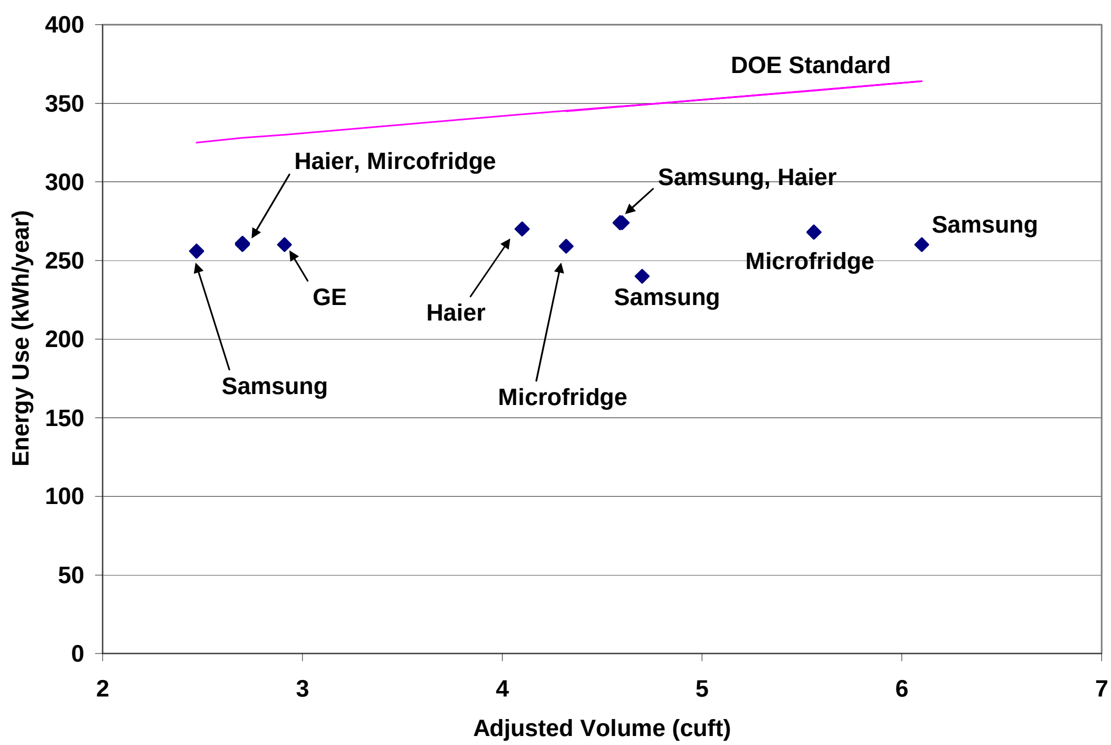

Figure 5.9.9 Product Class 11 Refrigerators listed in the ENERGY STAR Database

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[14] http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=480-3168-2-ND

APPENDIX 5-A. ENGINEERING DATA

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 5-A. ENGINEERING DATA

5-A.1 INTRODUCTION

The Energy-efficient Refrigerator Analysis Program (ERA) was used to calculate energy use for baseline and energy-saving configurations for the various product classes of refrigeration products. Inputs to this program were generated from reverse-engineering teardowns of select refrigerator and refrigerator-freezer models currently available. The values for the input variables are shown in tabular format in section 5-A.2. The input is provided to the extent possible in the format required for the Windows version of ERA. Because analysis was carried out with the DOE version of ERA for most of the products, in some cases the input format may not translate directly, and the output values may not match exactly.

The incremental cost curves describing costs to attain each analyzed efficiency level are based on the energy use output from the ERA program. Development of costs for these curves is described in chapter 5. The tables in section 5-A.3 show these incremental cost curves in tabular format, with identification of the design options required to reach each efficiency level shown.

As part of the engineering analysis, DOE solicited input from manufacturers on a range of technical topics affecting energy use in refrigeration products. The questionnaire used to facilitate these interviews is shown in section 5-A.4.

5-A.2 ERA INPUTS

The ERA inputs for each of the units selected for reverse-engineering analysis are shown below. Some general notes regarding the data include the following:

1. Compressor compartment insulation thickness is specified directly in Windows ERA, while DOS ERA used bottom wall thickness.

2. The ERA input for door openings is not provided, since DOE conducted analysis based on closed doors.

3. Windows ERA includes separate input for the air in the compressor compartment. DOS ERA used the air temperature underneath the cabinet for this region.

4. DOE conducted all analyses using single evaporator system configuration with HFC-134a refrigerant.

5. The tube and fin heat exchanger configuration implies forced convection air flow.

6. See the Windows ERA program for definitions of air flow directions for forced convection wire fin condensers.

7. Some products analyzed had spine fin evaporators, which are not supported by ERA. Input for a separate spine fin analysis spreadsheet calculation is provided in the tables below for these products.

8. Windows ERA does not allow superheat or subcooling input of 0 ˚C, although DOS ERA does. Suggested input is 0.5 ˚C in cases where input of 0 ˚C is indicated.

Table 5-A.2.1: ERA Inputs for Top-Mount Refrigerator-Freezers (Product Class 3)

Top-Mount Refrigerator-Freezers	16 ft^3 Baseline	21 ft^3 Baseline	21 ft^3 E*
General Data			
Fresh Food Volume (ft^3)	11.6	15.3	15.3
Freezer Volume (ft^3)	4.1	5.3	5.3
Total Volume (ft^3)	15.7	20.6	20.6
Adjusted Volume (ft^3)	18.3	23.9	23.9
Rated Energy Use (kWh/yr)	455	509	408
Calculated Max. Energy Use (kWh/yr)	455	511	511
Rated Energy Use Below Maximum (%)	0.0	0.3	20.1
Cabinet Dimensions			
Cabinet Height (cm)	146.7	165.6	165.6
Cabinet Width (cm)	70.8	75.3	75.3
Depth, from Door Flange (cm)	62.6	74.3	74.3
Depth, from Door Outer Surface (cm)	71.1	80.7	80.7
Liner Properties			
Outer Liner Thickness (mm)	0.4	0.4	0.4
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	1.0	1.5	2.0
Liner Conductivity (W/m-C)	0.16	0.16	0.16
Compressor Compartment Dimensions			
Top Depth (cm)	12.7	12.4	12.4
Bottom Depth (cm)	21.6	25.8	25.8
Height (cm)	26.0	16.0	16.0
Wall (vertical) (cm)	4.3	5.1	5.1
Wall (horizontal) (cm)	4.3	5.1	5.1
Freezer Section			
Insulation Thickness			
Top Wall (cm)	5.3	7.1	7.1
Side Wall (cm)	5.5	7.5	7.5
Back Wall (cm)	7.0	7.9	7.9
Door (cm)	6.2	7.2	7.2
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Freezer Wedge Depth (cm)	7.6	7.0	7.0

Top-Mount Refrigerator-Freezers	**16 ft^3 Baseline**	**21 ft^3 Baseline**	**21 ft^3 E***
Freezer Flange Width (cm)	3.8	3.8	3.8
Heat Paths			
Freezer Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
Fzr Cabinet Penetration Heat Leak (W)	1.5	0.0	0.0
Fresh Food Section			
Insulation Thickness			
Side Wall (cm)	3.8	4.8	4.8
Back Wall (cm)	5.0	4.9	4.9
Bottom Wall (cm)	4.3	5.1	5.1
Door (cm)	4.1	4.7	4.7
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Fresh Food Wedge Depth (cm)	0.1	7.6	7.6
Fresh Food Flange Width (cm)	3.8	3.8	3.8
Heat Paths			
FF Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
FF Cabinet Penetration Heat Leak (W)	1.5	0.0	0.0
Mullion			
Distance to Top (cm)	44.5	50.8	50.8
Thickness w/Liners (cm)	5.7	7.1	7.1
Resistivity w/Liners (m2-C/W-cm)	0.5	0.5	0.5
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Freezer Section (°C)	-15	-15	-15
Fresh Food Section (°C)	7.2	7.2	7.2
Air Under Cabinet (°C)	35.0	35.0	35.0
Compressor Compartment (˚C)	35.0	35.0	35.0
Air Entering Condenser (°C)	32.2	33.0	33.0
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	14.0	10.5	10.5
Heater On-Time (Min)	8.0	4.8	4.8
Defrost Power (W)	390	413	413
Other Cycle-Dependent Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0.3	0.3	0.3
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0	0	0
Outside Cabinet (W)	0	0	0
Liquid Refrigerant Line Anti-Sweat			

Top-Mount Refrigerator-Freezers	**16 ft^3 Baseline**	**21 ft^3 Baseline**	**21 ft^3 E***
Freezer Door Flange			
Cycle Average Energy (W)	4	3.8	3.8
Fraction Heat Leak (0-1)	0.5	0.3	0.3
Fresh Food Door Flange			
Cycle Average Energy (W)	0	0	0
Fraction Heat Leak (0-1)	0	0	0
Mullion			
Cycle Average Energy (W)	1.5	1.3	1.3
Heat Leak to Freezer (0-1)	0.25	0.25	0.25
Heat Leak to Fresh Food (0-1)	0.25	0.25	0.25
Evaporator Design			
Exit Superheat	2	2	0
Fin Type (flat, wavy, herringbone)	Spine	Flat	Flat
Fan Motor Type	AC-Input BLDC	Shaded Pole	Shaded Pole
Fan Power (W)	3.5	6.1	5.7
Air Flow Rate (Liter/s)	16.6	21.3	21.3
Tube Characteristics			
Width of Tube Row	52.1	45.7	45.7
Tube OD (mm)	9.4	7.9	7.9
Tube Wall Thickness (mm)	0.76	0.6	0.6
# of Tubes Deep	7	4	4
Tube Pitch (cm)	2.5	3.8	3.8
# of Tubes Normal to Airflow	2	6	6
Normal Tube Pitch (cm)	2.5	1.9	1.9
Fin Characteristics			
Fin Thickness (mm)	0.25	0.13	0.13
Fin Pitch (mm)	9.5	6.3	6.3
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.93	0.89	0.89
Spine Fin Input Data			
Spine Height (mm)	10.5	NA	NA
Spine Width (mm)	0.79	NA	NA
Condenser Design		[a]	[a]
Exit Subcooling (°C)	2	0	0
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin	Tube & Fin	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire	Wire	Wire

[a] Surface areas calculated by the condenser routine were increased by a factor of 2.56 for the 21 ft^3 top-mount refrigerators to calibrate with test data for condensing temperatures.

Top-Mount Refrigerator-Freezers	16 ft^3 Baseline	21 ft^3 Baseline	21 ft^3 E*
Fan Motor Type	Shaded Pole	Shaded Pole	AC-input BLDC
Fan Power (W)	11.2	9.4	3.3
Air Flow Rate (Liter/s)	30.0	26.0	31.2
Tube Characteristics			
Airflow Direction (W, L, H)	W	W	W
Tube OD (mm)	4.8	4.8	4.8
Tube Wall Thickness (mm)	0.8	0.6	0.6
Length of Tube in “L” Direction	59.6	20.1	20.1
# of Tubes in H Direction	1	8	8
Tube Pitch (cm)	2.5	2.5	2.5
# of Tubes in W Direction	14	6	6
Tube Pitch (cm)	2.5	2.5	2.5
Fraction Air through Exchanger (0-1)	0.6	0.9	0.9
Fin Characteristics			
Wire OD (mm)	1.5	1.1	1.1
# of Wires on 1-side per layer	95	29	29
Wire Mounting (1-side, 2-sides)	2-sides	2-sides	2-sides
Wire Fin Pitch (mm)	5.1	5.1	5.1
Wire Length (cm)	34.9	14.0	14.0
Wire Conductivity (W/m-K)	44.7	44.7	44.7
Compressor Data			
Manufacturer	Matsushita	Matsushita	Matsushita
Model #	DGS57C84RAU	SF51C97RAU6	DHS57C85RAU
Cycles per hour	1.0	1.0	1.0
Interchanger			
Effectiveness (0-1)	0.9	0.95	0.95

Table 5-A.2.2: ERA Inputs for Bottom-Mount Refrigerator-Freezers (Product Class 5)

Bottom-Mount Refrigerator-Freezers	18.5 ft^3	25 ft^3 E*, #1	25 ft^3 E*, #2
General Data			
Fresh Food Volume (ft^3)	13.1	17.8	17.6
Freezer Volume (ft^3)	5.4	7.3	7.7
Total Volume (ft^3)	18.5	25.1	25.3
Adjusted Volume (ft^3)	21.9	29.6	30.2
Rated Energy Use (kWh/yr)	476	475	478
Calculated Max. Energy Use (kWh/yr)	560	595	598
Rated Energy Use Below Maximum (%)	15.0	20.2	20.0
Cabinet Dimensions			
Cabinet Height (cm)	160.7	168.3	168.0
Cabinet Width (cm)	75.3	90.5	90.8
Depth, from Door Flange (cm)	69.2	72.4	71.3
Depth, from Door Outer Surface (cm)	76.8	79.4	78.3
Liner Properties			
Outer Liner Thickness (mm)	0.5	0.6	0.5
Outer Liner Conductivity (W/m-C)	44.7	43.3	44.7
Inner Liner Thickness (mm)	1.3	1.9	1.4
Liner Conductivity (W/m-C)	0.16	0.16	0.16
Compressor Compartment Dimensions			
Top Depth (cm)	16.5	17.1	12.7
Bottom Depth (cm)	27.0	27.3	25.4
Height (cm)	24.5	24.1	22.9
Wall (vertical) (cm)	7.0	6.9	6.6
Wall (horizontal) (cm)	7.0	6.9	6.6
Freezer Cabinet			
Insulation Thickness			
Side Wall (cm)	6.9	7.5	6.8
Back Wall (cm)	7.9	6.5	7.6
Bottom (cm)	7.0	6.9	6.6
Door (cm)	6.3	6.0	6.9
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.53
Wedge/Flange Dimensions			
Freezer Wedge Depth (cm)	5.1	6.4	5.1
Freezer Flange Width (cm)	3.8	3.8	5.4
Heat Paths			
Freezer Gasket Heat Leak (W/m-100C)	9.5	8.0	8.0
Fzr Cabinet Penetration Heat Leak (W)	0	3	0
Fresh Food Cabinet			
Insulation Thickness			
Top Wall (cm)	5.2	3.9	4.2
Side Wall (cm)	4.2	5.1	3.5

Bottom-Mount Refrigerator-Freezers	18.5 ft^3	25 ft^3 E*, #1	25 ft^3 E*, #2
Back Wall (cm)	5.7	6.8	4.1
Door (cm)	4.3	4.9	6.9
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.53
Wedge/Flange Dimensions			
Fresh Food Wedge Depth (cm)	10.2	11.4	0.0
Fresh Food Flange Width (cm)	3.8	3.8	3.4
Heat Paths			
FF Gasket Heat Leak (W/m-100C)	9.5	8.0	8.0
FF Cabinet Penetration Heat Leak (W)	0.0	3.0	0.0
Mullion			
Distance to Top (cm)	92.7	100.0	94.3
Thickness w/Liners (cm)	5.4	5.4	7.3
Resistivity w/Liners (m2-C/W-cm)	0.50	0.51	0.5
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Freezer Section (°C)	-15.0	-15.0	-15.0
Fresh Food Section (°C)	7.2	7.2	7.2
Air Under Cabinet (°C)	36.6	35.0	35.0
Compressor Compartment (˚C)	36.6	35.0	35.0
Air Entering Condenser (°C)	32.2	33.0	34.5
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	7.5	38.0	38.0
Heater On-Time (Min)	7.0	7.0	24.0
Defrost Power (W)	375	450	440
Other Cycle-Dependent Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	3	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Freezer Section (W)	0.7	0.0	4.2
Fresh Food Section (W)	0.0	0.4	0.0
Outside Cabinet (W)	0.0	0.0	1.5
Liquid Refrigerant Line Anti-Sweat			
Freezer Door Flange			
Cycle Average Energy (W)	1.0	3.8	3.0
Fraction Heat Leak (0-1)	0.75	0.5	0.75
Fresh Food Door Flange			
Cycle Average Energy (W)	0	0	0
Mullion			
Cycle Average Energy (W)	2	1.3	1.0
Heat Leak to Freezer (0-1)	0.75	0.5	0.5

Bottom-Mount Refrigerator-Freezers	**18.5 ft^3**	**25 ft^3 E*, #1**	**25 ft^3 E*, #2**
Heat Leak to Fresh Food (0-1)	0.15	0.25	0.25
Evaporator Design			
Exit Superheat (°C)	0.8	4.0	1.0
Fin Type (flat, wavy, herringbone)	Flat	Flat	Spine Fin
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	Shaded Pole	DC-Input BLDC
Fan Power (W)	6.2	6.5	3.8
Air Flow Rate (Liter/s)	20	30	16.6
Tube Characteristics			
Width of Tube Row	48.9[b]	71.1[c]	76.2
Tube OD (mm)	7.9	7.9	9.7
Tube Wall Thickness (mm)	0.5	0.5	1.1
# of Tubes Deep	4.5[b]	4.5[c]	7
Tube Pitch (cm)	3.8	3.6	2.5
# of Tubes Normal to Airflow	4	4	2
Normal Tube Pitch (cm)	1.9	1.9	2.5
Fin Characteristics			
Fin Thickness (mm)	0.13	0.13	0.25
Fin Pitch (mm)	5.1	5.1	9.5
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.98	0.89	1.0
Spine Fin Input Data			
Spine Height (mm)	NA	NA	10.5
Spine Width (mm)	NA	NA	0.8
Condenser Design			
Exit Subcooling (°C)	0.7	1.0	1.5
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin	Tube & Fin	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire	Wire	Wire
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	AC-Input BLDC	AC-Input BLDC	DC-Input BLDC
Fan Power (W)	3.8	3.7	2.6
Air Flow Rate (Liter/s)	30	30.8	23.7
Tube Characteristics			
Airflow Direction (W, L, H)	L	L	H
Tube OD (mm)	4.8	4.8	5.0
Tube Wall Thickness (mm)	0.5	0.6	0.64

[b] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 55.0 cm to compensate for the missing tubes.

[c] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 80.0 cm to compensate for the missing tubes.

Bottom-Mount Refrigerator-Freezers	**18.5 ft^3**	**25 ft^3 E*, #1**	**25 ft^3 E*, #2**
Length of Tube in "L" Direction (cm)	34.9	34.9	52.4
# of Tubes in H Direction	2	2	3
Tube Pitch (cm)	2.2	3.8	0.8
# of Tubes in W Direction	26	30	10
Tube Pitch (cm)	2.2	2.2	2.5
Fraction Air through Exchanger (0-1)	0.8	1.0	1
Fin Characteristics			
Wire OD (mm)	1.3	1.3	1.4
# of Wires on 1-side	55	51	206
Wire Mounting (1-side, 2-sides)	2-sides	2-sides	2-sides
Wire Fin Pitch (mm)	4.8	4.8	2.5
Wire Length (cm)	57.1	66.7	23.5
Wire Conductivity (W/m-K)	44.7	44.7	44.7
Compressor Data			
Manufacturer	Embraco	Tecumseh	Embraco
Model	EMX70HSC	TPG1370YXA	VEGY 8H
Cycles per hour	1.0	1.5	0.45
Interchanger			
Effectiveness (0-1)	NA	0.95	0.98
Compressor Shell Inlet Temperature (°C)	33.3	Unspecified	Unspecified

Table 5-A.2.3: ERA Inputs for Bottom-Mount Refrigerator-Freezers w/TTD Ice (Product Class 5A)

Bottom-Mount Refrigerator-Freezers w/TTD Ice	25 ft^3
General Data	
Fresh Food Volume (ft^3)	17.6
Freezer Volume (ft^3)	7.1
Total Volume (ft^3)	24.7
Adjusted Volume (ft^3)	29.2
Rated Energy Use (kWh/yr)	547
Calculated Max. Energy Use (kWh/yr)	685
% Rated Energy Use Below Maximum (%)	20.0
Cabinet Dimensions	
Cabinet Height (cm)	171.1
Cabinet Width (cm)	91.4
Depth, from Door Flange (cm)	68.6
Depth, from Door Outer Surface (cm)	76.2
Liner Properties	
Outer Liner Thickness (mm)	0.5
Outer Liner Conductivity (W/m-C)	44.7
Inner Liner Thickness (mm)	1.4
Liner Conductivity (W/m-C)	0.16
Compressor Compartment Dimensions	
Top Depth (cm)	13.5
Bottom Depth (cm)	26.7
Height (cm)	24.5
Wall (vertical) (cm)	6.8
Wall (horizontal) (cm)	6.8
Freezer Cabinet	
Insulation Thickness	
Side Wall (cm)	6.8
Back Wall (cm)	7.9
Bottom (cm)	6.8
Door (cm)	7.1
Insulation Resistivity	
All Walls (m2-C/W-cm)	0.48[d]
Wedge/Flange Dimensions	
Freezer Wedge Depth (cm)	2.5
Freezer Flange Width (cm)	4.5
Heat Paths	
Freezer Gasket Heat Leak (W/m-100C)	8[e]

[d] Product has insulation using cyclopentane blowing agent.

[e] The heat leak parameter entered into ERA was increased to 12.63 to account for additional gasket length, since the freezer compartment of this product has two drawers.

Bottom-Mount Refrigerator-Freezers w/TTD Ice	**25 ft^3**
Freezer Cabinet Penetration Heat Leak (W)	0
Fresh Food Cabinet	
Insulation Thickness	
Top Wall (cm)	5.2
Side Wall (cm)	5.1
Back Wall (cm)	4.7
Door (cm)	5.1
Insulation Resistivity	
All Walls (m2-C/W-cm)	0.48
Wedge/Flange Dimensions	
Fresh Food Wedge Depth (cm)	11.4
Fresh Food Flange Width (cm)	4.8
Heat Paths	
Fresh Food Gasket Heat Leak (W/m-100C)	8[f]
Fresh Food Cabinet Penetration Heat Leak (W)	3.0
Mullion	
Distance to Top (cm)	102.2
Thickness w/Liners (cm)	5.1
Resistivity w/Liners (m2-C/W-cm)	0.47
Air and Cabinet Temperatures	
Room Air (°C)	32.2
Freezer Section (°C)	-15.0
Fresh Food Section (°C)	7.2
Air Under Cabinet (°C)	35.0
Compressor Compartment (˚C)	35.0
Air Entering Condenser (°C)	32.2
Defrost and Controls Energy	
Defrost Type (Automatic, Manual)	Automatic
Timer Interval (Hr)	38.0
Heater On-Time (Min)	12.7
Defrost Power (W)	396
Other Cycle-Dependent Loads	
Freezer Section (W)	0
Fresh Food Section (W)	0
Outside Cabinet (W)	0
Constant Electrical Loads	
Freezer Section (W)	0
Fresh Food Section (W)	0
Outside Cabinet (W)	4.0
Liquid Refrigerant Line Anti-Sweat	

[f] The heat leak parameter entered into ERA was increased to 12.3 to account for additional gasket length, since the fresh food compartment of this product has French doors.

Bottom-Mount Refrigerator-Freezers w/TTD Ice	**25 ft^3**
Freezer Door Flange	
Cycle Average Energy (W)	3.8
Fraction Heat Leak (0-1)	0.5
Fresh Food Door Flange	
Cycle Average Energy (W)	0
Fraction Heat Leak (0-1)	0
Mullion	
Cycle Average Energy (W)	1.3
Heat Leak to Freezer (0-1)	.5
Heat Leak to Fresh Food (0-1)	.25
Evaporator Design	
Exit Superheat (°C)	0.8
Fin Type (flat, wavy, herringbone)	Flat
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	DC-Input BLDC
Fan Power (W)	1.5
Air Flow Rate (Liter/s)	16.0
Tube Characteristics	
Width of Tube Row	70.5[g]
Tube OD (mm)	7.9
Tube Wall Thickness (mm)	0.7
# of Tubes Deep	4.5[g]
Tube Pitch (cm)	3.8
# of Tubes Normal to Airflow	4
Normal Tube Pitch (cm)	2.5
Fin Characteristics	
Fin Thickness (mm)	0.15
Fin Pitch (mm)	5.1
Fin Conductivity (W/m-K)	190
Fraction Finned (0-1)	0.90
Condenser Design	
Exit Subcooling (°C)	0.7
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Tube & Fin
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	DC-Input BLDC
Fan Power (W)	1.6
Air Flow Rate (Liter/s)	24.0
Tube Characteristics	
Airflow Direction (W, L, H)	W
Tube OD (mm)	5.0

[g] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 79.3 cm to compensate for the missing tubes.

Bottom-Mount Refrigerator-Freezers w/TTD Ice	25 ft^3
Tube Wall Thickness (mm)	0.64
Length of Tube in "L" Direction (cm)	15.2
# of Tubes in H Direction	12
Tube Pitch (cm)	2.2
# of Tubes in W Direction	10
Tube Pitch (cm)	2.5
Fraction Air through Exchanger (0-1)	0.9
Fin Characteristics	
Wire OD (mm)	1.4
# of Wires on 1-side	22
Wire Mounting (1-side, 2-sides)	2-sides
Wire Fin Pitch (mm)	6.4
Wire Length (cm)	18.0
Wire Conductivity (W/m-K)	44.7
Compressor Data	
Manufacturer	Embraco
Model #	EGX90HLC
Cycles per Hour	1.0
Interchanger	
Effectiveness (0-1)	0.95

Table 5-A.2.4: ERA Inputs for Side-Mount Refrigerator-Freezers (Product Classes 4 and 7)

Side-Mount Refrigerator-Freezers	PC7 26 ft^3	PC7 26 ft^3 E*	PC4 22 ft^3
General Data			
Fresh Food Volume (ft^3)	16.5	16.5	14.8
Freezer Volume (ft^3)	9.5	9.5	7.0
Total Volume (ft^3)	26.0	26.0	
Adjusted Volume (ft^3)	32.0	32.0	26.3
Rated Energy Use (ft^3)	728	582	635
Calculated Max. Energy Use (kWh/yr)	729	729	637
% Rated Energy Use Below Maximum (%)	0.2	20.2	0.3
Cabinet Dimensions			
Cabinet Height (cm)	165.9	165.9	162.6
Cabinet Width (cm)	90.2	90.2	85.1
Depth, from Door Flange (cm)	72.0	72.0	69.3
Depth, from Door Outer Surface (cm)	80.3	80.3	77.8
Liner Properties			
Outer Shell Thickness (mm)	0.5	1	0.4
Shell Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	0.5	1	0.4
Liner Conductivity (W/m-C)	0.16	0.16	44.7
Compressor Compartment Dimensions			
Top Depth (cm)	15.9	15.9	24.1
Bottom Depth (cm)	27.9	27.9	30.5
Height (cm)	23.5	23.5	25.1
Wall (vertical) (cm)	8.3	8.3	5.8
Wall (horizontal) (cm)	8.3	8.3	5.8
Freezer Cabinet			
Insulation Thickness – Freezer			
Top Wall (cm)	7.2	7.2	6.2
Side Wall (cm)	5.7	5.7	7.3
Back Wall (cm)	7.8	7.8	5.7
Bottom (cm)	8.3	8.3	5.8
Door (cm)	6.4	6.4	5.7
Insulation Resistivity - Freezer			
All Walls (m2-C/W-cm)	0.50	0.50	0.5
Wedge/Flange Dimensions			
Freezer Wedge Depth (cm)	0.1	0.1	7.0
Freezer Flange Width (cm)	5.7	5.7	3.8
Heat Paths			
Fzr Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
Fzr Cabinet Penetration Heat Leak (W)	11.0	11.0	8.0
Fresh Food Cabinet			

Side-Mount Refrigerator-Freezers	PC7 26 ft^3	PC7 26 ft^3 E*	PC4 22 ft^3
Insulation Thickness – Fresh Food			
Top Wall (cm)	4.0	4.0	4.0
Side Wall (cm)	3.6	3.6	3.8
Back Wall (cm)	3.6	3.6	4.8
Bottom (cm)	6.2	6.2	4.7
Door (cm)	6.4	6.4	5.7
Insulation Resistivity – Fresh Food			
All Walls (m2-C/W-cm)	0.50	0.50	0.5
Wedge/Flange Dimensions			
Fresh Food Wedge Depth (cm)	0.1	0.1	11.4
Fresh Food Flange Width (cm)	3.6	3.6	3.8
Heat Paths			
FF Gasket Heat Leak (W/m-100C)	9.0	9.0	9.0
FF Cabinet Penetration Heat Leak (W)	8.0	8.0	5.0
Mullion			
Distance to Right Side Wall (cm)	49.2	49.2	49.4
Thickness w/Liners (cm)	3.5	3.5	3.7
Resistivity w/Liners (m2-C/W-cm)	0.53	0.53	0.52
Air and Cabinet Temperatures			
Room Air (°C)	32.3	32.2	32.3
Freezer Section (°C)	-15.0	-15.0	-15.0
Fresh Food Section (°C)	7.2	7.2	7.2
Air Under Cabinet (°C)	35.0	35.0	35.0
Compressor Compartment (˚C)	35.0	35.0	35.0
Air Entering Condenser (°C)	33.0	33.0	33.0
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	10.0	10.0	38.0
Heater On-Time (Min)	5.0	5.0	18.0
Defrost Power (W)	500	500	535
Other Cycle-Dependent Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Freezer Section (W)	0	0	0
Fresh Food Section (W)	0.5	0.4	0
Outside Cabinet (W)	0	0	1.3
Electric Anti-Sweat Heat			
Freezer Door Flange			
Cycle Average Energy (W)	2.1	2.1	0
Fraction Heat Leak (0-1)	0.5	0.5	0.5
Liquid Refrigerant Line Anti-Sweat			

Side-Mount Refrigerator-Freezers	PC7 26 ft³	PC7 26 ft³ E*	PC4 22 ft³
Freezer Door Flange			
Cycle Average Energy (W)	3.0	3.0	3.8
Fraction Heat Leak (0-1)	0.5	0.5	0.5
Fresh Food Door Flange			
Cycle Average Energy (W)	0	0	0
Fraction Heat Leak (0-1)	0	0	0
Mullion			
Cycle Average Energy (W)	3.0	3.0	1.3
Heat Leak to Freezer (0-1)	0.5	0.5	0.25
Heat Leak to Fresh Food (0-1)	0.25	0.25	0.25
Evaporator Design			
Exit Superheat (°C)	4.0	4.0	2.0
Fin Type (flat, wavy, herringbone)	Flat	Flat	Spine Fin
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	Shaded Pole	DC-Input BLDC
Fan Power (W)	5.8	5.8	3.3
Air Flow Rate (Liter/s)	21.3	21.3	21.3
Tube Characteristics			
Width of Tube Row	27.9[h]	27.9[h]	24.1
Tube OD (mm)	7.9	7.9	9.3
Tube Wall Thickness (mm)	0.7	0.7	0.8
# of Tubes Deep	7.5[h]	7.5[h]	16
Tube Pitch (cm)	3.8	3.8	2.9
# of Tubes Normal to Airflow	8	8	2
Normal Tube Pitch (cm)	1.3	1.3	5.1
Fin Characteristics			
Fin Thickness (mm)	0.2	0.2	0.25
Fin Pitch (mm)	5.1	5.1	9.5
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.77	0.77	1
Spine Fin Input Data			
Spine Height (mm)	NA	NA	10.5
Spine Width (mm)	NA	NA	0.8
Condenser Design	[i]	[i]	[j]
Exit Subcooling (°C)	0.0	0.0	0.0
Configuration (Static, Hot-wall, Tube &	Tube & Fin	Tube & Fin	Tube & Fin

[h] Number of tubes in the air flow direction alternate 7 and 8, averaging 7.5. ERA analysis was conducted by selecting 8 rows deep and decreasing the tube row width to 26.2 cm to compensate for the added tubes.

[i] Surface areas calculated by the condenser routine were increased by a factor of 2.63 for the 26 ft³ side-mount refrigerators to calibrate with test data for condensing temperatures.

[j] Surface area calculated by the condenser routine was increased by a factor of 1.4 for the 22 ft³ side-mount refrigerator to calibrate with test data for condensing temperatures.

Side-Mount Refrigerator-Freezers	PC7 26 ft^3	PC7 26 ft^3 E*	PC4 22 ft^3
Fin, Microchannel)			
Air-side Configuration (wire, plain, smooth wavy, herringbone, slit, louver)	Wire	Wire	Wire
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	AC-Input BLDC	Shaded Pole
Fan Power (W)	8.5	3.4	9.1
Air Flow Rate (Liter/s)	26	26	26
Tube Characteristics			
Airflow Direction (W, L, H)	W	W	H
Tube OD (mm)	4.8	4.8	4.7
Tube Wall Thickness (mm)	0.6	0.6	0.63
Length of Tube in “L” Direction	18.2	18.2	58.0
# of Tubes in H Direction	9	9	2
Tube Pitch (cm)	2.3	2.3	2.5
# of Tubes in W Direction	10	10	10
Tube Pitch (cm)	2.5	2.5	2.5
Fin Characteristics			
Wire OD (mm)	1.1	1.1	1.3
# of Wires on 1-side	23	23	111
Wire Mounting (1-side, 2-sides)	2-sides	2-sides	2-sides
Wire Fin Pitch (mm)	5.6	5.6	5.2
Wire Length (cm)	24.1	24.1	23.5
Wire Conductivity (W/m-K)	44.7	44.7	44.7
Fraction Air through Exchanger (0-1)	1	1	1
Compressor Data			
Manufacturer	Tecumseh	Embraco	Matsushita
Model #	TSA1374YAS	EGX70HLC	DC57C84RCU6
Cycles per Hour	1.12	1.16	0.7
Interchanger			
Effectiveness (0-1)	0.95	0.95	0.85

Table 5-A.2.5: ERA Inputs for Upright Freezers with Automatic Defrost (Product Class 9)

Upright Freezers	14 ft^3 Baseline	20 ft^3 Baseline	20 ft^3 E*
General Data			
Freezer Volume (ft^3)	13.7	20.1	20.1
Adjusted Volume (ft^3)	23.7	34.8	34.8
Rated Energy Use (kWh/yr)	621	745	671
Calculated Max. Energy Use (kWh/yr)	621	758	758
% Rated Energy Use Below Maximum (%)	0.0	1.8	11.5
Cabinet Dimensions			
Cabinet Height (cm)	130.2	156.2	156.2
Cabinet Width (cm)	71.3	83.8	83.8
Depth, from Door Flange (cm)	66.7	64.5	64.5
Depth, from Door Outer Surface (cm)	72.4	71.1	71.1
Liner Properties			
Outer Liner Thickness (mm)	0.4	0.9	0.9
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	0.4	2.2	2.2
Liner Conductivity (W/m-C)	44.7	0.16	0.16
Compressor Compartment			
Height (cm)	1.9	27.9	27.9
Top Depth (cm)	17.8	5.1	5.1
Bottom Depth (cm)	17.8	30.5	30.5
Wall (vertical) (cm)	6.2	6.2	6.2
Wall (horizontal) (cm)	6.2	6.2	6.2
Insulation			
Insulation Thickness			
Top Wall (cm)	6.4	4.8	4.8
Side Wall (cm)	6.4	5.7	5.7
Back Wall (cm)	6.4	5.1	5.1
Bottom Wall (cm)	6.2	6.2	6.2
Door Average Thickness (cm)	3.8	7.1	7.1
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Wedge Depth (cm)	9.5	8.9	8.9
Flange Width (cm)	5.9	4.7	4.7
Heat Paths			
Gasket Heat Leak (W/m-100C)	12	9	9
Cabinet Penetration Heat Leak (W)	15	17	17
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Air Under Cabinet (°C)	35.0	35.5	35.5

Upright Freezers	14 ft^3 Baseline	20 ft^3 Baseline	20 ft^3 E*
Air Entering Condenser (°C)	32.2	32.2	32.2
Compressor Compartment (˚C)	35.0	35.5	35.5
Cabinet (°C)	-17.8	-17.8	-17.8
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Automatic	Automatic	Automatic
Timer Interval (Hr)	12.0	9.0	9.0
Heater On-Time (Min)	5.1	18.0	18.0
Defrost Power (W)	425	370	370
Other Cycle-Dependent Loads			
Outside Cabinet (W)	0	0	0
Cabinet (W)	1.6	0.3	0.3
Constant Electrical Loads			
Outside Cabinet (W)	0	0	0
Cabinet (W)	0	0	0
Refrigerant Line Anti-Sweat	None	None	None
Evaporator Design			
Exit Superheat	5.0	0.0	0.0
Fin Type (flat, wavy, herringbone)	Flat	Flat	Flat
Fan Motor Type (Shaded Pole, AC-Input BLDC, DC-Input BLDC)	Shaded Pole	Shaded Pole	AC-Input BLDC
Fan Power (W)	7.4	11.2	4.5
Air Flow Rate (Liter/s)	26.0	23.7	23.7
Tube Characteristics			
Width of Tube Row	55.9[k]	50.2	50.2
Tube OD (mm)	7.8	8.6	8.6
Tube Wall Thickness (mm)	0.8	0.9	0.9
# of Tubes Deep	4.5[k]	9	9
Tube Pitch (cm)	3.8	3.2	3.2
# of Tubes Normal to Airflow	4	2	2
Normal Tube Pitch (cm)	1.3	2.5	2.5
Fin Characteristics			
Fin Thickness (mm)	0.18	0.24	0.24
Fin Pitch (mm)	4.6	5.1	5.1
Fin Conductivity (W/m-K)	190	190	190
Fraction Finned (0-1)	0.9	0.9	0.9
Condenser Design			
Exit Subcooling (°C)	3	1	1
Configuration (Static, Hot-wall, Tube & Fin, Microchannel)	Hot-wall	Hot-wall	Hot-wall
Design Data			

[k] Number of tubes in the air flow direction alternate 4 and 5, averaging 4.5. ERA analysis was conducted by selecting 4 rows deep and increasing the tube row width to 62.9 cm to compensate for the missing tubes.

Upright Freezers	**14 ft^3 Baseline**	**20 ft^3 Baseline**	**20 ft^3 E***
Total Area (sides) (m^2)	2.0	2.1	2.1
Width, Side Normal to Tubes (cm)	288	333	333
Number of Legs	26	30	30
Length of Tubing on Wall (m)	20.3	22.0	22.0
Tube OD (mm)	4.7	6.4	6.4
Tube Wall Thickness (mm)	0.8	0.8	0.8
Thickness of Liner (mm)	0.38	0.9	0.9
Thermal Conductivity (W/m-K)	44.7	44.7	44.7
Number of other Hot Walls (0-2)	1	1	1
Second Hotwall (Top)			
Total Area (m^2)	0.47	0.52	0.52
Width, Side Normal to Tubes (cm)	71	84	84
Number of Legs	7	8	8
Length of Tubing on Wall (m)	5.4	5.8	5.8
Compressor Data			
Manufacturer	Embraco	Matsushita	Matsushita
Model #	EMY60HER	DG73C12RAU6	DG73C12RAU6
Cycles per Hour	1.4	1.5	1.5
Interchanger			
Effectiveness (0-1)	0.7	0.98	0.98

Table 5-A.2.6: ERA Inputs for Chest Freezers with Manual Defrost (Product Class 10)

Chest Freezers	15 ft^3 Baseline	15ft^3 E*	20 ft^3 Baseline
General Data			
Freezer Volume (ft^3)	14.8	14.8	19.9
Adjusted Volume (ft^3)	25.6	25.6	34.4
Rated Energy Use (kWh/yr)	394	354	480
Calculated Max. Energy Use (kWh/yr)	397	397	484
Rated Energy Use Below Maximum (%)	0.7	10.8	0.8
Cabinet Dimensions			
Cabinet Length (cm)	116.8	116.8	155.9
Cabinet Width (cm)	68.6	68.6	69.9
Depth, from Door Flange (cm)	81.1	81.1	81.6
Depth, from Door Outer Surface (cm)	86.8	86.8	87.0
Liner Properties			
Outer Liner Thickness (mm)	0.5	0.5	0.5
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	1.3	1.3	0.4
Liner Conductivity (W/m-C)	44.7	44.7	44.7
Compressor Compartment Dimensions[1]			
Height (cm)	27.9	27.9	22.9
Depth (cm)	9.1	9.1	22.2
Fractional width of compartment (cm)	1	1	1
Top Wall Insulation Thickness (cm)	6.9	6.9	7.7
Front Wall Insulation Thickness (cm)	5.1	5.1	7.7
Insulation Thickness			
Side Wall (cm)	6.6	6.6	6.7
Bottom (cm)	6.4	6.4	7.0
Door (cm)	4.8	4.8	5.1
Insulation Resistivity			
All Walls (m2-C/W-cm)	0.5	0.5	0.50
Wedge/Flange Dimensions			
Wedge Depth (cm)	1.3	1.3	1.0
Flange Width (cm)	4.6	4.6	5.4
Heat Paths			
Gasket Heat Leak (W/m-100C)	9	9	9
Cabinet Penetration Heat Leak (W)	0.0	0.0	0.0
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Air Under Cabinet (°C)	38.0	38.0	36.0
Air Entering Condenser (°C)	32.2	32.2	33.0
Compressor Compartment (°C)	38.0	38.0	36.0

[1] Windows ERA allows incorporation of the compressor compartment either into the long or the short wall. DOS ERA allowed incorporation only into the short wall, so the short wall option should be entered for Windows ERA.

Chest Freezers	15 ft^3 Baseline	15ft^3 E*	20 ft^3 Baseline
Cabinet (°C)	-17.8	-17.8	-17.8
Defrost and Controls Energy			
Defrost Type (Automatic, Manual)	Manual	Manual	Manual
Other Cycle-Dependent Loads			
Outside Cabinet (W)	0	0	0
Inside Cabinet (W)	0	0	0
Constant Electrical Loads			
Outside Cabinet (W)	0.4	0.4	0.1
Inside Cabinet (W)	0	0	0
Refrigerant Line Anti-Sweat	None	None	None
Evaporator Design (Cold Wall)			
Exit Superheat	0.5	0.5	0.5
Tube OD (mm)	6.4	6.4	7.9
Tube Wall Thickness (mm)	0.8	0.8	0.8
Side Walls (perimeter)			
Total Area of Side Walls (m^2)	1.57	1.57	2.73
Number of Tube Legs	9	9	9
Width Normal to Tubes	49.1	49.1	73
Liner Thickness (mm)	1.3	1.3	0.4
Liner Conductivity (W/mK)	44.7	44.7	44.7
Bottom Surface			
Area of Bottom Surface (m^2)	0.17	0.17	0.3
Number of Tube Legs	3	3	2
Width Normal to Tubes	16.4	16.4	15
Condenser Design			
Exit Subcooling (°C)	0.5	0.5	0.5
Configuration	Hot-wall	Hot-wall	Hot-wall
Total Area (m^2)	2.0	2.0	2.4
Width of Side Normal to Tubes (cm)	53.3	53.3	53.7
Number of Legs	6	6	7
Length of Tubing on Wall (m)	22.3	22.3	29.5
Tube OD (mm)	4.8	4.8	4.8
Tube Wall Thickness (mm)	0.8	0.8	0.8
Thickness of Liner (mm)	0.5	0.5	0.5
Thermal Conductivity (W/m-K)	44.7	44.7	44.7
Number of other Hot Walls (0-2)	0	0	0
Second Hotwall	None	None	None
Compressor Data			
Manufacturer	Matsushita	Matsushita	Matsushita
Model #	SF51C97RAU6	DG57C84RAU6	DGH66C94RAU
Cycles per Hour	1.0	1.0	1.0
Interchanger			
Effectiveness (0-1)	0.9	0.9	0.7

Table 5-A.2.7: ERA Inputs for Compact Refrigerators (Product Class 11)

Compact Refrigerators	4 ft^3 Baseline	4 ft^3 E*	1.7 ft^3
General Data			
Fresh Food Volume (ft^3)	3.3	3.65	1.5
Freezer Volume (ft^3)	0.7[m]	0.44	0.2
Total Volume (ft^3)	4.0	4.1	1.7
Adjusted Volume (ft^3)	4.3	4.3	1.7[n]
Rated Energy Use (kWh/yr)	340	270	296
Calculated Max. Energy Use (kWh/yr)	345	345	317
Rated Energy Use Below Maximum (%)	1.5	22	6.8
Cabinet Dimensions			
Cabinet Height (cm)	83.5	83.8	47.0
Cabinet Width (cm)	47.3	49.5	44.5
Depth, from Door Flange (cm)	40.4	45.6	40.6
Depth, from Door Outer Surface (cm)	44.5	50.2	44.8
Liner Properties			
Outer Liner Thickness (mm)	0.8	0.5	0.4
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	1.3	1.1	1.3
Liner Conductivity (W/m-C)	0.16	0.16	0.16
Compressor Compartment Dimensions			
Height (cm)	21.6	20.3	19.1
Horizontal Wall Thickness (cm)	3.4	4.3	3.8
Top Depth (cm)	16.2	12.7	13.0
Vertical Wall Thickness (cm)	3.3	3.0	2.8
Bottom Depth (cm)	16.2	12.7	13.0
Insulation Thickness – Fresh Food			
Top Wall (cm)	2.5	4.1	3.4
Side Wall (cm)	2.7	4.1	3.4
Back Wall (cm)	3.3	5.8	3.5
Bottom (cm)	2.5	4.8	3.1
Door (cm)	2.8	4.3	3.3
Insulation Resistivity – Fresh Food			
All Walls (m2-C/W-cm)	0.50	0.50	0.50
Wedge/Flange Dimensions			
Fresh Food Flange Width (cm)	2.3	3.3	2.5

[m] The rated freezer volume is 0.7 ft^3 as indicated, but the volume based on observed freezer dimensions is 0.4 ft^3

[n] This product is classified as an all-refrigerator for testing and rating purposes, since its freezer compartment is less than 0.5 ft^3 in volume. It is not clear wheter the 4 ft^3 E* product was also rated as an all-refrigerator based on available data. DOE analyzed both 4 ft^3 products as basic refrigerators and the 1.7 ft^3 product as an all-refrigerator.

Compact Refrigerators	**4 ft^3 Baseline**	**4 ft^3 E***	**1.7 ft^3**
Fresh Food Wedge Depth (cm)	0	0	0.6
Heat Paths			
Gasket Heat Leak (W/m-100C)	12.0	9.0	12.0
Cabinet Penetration Heat Leak (W)	0	0	0
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Freezer Section (°C)	-9.4	-9.4	-3.9
Fresh Food Section (°C)	7.2	7.2	3.3
Air Under Cabinet (°C)	35.0	36.6	35.0
Compressor Compartment (°C)	35.0	36.6	35.0
Air Entering Condenser (°C)	32.2	32.2	32.2
Defrost and Controls Energy			
Defrost Type (Manual, Cycle)	Manual	Manual	Manual
Cycle-Dependent Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0	0	0
Anti-Sweat Heat	None	None	None
Evaporator Design			
Exit Superheat (°C)	0.0	0.1	2.0
Tube Height (mm) Width (mm) Hydraulic Diameter (mm)	4.4 9.5 6.1	4.7 9.5 6.3	4.3 9.5 5.9
Refrigerant Tube Length (m)	6.7	6.1	3.1
Number of Legs	11	10	8
Freezer Surfaces: Present (Y/N), Spacing to Cabinet Wall (cm)			
Top	N	N	N
Left	Y 1.4	Y 1.6	Y 15
Right	Y 1.4	Y 1.6	Y 1.3
Freezer Box Dimensions			
Width (cm)	38.7	38.4	21.0
Height (cm)	11.4	12.7	8.9
Depth (cm)	25.4	24.8	21.0
Inner Door (Y or N)	Y	Y	Y
Condenser Design			
Exit Subcooling (°C)	1.0	1.0	0.0
Heat Transfer Type (Static, Hot-wall, Tube & Fin, Microchannel)	Static	Static	Hot-wall
Static Condenser Details			
Fin Type	Wire	Wire	NA

Compact Refrigerators	4 ft^3 Baseline	4 ft^3 E*	1.7 ft^3
Tube OD (mm)	4.8	4.8	NA
Tube Wall Thickness (mm)	0.6	0.6	NA
Number of Tube Rows	9	9	NA
Tube Pitch (mm)	6.0	6.0	NA
Width of Tube Row (cm)	43.2	43.2	NA
Wire OD (mm)	1.5	1.5	NA
Wire Length (cm)	60.3	60.3	NA
# of Wires	98	98	NA
Wire Conductivity (W/m-K)	44.7	44.7	NA
Hot Wall Condenser Details			
First Hot Wall (sides)			
Total Area of Side Panels (m2)	NA	NA	0.33
Width of Side Normal to Tubes (cm)	NA	NA	94.0
Number of Legs	NA	NA	16
Length of Tubing on Wall (m)	NA	NA	6.0
Tube OD (cm)	NA	NA	3.9
Tube Wall (mm)	NA	NA	0.76
Liner Thickness (mm)	NA	NA	0.38
Thermal Conductivity (W/mK)	NA	NA	44.7
Second Hot Wall (top)			
Total Area (m2)	NA	NA	0.10
Width Normal to Tubes (cm)	NA	NA	23.5
Number of Legs	NA	NA	4
Length of Tubing on Wall (m)	NA	NA	1.7
Compressor Data			
Manufacturer	ZEL	LG	Huayi
Model #	GVT44AD	NSA36LACG	AES25DS
Cycles per Hour	4.0	5.0	3.0
Interchanger			
Effectiveness (0-1)	0.8	0.98	0.7

Table 5-A.2.8: ERA Inputs for Compact Chest Freezers (Product Class 18)

Compact Chest Freezers	3.4 ft^3	7.0 ft^3, #1	7.0 ft^3, #2
General Data			
Freezer Volume (ft^3)	3.4	7.0	7.0
Adjusted Volume (ft^3)	5.9	12.1	12.1
Rated Energy Use (kWh/yr)	213	277	276
Calculated Max. Energy Use (kWh/yr)	213	279	279
Rated Energy Use Below Maximum (%)	0	0.6	0.9
Cabinet Dimensions			
Cabinet Length (cm)	53.3	92.7	94.0
Cabinet Width (cm)	58.4	51.8	58.4
Depth, from Door Flange (cm)	76.2	74.6	73.3
Depth, from Door Outer Surface (cm)	81.3	80.0	78.7
Liner Properties			
Outer Liner Thickness (mm)	0.5	0.6	0.9
Outer Liner Conductivity (W/m-C)	44.7	44.7	44.7
Inner Liner Thickness (mm)	0.4	0.4	1.0
Liner Conductivity (W/m-C)	190	190	190
Compressor Compartment Dimensions[o]			
Height (cm)	21.0	28.6	22.9
Depth (cm)	19.7	18.1	22.9
Fractional width of compartment (0-1)	1	1	1
Top Wall Insulation Thickness (cm)	6.6	7.0	6.4
Front Wall Insulation Thickness (cm)	6.4	7.0	7.3
Insulation Thickness – Freezer			
Side Wall (cm)	6.7	6.0	6.4
Bottom Wall (cm)	6.3	5.1	7.3
Door (cm)	5.8	6.4	5.5
Insulation Resistivity – Freezer			
All Walls (m2-C/W-cm)	0.5	0.5	0.53
Wedge/Flange Dimensions			
Wedge Depth (cm)	1.0	1.0	1.9
Flange Width (cm)	3.8	4.0	4.4
Heat Paths			
Gasket Heat Leak (W/m-100C)	7.5	7.5	7.5
Cabinet Penetration Heat Leak (W)	0	0	0
Air and Cabinet Temperatures			
Room Air (°C)	32.2	32.2	32.2
Air Under Cabinet (°C)	35.0	35.0	35.0
Air Entering Condenser (°C)	32.2	32.2	32.2
Compressor Compartment (°C)	35.0	35.0	35.0

[o] Windows ERA allows incorporation of the compressor compartment either into the long or the short wall. DOS ERA allowed incorporation only into the short wall, so the short wall option should be entered for Windows ERA.

Compact Chest Freezers	**3.4 ft^3**	**7.0 ft^3, #1**	**7.0 ft^3, #2**
Cabinet Setpoint (°C)	-17.8	-17.8	-17.8
Defrost and Controls Energy			
Defrost Type (Manual, Auto)	Manual	Manual	Manual
Cycle-Dependent Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0	0	0
Constant Electrical Loads			
Inside Cabinet (W)	0	0	0
Outside Cabinet (W)	0.4	0.2	0.1
Anti-Sweat Heat	None	None	None
Evaporator Design			
Exit Superheat (°C)	0.5	0.5	0.0
Tube OD (mm)	8.0	7.6	6.4
Tube Wall Thickness (mm)	0.6	0.6	0.6
Liner Thickness (mm)	0.4	0.4	1.0
Liner Conductivity (W/m-K)	190	190	190
Total Area of Side Walls (m2)	1.1	1.43	1.5
Number of Legs	10	9	12
Width Normal to Tubes (cm)	68.3	72	64.8
Condenser Design			
Exit Subcooling (°C)	0.5	0.5	0.0
Heat Transfer Type (Static, Hot-wall, Tube & Fin, Microchannel)	Static	Hot-wall	Hot-wall
Static Condenser Details			
Fin Type	Wire	NA	NA
Tube OD (mm)	6.0	NA	NA
Tube Wall Thickness (mm)	0.64	NA	NA
Number of Tube Rows	14	NA	NA
Tube Pitch (mm)	4.6	NA	NA
Width of Tube Row (cm)	47.0	NA	NA
Wire OD (mm)	1.4	NA	NA
Wire Length (cm)	64.5	NA	NA
# of Wires	110	NA	NA
Wire Conductivity (W/m-K)	44.7	NA	NA
Hot Wall Condenser Details			
Total Area of Side Panels (m2)	NA	1.5	1.72
Width of Side Normal to Tubes (cm)	NA	53.3	241
Number of Legs	NA	7	32
Length of Tubing on Wall (m)	NA	20.2	19.6
Tube OD (mm)	NA	4.6	3.9
Tube Wall Thickness (mm)	NA	0.6	0.5
Liner Thickness (mm)	NA	0.64	0.9
Thermal Conductivity (W/mK)	NA	44.7	44.7

Compact Chest Freezers	**3.4 ft^3**	**7.0 ft^3, #1**	**7.0 ft^3, #2**
Compressor Data			
Manufacturer	Jiangsu Baixue[p]	Danfoss	ZEL
Model #	QDH3511G	TTE4.6GFK	GVY44AD
Cycles per Hour	2.25	1.3	2.0
Interchanger			
Effectiveness (0-1)	0.95	0.95	0.95

[p] Jiangsu Baixue Electric Appliances Co. Ltd.

5-A.3 INCREMENTAL COST DETAIL

The tables in this section identify the groups of design options and their associated costs for all analyzed efficiency levels for the reverse-engineering units for which the full incremental cost analysis was conducted.

Table 5-A.3.1: Incremental Cost Detail for 16 ft^3 Top-Mount Refrigerator-Freezer (Product Class 3)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 5.55 to 5.74	$1.43	$0.00	$0.00	$0.00	$0.37	$1.80	$6.52	$6.52
	Brushless DC Condenser Fan Motor	$3.75	$0.00	$0.00	$0.00	$0.98	$4.73		
15%	Increase Evaporator Size by 20%	$1.20	$0.00	$0.00	$0.00	$0.31	$1.51	$4.69	$11.21
	Increase Condenser Size by 20%	$1.69	$0.00	$0.00	$0.00	$0.44	$2.13		
	Increase compressor EER from 5.74 to 5.85	$0.83	$0.00	$0.00	$0.00	$0.21	$1.04		
20%	Increase compressor EER from 5.85 to 6.26	$8.15	$0.00	$0.00	$0.00	$2.12	$10.26	$10.26	$21.47
25%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$27.94	$49.41
	3.5 sqft VIP in FZR Cabinet	$11.49	$1.20	$1.48		$3.68	$17.86		
30%	8.7 sqft more VIP in FZR Cabinet	$28.43	$2.97	$3.67		$9.12	$44.19	$44.19	$93.60
35%	6.9 sqft VIP in FF Cabinet	$22.62	$1.22	$2.79		$6.92	$33.55	$33.55	$127.14
40%	8.4 sqft more VIP in FF Cabinet	$27.34	$1.47	$3.37		$8.37	$40.55	$40.55	$167.69
45%	8.4 sqft more VIP in FF Cabinet	$27.34	$1.47	$3.37		$8.37	$40.55	$40.55	$208.24

Table 5-A.3.2: Incremental Cost Detail for 21 ft^3 Top-Mount Refrigerator-Freezer (Product Class 3)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 4.92 to 5.55	$0.37	$0.00	$0.00	$0.00	$0.10	$0.47	$0.47	$0.47
15%	Increase compressor EER from 5.55 to 5.94	$2.93	$0.00	$0.00	$0.00	$0.76	$3.69	$3.69	$4.16
20%	Increase compressor EER from 5.94 to 6.08	$2.61	$0.00	$0.00	$0.00	$0.68	$3.29	$7.14	$11.30
	Increase Evaporator Size by 20%	$1.61	$0.00	$0.00	$0.00	$0.42	$2.03		
	Increase Condenser Size by 20%	$1.45	$0.00	$0.00	$0.00	$0.38	$1.83		
25%	Brushless DC Evaporator Fan Motor	$3.50	$0.00	$0.00	$0.00	$0.91	$4.41	$9.14	$20.44
	Brushless DC Condenser Fan Motor	$3.75	$0.00	$0.00	$0.00	$0.98	$4.73		
30%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$10.08	$30.52
35%	10.5 sqft VIP in FF Cabinet	$34.22	$1.42	$4.17		$10.35	$50.16	$50.16	$80.68
40%	13.4 sqft more VIP in FF Cabinet	$43.68	$1.82	$5.32		$13.21	$64.03	$64.03	$144.71
45%	6.8 sqft more VIP in FF Cabinet	$22.26	$0.93	$2.71		$6.73	$32.63	$63.32	$208.03
	6.2 sqft VIP in FZR Cabinet	$20.21	$1.60	$2.55		$6.33	$30.70		

Table 5-A.3.3: Incremental Cost Detail for 18.5 ft3 Bottom-Mount Refrigerator-Freezer (Product Class 5)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 5.72 to 6.06	$3.72	$0.00	$0.00	$0.00	$0.97	$4.69	$7.21	$7.21
	Increase Evaporator Size by 20%	$2.00	$0.00	$0.00	$0.00	$0.52	$2.52		
15%	Brushless DC Evaporator Fan Motor	$3.50	$0.00	$0.00	$0.00	$0.91	$4.41	$9.14	$16.34
	Brushless DC Condenser Fan Motor	$3.75	$0.00	$0.00	$0.00	$0.98	$4.73		
20%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$10.08	$26.42
25%	Increase compressor efficiency from 6.06 to 6.26	$5.40	$0.00	$0.00	$0.00	$1.40	$6.80	$9.32	$35.75
	Increase Condenser Size by 20%	$2.00	$0.00	$0.00	$0.00	$0.52	$2.52		
30%	Variable Anti-Sweat Heater Control	$17.48	$0.00	$0.00	$0.00	$4.54	$22.02	$22.02	$57.77
35%	12.6 sqft VIP in FF Cabinet	$41.09	$2.12	$5.06		$12.55	$60.82	$60.82	$118.59
40%	12.1 sqft more VIP in FF Cabinet	$39.59	$2.04	$4.87		$12.09	$58.60	$58.60	$177.19
45%	13.3 sqft more VIP in FZR Cabinet	$43.44	$3.00	$5.43		$13.49	$65.37	$65.37	$242.56

Table 5-A.3.4: Incremental Cost Detail for 25 ft^3 Bottom-Mount Refrigerator-Freezer (Product Class 5)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 4.79 to 5.42	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
15%	Increase compressor EER from 5.42 to 5.74	$1.80	$0.00	$0.00	$0.00	$0.47	$2.27	$2.27	$2.27
20%	Increase compressor EER from 5.74 to 6.14	$5.73	$0.00	$0.00	$0.00	$1.49	$7.22	$7.22	$9.49
25%	Increase compressor EER from 6.14 to 6.26	$3.24	$0.00	$0.00	$0.00	$0.84	$4.08	$20.44	$29.93
	Brushless DC Evaporator Fan Motor	$3.50	$0.00	$0.00	$0.00	$0.91	$4.41		
	Variable Anti-Sweat Heater Control	$9.48	$0.00	$0.00	$0.00	$2.46	$11.94		
30%	Increase Condenser Size by 20%	$4.90	$0.00	$0.00	$0.00	$1.27	$6.17	$10.90	$40.82
	Brushless DC Condenser Fan Motor	$3.75	$0.00	$0.00	$0.00	$0.98	$4.73		
35%	Increase Evaporator Size by 20%	$2.60	$0.00	$0.00	$0.00	$0.68	$3.27	$66.38	$107.21
	13.2 sqft VIP in FF Cabinet	$42.98	$1.86	$5.25		$13.02	$63.11		
40%	16.3 sqft more VIP in FF Cabinet	$53.24	$2.31	$6.50		$16.13	$78.18	$78.18	$185.38
45%	14.1 sqft VIP in FZR Cabinet	$46.03	$2.83	$5.72		$14.19	$68.77	$68.77	$254.15

Table 5-A.3.5: Incremental Cost Detail for 22 ft^3 Side-Mount Refrigerator-Freezer with TTD Ice (Product Class 7)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 5.51 to 5.89	$2.85	$0.00	$0.00	$0.00	$0.74	$3.59	$9.92	$9.92
	Brushless DC Condenser Fan Motor	$3.75	$0.00	$0.00	$0.00	$0.98	$4.73		
	Increase Evaporator Size by 20%	$1.27	$0.00	$0.00	$0.00	$0.33	$1.60		
15%	Increase compressor EER from 5.89 to 6.26	$7.85	$0.00	$0.00	$0.00	$2.04	$9.88	$13.53	$23.45
	Increase Condenser Size by 20%	$2.89	$0.00	$0.00	$0.00	$0.75	$3.65		
20%	11 sqft VIP in FF Cabinet	$35.92	$1.77	$4.4.1		$10.95	$53.05	$53.05	$76.50
25%	13 sqft more VIP in FF Cabinet	$42.58	$2.10	$5.23		$12.98	$62.89	$62.89	$139.39
30%	1.8 sqft more VIP in FF Cabinet	$5.85	$0.29	$0.72		$1.78	$8.64	$63.81	$203.20
	11.3 sqft VIP in FZR Cabinet	$36.90	$2.30	$4.59		$11.38	$55.17		
35%	9.2 sqft more VIP in FZR Cabinet	$30.01	$1.87	$3.73		$9.26	$44.86	$60.69	$263.89
	3.4 sqft VIP in FZR Door	$10.97	$0.27	$1.32		$3.27	$15.82		
40%	1.8 sqft more VIP in FZR Door	$5.75	$0.14	$0.69		$1.71	$8.29	$95.38	$359.27
	8 sqft VIP in FF Door	$26.28	$0.42	$3.12		$7.75	$37.75		
	Variable Speed Compressor	$39.31	$0.00	$0.00	$0.00	$10.22	$49.52		

Table 5-A.3.6: Incremental Cost Detail for 26 ft^3 Side-Mount Refrigerator-Freezer with TTD Ice (Product Class 7)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 5.58 to 5.93	$2.63	$0.00	$0.00	$0.00	$0.68	$3.31	$12.44	$12.44
	Brushless DC Evaporator Fan Motor	$3.50	$0.00	$0.00	$0.00	$0.91	$4.41		
	Brushless DC Condenser Fan Motor	$3.75	$0.00	$0.00	$0.00	$0.98	$4.73		
15%	Increase compressor EER from 5.93 to 6.04	$1.61	$0.00	$0.00	$0.00	$0.42	$2.02	$2.02	$14.46
20%	Increase compressor EER from 6.04 to 6.26	$5.94	$0.00	$0.00	$0.00	$1.54	$7.48	$17.56	$32.03
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
25%	Increase Evaporator Size by 20%	$1.16	$0.00	$0.00	$0.00	$0.30	$1.46	$40.59	$72.62
	Increase Condenser Size by 20%	$2.42	$0.00	$0.00	$0.00	$0.63	$3.05		
	7.5 sqft VIP in FF Cabinet	$24.47	$1.16	$3.00		$7.44	$36.08		
30%	12.2 sqft more VIP in FF Cabinet	$39.86	$1.89	$4.88		$12.13	$58.76	$58.76	$131.38
35%	7.2 sqft more VIP in FF Cabinet	$23.44	$1.11	$2.87		$7.13	$34.56	$62.66	$194.04
	5.8 sqft VIP in FZR Cabinet	$18.93	$1.04	$2.34		$5.80	$28.10		
40%	14.1 sqft VIP in FZR Cabinet	$45.96	$2.53	$5.67		$14.08	$68.23	$68.23	$262.27
45%	3.3 sqft more VIP in FZR Cabinet	$10.91	$0.60	$1.35		$3.34	$16.20	$83.22	$345.50
	6.2 sqft VIP in FZR Door	$20.14	$0.42	$2.41		$5.97	$28.93		
	8.0 sqft VIP in FF Door	$26.65	$0.42	$3.17		$7.86	$38.09		

Table 5-A.3.7: Incremental Cost Detail for 14 ft^3 Upright Freezer with Auto Defrost (Product Class 9)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Brushless DC Evaporator Fan Motor	$3.50	$0.00	$0.00	$0.00	$0.91	$4.41	$6.38	$6.38
	Add 1" Insulation to Door	$0.65	$0.00	$0.00	$0.91	$0.41	$1.97		
15%	Increase Compressor EER from 5.04 to 5.43	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$6.38
20%	Increase Compressor EER from 5.43 to 5.95	$3.38	$0.00	$0.00	$0.00	$0.88	$4.25	$4.25	$10.64
25%	Increase Compressor EER from 5.95 to 6.08	$2.54	$0.00	$0.00	$0.00	$0.66	$3.19	$23.63	$34.27
	Increase Evaporator Size by 20%	$1.47	$0.00	$0.00	$0.00	$0.38	$1.85		
	Convert condenser to forced convection with BLDC fan motor	$6.75	$0.00	$0.00	$0.00	$1.76	$8.51		
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
30%	Add 0.36" Insulation to Cabinet	$4.54	$0.00	$0.00	$17.35	$5.69	$27.58	$27.58	$61.84
35%	Add another 0.64" Insulation to Cabinet	$7.87	$0.00	$0.00	$0.00	$2.05	$9.91	$27.84	$89.69
	3.7 sqft VIP in Cabinet	$12.05	$0.41	$1.77		$3.70	$17.93		
40%	17.6 sqft more VIP in Cabinet	$57.37	$1.94	$8.42		$17.61	$85.35	$85.35	$175.03
45%	16.4 sqft more VIP in Cabinet	$53.75	$1.82	$7.89		$16.50	$79.95	$83.89	$258.92
	0.8 sqft VIP in Door	$2.70	$0.03	$0.39		$0.81	$3.94		

Table 5-A.3.8: Incremental Cost Detail for 20 ft^3 Upright Freezer with Auto Defrost (Product Class 9)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Brushless DC Evaporator Fan Motor	$3.50	$0.00	$0.00	$0.00	$0.91	$4.41	$6.43	$6.43
	Add 1" Insulation to Door	$0.69	$0.00	$0.00	$0.91	$0.42	$2.02		
15%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$10.08	$16.51
20%	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$16.51
25%	Increase compressor EER from 5.73 to 6.00	$2.03	$0.00	$0.00	$0.00	$0.53	$2.55	$4.24	$20.75
	Increase Evaporator Size by 20%	$1.34	$0.00	$0.00	$0.00	$0.35	$1.69		
30%	Increase compressor EER from 6.01 to 6.24	$6.21	$0.00	$0.00	$0.00	$1.61	$7.82	$10.57	$31.32
	Increase Evaporator Size by Additional 30%	$2.01	$0.00	$0.00	$0.00	$0.52	$2.53		
	Increase Door Insulation Thickness 1/4"	$0.17	$0.00	$0.00	$0.00	$0.04	$0.22		
35%	Remove 1/4" Door Insulation	-$0.17	$0.00	$0.00	$0.00	-$0.04	-$0.22	$32.62	$63.95
	Forced Convection Condenser with BLDC Cond Fan	$6.75	$0.00	$0.00	$0.00	$1.76	$8.51		
	Add 0.15" Insulation to Cabinet	$1.97	$0.00	$0.00	$17.35	$5.02	$24.34		
40%	Add Additional 0.55" Insulation to Cabinet	$7.26	$0.00	$0.00	$0.00	$1.89	$9.15	$9.15	$73.09
45%	11.7 sqft VIP in FZR Cabinet	$38.31	$1.06	$5.59		$11.69	$56.65	$61.55	$134.64
	Add Additional 0.3" Insulation to Cabinet	$3.88	$0.00	$0.00	$0.00	$1.01	$4.89		

Table 5-A.3.9: Incremental Cost Detail for 15 ft^3 Chest Freezer (Product Class 10)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 4.92 to 5.48	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
15%	Increase compressor EER from 5.48 to 5.81	$2.33	$0.00	$0.00	$0.00	$0.60	$2.93	$2.93	$2.93
20%	Increase compressor EER from 5.81 to 6.08	$3.59	$0.00	$0.00	$0.00	$0.93	$4.52	$5.97	$8.90
	Add 0.5" Insulation to Door	$0.24	$0.00	$0.91	$0.00	$0.30	$1.45		
25%	Add another 0.5" Insulation to Door	$0.23	$0.00	$0.00	$0.00	$0.06	$0.29	$4.68	$13.57
	Increase Condenser Size by 45%	$3.48	$0.00	$0.00	$0.00	$0.90	$4.38		
30%	Increase Evaporator Size by 30%	$3.11	$0.00	$0.00	$0.00	$0.81	$3.91	$4.22	$17.79
	Add another 0.5" Insulation to Door	$0.24	$0.00	$0.00	$0.00	$0.06	$0.30		
35%	Remove 0.5" Insulation from Door	-$0.24	$0.00	$0.00	$0.00	-$0.06	-$0.30	$27.28	$45.07
	Add 0.5" Insulation to Cabinet	$4.54	$0.00	$0.00	$17.35	$5.69	$27.58		
40%	Add another 0.5" Insulation to Cabinet	$4.40	$0.00	$0.00	$0.00	$1.14	$5.54	$5.54	$50.61
45%	Variable Speed Compressor	$44.09	$0.00	$0.00	$0.00	$11.46	$55.55	$55.55	$106.16

Table 5-A.3.10: Incremental Cost Detail for 20 ft^3 Chest Freezer (Product Class 10)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Condenser Size by 29%	$1.68	$0.00	$0.00	$0.00	$0.44	$2.12	$4.70	$4.70
	Add 1" Insulation to Door	$0.62	$0.00	$0.00	$0.91	$0.40	$1.93		
	Increase compressor EER from 5.71 to 5.78	$0.53	$0.00	$0.00	$0.00	$0.14	$0.66		
15%	Increase compressor EER from 5.78 to 6.07	$3.54	$0.00	$0.00	$0.00	$0.92	$4.46	$4.46	$9.16
20%	Increase compressor EER from 6.07 to 6.25	$4.86	$0.00	$0.00	$0.00	$1.26	$6.12	$30.09	$39.25
	Add 0.14 in Insulation to Cabinet	$1.67	$0.00	$0.00	$17.35	$4.95	$23.97		
25%	Add another 0.38 in Insulation to Cabinet	$4.52	$0.00	$0.00	$0.00	$1.17	$5.69	$5.69	$44.94
30%	Add another 0.48 in Insulation to Cabinet	$5.50	$0.00	$0.00	$0.00	$1.43	$6.94	$6.94	$51.88
35%	Variable Speed Compressor	$41.08	$0.00	$0.00	$0.00	$10.68	$51.75	$51.75	$103.64
40%	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$103.64
45%	10.2 sqft VIP in Bottom Wall	$33.46	$1.39	$4.95		$10.35	$50.14	$64.00	$167.64
	2.9 sqft VIP in Door	$9.53	$0.10	$1.37		$2.86	$13.86		

Table 5-A.3.11: Incremental Cost Detail for 1.7 ft^3 Compact Refrigerator (Product Class 11)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase evaporator size by 20%	$0.27	$0.00	$0.00	$0.00	$0.07	$0.34	$2.44	$2.44
	Increase condenser size by 20%	$0.39	$0.00	$0.00	$0.00	$0.10	$0.49		
	Add 0.75" Insulation to Door	$0.13	$0.00	$0.00	$0.45	$0.15	$0.72		
	Increase compressor EER from 3.02 to 3.09	$0.70	$0.00	$0.00	$0.00	$0.18	$0.88		
15%	Increase compressor EER from 3.09 to 3.27	$1.80	$0.00	$0.00	$0.00	$0.47	$2.27	$2.27	$4.70
20%	Increase compressor EER from 3.27 to 3.46	$1.90	$0.00	$0.00	$0.00	$0.49	$2.39	$2.39	$7.10
25%	Increase compressor EER from 3.46 to 3.47	$0.10	$0.00	$0.00		$0.03	$0.13	$11.78	$18.88
	Add 0.23" Insulation to Cabinet	$0.72	$0.00	$0.00	$8.53	$2.40	$11.65		
30%	Add 0.31" Insulation to Cabinet	$0.98	$0.00	$0.00	$0.00	$0.25	$1.23	$1.23	$20.11
35%	Add 0.21" Insulation to Cabinet	$0.68	$0.00	$0.00	$0.00	$0.18	$0.85	$7.20	$27.31
	Add 1.6 sqft VIP in Door	$5.15	$0.29	$1.07		$1.69	$8.20		
40%	Add Another 0.7 sqft VIP in Door	$2.14	$0.12	$0.44		$0.70	$3.40	$16.29	$45.46
	Add 2.3 sqft VIP in Cabinet	$7.53	$1.02	$1.68		$2.66	$12.89		
45%	Add Another 2.9 sqft VIP in Cabinet	$9.38	$1.27	$2.09		$3.31	$16.06	$16.06	$61.52

Table 5-A.3.12: Incremental Cost Detail for 4.0 ft^3 Compact Refrigerator (Product Class 11)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Add 0.75" Insulation to Door	$0.15	$0.00	$0.00	$0.45	$0.16	$0.75	$4.28	$4.28
	Increase compressor EER from 4.57 to 4.85	$2.80	$0.00	$0.00	$0.00	$0.73	$3.53		
15%	Increase compressor EER from 4.85 to 5.14	$2.90	$0.00	$0.00	$0.00	$0.75	$3.65	$3.65	$7.94
20%	Increase compressor EER from 5.14 to 5.33	$1.90	$0.00	$0.00	$0.00	$0.49	$2.39	$2.67	$10.61
	Increase Condenser Size by 8%	$0.22	$0.00	$0.00	$0.00	$0.06	$0.28		
25%	Increase Condenser Size to 20% more than initial size	$0.32	$0.00	$0.00	$0.00	$0.08	$0.40	$11.64	$22.24
	Add 0.10" Insulation to Cabinet	$0.39	$0.00	$0.00	$8.53	$2.32	$11.23		
30%	Add another 0.19" Insulation to Cabinet	$0.72	$0.00	$0.00	$0.00	$0.19	$0.91	$0.91	$23.15
35%	Add another 0.26" Insulation to Cabinet	$0.99	$0.00	$0.00	$0.00	$0.26	$1.24	$1.24	$24.39
40%	Add another 0.20" Insulation to Cabinet	$0.74	$0.00	$0.00	$0.00	$0.19	$0.93	$8.66	$33.06
	Add 1.4 sqft VIP in Cabinet	$4.71	$0.42	$1.01		$1.60	$7.73		
45%	Add Another 3.8 sqft VIP in Cabinet	$12.46	$1.10	$2.66		$4.22	$20.44	$20.44	$53.50

Table 5-A.3.13: Incremental Cost Detail for 3.4 ft^3 Compact Chest Freezer (Product Class 18)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 3.74 to 4.17	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42	$5.42	$5.42
15%	Increase compressor EER from 4.17 to 4.29	$1.23	$0.00	$0.00	$0.00	$0.32	$1.55	$2.96	$8.38
	Add 1" Insulation to Door	$0.20	$0.00	$0.00	$0.91	$0.29	$1.41		
20%	Remove 1/4" Insulation from Door	-$0.05	$0.00	$0.00	$0.00	-$0.01	-$0.06	$24.17	$32.54
	Add 0.48" Insulation to Cabinet	$1.88	$0.00	$0.00	$17.35	$5.00	$24.23		
25%	Add another 0.27" Insulation to Cabinet	$1.03	$0.00	$0.00	$0.00	$0.27	$1.30	$13.79	$46.33
	2.1 sqft VIP in Bottom Wall	$6.85	$1.39	$1.62		$2.56	$12.42		
	Add 1/4" Insulation to Door	$0.05	$0.00	$0.00	$0.00	$0.01	$0.06		
30%	Remove all design options through 25% Level	-$15.50	-$1.39	-$19.88		-$9.56	-$46.33	$16.67	$63.00
	Variable Speed Compressor	$50.00	$0.00	$0.00	$0.00	$13.00			
35%	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$63.00
40%	N/A	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$63.00
45%	Add 0.75" Insulation to Door	$0.15	$0.00	$0.00	$0.91	$0.28	$1.34	$24.25	$87.25
	Add 0.21" Insulation to Cabinet	$0.83	$0.00	$0.00	$17.35	$4.73	$22.91		

Table 5-A.3.14: Incremental Cost Detail for 7.0 ft^3 Compact Chest Freezer (Product Class 18)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase compressor EER from 4.50 to 5.03	$5.30	$0.00	$0.00	$0.00	$1.38	$6.68	$6.68	$6.68
15%	Increase compressor EER from 5.03 to 5.27	$2.40	$0.00	$0.00	$0.00	$0.62	$3.02	$4.25	$10.93
	Add 0.15" Insulation to Door	$0.06	$0.00	$0.00	$0.91	$0.25	$1.23		
20%	Add 0.60" Insulation to Door	$0.25	$0.00	$0.00	$0.00	$0.07	$0.32	$24.59	$35.52
	Add 0.24" Insulation to Cabinet	$1.92	$0.00	$0.00	$17.35	$5.01	$24.28		
25%	Add another 0.34" Insulation to Cabinet	$2.68	$0.00	$0.00	$0.00	$0.70	$3.38	$3.38	$38.90
30%	Add another 0.17" Insulation to Cabinet	$1.36	$0.00	$0.00	$0.00	$0.35	$1.71	$18.48	$57.38
	Add 3.1 sqft VIP in Bottom Wall	$10.09	$1.04	$2.18		$3.46	$16.77		
35%	Remove all design options through 30% Level	-$24.06	-$1.04	-$20.44		-$11.84	-$57.38	$5.62	$63.00
	Variable Speed Compressor	$50.00	$0.00	$0.00	$0.00	$13.00	$63.00		
40%	Add 0.26" Insulation to Cabinet	$2.05	$0.00	$0.00	$17.35	$5.04	$24.43	$24.43	$87.43
45%	Add another 0.47" Insulation to Cabinet	$3.74	$0.00	$0.00	$0.00	$0.97	$4.71	$4.71	$92.15

5-A.4 ENGINEERING QUESTIONNAIRE

The engineering questionnaire used as a guide for engineering discussions during manufacturer interviews is shown in this section. Some of the information provided in the questionnaire has been redacted to protect vendor information.

DESIGN FOR ENERGY IMPROVEMENT INFORMATION REQUEST

DOE would like to confirm information on the incremental costs of increasing product efficiency by understanding the design options involved in the efficiency improvement.

1. Market Share of products you sell

To help DOE discover manufacturer sub-groups and the relative importance of various product classes to specific manufacturers, please disaggregate your annual unit shipments for each product category as shown below. Please also indicate whether you purchase these products from other manufacturers (i.e. private label), and whether the factory that supplies the product is located in the USA.

Product Class (response for PC1 through PC20 not including built-in products)	% Private Label?	% Made in USA?	Yearly Unit Shipments
1. Refrigerators and refrigerator-freezers with manual defrost.			
2. Refrigerator-freezer—partial automatic defrost.			
3a. Refrigerator-freezer—automatic defrost with top-mounted freezer without through-the-door ice service			
3b. All-refrigerator—automatic defrost.			
4. Refrigerator-freezers—automatic defrost with side-mounted freezer without through-the-door ice service.			
5. Refrigerator-freezers—automatic defrost with bottom-mounted freezer without through-the-door ice service.			
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.			
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.			
8. Upright freezers with manual defrost.			
9. Upright freezers with automatic defrost.			
10. Chest freezers and all other freezers except compact freezers.			
11. Compact refrigerators and refrigerator-freezers with manual defrost.			
12. Compact refrigerator-freezer—partial automatic defrost.			
13a. Compact refrigerator-freezers—automatic defrost with top-mounted freezer compact all-			

refrigerator—automatic defrost.			
13b. Compact all-refrigerator—automatic defrost.			
14. Compact refrigerator-freezers—automatic defrost with side-mounted freezer.			
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.			
16. Compact upright freezers with manual defrost.			
17. Compact upright freezers with automatic defrost.			
18. Compact chest freezers.			
19. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.			
20. Chest freezers with automatic defrost.			
21. Wine Coolers			
22. Built-in Refrigerators, Refrigerator-Freezers, and Freezers (please provide percentage breakdown by Product Class for units presenting at least 5% of unit sales)			

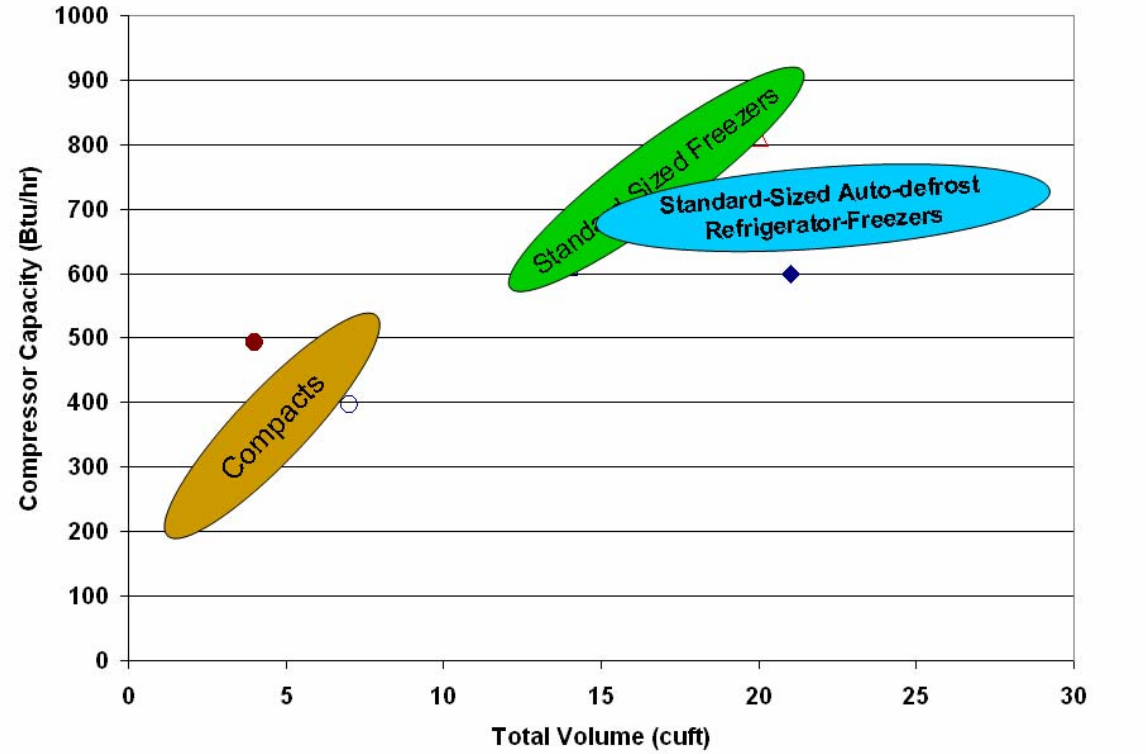
a. What percentage of products classified as product class 4 or 7 (side-by-sides) have convertible bottom drawers?
b. What percentage of product class 5 and what percentage of product class 19 products are French-door?

2. Product Technical Descriptions

The following series of exhibits and questions address technical characteristics of key refrigerator and freezer components for both baseline and improved-efficiency products.

Compressors

Please comment on the typical capacities of compressors used in the indicated products.



- Should there be differences in capacity levels for auto-defrost and manual defrost freezers?
- What capacity/volume relationship is representative for standard-sized manual-defrost refrigerators?

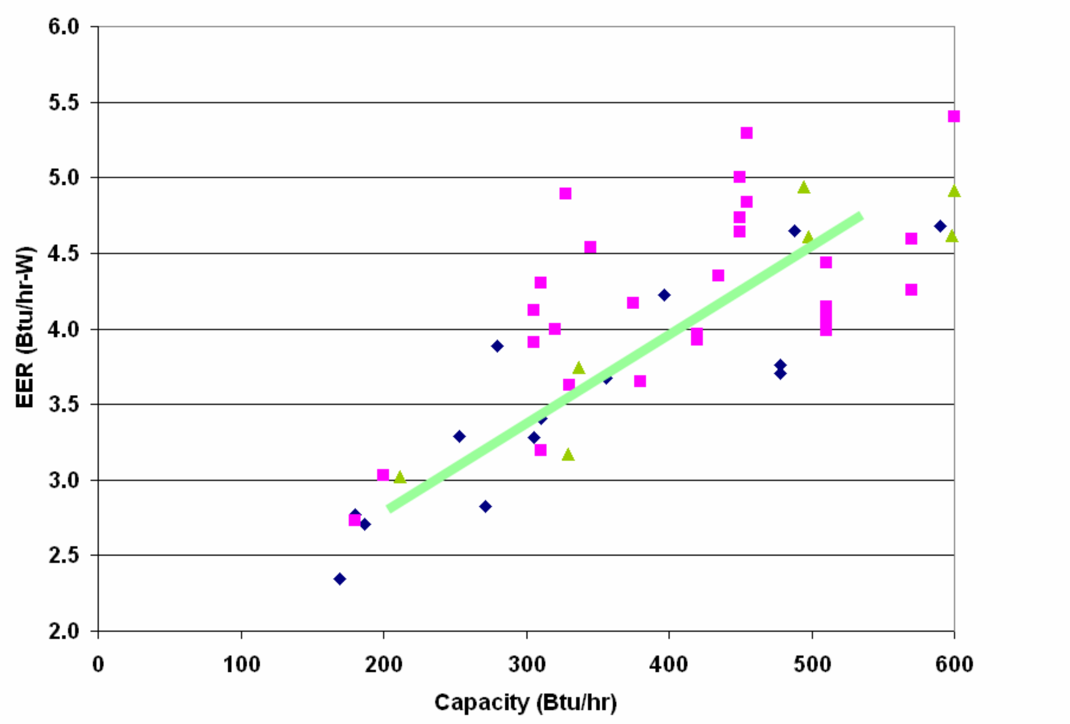
Please comment on the indicated typical EER of compressors used in standard and Energy Star products.

	Typical Nominal Compressor EER	
Products	Std-Efficiency	E*
Standard-Sized Refrigerator-Freezer Auto-Defrost	5.4	5.9
Standard-Sized Freezers	5.0	5.7

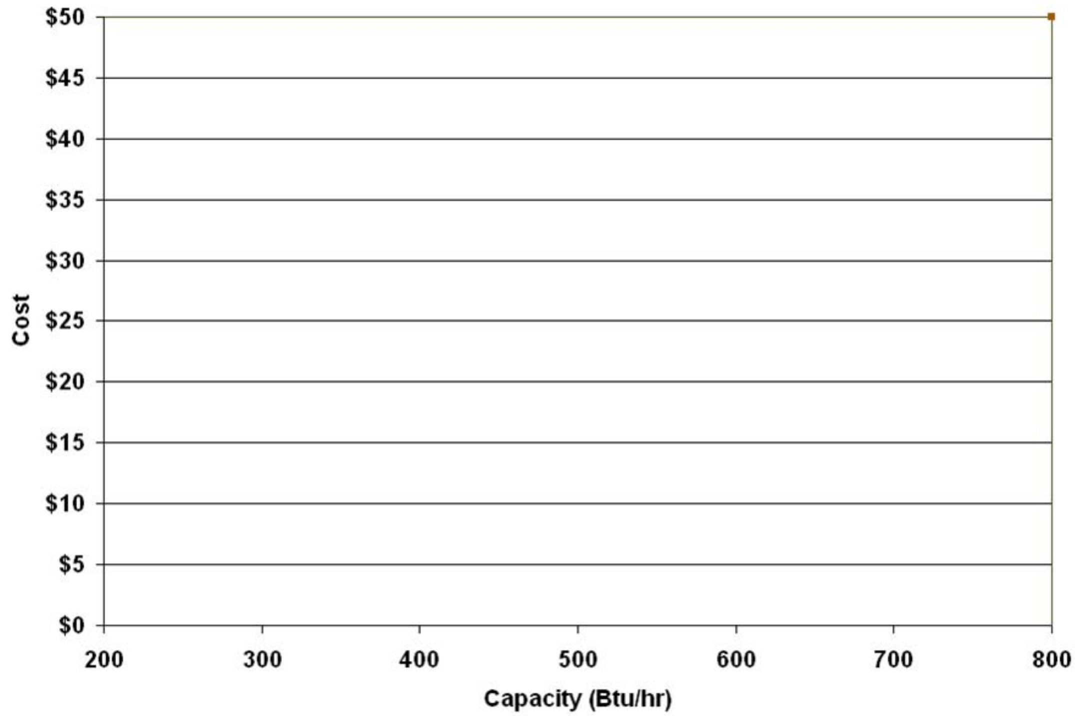
- Should there be differences between compressor EER used in auto-defrost and manual defrost freezers?

Typical EER trend for compressors used in compact refrigerators and freezers:

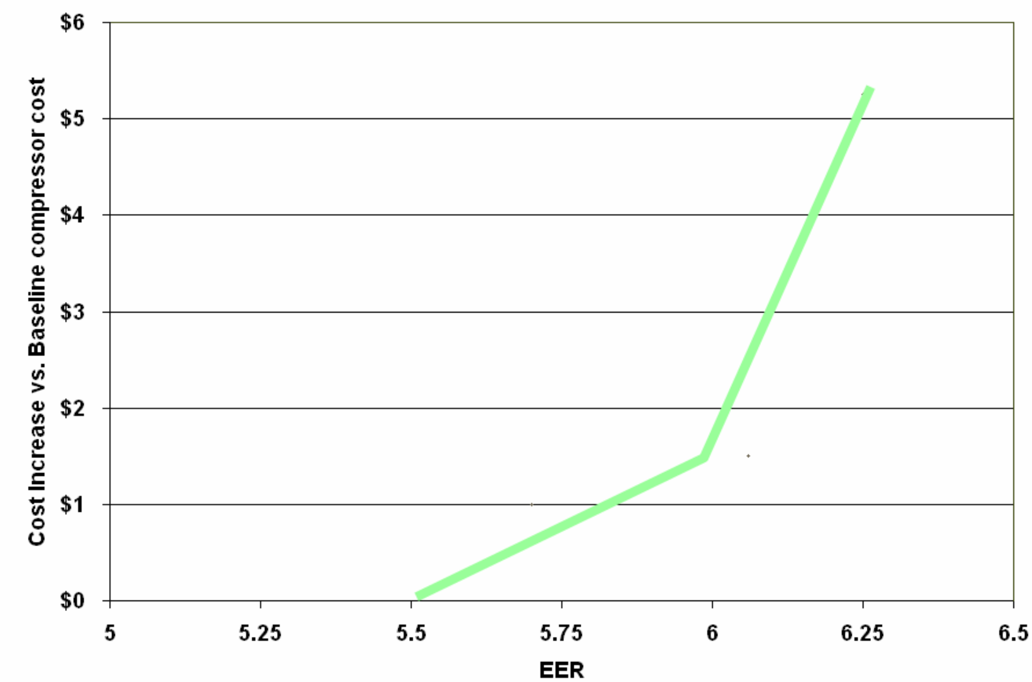
- Is variation in compressor EER in compact products dependent primarily on capacity, as illustrated in the line in the plot below?
- Note that while a range of EER is offered by compressor vendors, it is not clear that the range of EER's actually being used in products is as broad--Is this driven by cost pressures for compact products?



Is the Illustrated Typical Cost vs. Capacity for Baseline Product compressors accurate?



Is the Illustrated Curve for incremental cost for higher EER compressors for standard-sized refrigerator-freezers accurate?



- What percentage of your baseline unit shipments use variable-speed compressors, and what percentage of Energy Star-rated products do?
- If you use variable-speed compressors in your products, do you run them at two or three speeds, or do you modulate the speed based on demand?
- Is $30 an appropriate cost increase for a variable-speed compressor as compared to a baseline efficiency single-speed compressor purchased from the vendor for standard-sized refrigerator-freezers? What other costs need to be considered?

Evaporator Heat Exchanger Characteristics

In the following table, please comment on the typical key details of evaporator heat exchangers.

Product Type	**Type**	**Core Volume (cuft)**	**Tube Outer Dia (inch)**	**Tube Length (ft)**	**Fin Surface or cold plate surface (sqft)**
Standard-Sized Refrigerator-Freezers	Forced Convection	0.21	0.33 (0.008 wall)	37	18
Standard-Sized Upright Freezers	Forced Convection	0.18	0.33 (0.008 wall)	32	18
Product Type	**Type**	**Tube Outer Dia (inch)**	**Specific Tube Length (inch per Btu/hr compressor capacity)**	**Fin Surface (sqin per Btu/hr compressor capacity)**	
Standard-Sized Chest Freezers	Cold Wall	0.3	1.7		
Compact Basic Refrigerators	Roll Bond	Channels 0.18 high x 0.38 wide	0.55	0.6	
Compact Chest Freezers	Cold Wall	0.3	2.0		

- All forced-convention evaporators use aluminum tubes?
- Typical forced-convection evaporator fin style is flat aluminum with oval gaps to slide over tube serpentine?
- Any use of internally-enhanced tubes?
- Any use of enhanced fins?
- What percentage of refrigerator/freezers use more than one evaporator?
- What percentage of refrigerator/freezers use other than forced-convection evaporators?
- Do you employ wide fin spacing and lack of fin surface enhancements for frost tolerance and quick melt runoff?

- Is there a typical evaporator air flow rate vs. compressor capacity relationship? If so, can you detail it?
- Are you aware of any further significant system improvements that may be possible through evaporator heat exchanger changes? (for example, via eggcrate evaporators, spine-fin?)
- If you use spine-fin heat exchangers, is their performance for volume/fan power better than for flat-fin heat exchangers? Or was your decision driven by cost? What about frost tolerance and internal enhancements?

Condenser Heat Exchanger Characteristics
In the following table, please comment on the typical key details of evaporator heat exchangers.

Product Type	**Type**	**Tube Outer Dia (inch)**	**Tube Length (ft)**	**Wire Fin Diameter (inch)**	**Wire Fin Total Length (ft)**
Standard-Sized Refrigerator-Freezers	Forced Convection Steel Tube Wire Fin	0.19 (0.025 wall)	50	0.05	300
Product Type	**Type**	**Tube Outer Dia (inch)**	**Tube Wall (inch)**	**Specific Tube Length (inch per Btu/hr compressor capacity)**	**Specific Wire Fin Length (foot per Btu/hr compressor capacity)**
Standard-Sized Upright Freezers	Hot Wall	0.19	0.03	1.0	N/A
Standard-Sized Chest Freezers	Hot Wall	0.19	0.03	1.3	N/A
Compact Basic Refrigerators	Static or Hot Wall	0.19	0.025	Hot Wall 1.5 Static 0.4	0.4
Compact Chest Freezers	Hot Wall or Static	0.19	0.025	Hot Wall 1.7 Static 0.9	0.7

- Any use of internally-enhanced tubes?
- Most external condenser heat exchangers designs appear to be based on steel wire fins. What are the key drivers leading to this design choice?
    - Is in-field dust-covered performance a consideration?
    - Are enhanced-surface designs too expensive?
    - Or perhaps not worthwhile because there is enough space for lower-cost wire fin design?
    - Performance degradation when dirty?
    - Or can't do better than wire fin for a given volume and the typically low fan power?
- Is there a relationship between typical condenser air flow rate vs. the compressor capacity? If so, can you detail it?

- During teardowns we noted that some manufacturers use “rolled up” heat exchangers vs. the typical flat external condenser heat exchangers. What are the benefits and drawbacks of such heat exchangers?

Evaporator and Condenser Fans

- Are the indicated characteristics for fan motors typical for refrigerator-freezers?

Shaded Pole Evaporator Fan Typical Wattage	6 W
Shaded Pole Condenser Fan Typical Wattage	9 W
Percent Wattage Reduction with Brushless DC	65%
Cost impact Evaporator Fan switch to BLDC	$3.00
Cost impact Condenser Fan switch to BLDC	$2.50

- Is there any room for further, significant energy efficiency improvement via fan blade/air flow path design improvements (i.e. PAX fan)?
- Do you consider PSC fan motors a viable intermediary step between SP and BLDC fan motors?
- Do any of your fans run at multiple speeds, for example to match the output of a variable-speed compressor?
- What are the benefits or drawbacks associated with using BLDC motors that are based on DC-power input vs. AC-power input? What is the cost difference between such motors?

Cabinet Insulation Characteristics (as applicable)

In the following table, please comment on the typical average insulation thicknesses.

Product Type	**Insulation Thickess (inches)**
Standard-Sized Refrigerator-Freezers with Automatic Defrost—Fresh Food Compartment	1.9
Standard-Sized Refrigerator-Freezers with Automatic Defrost—Freezer Compartment	2.7
Standard-Sized Upright Freezers	2.3
Standard-Sized Chest Freezers	2.5
Compact Basic Refrigerators	1.2
Compact Chest Freezers	2.5

What typical insulation thickness would be used for the following product types?

- Standard-sized refrigerator with manual or partial automatic defrost?
- Compact refrigerator-freezers?

- Standard-sized all-refrigerators?
- Compact all-refrigerators?
- Differences in typical average insulation thicknesses for built-in products?

- Is the state-of-the-art current insulation system based on HFC-245fa blowing agent with cabinet preheating and high pressure injection? Is the conductivity typically achieved for this system 0.13 Btu-in/hr-ft^2-ºF at room temperature? Do you use any other insulation systems?

- Is there any significant further cabinet load reduction possible through lower conductivity foam?
- Have you considered switching to low Global-Warming-Potential (GWP) blowing agents? If so, what are the drivers for these changes? What are the conductivity, cost impacts?
- Are you using any vacuum-insulated panels (VIPs) in any products?
- If you have or were considering the adoption of VIPs can you detail how you would incorporate them into your products, what the capital costs, and what the marginal product costs of such a step would be?
- Have you considered gas-filled panels? If so, what drove you to adopt, or not to adopt them?

Door Frame:

- What are the key aspects of good state-of-the-art door frame/gasket area design? To what extent does a typical product adhere to this? What is the range of load impact of poor door frame region designs (i.e. in Btu/hr-ft)?
- Is there any value to using double-gaskets?
- Some refrigerators have extra-strong magnets requiring special handle designs to assist with door-opening. How much load reduction is possible with such an approach?

Through-the-Door Dispensers:

- Today's TTD systems don't appear to represent thermal loads as high as suggested by the energy allowance associated with this feature, based for example on max energy difference between product classes 7 and 4. Is there more to the energy impact than the thermal load difference? How much anti-sweat heating wattage is typically used around your TTDs?

Anti-sweat Heaters:

- Most anti-sweat heaters appear to use hot liquid. Is this correct? Is there any continued use of hot gas anti-sweat systems?
- Is there data available indicating average duty cycle of such heaters for typical in-home installation? Does this depend on use of anti-sweat heater for freezer door frame, mullion door frame, ducts, etc.?
- For example, do your products use resistance heaters within the fresh food return air duct to prevent frost accumulation? If so, is it always on or controlled based on humidity?

Defrost:

- What are your thoughts about benefits and drawbacks of precool prior to the defrost cycle?

- The DOE energy test energy impact of defrost is small, particularly with variable defrost. Is this a good reflection of in-field defrost impacts?
- Are dedicated controllers available to allow variable defrost to be used in products which otherwise use non-electronic controls?

Expansion Devices:

- Is there any performance improvement potential with expansion devices other than capillary tube? What about for variable-speed compressor systems?
- Do you use any expansion device besides capillary tubes?

Energy Efficiency Conversion Costs

- What design changes are typically associated with converting baseline products mentioned above in Question 1 to Energy Star?
- What are the marginal costs of the individual design options selected?
- When considering energy efficiency improvements to achieve or exceed Energy Star, do different product classes take different pathways or are pathways similar?
- Are the cost increments higher for some classes than others for a given performance improvement over baseline? (think 10%, 15%, 20%, 25%, 30%, 35%, 35+ improvement over today's baseline)

Thoughts/feedback on alternative refrigeration cycles/implementations:

- Dual-evaporator systems attempting to cool fresh food compartment at higher evaporator temperatures.
- Ejector system.
- Stirling.
- Thermoacoustic.
- Thermoelectric.

APPENDIX 5-B. ERA MODEL DEVELOPMENT AND WINERA USERS MANUAL

TABLE OF CONTENTS

APPENDIX 5-B. ERA MODEL DEVELOPMENT AND WINERA USERS MANUAL

5-B.1 INTRODUCTION

The Energy-efficient Refrigerator Analysis Program (ERA), formerly called the EPA Refrigerator Analysis Program, serves as an important tool in the engineering analysis, described in Chapter 5 of the TSD. This appendix provides background description of the evolution of the program since its creation in the late 1980s, provides details regarding changes made to the program as part of this rulemaking, and provides program operation guidance for the user. ERA has undergone extensive analytical upgrades and has also been converted to a Window-based program. The program has its own internal help utility to provide additional assistance to the user beyond the information provided in this appendix.

5-B.2 HISTORY OF ERA MODEL

ERA has seen several major improvements since its creation. This section describes the characteristics of the initial version of ERA and the subsequent modifications to the model prior to the current DOE rulemaking, including involvement in the Thailand refrigeration appliance efficiency standards analysis and in refrigerator energy use analysis training workshops in China in the 1990s.

5-B.2.1 DOE Refrigeration Appliance Efficiency Standards

Preparation of the current DOS version of ERA (EPA Refrigerator Analysis Program) was initiated under EPA-sponsorship during the late 1980s. This was undertaken by the EPA as part its involvement in the establishment of energy standards for refrigerators, refrigerator-freezers, and freezers under the National Appliance Energy Conservation Act of 1987 (NAECA). A developmental version of the program was used by the DOE (Lawrence Berkeley Laboratory) as a partial basis for the energy standard established in 1989 (effective in 1993). The LBL work also involved an extensive testing of the model against manufacturer-supplied refrigeration appliance design and test data. Based on these comparisons and manufacturer review comments through its industry organization (AHAM), development of the model continued until its release in 1997 [1].

ERA combined an analysis of the refrigeration load requirements of the cabinet with a simulation of the capacity and efficiency of the refrigeration cycle. The cabinet loads module was a modest enhancement of a program developed for the DOE during the late 1970s [2], including the consideration of door-opening effects on the load and an ability to deal with complex insulation systems. The cycle module was a derivative of the NIST CYCLE 7 program [3] which used the CSD equation of state to represent the thermodynamic properties of pure and mixed refrigerants [4], adapting routines for calculating refrigerant properties from REFPROP3 [5]. Using this new program, EPA carried out an extensive investigation of the potential for energy efficiency improvements [6].

The program, and its User's Manual, were first released to the public in 1993, and for a few years were downloadable from the EPA website [7].

Subsequent to the 1993 final rule, DOE published updated standards for refrigerators, refrigerator-freezers and freezers in 1997, becoming effective in 2001. This involved use of the final released EPA version of ERA [1].

5-B.2.2 Thailand Refrigeration Appliance Efficiency Standards

Under three separate contracts from the Thai National Energy Policy Office, a modified version of the program was used by the program author[a] to establish minimum efficiency performance standards (MEPS) for residential refrigerators and refrigerator-freezers used in Thailand [8, 9, 10]. The first study established goals for two categories of appliances: a one-door manual defrost refrigerator, and a two-door automatic-defrost refrigerator-freezer. Three levels of MEPS were proposed, a "long-term goal" (assumed to be achievable within 10 years, and tier1 and tier 2 standards which allowed 30% and 15% energy use over the long-term goal.

As in the earlier DOE work, the local manufacturing industry was involved in the review and assessment of the proposed standard.

In response to highly negative comments on the achievability of any of the proposed efficiency levels, a second contract was awarded to prepare and test refrigerators that would meet or exceed the long-term energy target. Working with Sano Electric Company of Thailand, four prototype units were designed and tested: 31-liter and 41.5-liter one-door refrigerators, and 78.5-liter and 126.5-liter two-door refrigerator-freezers. Using available technology, the achieved energy reductions were over 20% for the one-door units, and over 34% for the two-door units, meeting the long-term target levels. Within several years, the proposed standards became law.

5-B.2.3 ERA Training Workshop in China

In response to a request from China's State Bureau of Technical Supervision (SBTS), LBNL hosted a training seminar on the use of ERA for three research engineers. The results of this training provided an increased understanding of approaches to achieve improved standards, leading to a more substantial series of cost-effective cooperative efforts towards creating China's standards program [11].

As part of a subsequent large program sponsored by the UN Global Environmental Fund (GEF), ThermoSoft carried out a one-week training workshop in Beijing [12]. The participants included 40 engineers from 20 manufacturers located throughout China. Although focused on the use of ERA as a design tool, the workshop covered the then-current component technologies available

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[a] A consultant, established under the name ThermoSoft. This work was subcontracted through ERM-Siam.

worldwide, providing an opportunity for a lively exchange of ideas. Each of the participants utilized ERA to perform analyses of their proprietary appliance models.

5-B.3 CHARACTERISTICS OF THE DOS VERSION OF ERA

ERA was developed employing then-current computer technology of the 1980s. The cabinet loads module was a minor upgrade of an earlier program used for efficiency standards, and an existing simplified heat pump cycle model was adapted to represent the refrigerator cycle. Written in FORTRAN, with a very extensive set of assembly language routines to provide a smooth user-interface, the program was hosted in DOS.

Because of the complexities of the program, and the limitations of DOS, it was broken into three modules, linked by data files and a batch file that managed the information and program execution flow. Both the MENU module (which provided the user-input interface) and the cycle execution module used nearly all of the available 600+ Kbytes of DOS accessible memory.[b] This memory limitation, inherent in DOS (which can address only 655,360 bytes of conventional memory, 10×2^{16}), imposed a fundamental limitation on the design of the program and the details that could be considered in any analysis.

ERA was constructed to take maximum advantage of the available capabilities provided by DOS, leading to somewhat complicated coding and sharing of memory spaces for certain functions. Because of the limitations imposed by DOS, ERA was designed to fit within the capabilities of a specific compiler, Microsoft FORTRAN 5.0, which was discontinued in the early 1990s. As a result, ERA is not compliable with any other version FORTRAN compiler. Further, the program requires access to the specially-developed assembly language user-interface module. As a consequence, although the source code has been made available upon request, no entity other than ThermoSoft has been able to compile it.

Because of these restrictions, the thermophysical property routines within the DOS version cannot be upgraded beyond Refprop 4.0, nor can additional fluids be considered.[c] Hence, no changes to the refrigerant properties capabilities of ERA have been made since the mid-1990s.

5-B.3.1 Modifications to ERA Since its Public Release

Given the DOS-imposed restrictions, options for upgrades to the model have been limited within this environment. However, during on the work in Thailand, several minor enhancements were made:

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[b] Of course, the program executable object had to load within this space, limiting the available memory space for data objects.

[c] Later versions of Refprop use a different structure.

- Calculation of the hot-wall effective heat transfer area. This involved specification of the tubing routing and additional details about the wall area. The outer shell, to which the tubing is pressed by the expanded foam, was treated as a thermal fin to estimate the effective heat transfer area. This capability was used during the development of the prototype models in Thailand while investigating the effects of improved hot wall design of the energy use.

- Addition of a similar analysis sub-model to calculate the effective heat transfer area for a cold-wall evaporator.

- Added multiple-speed capability to the compressor model. The efficiency-based model, which was valid only for R-12, was removed to provide this capability.

- Improved evaporator analysis in the single-door refrigerator to more correctly incorporate the radiative heat transfer effects. This led to an improvement between the model predictions and test results for the compact-refrigerator category.

Although no changes to the model were made in the model's use of compressor maps, experience working with Thai manufacturers highlighted the importance of high-quality calorimeter data.[d] As a result, each of the manufacturer-supplied maps was analyzed for consistency by examining the corresponding volumetric and isentropic efficiencies. An ability to qualify a compressor map on the basis of the underlying volumetric and isentropic efficiencies is built into the current revision of the model (see below).

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[d] Similar experience with poorly constructed manufacturer-supplied compressor maps was encountered during the EPA Multiple Pathways project [6].

5-B.4 OBJECTIVES OF THE CURRENT PROJECT

A thorough revision of the ERA program, now entitled the "**E**nergy-Efficient **R**efrigerator **A**nalysis" program, is being undertaken for the current rulemaking to meet the following objectives:

- Enhancement of the user-interface to a Windows environment
- Employment of the most current refrigerant property routines
- Incorporation of a broad range of evaporator and condenser algorithms that correspond to the technologies now found in modern refrigerators
- Improved compressor modeling, with built-in procedures for validating supplied compressor maps
- Improvements where desirable in the cabinet loads analysis and cycle performance algorithms.
- Preparation of internal documentation of the program through extensive context-sensitive Help files.

In addition to these objectives, support has been provided in the use of the DOS-version of ERA for the current standards development work. To assist this effort, a small suite of stand-alone programs has been prepared to calculate the required input values to ERA. This suite consists of:

ERAEVAP – for the calculation of the net heat transfer capabilities of a variety of evaporator designs;

ERACOND – for the calculation of the net heat transfer capabilities of a variety of condenser designs; and

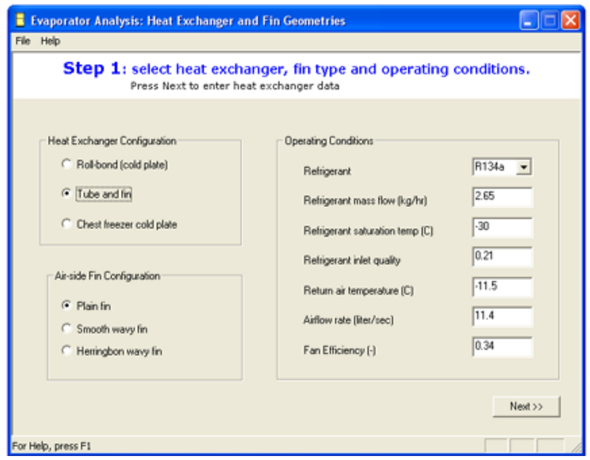
COMPMAP – a program to validate compressor maps by the calculation and display of isentropic and volumetric efficiencies, and the construction of new maps based on methods for smoothing the efficiencies as a function of compression ratio.

Each of these models contains algorithms that will be incorporated into the final Windows version of ERA, including the refrigerant algorithms. They are stand-alone programs, designed only for interim use. However, since they provide a technical basis for the new version of ERA and have been used in the ongoing engineering analyses, they are described next.

5-B.4.1 Evaporator Analysis Program – ERAEVAP

User Interface

ERAEVAP is a data-wizard based Windows program that guides the user through several steps in the specification of the evaporator design parameters.

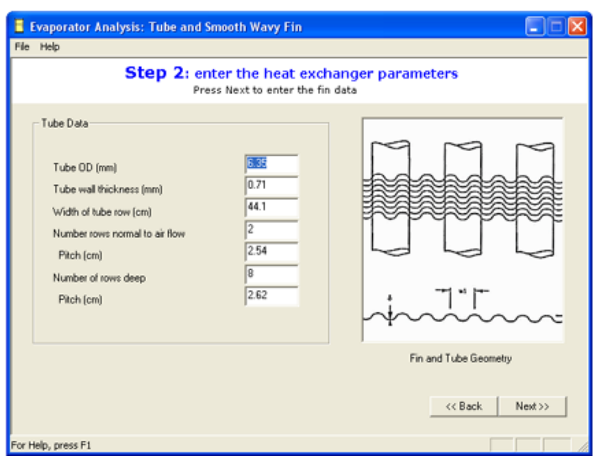


Step1 requires selection of the heat exchanger type (roll-bond freezer compartment, tube and fin fan-forced evaporator, or a chest freezer cold-wall). Three options are represented for a tube and fin configuration: plain fin, smooth wavy fin, and herringbone fin.

Refrigerant choices are: R134a, R152a, R290 (propane), R404A, R507A, R600a (isobutane), and R744 (carbon dioxide). Refrigerant properties are calculated using the NIST Refprop 8.0 routines, supplied as a linkable dll.

Other typical value operating parameters are user-specified: refrigerant mass-flow, refrigerant saturation temperature, refrigerant inlet quality, return or cabinet air temperature, and the airflow rate and corresponding fan efficiency (fan-forced analyses only).[e]

Step 2 depends on the heat exchanger configuration selected above. The illustration shows the input dialog for a tube and wavy fin design. In this instance, the tube dimensions, vertical pitch (normal to the air flow) and horizontal pitch (along the direction of the air flow) are specified.

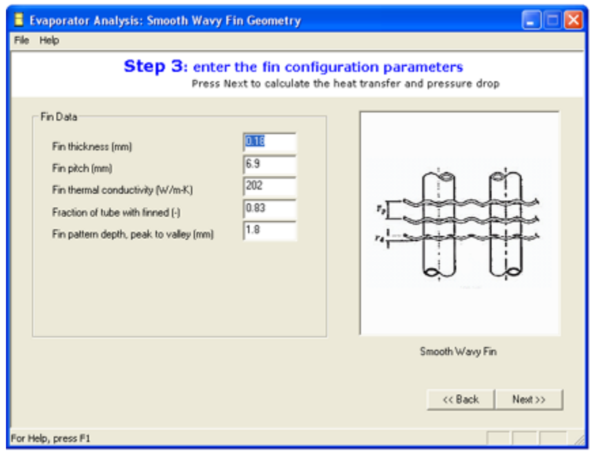


Each data dialog contains a simple illustration of the component under consideration.

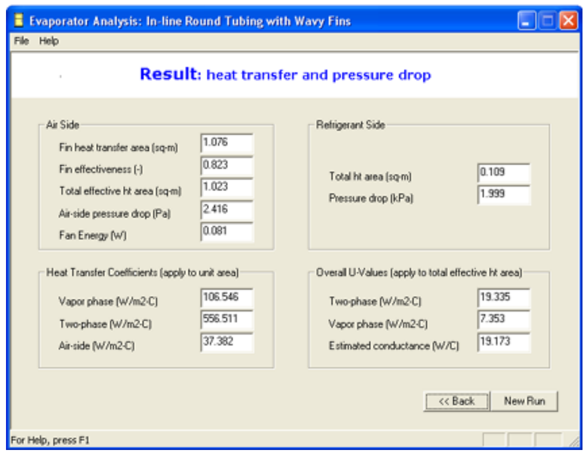
[e] These data must be user-defined since the program is not integrated into an overall cycle analysis.

Step 3, in this example, presents a dialog that requests information on the design of the fin. For the example of a wavy fin, the requested data are: fin thickness and pitch, fin thermal conductivity, fraction of the tube row that is finned, and fin pattern depth.

The number of steps required to define the evaporator depends on the design. For example, roll-bond and chest freezer evaporators only require two steps.



Results displayed depend on the type of evaporator modeled. In the case of a tube and fin design, the output includes the fin heat transfer area and effectiveness, the total effective heat transfer area, air-side pressure drop and fan energy, and the refrigerant-side pressure drop. In addition, the display lists the overall U-values that are to be used as input to ERA. These are shown specific to the input requirements of the DOS version of ERA.[f]



Roll-bond Evaporator

ERAEVAP uses the Dittus-Bolter equation [13] to determine the heat transfer coefficients for the air and the vapor phase of the refrigerant. A radiative component is added on the air-side. Liquid phase heat transfer is calculated using the Bo Pierre correlation [14]. The overall heat transfer rate is dominated by the air-side resistance. Heat transfer resistance across the roll-bond surface is assumed to be negligible.

The pressure drop in the evaporating heat transfer regime is calculated by marching stepwise downstream, calculating the local pressure gradient, and summing the local pressure drops to determine the total pressure drop. The local pressure drop is calculated using the Lockhart-Martinelli correlation [15].

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[f] As noted earlier, the stand-alone programs are intended only as an assist towards preparing input values needed by DOS ERA. Hence, they are considered an interim step in the development of the final Windows version of the updated ERA program.

Chest Freezer Cold Wall

Both air-side and refrigerant-side heat transfer rates are determined in the same manner as with a roll-bond. Calculation of the refrigerant pressure drop also uses the Lockhart-Martinelli correlation.

The refrigerant tubes are pressed on the inside surface of the chest freezer liner, which because of its small thickness acts like a thermal fin. With adjustment made for the end tubes, each parallel tube is represented as having a fin of width:

$$W_f = \text{Width of plate normal to the tube} / (2 * \text{number of tubes}),$$

The effectiveness for this equivalent fin is:

$$\eta = (k\ \delta / h)^{0.5} \tanh [W_f * (h / k\ \delta)^{0.5}] / W_f$$

For typical designs the effectiveness should be close to unity.

Tube and Fin Evaporator

Three fin options are modeled for the tube and fin design: plain fin, wavy fin, and herringbone fin. Refrigerant-side heat transfer and pressure drop are calculated in the same manner as described above. The air-side heat transfer rate depends on the type of fin and its design.

Equations for representing plain fin and herringbone fin designs were based on studies by Wang [16]. The wavy fin configuration was represented by correlations published by Mirth and Ramadhyani [17].[g] Because the correlations are quite complex, they are not reproduced here. However, both references are readily available.

The modeling and calculation approaches used in ERAEVAP will be employed in the final Windows version of ERA where analyses of the heat transfer and pressure drop characteristics of the evaporator will be built into the program. ERAEVAP will not be part of the Windows ERA package.

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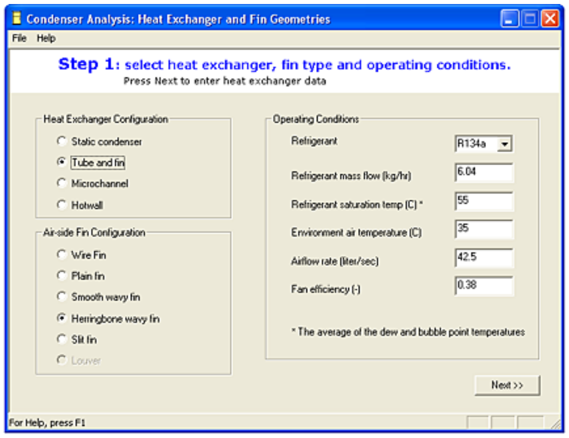
[g] Reference [16] is a summary of many studies performed and published by Wang and his colleagues for a wide variety of fin configurations, including louver fins, and slit-fins. It includes a summary of the work done on wavy fins by Mirth and Ramadhyani, but incorrectly reproduces their correlation.

5-B.4.2 Condenser Analysis Program – ERACOND

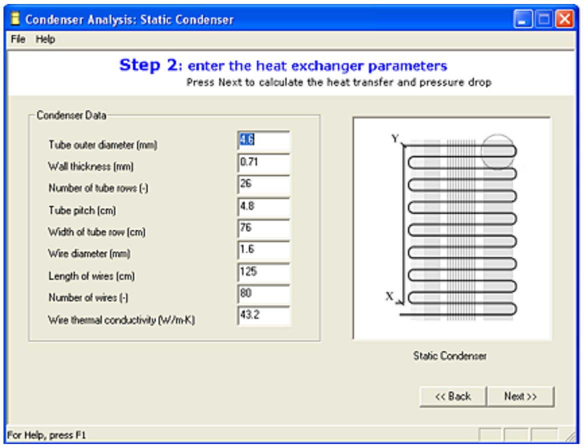
Condenser Design Options

Four generic classes of condensers are modeled: 1) static condenser, 2) various tube and fin designs, 3) microchannel design, and 4) a hot wall condenser. For each of these, the user defines the refrigerant mass flow rate, the saturation temperature, and the temperature of the environment (room or under-cabinet). The air flow rate and fan efficiency are also specified for the fan-forced designs.



Static Condenser

The static condenser model uses correlations developed by Bansal and Chin [18], who relied heavily on the work by Tagliafico and Tamda [19]. Design data include tube spacing and length, wire diameter, conductivity, and length, and the number of wires on both sides of the tubing. Heat transfer from the connecting bare tube is included in the analysis.



Refrigerant-side heat transfer is calculated according to the Shah correlation [20, 21]. Pressure drop is calculated according to the Lockhart-Martinelli correlation, assuming for the purposes of analysis that 15% of the tube is in the superheated vapor phase regime, 80% in two-phase condensation, and 5% in the subcooled regime.[h]

All of the condenser models to be described use the same approach to determining refrigerant-side heat transfer and pressure drop.

Wire Fin Condensers

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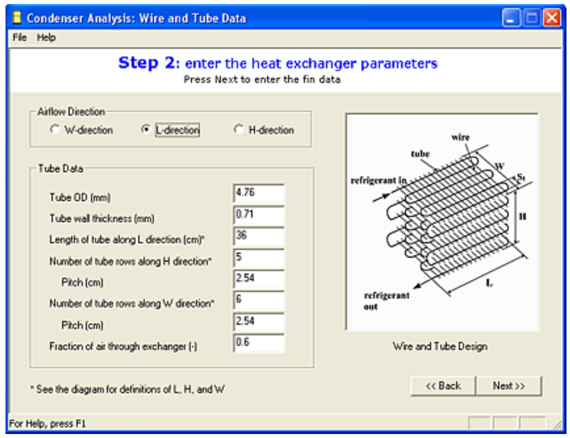
[h] This assumption will be replaced by the cycle model for the condenser in the Windows version of ERA, which will model the entire cycle system.

Wire fin condensers are found in many domestic refrigerators. ERACOND provides three options for air flow across the unit, listed in the data dialog as along the W-, L- or H-directions. Since the heat exchanger is normally located under the cabinet in the compressor space, not all of the air flow will cross the unit. Hence, a required input is the fraction of the total air flow through the condenser.

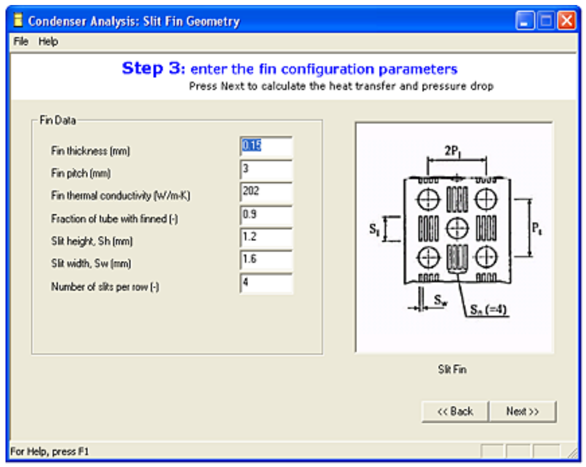


Calculation of the air-side heat transfer rate employs the Lee, et al correlation [22], which accounts for the orientation of the heat exchanger relative to the air flow.

Tube and Extended Fins

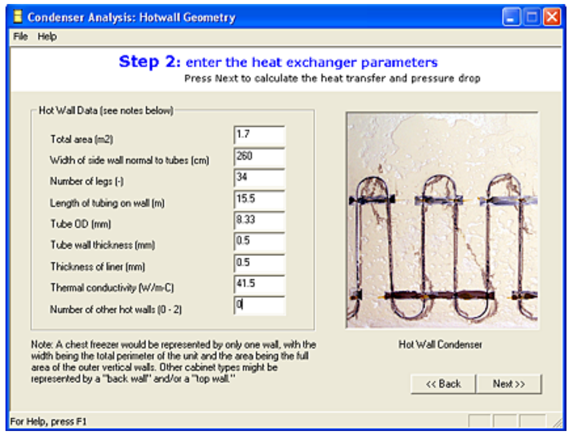
Calculation of the fin heat transfer uses the Wang correlations [16] for the plain fin, the herringbone fin, and the slit fin configurations. Representation of a wavy fin heat transfer uses the Mirth and Ramadhyani correlation [17].

Both sets of correlations also estimate the air flow pressure drop thought the fins. Although calculated and displayed in the output, they do not consider other air flow restrictions, and therefore represent low values for the fan energy.



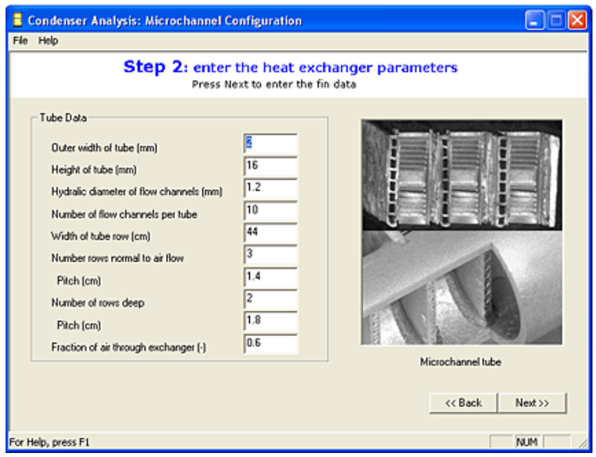
Hotwall Condenser

A hotwall condenser can be modeled as a single wall, as in a chest freezer, or by multiple walls, as in an upright freezer or refrigerator. The heat transfer effectiveness of each wall is determined. As with the evaporator cold wall, the major heat flow resistance is on the air-side. An overall pressure drop is calculated for the connected tubing using the Lockhart-Martinelli algorithm, with the Shah correlation used for the refrigerant condensing regime.



Microchannel and Louver Design

A microchannel condenser is assumed to use a louver-type fin. The refrigerant-side design determines the refrigerant flow rates and corresponding heat transfer coefficients and pressure drop. Design parameters for the louver determine the air-side heat transfer and air flow pressure drop. They are calculated using correlations developed by Wang [16].



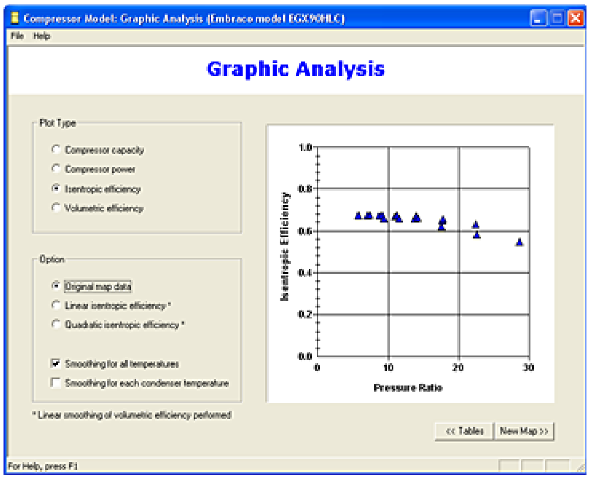
These same correlations, adopted by ERA, are used in the current (Mark VI) on-line version of the Oak Ridge heat pump model [23].

Compressor Model – COMPMAP

COMPMAP is an auxiliary program to the Windows version of ERA. The program graphically displays the isentropic and volumetric efficiencies implied by a compressor map, as a function of pressure ratio, providing a visual indication of whether the map is well formed. If desired, the map can be rebuilt based on various options for smoothing these underlying efficiencies.

COMPMAP may also be used to scale an existing map to a different COP and/or capacity. The program can import maps previously used with the DOS version of ERA or prepare new maps for use with the DOS version

COMPMAP can be used in stand-alone mode or can be directly called by ERA. This provides a built-in tool to validate and prepare maps for use in a simulation.



No assumption is made about the specific dependence of isentropic or volumetric efficiency on pressure ratio, other than that some correlation should exit. Using the efficiency values calculated for the particular map, the user is offered a choice of using the map as-is, or using a linear or quadratic smoothing of the efficiencies against the pressure ratio. This can be done for individual condenser temperatures if desired, preserving much of the original map while removing apparent randomness of performance as a function of the evaporator temperature.

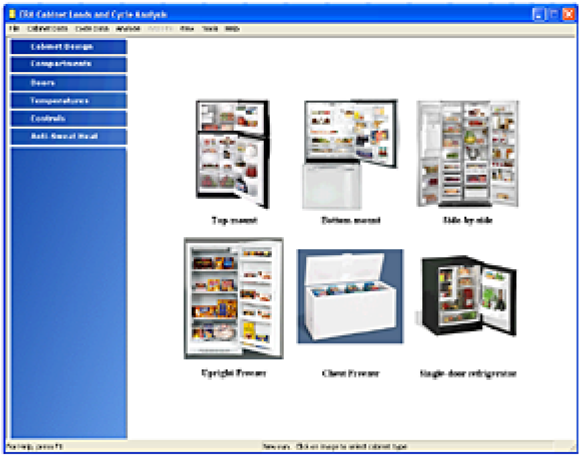
5-B.4.3 Windows Version of ERA

User Interface

ERA uses a highly-graphical interface, providing multiple options for selecting from the various cabinet and component choices. It is designed to guide the user carefully through the data input and editing process to ensure data consistency. Prior to an actual simulation of the refrigeration appliance performance, the user is presented a summary of the selected design variables.

Cabinet Mode

ERA operates in one of four view modes: 1) cabinet design mode (shown in the image), 2) cycle design mode, 3) simulation mode, and 4) reports mode. Each is characterized by its own sidebar, containing hotspots for selecting component or report options. The color of the sidebar provides an additional visual clue to highlight the particular mode that is current.

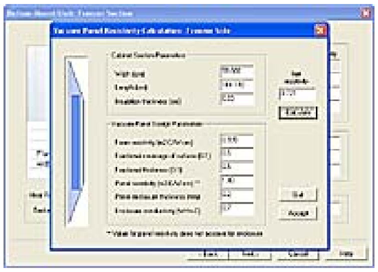


To define a new analysis, the user may either begin with a default set of design parameters and proceed through the editing process, or may read in an existing data file to be used as-is or edited.

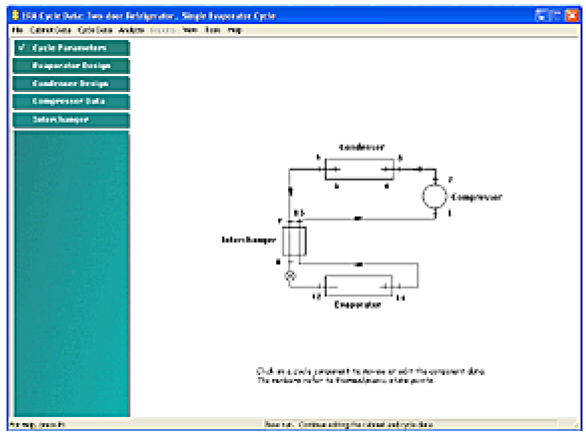
Each analysis must begin with a selection of the basic cabinet design parameters: cabinet category (shown on the desktop) and the overall dimensions of the unit. Once these basic choices have been made, the remaining categories of cabinet design data may be specified in any order. Data wizards, similar to those illustrated above for the stand-alone programs, guide the user at each stage.

As each category of data is processed, a check mark is drawn on the sidebar to indicate the completeness of the editing progress.

In some instances, special-function dialogs may be summoned to assist in the preparation of an input value. For example, the image to the right shows a dialog used to calculate the effective resistivity of a cabinet wall that contains a vacuum panel or some equivalent high thermal resistance element.



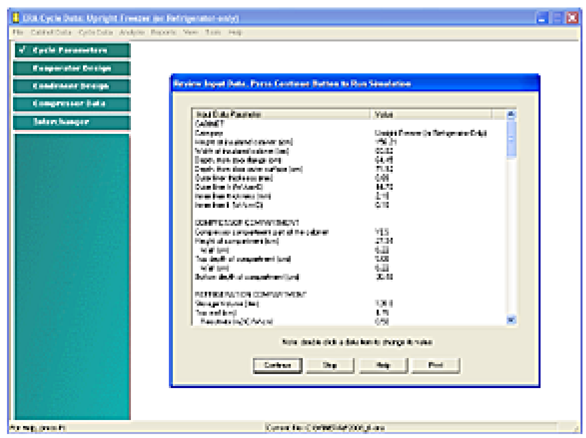
Cycle Mode



Once the basic cabinet type has been selected, the user may specify the cycle parameters. This would begin with a selection of the basic cycle type (single evaporator, dual loop, dual evaporator, or Lorenz cycle). Once this choice has been made, a simple schematic of the chosen cycle category is displayed on the desktop. The user may then continue to define the cycle parameters by clicking on the desktop to select the component of interest, or may use the sidebar or the the drop-down menu to select the next component to be defined.

The displayed desktop image and its associated hotspots depend on the specific cycle category selected.

Simulation Mode

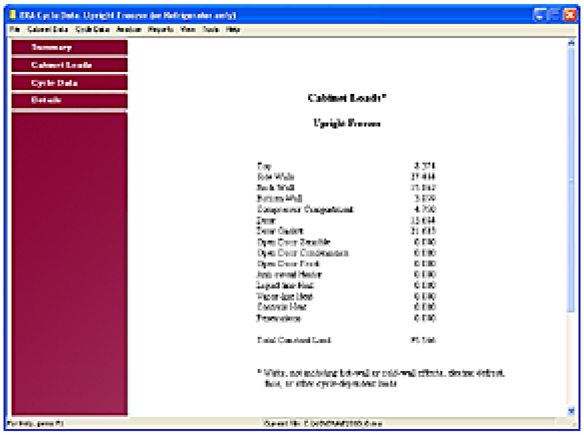


Prior to simulation of the cabinet loads and cycle behavior, the user is presented with a summary of the defined input. A data item can be selected for further editing by double-clicking on the summary line displaying the item in the data review dialog.

Once the data has been reviewed and accepted, the user selects the Continue button to start the simulation.

Reports Mode

At the completion of the simulation (which is instantaneous for the cabinet loads), the program automatically switches to reports mode and displays the results on the desktop. The example here shows the calculated cabinet loads. Results for the cycle analysis, overall performance parameters, or a more detailed summary, can be selected using the side-bar or the drop-down menu for reports.



Cabinet Loads

As of this preliminary documentation, only the cabinet loads have been modeled.

Each of the cabinet walls has at least one beveled edge where it joins another wall. Hence, some adjustment needs to be made for the difference between the inside and outside surfaces of the wall – that is, the conduction is not strictly one-dimensional. Detailed finite difference calculations carried out for a flat wall with adiabatic beveled edges (where the walls connect) show that a very good approximation can be obtained by representing the beveled wall as an equivalent wall of one dimensional heat transfer, where the equivalent wall area is:

$$\text{Area}_{\text{equiv}} = 0.25 \text{ Area}_{\text{outside}} + 0.75 \text{ Area}_{\text{inside}}$$

This is nearly identical to the method adopted in the DOS version of ERA, which also made adjustments for corner effects where three walls join. Hence, the previous methodology was retained, with minor corrections made as needed.

The loads analysis does not yet consider cycle-dependent interactions such as hot- or cold-walls, fan energies, defrost, or other cycle-dependent heat terms. These will be incorporated during the cycle portion of the simulation.

Refrigerant Properties

The fluid choices for the refrigeration cycle are: R134a, R152a, R290, R404A, R507A, or R600a. Thermodynamic properties are based on Refprop 8.0 [24]. To speed the computations, an approach to using the Helmholtz equation of state outlined by one of the authors of Refprop [25] has been adopted as the primary simulation option for ERA. This reference contains required property data for R-404A and R-507A. Data for the other refrigerants represented by ERA have been obtained from the Refprop fluid database.

A secondary option to use the full set of the more comprehensive, but considerably slower,[i] Refprop routines will be offered for those instances when the user might wish to confirm the simulated performance.

Because Refprop does not supply a complete set of thermophysical properties for all of the refrigerants over the full set of temperatures and pressures, correlations for the thermal conductivity and viscosity were developed from refrigerant manufacturer literature. In general, uncertainties in these properties are less important than uncertainties in the thermodynamic properties since the net heat transfer resistance is normally dominated by the air-side.

Cycle Analysis

The cycle model, currently under development, will adopt the general approach employed in the DOS version of ERA. An iterative solution procedure will be required to simultaneously satisfy the heat transfer and mass flow equations throughout the loop. Where the cycle components affect the cabinet loads, adjustments to the loads will be calculated.

Several major differences will appear between the Windows and DOS versions of ERA:

- Only a map-based compressor model will be used. This decision is based on experience gained using ERA with actual equipment, where compressor information for the actual unit was needed to accurately reflect the energy consumption. The accompanying compressor module, COMPMAP, can be employed to create or modify map data.

- The heat exchanger performance routines will be integrated into the overall cycle simulation. Hence, the effects of parameters such as refrigerant mass flow, and entering temperature and pressure on the heat exchanger performance will be automatically taken into account at each stage of the simulation.

- An improved iteration approach will be used to ensure rapid and proper convergence. The solution method used in the ORNL Mark series heat pump looks promising [26].

Tools

The new version of ERA provides several tools to assist in preparing the program inputs and in interpreting the results:

Compressor Map program. COMPMAP may be run directly from ERA by selecting this option from the Tools menu. It provides a means of viewing and/or adjusting a map that is to be used in

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[i] Both Lemmon [25] and ThermoSoft experience obtained with a heat pump model confirm that the Helmholtz method can result in computation time reductions of a factor of 30 to 40 over the full set of Refprop routines.

the cycle simulation. When selected, ERA is minimized until the compressor map program is dismissed,

Refrigerant Properties. A calculation of the refrigerant properties for the selected refrigerant can be made given certain specified state points. The calculations are carried out using the Helmholtz method.

Unit Conversion. This tool can be used to convert to different units values of length, flow rate, temperature, thermal conductivity, volume, energy, or power.

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CHAPTER 6. MARKUPS FOR EQUIPMENT PRICE DETERMINATION

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 6. MARKUPS FOR EQUIPMENT PRICE DETERMINATION

6.1 INTRODUCTION

To carry out its analyses, DOE needed to determine the cost to the consumer of baseline products and the cost of more-efficient units. As discussed in chapter 8, DOE developed retail prices for baseline products using proprietary retail price data collected by The NPD Group. For products with higher-than-baseline efficiency, DOE estimated the consumer prices by applying appropriate markups to the manufacturer incremental equipment costs estimated in the engineering analysis.

6.1.1 Distribution Channels

The appropriate markups for determining consumer equipment prices depend on the type of distribution channels through which products move from manufacturers to purchasers. At each point in the distribution channel, companies mark up the price of the equipment to cover their business costs and profit margin.

Data from the Association of Home Appliance Manufacturers (AHAM)[1] indicate that an overwhelming majority of residential appliances are sold through retail outlets. Because DOE is not aware of any other distribution channel that plays a significant role for residential refrigeration products, DOE assumed that all of the residential products are purchased by consumers from retail outlets. DOE did not include a separate distribution channel for refrigeration products included as part of a new home, as it did not have information on the extent to which these products are "pre-installed" by builders in new homes.

6.2 MARKUP CALCULATION PROCEDURE

As just discussed, at each point in the distribution channel, companies mark up the price of the equipment to cover their business costs and profit margin. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (*CGS*). Inputs for calculating the gross margin are all corporate costs—including overhead costs (sales, general, and administration); research and development (R&D) and interest expenses; depreciation, and taxes—and profits. In order for sales of a product to contribute positively to company cash flow, the product's markup must be greater than the corporate gross margin. Individual products may command a lower or higher markup, depending on their perceived added value and the competition they face from similar products in the market.

In developing markups for manufacturers and retailers, DOE obtained data about the revenue, *CGS*, and expenses of firms that produce and sell the products of interest. For retailers, DOE's approach categorizes the expenses into two categories: labor-scaling costs (*LSC*), which are fixed labor and occupancy expenses that increase in proportion to the amount of labor required to produce or sell the product, and non-labor-scaling costs (*NLSC*), which are variable operating costs that do not scale with labor and vary in proportion to *CGS*.

6.2.1 Approach for Manufacturer Markups

DOE uses manufacturer markups to transform a manufacturer's equipment costs into a manufacturer sales price. Using the *CGS* and gross margin, DOE calculated the manufacturer markup (MU_{MFG}) with the following equation:

$$MU_{MFG} = \frac{CGS_{MFG} + GM_{MFG}}{CGS_{MFG}}$$

where:

MU_{MFG} =	Manufacturer markup,
CGS_{MFG} =	Manufacturer's cost of goods sold or Manufacturer Production Cost (*MPC*), and
GM_{MFG} =	Manufacturer's gross margin.

The manufacturer's *CGS* (or *MPC)* plus its *GM* equals the manufacturer selling price (*MSP*).

6.2.2 Approach for Retailer Markups

DOE based the retailer markups for residential refrigeration products on financial data from the U.S. Census Business Expenditure Survey. DOE organized the financial data into balance sheets that break down cost components incurred by firms that sell the products.[a] The key assumptions that DOE used to estimate the retailer markups using these financial data were:

1. The balance sheets faithfully represent the various average costs incurred by firms selling home appliances.

2. These costs can be divided into two categories:
   a. Costs that vary in proportion to the manufacturer sales price (variable costs); and
   b. Costs that do not vary with the manufacturer sales price (fixed costs).

3. Retailer sales prices vary in proportion to retailer costs that are included in the balance sheets.

In support of the first assumption, the balance sheets itemize firm costs into a number of expense categories, including *CGS*, operating labor and occupancy costs, and other operating

[a] The retailers to whom these financial data refer handle multiple commodity lines.

costs and profit. Although retailers tend to handle multiple commodity lines, the data provide the most accurate available indication of home appliance expenses.

Information obtained from the trade literature pertaining to the heating, ventilation, and air-conditioning (HVAC) contracting industry tends to support the second assumption. This information indicates that retailer markups should vary according to the quantity of labor and materials used to sell or distribute the equipment, with markups on labor tending to be much larger than markups on materials.[2] This information also describes markups as varying much more in relation to sales volume than in relation to other factors, including appliance efficiency. This last finding strongly suggests that labor inputs vary more with sales volume than with appliance cost or efficiency. In the discussion that follows in section 6.3, DOE assumes a division of costs between those that do not scale with the manufacturer sales price (fixed costs—labor and occupancy expenses referred to above as *LSC*), and those that do (variable costs—operating expenses and profit referred to above as *NLSC*). This division of costs led to the estimate of retailer markups described below in section 6.3.

In support of the third assumption, the retailer industries are relatively competitive, and consumer demand for residential home appliances is relatively inelastic, i.e. the demand is not expected to decrease significantly with a relatively small increase in price. The large number of household appliance stores listed by the U.S. Census Bureau in its *Statistics of U.S. Businesses* indicates the competitive nature of the market.[3] For example, there are more than 10,000 household appliance store establishments and over 5000 merchant wholesaler establishments of service equipment in the U.S.[b] According to standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[4]

Using the above assumptions, DOE developed baseline and incremental markups to transform the manufacturer sales price into a consumer equipment price. DOE used the baseline markups, which cover all of a retailer's costs (i.e., both *LSC* and *NLSC*), to determine the sales price of baseline models. The baseline markup relates the manufacturer sales price to the retailer sales price. DOE considers baseline models to be equipment sold under existing market conditions (i.e., without new energy efficiency standards). DOE calculated the baseline markup (MU_{BASE}) for retailers using the following equation:

$$MU_{BASE} = \frac{CGS_{RTL/DIST} + GM_{RTL/DIST}}{CGS_{RTL/DIST}} = \frac{CGS_{RTL/DIST} + (LSC_{RTL/DIST} + NLSC_{RTL/DIST})}{CGS_{RTL/DIST}}$$

where:

MU_{BASE} = Baseline retailer markup,
$CGS_{RTL/DIST}$ = Retailer's cost of goods sold,
$GM_{RTL/DIST}$ = Retailer's gross margin,

[b] DOE determined the number of establishments for household appliance stores based on the following North American Industry Classification System (NAICS) code and description: 443111, *Household Appliance Stores*.

$LSC_{RTL/DIST}$ = Retailer's labor-scaling costs, and
$NLSC_{RTL/DIST}$ = Retailer's non-labor-scaling costs.

Incremental markups cover only those costs that scale with a change in the manufacturer's sales price (i.e., *NLSC*). Incremental markups are coefficients that relate the change in the manufacturer sales price of higher-efficiency models to the change in the retailer sales price. DOE considers higher-efficiency models to be equipment sold under market conditions with new efficiency standards. It calculated the incremental markup (MU_{INCR}) for retailers using the following equation:

$$\boldsymbol{MU_{INCR} = \frac{CGS_{RTL/DIST} + NLSC_{RTL/DIST}}{CGS_{RTL/DIST}}}$$

where:

MU_{INCR} = Incremental retailer markup,
$CGS_{RTL/DIST}$ = Retailer's cost of goods sold, and
$NLSC_{RTL/DIST}$ = Retailer's non-labor-scaling costs.

6.3 MANUFACTURER MARKUPS

DOE developed an average manufacturer markup by examining the annual Securities and Exchange Commission (SEC) 10-K reports filed by four publicly-traded manufacturers primarily engaged in appliance manufacturing and whose combined product range includes residential refrigeration products.[5] The four manufacturers represent a nearly 50 percent market share for major appliances. Because these companies are typically diversified, producing a range of different appliances, an industry average markup was assumed by DOE to be representative for the manufacture of refrigeration products. DOE evaluated markups for the years 2002─2005.

Table 6.3.1 lists the average corporate gross margin during the years 2002─2005, and corresponding markups, for each of the four manufacturers. The average markup value based on these four companies is 1.26, which is the value that DOE used.

Table 6.3.1 Major Appliance Manufacturer Gross Margins and Markups

	Mfr A	Mfr B	Mfr C	Mfr D
Average Net Revenues (Million)	$372	$280	$4770	$12,682
Corporate Gross Margin	15%	28%	16%	22%
Markup	1.18	1.39	1.19	1.28

Source: SEC 10-K reports (2002-2005)

6.4 RETAILER MARKUP

DOE used financial data from the U.S. Census Business Expenditure Survey (BES), in the "Household Appliance Stores" category, to calculate markups used by retailers that apply to residential refrigeration products.[c] [6] Table 6.4.1 shows the BES data that DOE used and the estimated retail markups.

Table 6.4.1 Data Used to Calculate Retailer Markups for Residential Refrigeration Products

Item	Million Dollars
Sales (revenue)	10343
Cost of Goods Sold (CGS)	7151
Gross Margin (GM)	3193
Labor-Scaling Costs (LSC)	
Payroll	1366
Fringe Benefits	208
Contract Labor	69
Taxes and License Fees	53
Lease and Rental Payments	238
Telephone and Communications	58
Utilities	70
Repair and Maintenance	36
LCS Subtotal:	2098
Non-Labor-Scaling Costs (NLSC)	
Depreciation and Amortization	94
Office Supplies	37
Packaging and Other Materials	0
Advertising Services	274

[c] DOE used the 1997 BES because the 2002 BES did not contain sufficient data for the calculation of gross margin or cost of goods sold.

Legal Services	8
Accounting, Auditing, and Bookkeeping	19
Computer Related Services	10
Other Operating Expenses	389
Net Profit Before Taxes	263
NLCS Subtotal:	1094
Baseline Markup (MU_{BASE}) = (CGS+GM)/CGS	**1.45**
Incremental Markup (MU_{INCR}) = (CGS+NLSC)/CGS	**1.15**

6.5 SALES TAXES

The sales tax represents state and local sales taxes that are applied to the consumer equipment price of the equipment. The sales tax is a multiplicative factor that increases the consumer equipment price.

DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[7] DOE derived population-weighted average tax values for each Census division and large state, as shown in Table 6.5.1 below.

Table 6.5.1 Average Sales Tax Rates by Census Division and Large State

Census Division/State	Tax Rate
New England	4.96%
Mid Atlantic	6.54%
East North Central	6.93%
West North Central	6.77%
South Atlantic	6.17%
East South Central	7.90%
West South Central	8.37%
Mountain	6.50%
Pacific	5.20%
New York State	8.25%
California	9.00%
Texas	8.05%
Florida	6.70%

DOE then derived U.S. average tax values for each product (as shown in Table 6.5.2 below) based on the product's saturation within each Census division and large state. It determined the saturations from the DOE Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey.[8]

Table 6.5.2 Average Sales Tax Rates by Product

Product	Tax Rate
Refrigerators (Standard-size and compact)	7.08%
Freezers (Standard-size and compact)	6.94%

6.6 SUMMARY OF MARKUPS

Table 6.6.1 summarizes the markups at each stage in the distribution channel and the average sales tax.

Table 6.6.1 Summary of Markups

Markup	Baseline	Incremental
Manufacturer	1.26	
Retailer	1.45	1.15
Sales Tax	1.069	

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CHAPTER 7. ENERGY USE DETERMINATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 7. ENERGY USE DETERMINATION

To perform the life-cycle cost (LCC) and payback period (PBP) calculations described in chapter 8, the U.S. Department (DOE) needed to determine the savings in operating cost that consumers would derive from more efficient products. DOE uses data on annual energy consumption, along with energy prices, to develop the most significant component of consumer operating cost. (Maintenance and repair costs are the other components.) This chapter describes how DOE determined the annual energy consumption of refrigeration products.

The engineering analysis described in chapter 5 reports energy use derived from the DOE test procedure. This test produces standardized results that can be used o compare the performance of different brands of the same product class operating under similar conditions. Actual energy usage in the field, however, often differs from that estimated by the test procedure. Researchers have conducted studies that measure the field consumption of refrigerator-freezers, comparing such measurements to the DOE test results. DOE's review of several such studies is described in appendix 7-A and summarized in section 7.3.9. The review confirmed that energy use measured in the field often differs considerably from the usage measured by the DOE test procedure.

To determine the field energy use by products that would meet potential new energy efficiency standards, DOE used data from the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS).[1] RECS queries a national sample of households to collect statistical information on household consumption of and expenditures for energy, along with data on energy-related characteristics of the housing units and households. RECS provides enough information to establish the type of refrigeration product (the product class) used in each household, and provides an estimate of the household energy consumption attributable to refrigerators or freezers. As a result, DOE was able to develop a unique household sample for most of the representative product classes for standard-size units.

DOE did not use RECS to evaluate energy consumption by compact refrigerators and freezers, because many of those products are used outside the residential sector, such as in college dormitories, hotels and motels, and offices.

7.1 HOUSEHOLD SAMPLES FOR REFRIGERATION PRODUCTS

DOE developed household samples for refrigeration products from the 2005 RECS. The survey, which sampled 4,382 housing units, was constructed to represent the household population throughout the United States.

RECS results reveal whether a household uses a standard-size refrigerator or freezer. For households that have a standard-size refrigerator, RECS specifies whether the freezer is top- or bottom-mounted or is side-mounted. Thus units in the sample that have top-mounted freezers cannot be distinguished from those having bottom-mounted freezers (product classes 3 and 5). For a household's primary (or "first") refrigerator, RECS specifies whether there is through-the-door ice service. For households that have standard-size freezers, RECS specifies whether the unit is upright or a chest-type. With the above data, DOE was able to assign each household record to one of the five product classes considered for potential new efficiency standards (Table 7.1.1).

Table 7.1.1 Refrigeration Products in Households by Product Class

Product Class	Number of Household Records*	Percent of Total Household Records*	Relative Standard Error Due to Sampling*
3. Refrigerator-freezer: automatic defrost with top-mounted freezer and no TTD[†] ice service 5. Refrigerator-freezer: automatic defrost with bottom-mounted freezer and no TTD ice service	2,303	52.6%	2.1%
7. Refrigerator-freezer: automatic defrost with side-mounted freezer and TTD ice service	1,026	23.4%	3.1%
9. Upright freezer with automatic defrost	248	5.7%	6.4%
10. Chest freezer and all other freezers except compact models	369	8.4%	5.2%

* From the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS).
[†] Through-the-door.

The relative standard errors associated with the subsamples that contain specific product classes are not considered so large as to affect the validity of the derived results presented in this chapter. Specifically, the relative standard error of a sample of size N, expressed as a percentage, is 100 divided by the square root of (N-1). For the full 2005 RECS sample, the associated relative standard error due to sampling is 1.5 percent. For the subsamples containing product classes 9 and 10, the associated relative standard errors are 6.4 percent and 5.2 percent, respectively. Although the standard error for the smallest subsample is more than four times the error for the entire 2005 RECS, it still is less than 10 percent, a relative standard error considered small enough to yield meaningful results. Therefore, DOE believes the results generated from the household samples for refrigeration products are representative of U.S. households using those appliances.

7.2 APPROACH FOR STANDARD-SIZE PRODUCTS

The Residential Energy Consumption Survey (RECS) reports the annual field energy consumption of each household's refrigeration product(s), a quantity referred to as FEC_{RECS}. DOE treated the reported energy consumption as the actual consumption of the refrigeration product(s) in each household. Because the energy consumed by a household's refrigerator or freezer varies depending on operating conditions, user behavior, and other factors, DOE applied a multiplicative usage adjustment factor (UAF) to the labeled energy use of each product to reflect those factors.

To develop a UAF for each RECS household, DOE utilized information that RECS provides on the interior volume and age of each refrigeration product. Using this information and the unit's product class, DOE determined for each household unit the maximum allowable tested energy consumption, referred to as TEC_{STD}, as stipulated by the energy conservation standard in effect at the time the household purchased the product. Because TEC_{STD} differentiates among current levels of energy efficiency, it guards against overestimating the energy savings to be derived from potential new standards. Using FEC_{RECS} and TEC_{STD}, DOE developed the UAF for each household to capture the combined effects of consumer behavior (*e.g.*, door openings); operating conditions (*e.g.*, room temperature and humidity); and product characteristics (*e.g.*, efficiency relative to the maximum allowable). The UAF adjusts the maximum allowable energy use when the unit was tested to arrive at the field energy consumption of the refrigeration product. UAF is represented by the following expression.

$$\mathrm{UAF} = \frac{FEC_{RECS}}{TEC_{STD}}$$

Eq. 7.1

Where:

UAF = usage adjustment factor;
FEC_{RECS} = refrigeration product's field energy consumption as reported for the RECS household; and
TEC_{STD} = maximum allowable tested energy consumption based on the standard in effect at the time the household purchased the refrigeration product; for products purchased before 1990 (when the first national standard came into effect), DOE used the shipments-weighted average energy consumption for that vintage to scale the standard.

DOE was better able to estimate the efficiency of ENERGY STAR products and thus develop a UAF that more accurately represents only behavior and operating conditions. DOE used an income-based statistical model, described in section 7.3.4, to identify households likely to own an ENERGY STAR appliance. In those cases, UAF was defined as follows.

$$\text{UAF} = \frac{FEC_{RECS}}{TEC_{ES}}$$

Eq. 7.2

Where:

UAF = usage adjustment factor,
FEC_{RECS} = refrigeration product's field energy consumption as reported for the RECS household, and
TEC_{ES} = tested energy consumption based on the ENERGY STAR criteria in effect at the time the household purchased the refrigeration product.

DOE conducted its analysis with an awareness of proposed revisions to the DOE test procedure for refrigerator-freezers, which will stipulate lower temperatures for the fresh food compartment and the freezer than those the currently prescribed. DOE has not identified how the tested energy consumption under the new procedure will compare to that determined under the current procedure. DOE expects this adjustment to take the form of a multiplicative factor termed the "efficiency standard adjustment factor," or ESAF. The ESAF is expected to be multiplicative, because the energy use for a refrigeration unit is close to proportional to the difference between its interior and exterior temperatures. For the current preliminary analysis, DOE assumed that this factor is constant for each product class, and does not vary with product efficiency or adjusted volume. See chapter 5 for a complete discussion of the derivation of these values. DOE determined the preliminary value of the ESAF for refrigerator-freezers to be:

- 1.124 for product class 3,
- 1.18 for product class 5,
- 1.14 for product class 7,
- 1.00 for product class 9, and
- 1.00 for product class 10.

If the ESAF is multiplicative, it does not affect DOE's estimate of appliance energy consumption by consumers, *FEC* The mathematical demonstration of this equivalence is shown below, after several additional terms are defined. Fundamentally, the value of the ESAF does not affect estimates of field energy use, because changes in the test procedure do not affect consumer behavior or operation of an appliance within a household. Field energy consumption of future appliances built to meet a national standard, however, may be affected by the test procedure used to define the standard. For this reason, DOE assumed that the effects of consumer behavior and operating conditions, characterized by the UAF, are separate from the effects of the test procedure, characterized by the ESAF. DOE therefore separated the UAF values calculated from the RECS household sample from the ESAF, which does not vary across the household sample.

If appropriate, DOE will incorporate a more complete and accurate model for the ESAF based on ongoing analysis and additional information collected from interested parties. Therefore, although a constant, multiplicative ESAF does not affect estimated annual energy use, DOE has chosen to show where the factor would enter into its calculations. To that end, DOE defined a new term, $TEC_{STD\text{-}REV\text{-}TP}$, which is determined with the following expression.

$$TEC_{STD-REV-TP} = ESAF \times TEC_{STD-EXIST-TP} \qquad \textbf{Eq. 7.3}$$

Where:

$TEC_{STD\text{-}REV\text{-}TP}$ = maximum allowable tested energy consumption based on the standard in effect at the time the household purchased the refrigeration product, revised to reflect proposed lower temperatures for the fresh food and freezer compartments;
$ESAF$ = efficiency standard adjustment factor; and
$TEC_{STD\text{-}EXIST\text{-}TP}$ = maximum allowable tested energy consumption based on the standard in effect at the time the household purchased the refrigeration product, reflecting current DOE test procedure conditions.

Substituting $TEC_{STD\text{-}REV\text{-}TP}$ for TEC_{STD} in Eq. 7.1 produces the following expression for UAF.

$$\text{UAF} = \frac{FEC_{RECS}}{ESAF \times TEC_{STD-EXIST-TP}} \qquad \textbf{Eq. 7.4}$$

After the UAFs were determined for each household within a given sample, DOE adjusted the tested energy consumption for a new refrigeration product (TEC_{NEW}) (such as those analyzed in the engineering analysis) into a field-adjusted annual energy consumption, referred to as FEC_{NEW}, using the following expression.

$$FEC_{NEW} = TEC_{NEW} \times UAF \qquad \textbf{Eq. 7.5}$$

Where:

FEC_{NEW} = field-adjusted annual energy consumption of new refrigeration product, and
TEC_{NEW} = tested energy consumption of new refrigeration product.

DOE assumed that the UAF a given household would be the same for products that meet some future energy efficiency standard as it is for their current appliance. In conducting the life-cycle cost analysis (chapter 8), DOE substituted the refrigeration product recorded in RECS with a new product of identical product class and size that the household is assumed to purchase in the year when the new standard goes into effect.

If the ESAF is a multiplicative factor, as DOE assumed for this analysis, and the energy use required by the new standard is reduced from the current standard by a factor R (*e.g.*, a 10-

percent efficiency improvement would mean R = 0.1), then for an appliance that meets the new standard, tested under the new test procedure, the field energy consumption is

$$
\begin{aligned}
FEC_{NEW-STD} &= TEC_{NEW-STD} \times UAF = TEC_{NEW-STD} \times \frac{FEC_{RECS}}{ESAF \times TEC_{STD-EXIST-TP}} \\
&= FEC_{RECS} \times \frac{TEC_{NEW-STD} / TEC_{STD-EXIST-TP}}{ESAF} \\
&= FEC_{RECS} \times \frac{(1-R) \times ESAF \times TEC_{STD-EXIST-TP} / TEC_{STD-EXIST-TP}}{ESAF} \\
&= (1-R) \times FEC_{RECS}
\end{aligned}
\qquad \textbf{Eq. 7.6}
$$

A multiplicative ESAF therefore is not needed to calculate energy savings related to a higher efficiency standard, which can be calculated using only FEC_{RECS} and R.

7.3 USAGE ADJUSTMENT FACTORS FOR STANDARD-SIZE PRODUCTS

This section describes how DOE developed usage adjustment factors (UAFs) from the data provided for each household in RECS. It also describes how DOE developed minimum and maximum UAFs based on the highest and lowest plausible energy consumption of refrigeration products in the field. DOE's methods of acconting for second refrigerators and ENERGY STAR products are also described.

7.3.1 Field Energy Consumption for One or More Refrigerators

RECS reports the annual energy consumption of each household's refrigerator(s) or freezer in terms of thousands of British thermal units (BTUs) per year, which DOE converted to kilowatt-hours (kWh) per year. The reported end-use quantities were not based on data obtained by placing meters on individual appliances; rather, a regression technique was used to estimate how much of the total annual electricity consumption for each household can be attributed to each end-use category.[a] The regression equations also were used to infer energy consumption when the billing data were missing or inadequate. The refrigerator component for electricity consisted of all electricity used to operate refrigerators. The electricity used to operate freezers was assigned to a separate component under the category of "general appliance."

[a] The desire to use a large number of independent variables without using a large number of interaction terms and the desire to adapt the regression procedures to account for heteroscedastic error terms led to the use of a nonlinear regression technique. For more information, see: http://www.eia.doe.gov/pub/consumption/residential/append_c.pdf

When a house has two or more refrigerators in RECS[b], the energy consumption of all the refrigerators is included in the term for “electric refrigerator use.” DOE’s analysis required separate consideration of each individual refrigerator in a household.

Total refrigerator field energy consumption (*FEC*) for households having two refrigerators can be expressed as:

$$FEC = (UAF_1 \times TEC_{STD1}) + (\frac{Mon}{12} \times UAF_2 \times TEC_{STD2}) \qquad \textbf{Eq. 7.7}$$

Where:

UAF = usage adjustment factor,
TEC = test energy consumption, and
Mon = number of months per year the second refrigerator is on.[c]
The subscript numerals 1 and 2 refer to the first and second refrigerator, respectively.

TEC_{STD} refers to the maximum annual energy consumption allowed by the efficiency standards in effect when the product was manufactured. This value depends on the age and adjusted volume of the refrigerator. DOE assigned values for the age and adjusted volume of the second refrigerator the same way as for the first refrigerator. After these were assigned, the TEC_{std} for the second refrigerator was calculated.

The location of the second refrigerator, often in either a garage or basement, affects its UAF. DOE assumed that for most households, the second refrigerator is in the garage. In those cases the UAF of the second refrigerator is the same as that of the first. If the second refrigerator operates for 12 months of the year, and the house is in the northern part of the country, however, the unit was assumed to be in a basement. (North is defined as Census Districts 1, 2, 3, and 4 plus New York, as well as other areas experiencing at least 5,000 heating degree-days. Because the operating environment of a basement on average is colder than that of the first refrigerator, DOE estimated the UAF of the second refrigerator to be 70 percent of the UAF of the first. This estimate was based on results of a simulation performed under basement conditions versus Results from the DOE test procedure. Although DOE did not use RECS to develop a household sample for compact refrigerators, DOE included in its analysis of standard-sized products those households having a second refrigerator that was a compact. The compact was assigned a volume based on the volume distribution in the California Energy Commission appliance database,[2] and assigned a UAF as if it were standard-sized.

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[b] Of the households in RECS 2005, 19.6 percent reported having two refrigerators; 1.2 percent reported having three. DOE considered only those households having one or two refrigerators.

[c] RECS reports months of operation for a second refrigerator.

The UAF for each refrigerator can be calculated based on the above assumptions. For most households, the UAF for both first and second refrigerators is calculated as:

$$UAF = \frac{FEC}{\left(TEC_{STD1} + (\frac{Mon}{12} \times TEC_{STD2})\right)} \qquad \textbf{Eq. 7.8}$$

For households in which the second refrigerator is assumed to be in the basement, the UAF for the first refrigerator is calculated as:

$$UAF_1 = \frac{FEC}{\left(TEC_{STD1} + (0.70 \times \frac{Mon}{12} \times TEC_{STD2})\right)} \qquad \textbf{Eq. 7.9}$$

and the UAF for the second refrigerator is calculated as:

$$UAF_2 = 0.70 \times UAF_1 \qquad \textbf{Eq. 7.10}$$

7.3.2 Tested Energy Consumption

For each refrigeration unit in a RECS home, the maximum allowable tested energy consumption based on the standard in effect at the time the refrigeration product was manufactured (TEC_{STD}) depends on the unit's product class, size, and age (vintage). If the household was assigned a refrigerator having an ENERGY STAR designation (using the model derived in section 7.3.4), DOE calculated the maximum allowed tested energy consumption for an ENERGY STAR unit of the appropriate vintage rather than the maximum allowed by the concurrent standard.

Each unit's product class was identified as described in section 7.1. The size and vintage were determined as described below.

7.3.2.1 Size

The possible answers to the RECS question regarding the size of the first refrigerator or freezer are shown in Table 7.3.1. The distribution of actual sizes is not uniform within the RECS size bins. To estimate the actual size of each unit, DOE estimated the distribution of sizes within each bin. To approximate that distribution, DOE used data on refrigerator models from the 2009 California Energy Commission (CEC) appliance model database.[2] The figures in appendix 7-B show the number of models by size within each RECS size bin for each considered product classes. The size assigned to a sample refrigerator within a RECS size bin was assigned randomly using probabilities derived from the CEC data.

Table 7.3.1 Size Bins for Refrigerators and Freezers

Bin*	Size of First Refrigerator *cu ft*†
1	Very small (10 or fewer)
2	Small (11 to 14)
3	Medium (15 to 18)
4	Large (19 to 22)
5	Very large (more than 22)

* Bins defined in Residential Energy Consumption Survey, 2005.
† Cubic feet.

The maximum allowed energy consumption depends on the year the product was produced, its product class, and adjusted volume. For a refrigerator-freezer, the adjusted volume is equal to the internal volume of the fresh food compartment plus 1.63 times the internal volume of the freezer compartment.[3] Using the CEC database,[2] DOE used the following linear regression to calculate the adjusted volume (Vol_{adj}) from the total volume (Vol_{tot}):

$$Vol_{adj} = Vol_{tot} \times Slope + Intercept \qquad \textbf{Eq. 7.11}$$

DOE performed this calculation for each product class, deriving the parameters shown in Table 7.3.2.

Table 7.3.2 Parameters for Calculating Adjusted Volume from Total Volume of Refrigerator-Freezers

Product Class	Slope	Intercept	R^2 †	Count
3. Refrigerator-freezers: automatic defrost with top-mounted freezer and no TTD* ice service	1.2205	-1.1049	0.9691	1,803
5. Refrigerator-freezers: automatic defrost with bottom-mounted freezer and no TTD ice service	1.1851	0.0159	0.9929	778
7. Refrigerator-freezers: automatic defrost with side-mounted freezer and TTD ice service	1.3170	-1.9992	0.9906	1,866

*Through-the-door.
† R^2 is the *coefficient of determination*, a measure of how well the model fits the data.

7.3.2.2 Assigning Vintage and ENERGY STAR Status

The vintage of a refrigerator reflects the minimum efficiency standards that were in effect at the time it was purchased. Table 7.3.3 lists the relevant energy efficiency standards and the dates each became effective. The formula that expresses the standard is for maximum allowable kWh per year as a linear function of adjusted volume (AV).[4, 5]

Table 7.3.3 Energy Conservation Standards for Refrigeration Products

Product Class	1990	Jan. 1, 1993	July 1, 2001
3. Top-mount refrigerator-freezers without TTD* ice service	23.5AV+471	16.0AV + 355	9.80AV+276.0
5. Bottom-mount refrigerator-freezers without TTD ice service	27.7AV+488	16.5AV + 367	4.60AV+459.0
7. Side-by-side refrigerator-freezers with TTD ice service	30.9AV+547	16.3AV + 527	10.10AV+406.0
9. Upright freezers with automatic defrost	16.0AV+623	14.9AV + 391	12.43AV+326.1
10. Chest freezers	14.8AV+233	11.0AV + 160	9.88AV+143.7

*Through-the-door.

The vintage also reveals which ENERGY STAR criteria were in effect. The effective dates of successive ENERGY STAR specifications are shown in Table 7.3.4.[6 7]

Table 7.3.4 ENERGY STAR Criteria for Refrigeration Products

ENERGY STAR Criterion	Effective Date
Refrigerators*	
15% less energy than NAECA† 2001 maximum allowed	January 1, 2004
10% less energy than NAECA 2001 maximum allowed	January 1, 2001
20% less energy than NAECA 1993 maximum allowed	June 1996
Freezers	
10% less energy than NAECA 2001 maximum	January 1, 2003

* The criteria that became effective in 2008 (20% less energy than NAECA 2001 maximum) do not apply to units described in RECS 2005.

† National Appliance Energy Conservation Act

RECS assigns the age of a refrigeration product to one of the five bins listed in Table 7.3.5.

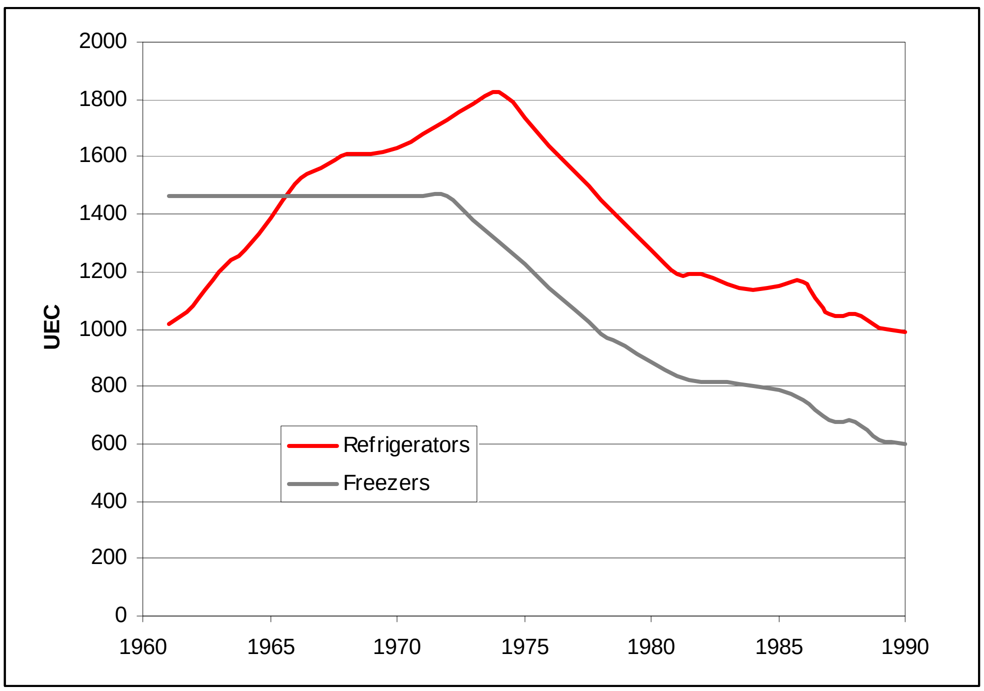
Table 7.3.5 Vintage Bins for Refrigeration Products

Bin*	Age of Unit *years*
1	Less than 2
2	2 to 4
3	5 to 9
4	10 to 19
5	20 or more

* Bins defined in Residential Energy Consumption Survey, 2005.

The dates refrigerator standards took effect do not correspond exactly to the age bins in RECS. When the age bin of a refrigerator is insufficient to determine which standard applied, DOE chose a year from within the bin to assign as the vintage of that refrigerator. After the year was chosen using the survival curve developed for appliance lifetime, the standard appropriate to that vintage was applied.

For refrigeration products shipped before 1990, DOE derived an efficiency index based on trends in the average unit energy consumption (UEC) for historical shipments of refrigerators and freezers. Figure 7.3.1shows the trends in UEC from 1960 to 1990.



Source: AHAM Factbooks

Figure 7.3.1 Average Unit Energy Consumption, 1961 to 1990 Shipments

There are likely to be fewer of the oldest refrigerators within any vintage bin, both because older refrigerators tend be replaced and because fewer refrigerators were produced in earlier years. This trend is revealed in Figure 7.3.2, which shows the weighted number of households by vintage from the 2005 RECS. For this figure, the refrigerators in each bin were assigned equally to each year. A better approach would be to assign more refrigerators to the more recent years within each bin by calculating the survival probability [that is, the probability of a refrigerator surviving (remaining in use)] for a number of years. The survival probability is calculated using the number of refrigerators of each vintage bin reported by RECS as a fraction of the number of refrigerators shipped in that range of years. The survival probability accounts for the increases in shipments over time, as well as the refrigerators that retire from use. The survival probability function used to assign vintages is the same as the lifetime function derived for use in the life-cycle cost analysis. The derivation of all parameter values is described in chapter 8.

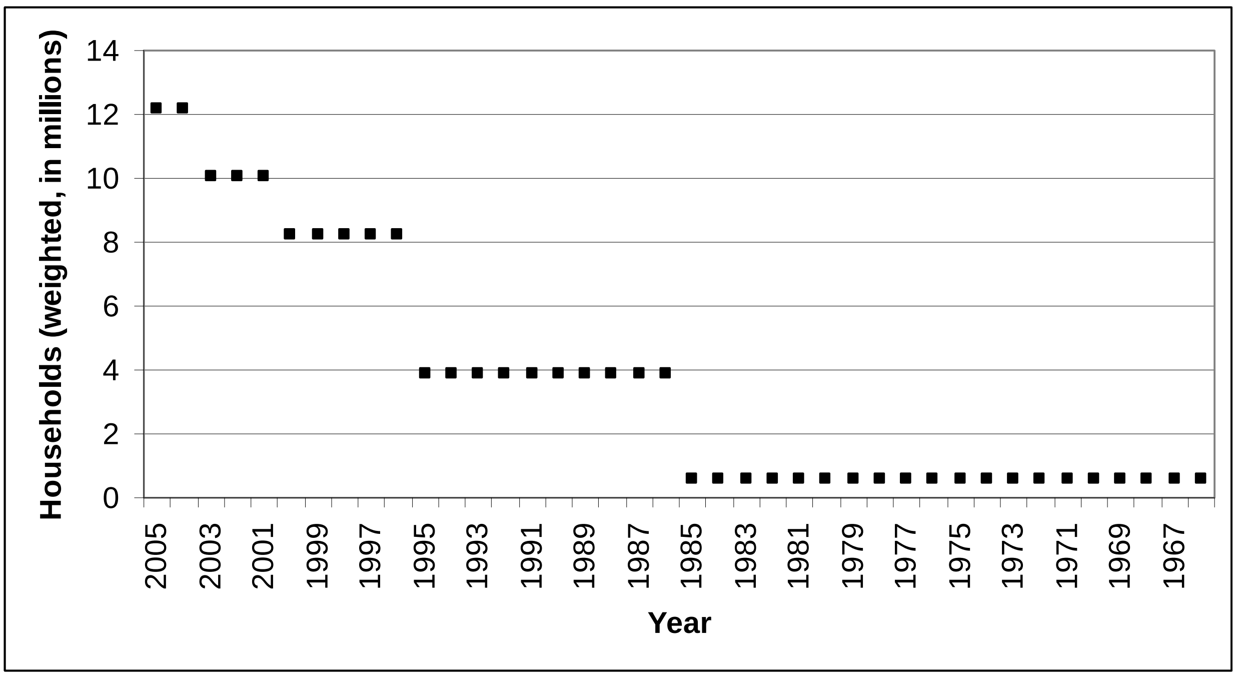


Figure 7.3.2 Weighted Households by Refrigerator Vintage

The survival probability was calculated as:

$$P = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta$$
$$P = 1 \text{ for } x \le \theta \qquad \textbf{Eq. 7.12}$$

Where:

x = number of years (appliance age),

α = 13.91, Weibull scale parameter,
β = 1.68, Weibull shape parameter, and
θ = 5, Weibull delay parameter.

Figure 7.3.3 shows the survival probability curve for standard-sized refrigerators.

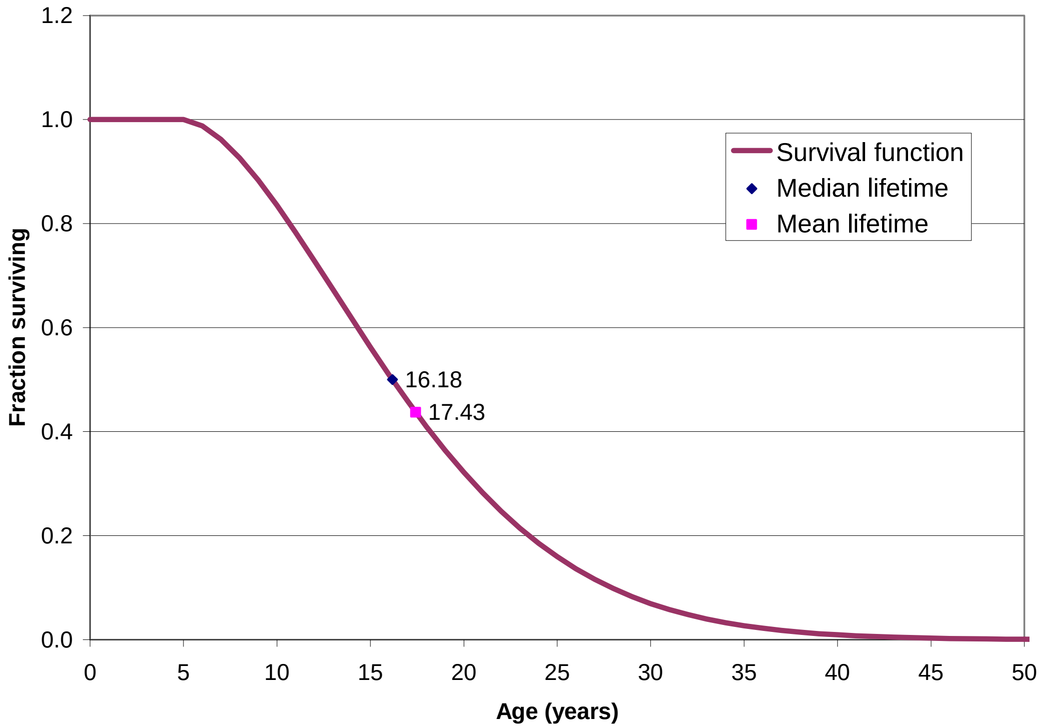


Figure 7.3.3 Survival Probability of Refrigerators by Age

The same fitting technique was used for freezers. The scale, shape, and delay parameters for freezers are:

α = 19.49, Weibull scale parameter,
β = 2.40, Weibull shape parameter, and
θ = 5, Weibull delay parameter.

The survival curve for freezers (Figure 7.3.4) does not fall off as quickly as does the one for refrigerators (Figure 7.3.3), indicating a longer mean product lifetime.

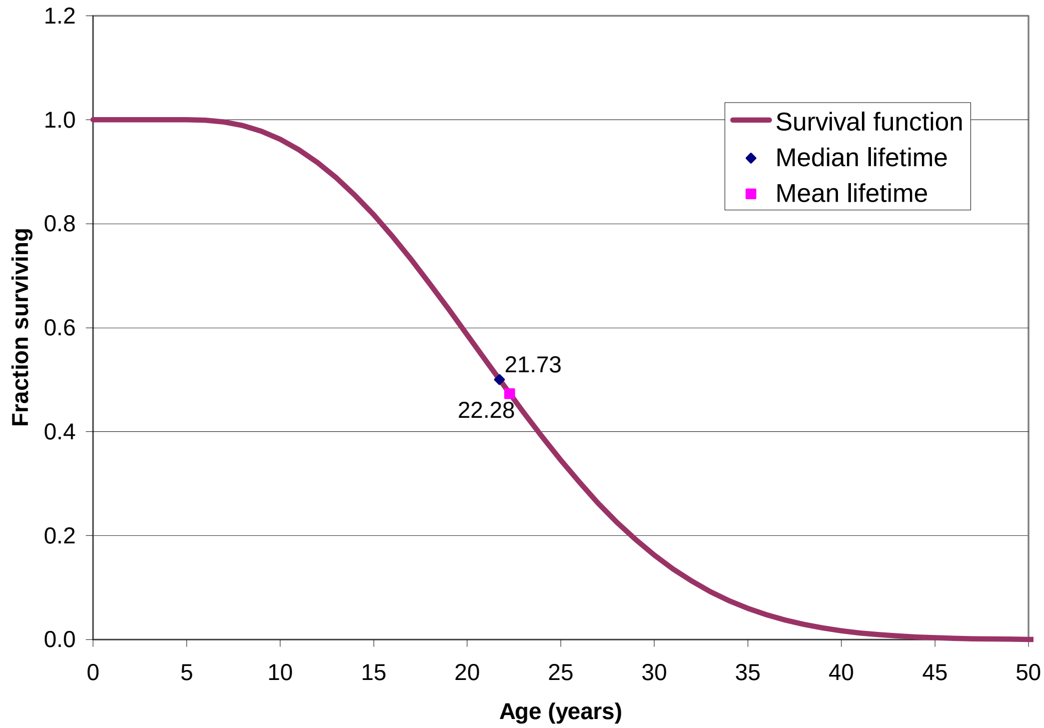


Figure 7.3.4 Survival Probability of Freezers by Age

A multistep process was followed to assign an age to a given refrigeration product in a REC household. First, the product's age range (based on RECS bin) was compared with the Weibull delay parameter. For both refrigerators and freezers, the delay was fixed at 5 years, which falls between two RECS age bins. If the age bin contained appliances younger than the delay (in years), then an age within the bin was assigned randomly to the product, with no age preferred. If the bin contained appliances older (in years) than the delay, a survival value was selected randomly from within the range given for the relevant bin. For this purpose, each bin was assumed to extend to the beginning of the next bin. Table 7.3.6 shows the survival values assigned to household refrigerators by age bin.

Table 7.3.6 Refrigerator Survival Probabilities Associated with Age Bins

Age Bin	**Age *years***		**Survival Value**	
	Start	Less than	Start	End
1	0	2	NA	NA
2	2	5	NA	NA
3	5	10	1.000	0.8196
4	10	20	0.8196	0.3051
5	20	100	0.3051	0.0000

The age of the unit was calculated from the assigned survival value using the inverse survival probability function:

$$Age = \alpha \times \left(\ln\left(\frac{1}{SP} \right) \right)^{\left(\frac{1}{\beta} \right)} + \theta \qquad \textbf{Eq. 7.13}$$

Where:

SP = randomly selected survival value,
α = Weibull scale parameter,
β = Weibull shape parameter, and
θ = Weibull delay parameter.

After an age was assigned to the refrigerator or freezer, it was clear what efficiency standards and (if applicable) ENERGY STAR specifications were in effect when it was sold.

7.3.3 Energy Use of Second Refrigerators

When a household purchases a new refrigerator, some first units become second units. See chapter 8 for a discussion of how DOE modeled the conversion of refrigerators from first to second units. A second refrigerator, generally located in a basement or garage, enters a new operating environment and may be used less than year-round. For those units that become a second refrigerator, therefore, the annual energy consumption changes, presumably remaining at the new level for the rest of its lifetime.

Field energy consumption for the first (*FEC*1) and second (*FEC*2) phases of a refrigerator's lifetime can be expressed as:

$$FEC1 = (UAF_1 \times TECstd) \qquad \textbf{Eq. 7.14}$$

$$FEC2 = (\frac{Mon}{12} \times UAF_2 \times TECstd) \qquad \textbf{Eq. 7.15}$$

Where:

UAF_1 = usage adjustment factor for first phase of the unit's lifetime,
UAF_2 = usage adjustment factor for second phase,[d]
TEC = test energy consumption, and
Mon = number of months per year refrigerator is on.

7.3.4 Estimated Number of ENERGY STAR Refrigerators

As stated earlier, DOE used Eq. 7.2 to derive the UAF for RECS households likely to own an ENERGY STAR appliance. Although RECS 2005 provides information on ownership of ENERGY STAR refrigerators purchased between 2001 and 2005, the data seem to greatly overestimate the stock of ENERGY STAR refrigerators compared to data regarding shipments made during those years. DOE therefore developed a method that predicts ENERGY STAR ownership in the RECS sample based on annual average market shares of ENERGY STAR refrigerators and on household income.

DOE based its approach on a study from Natural Resources Canada[8] that reported ENERGY STAR buyers based on three income categories. DOE assumed that the relative behavior of each income category is the same in the United States as for Canadian consumers. After matching the three income categories to RECS income bins, DOE assigned a probability of owning an ENERGY STAR unit to each household record as a function of its income. This probability was then scaled to reflect income levels in the RECS sample and national ENERGY STAR sales. The following equation was used.

$$Estar_{year} = scale_{year} \times (F_{low} \times P\_Estar_{low} + F_{mid} \times P\_Estar_{mid} + F_{high} \times P\_Estar_{high}) \quad \textbf{Eq. 7.16}$$

Where:

$Estar_{year}$ = percent of annual national refrigerator sales that were ENERGY STAR qualified;
$F_{low|mid|high}$ = percent of weighted number of RECS 2005 households in low, medium, and high income bins;
$P\_Estar_{low|mid|high}$ = probability of households in an income bin buying an ENERGY STAR appliance; and
$scale_{year}$ = scaling factor to obtain the appropriate percent of ENERGY STAR refrigerators for each vintage.

Table 7.3.7 shows the market shares of ENERGY STAR refrigerators ($Estar_{year}$), which were obtained from the ENERGY STAR program.[9] The market shares of ENERGY STAR freezers are estimates.

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[d] This UAF accounts for the changed operating environment during the second phase.

Table 7.3.7 Market Share of ENERGY STAR Products

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005
Refrigerators	25.3%	19.0%	25.0%	27.0%	17.3%	20.1%	25.7%	33.2%	32.9%
Freezers	-	-	-	-	-	-	10%	10%	10%

The scaling factor for each year was calculated as:

$$scale_{year} = \frac{Estar_{year}}{(F_{low} \times P\_Estar_{low} + F_{mid} \times P\_Estar_{mid} + F_{high} \times P\_Estar_{high})} \qquad \textbf{Eq. 7.17}$$

A household in the low-income bin that purchased a refrigerator in a given year was a assigned a probability $Scale_{year}$ times P_Estar_{low} for having an ENERGY STAR refrigerator. A similar approach was taken for households in the mid- and-high income bins.

7.3.5 Validating Field Energy Consumption

The values for refrigerator energy consumption reported in RECS 2005 ranged from 6 kWh to more than 10,000 kWh for households having one refrigerator. DOE developed an approach that utilized the UAFs calculated for each household to confirm whether the reported values for refrigerators (and freezers) were reasonable. This approach required calculating maximum and minimum plausible UAFs for various refrigeration products.

A range of possible UAFs can apply to a given refrigerator, based on the range of possible refrigerator sizes and ages consistent with the household's RECS response. If the range of UAFs for a given household was entirely outside the boundaries of what DOE considered to be plausible, DOE excluded the household from the LCC analysis. Such outliers occur if the maximum possible UAF for a record is lower than the minimum plausible UAF or if the minimum UAF is higher than the maximum plausible UAF.

If the range of UAFs for a given household intersected the range of plausible UAFs, the UAFs outside the boundaries were brought to the minimum or maximum plausible value. Thus, a household was not excluded from the sample if it had a plausible UAF.

7.3.6 Maximum Usage Adjustment Factor

To evaluate the maximum plausible UAF, DOE estimated the maximum plausible energy consumption of a refrigerator if it were running continuously. DOE's calculation of the maximum electricity consumption assumes that the compressor runs constantly, comparable to leaving the door open 24 hours a day for 365 days a year. The evaporator and condenser fans, the interior lights, and the gasket heater (found only on refrigerators built before 1993) also were assumed to run continuously. DOE assumed that both the refrigerator and freezer compartment have a 20-W light bulb. The defrost cycle is often initiated based on the compressor run time.

DOE assumed the defrost cycle runs for 10 minutes every 10 hours, which is the default input to the EPA's refrigerator analysis (ERA) model.[10]

Table 7.3.8 shows the power consumption and times DOE estimated for various components of each cycle for the ice maker. In real-world operation the compressor must run longer than indicated in Table 7.3.8 in order to extract the heat from the ice maker components, along with the latent heat of freezing from freezing water to make ice. To calculate the maximum theoretical electricity consumption, DOE assumed that the compressor already runs continuously, so there is no additional compressor run time. The components consume a total of 6.3 Watt-hours per ice-making cycle.[11] The value used for maximum ice-making cycles per day was nine.[12]

Table 7.3.8 Power Consumption for Ice Maker Components

Component	Watts	Length of Cycle
Mold heater	185	2 minutes
Solenoid valve	20	8 seconds
Motorized ejector	3	2 minutes

The formula for calculating the maximum plausible UAF is:

$$MaxUAF_{pl} = \frac{(W_{Comp} + W_{Fans} + W_{Lights} + W_{Gasket} + W_{Defrost} \times 1.7\%) \times 365 \times 24 / 1000 + kWh_{Ice}}{\mathrm{TEC}_{\mathrm{STD\text{-}EXIST\text{-}TP}} \times ESAF},$$

Eq. 7.18

Where:

W_{Comp} =	the power (in Watts) used by the compressor;
W_{Fans} =	the power (in Watts) used by the fans;
W_{Lights} =	the power (in Watts) used by the light;
W_{Gasket} =	the power (in Watts) used by the gasket heater;
$W_{Defrost}$ =	the power (in Watts) used by the defrost cycle, which is active 1.7 percent of the time
kWh_{Ice} =	the energy (in kWh) used to complete nine ice-making cycles per day (including mold heater, solenoid, and ejector) in one year;
$\mathrm{TEC}_{\mathrm{STD\text{-}EXIST\text{-}TP}}$ =	the test energy consumption; and
ESAF =	the efficiency standard adjustment factor.

DOE collected the wattage for most components for the baseline models in several product classes from the Technical Support Documents (TSDs) developed in the analyses leading to the 2001 standard, the July 1995 notice of proposed rulemaking,[13] and the November 1989 final rule.[14] The earlier TSDs (March 1982[15] and June 1980[16]) did not report baseline energy use for the compressor. The documents, however, do report the amount of time the refrigerator was running during the test procedure. DOE calculated the maximum plausible annual energy consumption by (1) increasing the test procedure output to what it would be if the refrigerator were running continuously and (2) adding a continuously burning 40-W light bulb.

The equation given above was used to calculate the maximum theoretical UEC and UAF for each baseline model in the TSDs. The theoretical maximum UAFs based on past TSDs for all of the analyzed product classes are shown in Tables 7.3.9 through 7.3.13.

Table 7.3.9 Theoretical Maximum Energy Consumption for Baseline Product Class 3 Refrigerator-Freezers

Baseline (TSD)	Compressor *W*	Evaporator Fan *W*	Condenser Fan *W*	Lights *W*	Gasket Heater *W*	Defrost *W*	Defrost % Time On *%*	Ice Making *kWh*	Test Procedure *kWh*	Time on *%*	Max UEC* *kWh*	Max UAF†
2001	124	4.5	4.5	40	0	450	1.7%	20.6	544	-	1,598	2.93
Jul-95	145	9.1	12	40	0	450	1.7%	20.6	788	-	1,891	2.40
Nov-89	186	10	13.5	40	19	450	1.7%	20.6	1,073	-	2,436	2.27
Mar-82	-	-	-	40	-	-	-	-	1,518	65%	2,428	1.60
Jun-80	-	-	-	40	-	-	-	-	1,805	53%	3,381	1.87

* Unit Energy Consumption.
† Usage adjustment factor.

Table 7.3.10 Theoretical Maximum Energy Consumption for Baseline Product Class 5 Refrigerator-Freezers

Baseline (TSD)	Compressor *W*	Evaporator Fan *W*	Condenser Fan *W*	Lights *W*	Gasket Heater *W*	Defrost *W*	Defrost % Time On *%*	Ice Making *kWh*	Test Procedure *kWh*	Time on *%*	Max UEC* *kWh*	Max UAF†
2001	133	4.5	4.5	40	0	450	1.7%	20.6	573	-	1,677	3.69
Jul-95	143	10.5	10.0	40	0	450	1.7%	20.6	845	-	1,864	2.76
Nov-89	187	10.0	13.5	40	12	450	1.7%	20.6	1,324	-	2,387	2.13
Mar-82	-	-	-	40	-	-	-	-	2,209	63%	3,340	1.79

* Unit Energy Consumption.
† Usage adjustment factor

Table 7.3.11 Theoretical Maximum Energy Consumption for Baseline Product Class 7 Refrigerator-Freezers

Baseline (TSD)	Compressor *W*	Evaporator Fan *W*	Condenser Fan *W*	Lights *W*	Gasket Heater *W*	Defrost *W*	Defrost % Time On *%*	Ice Making *kWh*	Test Procedure *kWh*	Time on *%*	Max UEC* *kWh*	Max UAF†
2001	141	8.0	4.5	40	0.0	450	1.7%	20.6	764		1,777	2.33
Jul-95	150	8.0	11.6	40	0.0	450	1.7%	20.6	912		1,920	2.11
Nov-89	186	10	14	40	-	0	1.7%	20.6	1,756		2,442	1.39
Mar-82	-	-	-	40	-	-	-	-	2,517	52%	4,597	1.83
Jun-80	-	-	-	40	-	-	-	-	2,422	53%	4,284	1.77

Note: The Max UAF derived from the 1989 TSD does not agree with the rest of the sample, making the R^2 drop from 0.99 to 0.41; thus it has been excluded from the regression.
* Unit Energy Consumption.
† Usage adjustment factor

Table 7.3.12 Theoretical Maximum Energy Consumption for Baseline Product Class 9 Freezers

Baseline (TSD)	Compressor *W*	Evaporator Fan *W*	Condenser Fan *W*	Lights *W*	Gasket Heater *W*	Defrost *W*	Defrost % Time On *%*	Test Procedure *kWh*	Time on *%*	Max UEC* *kWh*	Max UAF† *kWh*
2001	119	4.5	0.0	20	0	450	1.7%	663	-	1,260	1.90
Jul-95	126	9.0	0.0	20	0	450	1.7%	759	-	1,357	1.79
Nov-89	169	10.0	0.0	20	9	450	1.7%	1,088	-	1,822	1.67
Mar-82	-	-	-	20	-	-	-	1,303	81%	1,784	1.37
Jun-80	-	-	-	20	-	-	-	1,332	87%	2,194	1.65

* Unit Energy Consumption.
† Usage adjustment factor

Table 7.3.13 Theoretical Maximum Energy Consumption for Baseline Product Class 10 Freezers

Baseline (TSD)	Compressor *W*	Evaporator Fan *W*	Condenser Fan *W*	Lights *W*	Gasket Heater *W*	Defrost *W*	Defrost % Time On *%*	Test Procedure *kWh*	Time on *%*	Max UEC *kWh*	Max UAF† *kWh*
2001	85	0	0	20	0	0	0.0%	394	-	916	2.32
Jul-95	101	0	0	20	0	0	0.0%	472	-	1,059	2.25
Nov-89	187	0	0	20	0	0	0.0%	557	-	1,813	3.26
Mar-82	-	-	-	20	-	-	-	1,215	80%	1,695	1.39
Jun-80	-	-	-	20	-	-	-	1150	69%	1842	1.60

Note: The Baseline model from the 1989 TSD was excluded because its compressor power was 100 W higher than to be expected if it followed the trend in W/cu ft between 1995 and 2001.

The maximum annual energy consumption allowed by a given standard scales linearly with volume. DOE assumed that in the extreme case used to determine the maximum plausible energy consumption, annual energy consumption also scales linearly with volume. Therefore, the maximum theoretically possible UAF is constant for each production year and product class, regardless of volume.

Older refrigerators generally had low maximum plausible UAFs. As the minimum efficiency allowed by standards increased, compartments became better insulated and the refrigeration cycle more efficient. The compressor therefore uses less energy to maintain conditions inside the cabinet and so runs for less time. Ordinary test procedure operation thus represents a smaller and smaller fraction of the extreme, all-out energy consumption used in the calculations described in this section. Thus, the test procedure energy use (TEC) for older refrigerators is closer to their maximum theoretically possible field energy consumption than it is for newer refrigerators.

The maximum theoretically possible UAF (MaxUAF) scales linearly with age, as shown in Figure 7.3.5.

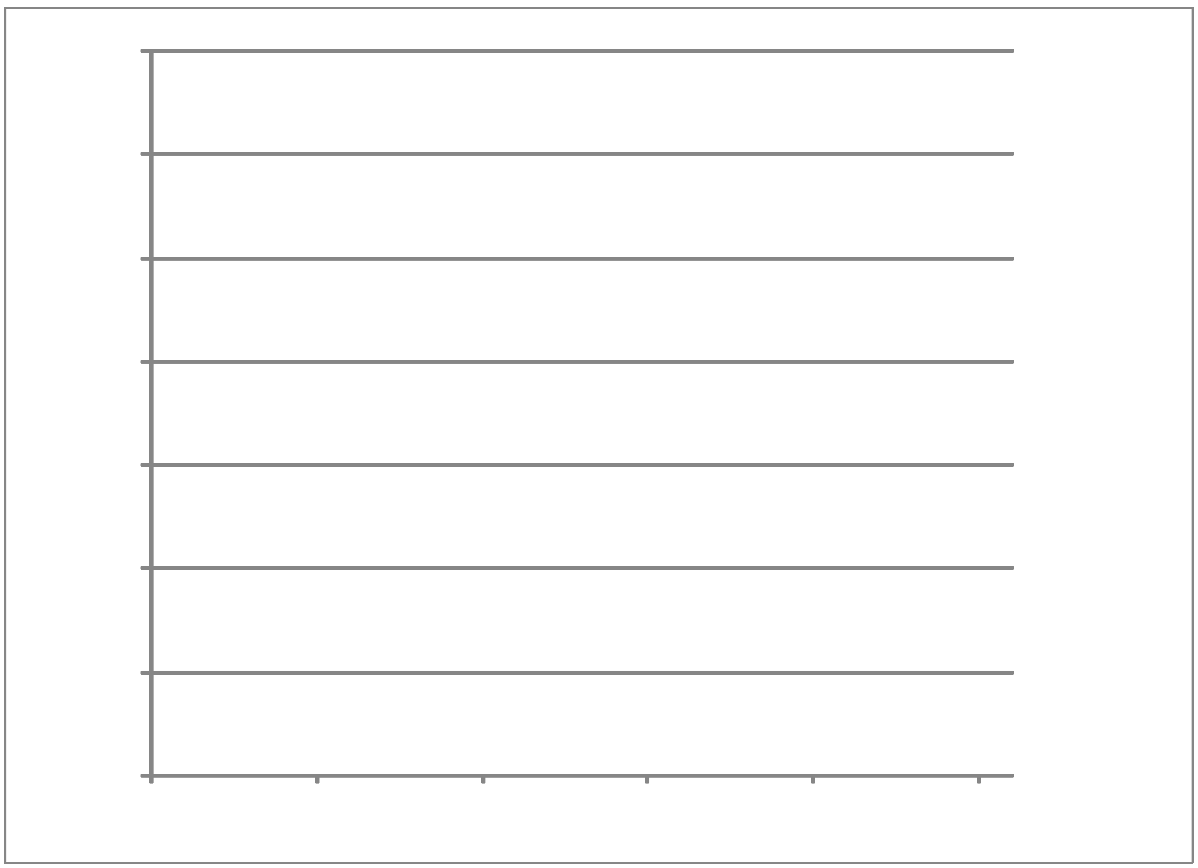

Figure 7.3.5 Maximum Usage Adjustment Factor by Product Age in 2005

DOE performed a linear regression to fit MaxUAF by vintage, thus providing a value of MaxUAF for a unit of any age. Table 7.3.14 shows the intercept and slope of the regression line for MaxUAF for each product class. The quality of the linear fit from the regression for each product class is shown by the R^2 value.

Table 7.3.14 Regression Parameters by Product Class for Maximum Usage Adjustment Factor

Product Class	Description	Slope	Intercept	R^2
3	Top-mount refrigerator-freezer	-0.0554	3.0796	0.9033
5	Bottom-mount refrigerator-freezer	-0.0733	3.0835	0.9298
7	Side-by-side refrigerator-freezer with TTD ice service	-0.0307	2.4140	0.9033
9	Upright freezer	-0.0187	1.9671	0.6832
10	Chest freezer	-0.0434	2.5638	0.9034

DOE compared the MaxUAF value to the smallest possible UAF for the refrigerator for each RECS record to determine whether the household's refrigerator energy use was plausible and the RECS record should be retained in the analysis.

7.3.7 Minimum Usage Adjustment Factor

To estimate the least plausible UAF, DOE used EPA's refrigerator analysis (ERA) model.[10] DOE used the default models in ERA for product classes 3 and 10. Values for the other product classes were derived from the default models for those product classes. DOE assumed that product classes 3 and 5 have identical minimum UAFs.

For each year a TSD was published, DOE modified the ERA input file to better match the characteristics of the baseline model described in the TSD. Then the ERA model was run under test procedure conditions and under very favorable conditions (such as in an air-conditioned kitchen or a basement). The temperature settings for the compartments were assumed to be the maximum allowed by the ERA model. DOE also assumed that any gasket heater was turned off. Tables 7.3.15 and 7.3.16 show the temperature settings used to model both these "ideal" conditions and test conditions.

Table 7.3.15 Temperature Settings for Refrigerators Under Test and Ideal Conditions

	Ambient Temp.	Air Entering Condenser	Air Under Cabinet	Fresh Food Compartment	Freezer Compartment
Test Conditions	32.2 °C (90.0 °F)	37.8 °C (100.0 °F)	35 °C (95.0 °F)	7.22 °C (45.0 °F)	-15 °C (5.0 °F)
Ideal Conditions	17 °C (62.6 °F)	19 °C (66.2 °F)	19 °C (66.2 °F)	10 °C (50.0 °F)	-2 °C (28.4 °F)

Table 7.3.16 Temperature Settings for Freezers Under Test and Ideal Conditions

	Ambient Temp.	Air Entering Condenser	Air Under Cabinet	Freezer Compartment
Test Conditions	32.2 °C (90.0 °F)	37.8 °C (100.0 °F)	35 °C (95.0 °F)	-17.8 °C (0.0 °F)
Ideal Conditions	12 °C (53.6 °F)	14 °C (57.2 °F)	14 °C (57.2 °F)	-9.99 °C (14.0 °F)

In order to validate the model, DOE compared the ERA simulation model under test procedure conditions to the results of the test procedure reported in each TSD. In addition to the temperatures listed in Tables 7.3.15 and 7.3.16, the other control settings during the test were:

- Defrost controls were not operative during the test procedure.
- Anti-sweat heater switch was set to the position that consumes the maximum energy.

The 1995 TSD also mentions a correction factor to adjust the ERA model results based on the tested consumption. Correction factors for DOE's modeling for this analysis, as well as the values cited in the 1995 TSD, are listed in Table 7.3.17. If the error percentage is greater than 0, it means that the ERA model overestimated the energy use in the test procedure, and the value of *CAL* in Eq. 7.19 is greater than 1.

Table 7.3.17 Model Errors by Product Class and Vintage

Product Class	DOE % Error			Estimate from 1995 TSD %
	1989	**1995**	**2001**	
Top-Mount	5.93	4.14	22.29	5.93
Side-by-Side	12.15	5.16	8.54	12.15
Upright Freezer	19.67	15.54	17.74	19.67
Chest Freezer	0.64	12.11	11.84	0.64

The simulation models produced the same range of error as those specified in the 1995 TSD. When calculating the minimum UAF, this calibration factor cancels out, as shown in the following equation, because the ERA model also over-estimates the energy use in the ideal conditions by the same factor. DOE defined the minimum plausible UAF as:

$$MinUAF = \frac{FEC_{ERA}^{Ideal}}{TEC_{ERA} \times ESAF} = \frac{FEC_{RECS} / CAL}{TEC_{RECS} \times ESAF / CAL} \qquad \textbf{Eq. 7.19}$$

Where:

FEC_{Ideal_ERA} = minimum field energy consumption modeled in ERA under ideal conditions,
TEC_{ERA} = test energy consumption modeled in ERA under existing test procedure conditions,
FEC_{RECS} = field energy consumption of the RECS record,

TEC_{RECS}	= test consumption calculated based on the volume and age designated for the UAF calculation,
CAL	= calibration factor defined by the ratio between the results from the ERA model and the test procedure,
ESAF	= efficiency standard adjustment factor.

Figure 7.3.6 shows the results of calculating the minimum plausible UAF as a function of vintage.

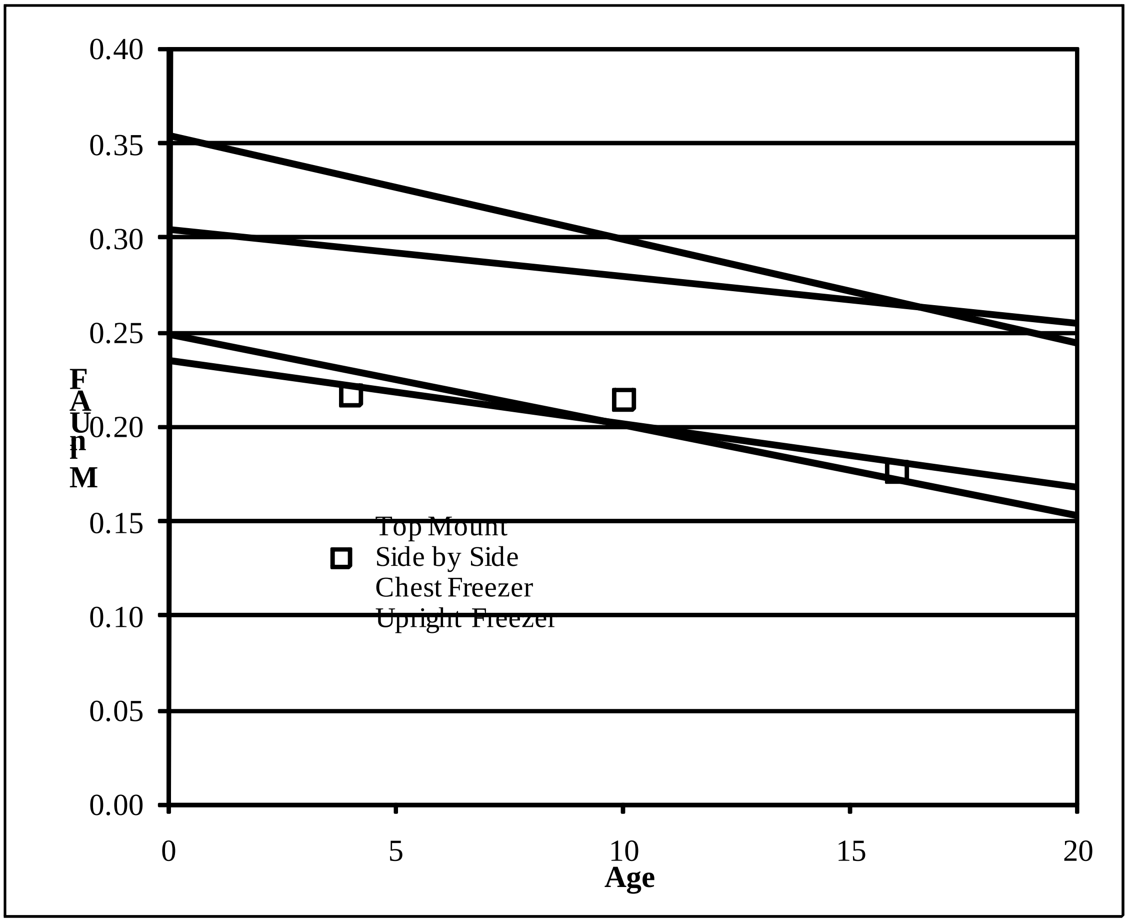

Figure 7.3.6 Minimum Plausible Usage Adjustment Factor as a Function of Product Age in 2005

DOE performed a linear regression for each product class in order to model the relation between the minimum UAF and the vintage of a unit. The following table shows the resulting parameters.

Table 7.3.18 Regression Results Based on Unit Vintage

Product Class	Slope	Intercept	R^2
Top-Mount	-0.0048	0.2496	0.909
Side-by-Side	-0.0033	0.2356	0.8022
Upright Freezer	-0.0025	0.3000	0.8107
Chest Freezer	-0.0055	0.3325	0.6448

DOE assumed that minimum UAFs are constant across volumes, that bottom-mount and top-mount products have the same minimum UAF, and that through-the-door ice service does not affect the minimum UAF.

7.3.8 Results by Product Class

Figures 7.3.7 through 7.3.16 show the distribution of UAFs for the RECS households in the subsample that represents each standard-sized product class. Each figure shows the distribution of UAFs before and after the truncation produced by applying the minimum and maximum UAFs. The distribution used for LCC analysis is the distribution after removing households having implausible UAFs.

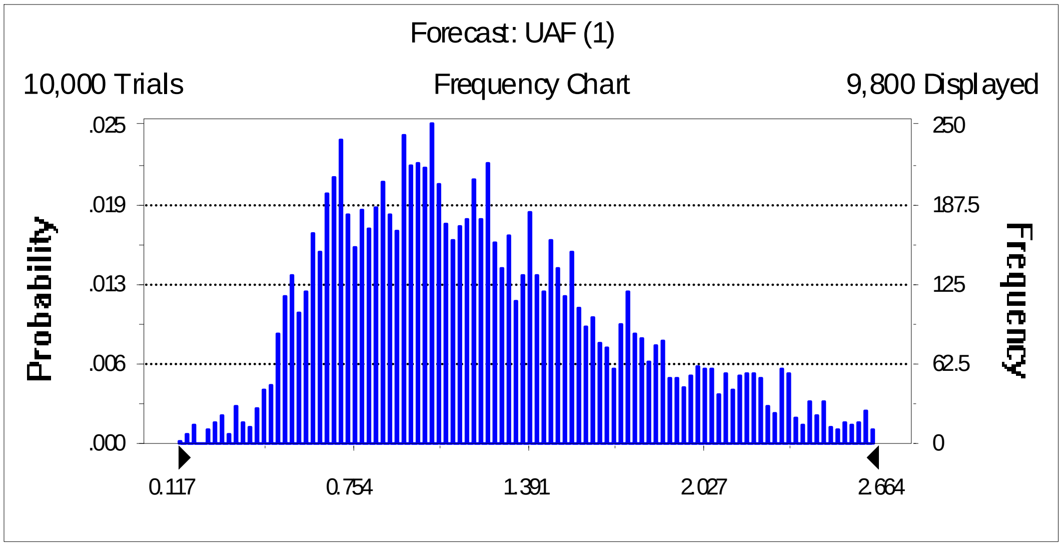

Figure 7.3.7 Initial UAF Distribution for Standard-Size Top-Mount Refrigerator-Freezers (Product Class 3)

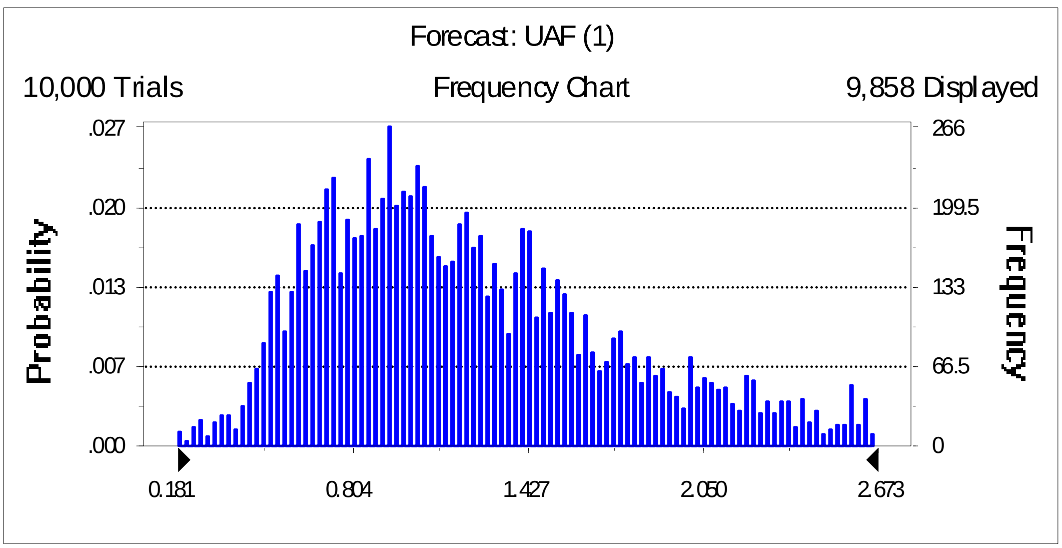

Figure 7.3.8 Final UAF Distribution for Standard-Size Top-Mount Refrigerator-Freezers (Product Class 3)

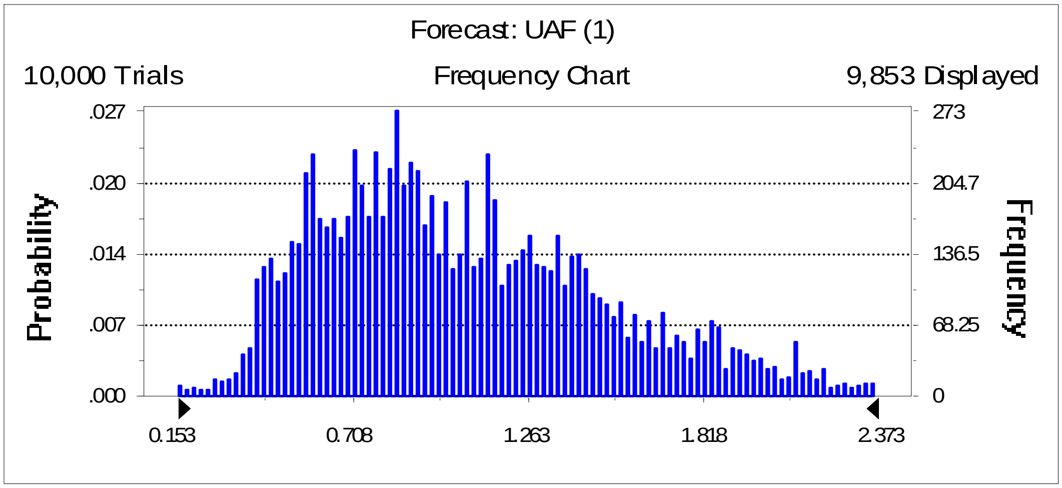

Figure 7.3.9 Initial UAF Distribution for Standard-Size Bottom-Mount Refrigerator-Freezers (Product Class 5)

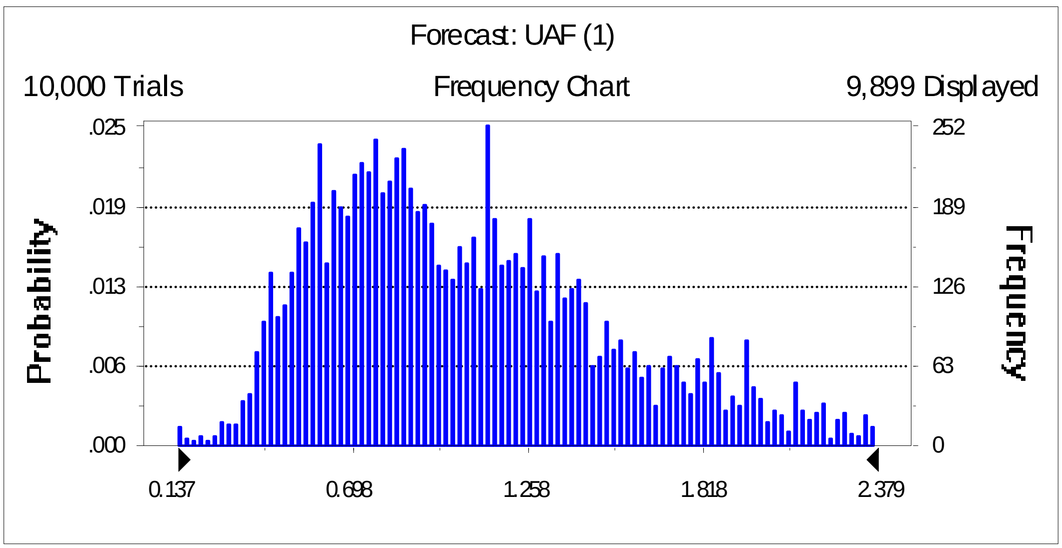

Figure 7.3.10 Final UAF Distribution for Standard-Size Bottom-Mount Refrigerator-Freezers (Product Class 5)

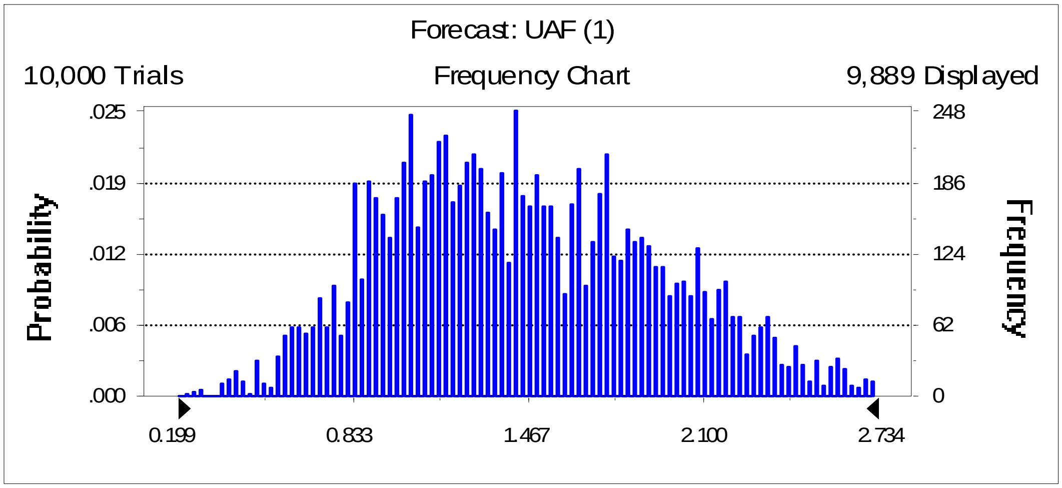

Figure 7.3.11 Initial UAF Distribution for Standard-Size Side-by-side Refrigerator-Freezers (Product Class 7)

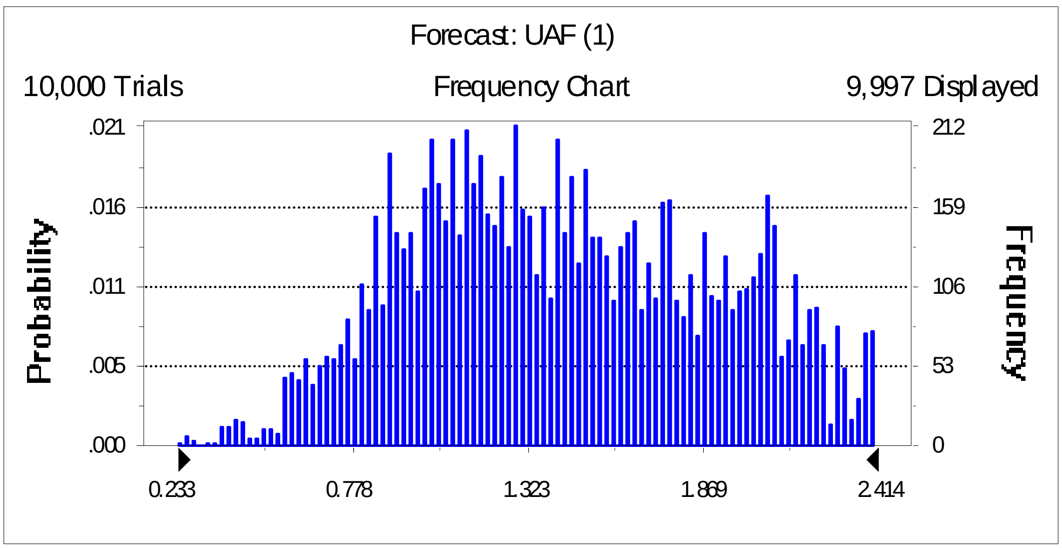

Figure 7.3.12 Final UAF Distribution for Standard-Size Side-by-side Refrigerator-Freezers (Product Class 7)

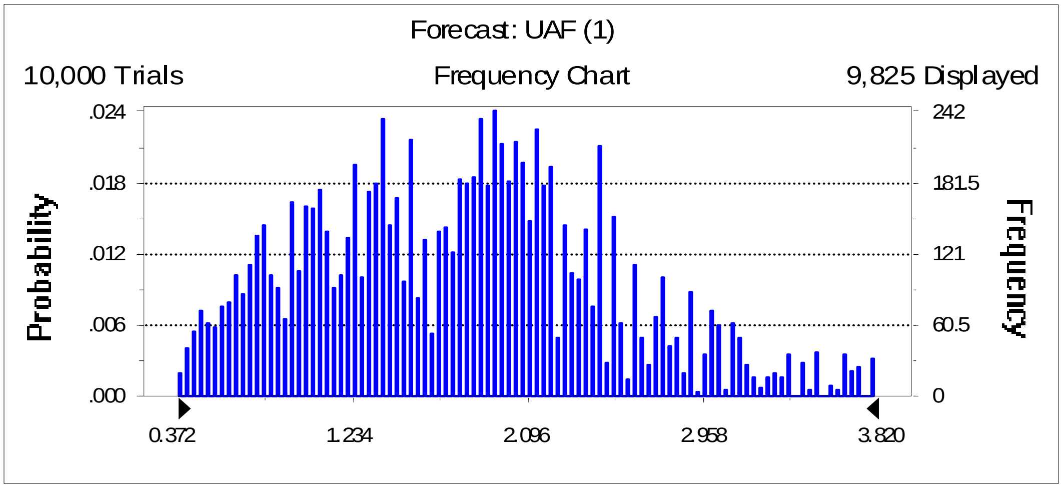

Figure 7.3.13 Initial UAF Distribution for Standard-Size Upright Freezers (Product Class 9)

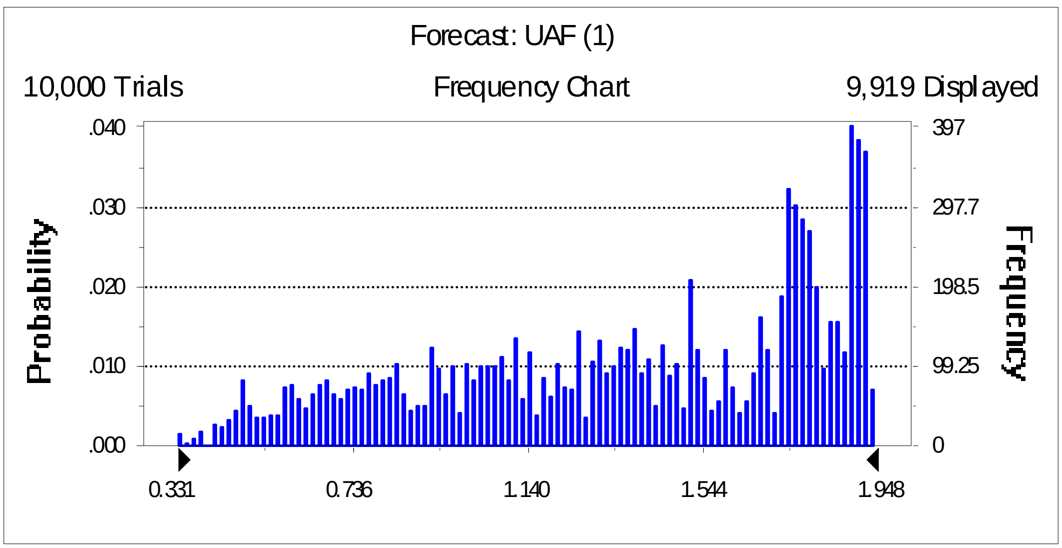

Figure 7.3.14 Final UAF Distribution for Standard-Size Upright Freezers (Product Class 9)

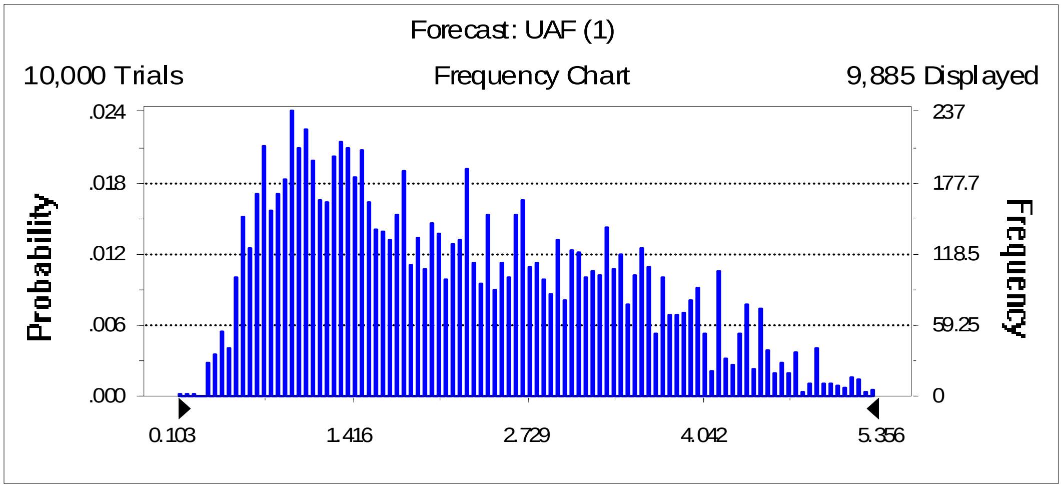

Figure 7.3.15 Initial UAF Distribution for Standard-Size Chest Freezers (Product Class 10)

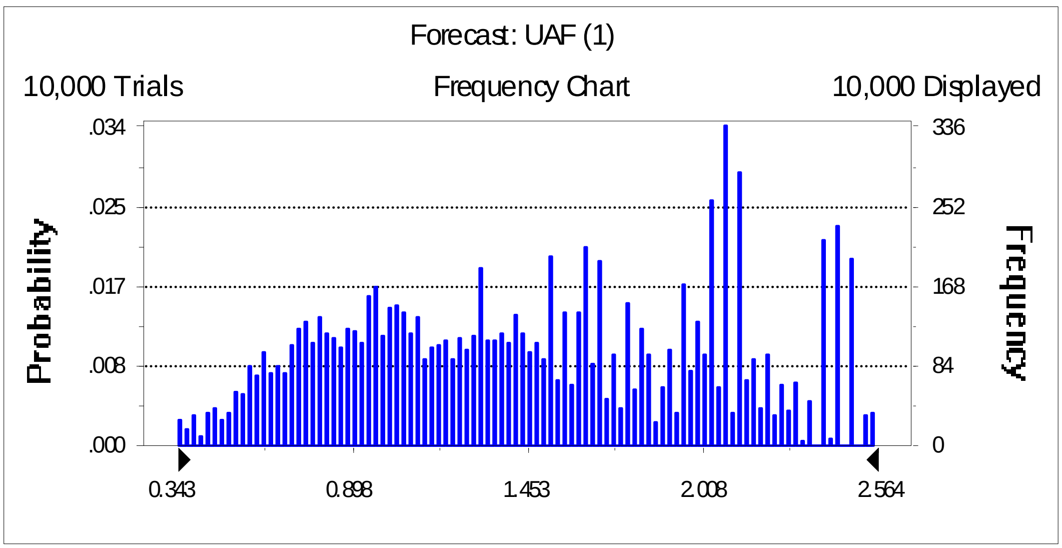

Figure 7.3.16 Final UAF Distribution for Standard-Size Chest Freezers (Product Class 10)

The maximum plausible UAF limits the freezer sample more than the refrigerator-freezer sample. The maximum is more restrictive for freezers because their compressors are assumed to run more than 80 percent of the time in normal operation, as opposed to 52 percent to 65 percent of the time for refrigerators. As a result, increasing appliance energy use to its theoretical maximum, to reflect a compressor that runs 100 percent of the time, has a smaller effect for freezers. RECS also has a simpler model for estimating household energy use for freezers than it does for refrigerator-freezers, which may contribute to the wide range of energy consumption assigned to freezers across the household sample. The minimum and maximum UAF thresholds enabled DOE to remove from the sample households having unrealistic freezer energy consumption.

Table 7.3.19 summarizes the characteristics of the UAFs before and after the final sample was selected.

Table 7.3.19 Usage Adjustment Factors Before and After Excluding Minimums and Maximums

	Complete RECS Sample				After Selecting Sample Based On Min and Max Plausible UAF			
Product Class	**Mean UAF**	**Min UAF**	**Max UAF**	**Sample Size**	**Mean UAF**	**Min UAF**	**Max UAF**	**Sample Size**
Top-mount refrigerator-freezer	1.254	0.115	4.203	2,303	1.227	0.134	3.08	2,231
Bottom-mount refrigerator- freezer	1.079	0.097	3.155	2,303	1.077	0.134	2.888	2,242
Side-by-side refrigerator-freezer	1.46	0.17	4.219	1,026	1.437	0.201	2.414	871
Upright freezer	1.7988	0.324	5.367	248	1.37	0.316	1.967	170
Chest freezer	2.248	0.103	7.795	369	1.479	0.343	2.564	243

7.3.9 Distributions: Comparison with Other Studies

The variation in UAFs within the national RECS sample has several causes, including indoor temperature, appliance age, and varying usage patterns. Meier et al.[17] and Miller and Pratt[18] indicate that refrigerator energy use varies significantly in response to ambient temperature, which implies that climate contributes to variation in household energy use. In addition, refrigerators generally use more energy as they age, [19] and the RECS sample includes appliances having a wide range of ages. Household choices regarding the frequency of door opening and how often and how much warm food is loaded into the unit, along with the ambient temperature in the kitchen, likely add to variability. In addition, the DOE test procedure does not measure energy consumed by ice making, so it is not reflected in the labeled energy consumption. The presence or absence of an automatic ice maker, as well as variation in the amount of ice made, also contribute to the variation in UAF within and between product classes.

In addition to their significant width, the UAF distributions shown in Figures 7.3.7 through 7.3.16 do not have a mean value of 1, indicating that the average energy use for a refrigerator drawn from the American residential stock differs from the labeled energy use of that same refrigerator when it was new. This result is consistent with reports in the literature. A full literature survey, available in appendix 7-A, is summarized here. Refrigerator energy use may be characterized by three measures:

(A) the label on the product when new, derived from the DOE test procedure;

(B) the results of the DOE test procedure on a particular appliance after it has been used in the field; and
(C) the *in situ* (ideally directly measured) energy consumption in a user's home.

The UAF for a given refrigerator is the ratio of (C) to (A). Studies described in the literature examined two classes of refrigerators: new or likely new (installed in new homes), for which the usual comparison is (C) to (A); and recycled/disposed refrigerators, for which all possible pairs of measures have been compared.

Studies of new (or likely new) refrigerators in consumers' homes reveal a wide variation in energy use among consumers. The mean energy consumption cited in those studies lies within 40 percent of the appliance label.[20] The literature indicates that refrigerators in cooler climates tend to use less energy than their labeled energy consumption,[19] whereas those in warmer locations tend to use more energy than labeled. This difference contributes to the width of the national UAF distributions.

Studies of non-new refrigerators generally examine refrigerators collected as part of early replacement programs operated by electric utilities. Such studies are used to measure the effect of the utility program and to obtain credit for the energy reductions resulting from replacing old appliances. The non-new refrigerators described in the literature, which must be in use by their owners, commonly are relatively old. Measurements, both *in situ* and from the DOE test procedure, show these refrigerators use significantly more energy than the labeled consumption. KEMA[21] used the DOE procedure to test 136 such refrigerators. This comparison of (B) to (A) isolates the effect of age from those of user behavior or environment. KEMA found that the median increase in energy consumption relative to labeled use was 46 percent, and that roughly 15 percent of the sample used more than twice the labeled energy. Only 7 percent of the sample used less than labeled. When Peterson *et al.*[22] combined the data from several studies (of a total of 193 recycled refrigerators), they found that the average increase in energy consumption, as measured by the DOE test procedure, was 50 percent, with 25 percent of refrigerators using more than 1.7 times their labeled energy. Miller and Pratt[18] performed a regression analysis on in-use refrigerators in New York public housing [a (C) to (A) comparison], deducing an average 1.4-percent increase in energy use per year. These studies indicate that the UAF distribution for old refrigerators is expected to be wide and to have a mean significantly higher than 1.

Several aspects of in-use refrigerator operation are not reflected in the DOE test procedure and therefore affect the UAF. In particular, the DOE test does not measure the energy used by ice makers. Estimates of the effect of this omission range from 5 percent to 26 percent,[11] with a rough estimate of 10 percent being common and consistent with published direct measurements. Through-the-door (TTD) ice making may consume more energy than non-TTD ice making. DOE therefore expects the UAF distribution from product classes that include TTD ice makers to have a somewhat higher mean than classes that do not. The size of the difference depends on the fraction of non-TTD refrigerators that use ice makers, and the possible difference in ice-making behavior among users of various product classes. Meier and Martinez[11] also report that ice-making energy may increase over time, compounding the increased energy use with age.

A national sample of refrigerators, such as RECS, covers refrigerators in various climate zones and of various ages. As such, DOE expects those two factors (as well as behavioral differences among users) to produce significant scatter in the UAF. If new refrigerators use energy at close to their labeled rate as determined by the DOE test, and refrigerators at retirement use significantly more energy when tested using the same procedure, the national mean UAF is expected to be greater than 1. DOE could not conclude from the literature that a particular value or distribution should be assigned to the UAF, Therefore, DOE cannot justify further adjusting the UAF distribution derived from RECS.

7.4 ENERGY USE OF COMPACT REFRIGERATION PRODUCTS

As mentioned in the introduction to this chapter, compact refrigerators and freezers are used in homes, college dormitories, hotels and motels, and some commercial buildings. DOE found no data on the typical field energy consumption of compact refrigeration products. It therefore assumed that the average field energy use of compact refrigerators and freezers of a given size is the same as the maximum energy use allowed by the DOE standard, as measured in the DOE test procedure. In effect, DOE assumed that variation in field energy use of compact products is a function solely of volume. To represent the distribution of volumes in the field, DOE used data from the 2008 CEC appliance model database.[2] Figures in appendix 7-B show the distribution of appliance sizes represented within the database.

DOE used the CEC database to develop a linear equation relating listed total volume to adjusted volume for product class 11. The parameters of the equation are listed in Table 7.4.1. For compact freezers, the adjusted volume is equal to 1.73 times the volume.[3] DOE then used the relation between adjusted volume and energy use described by the DOE test procedure to relate the distribution of volumes in the CEC database to a distribution of energy use values.

Table 7.4.1 Parameters for Calculating Adjusted Volume from Total Volume for Compact Refrigerators

Product Category	Slope	Intercept	R^2	Count
Compact Refrigerators	1.0458	-0.0905	0.9822	187

7.5 ANNUAL ENERGY CONSUMPTION BY EFFICIENCY LEVEL

This section reports the annual field energy consumption calculated for refrigeration products that meet new efficiency standards if they were used in RECS 2005 homes. As described in section 7.2, DOE calculated field-adjusted annual energy consumption for each home's refrigeration product by multiplying the tested energy consumption of a new refrigeration product, measured using the existing test procedures, by the efficiency standard adjustment factor (ESAF), which is a constant for each product class, and by the UAF for that household.

As discussed in chapter 5, DOE analyzed specific efficiency levels for the considered product classes. Tables 7.5.1 through 7.5.6 show the considered efficiency levels and corresponding annual energy consumption for each product class. The tables for standard-sized products show the average annual energy consumption according to the proposed DOE test procedure ("proposed test") and in the average energy use based on the corresponding RECS 2005 household subsamples ("field"). The tables for compact appliances (product classes 11 and 18) show the average annual energy consumption according to the proposed DOE test procedure, using a distribution of product volumes based on the CEC appliance database.

Table 7.5.1 Product Class 3, Top-Mount Refrigerator-Freezers Without Through-the-Door Ice Service: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Proposed Test	Field
	kWh/year	*kWh/year*
Baseline	534	657
1 (10%)	481	591
2 (15%)	454	558
3 (20%)	428	526
4 (25%)	401	493
5 (30%)	374	460
6 (35%)	347	427
7 (40%)	321	394
8 (45%)	294	361

Table 7.5.2 Product Class 5, Bottom-Mount Refrigerator-Freezers Without Through-the-Door Ice Service: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Proposed Test	Field
	kWh/year	***kWh/year***
Baseline	652	699
1 (10%)	587	629
2 (15%)	554	594
3 (20%)	522	559
4 (25%)	489	524
5 (30%)	456	489
6 (35%)	424	454
7 (40%)	391	419
8 (45%)	359	384

Table 7.5.3 Product Class 7, Side-by-side Refrigerator-Freezers with Through-the-Door Ice Service: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Proposed Test	Field
	kWh/year	***kWh/year***
Baseline	756	1087
1 (10%)	680	979
2 (15%)	643	924
3 (20%)	605	870
4 (25%)	567	815
5 (30%)	529	761
6 (35%)	491	707
7 (40%)	454	652

Table 7.5.4 Product Class 9, Upright Freezers: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Proposed Test	Field
	kWh/year	***kWh/year***
Baseline	717	980
1 (10%)	646	882
2 (15%)	610	833
3 (20%)	574	784
4 (25%)	538	735
5 (30%)	502	686
6 (35%)	466	637
7 (40%)	430	588
8 (45%)	394	539

Table 7.5.5 Product Class 10, Chest Freezers: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Proposed Test	Field
	kWh/year	***kWh/year***
Baseline	428	623
1 (10%)	385	561
2 (15%)	364	530
3 (20%)	342	498
4 (25%)	321	467
5 (30%)	300	436
6 (35%)	278	405
7 (40%)	257	374
8 (45%)	235	343

Table 7.5.6 Compact Refrigerators and Freezers: Average Annual Energy Use by Efficiency Level

Efficiency Level (percent less than baseline energy use)	Product Class	
	11: Compact refrigerators and refrigerator-freezers with manual defrost (kWh)	18: Compact chest freezers (kWh)
Baseline	325	313
10%	292	282
15%	276	266
20%	260	250
25%	244	235
30%	227	219
35%	211	203
40%	195	188
45%	179	172

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APPENDIX 7-A. LITERATURE SURVEY OF ENERYG CONSUMPTION BY RESIDENTIAL REFRIGERATOR-FREEZERS

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 7-A. LITERATURE SURVEY OF ENERGY CONSUMPTION BY RESIDENTIAL REFRIGERATOR-FREEZERS

7-A.1 INTRODUCTION

Efficient refrigerator-freezers reduce peak energy consumption as well as total household energy use. As a result, electric utilities regard replacement programs for these appliances as an attractive and effective way to reduce residential energy consumption. To estimate the amount of electricity savings attributable to an energy-efficient refrigerator-freezer program, utilities must evaluate the difference between the pre- and post-program energy consumption of the appliance stock. The challenge to accurately estimate the electricity savings of a refrigerator-freezer replacement program lies in estimating the real-life consumption of the original and replacement units.

Estimation of appliance energy consumption may be undertaken in three ways, all of which are represented in the literature:

A) The labeled energy consumption on a new appliance, based on the U.S. Department of Energy (DOE) test procedure undertaken on a sample of several identical appliances, and reported by the appliance manufacturer
B) The DOE test procedure applied to a particular appliance (often not a new appliance), and
C) Measurement for some period of time *in situ* in a household.

Most studies compare two of these measurements in order to evaluate energy use. For example, a study might compare the results of the DOE test procedure on an old refrigerator with the labeled energy consumption when new to isolate the effect of appliance age, while eliminating possible effects due to user behavior. This appendix refers to such a study as comparing (B) to (A).

Researchers have conducted studies that measure the field consumption of refrigerator-freezers to compare *in situ* measurements to the DOE test results, represented either by the labeled results ((C) to (A)), or through direct testing under DOE conditions ((C) to (B)). When such field studies are evaluated, the lack of consistency among study conditions (such as geographic location, housing type, and the number and type of units), limited time of direct measurements, and the degradation of efficiency throughout the lifetime of a refrigerator-freezer contribute to the challenge of estimating potential energy consumption savings from new units.

This appendix summarizes available literature regarding the comparison of different measurement methods for refrigerator-freezers in order to evaluate reasonable possible values for the ‘usage adjustment factor’ (UAF), which is an estimate of the ratio of (C) to (A). There are very few published measurements of freezers or compact appliances, so DOE addresses only refrigerator-freezers in this summary. Section 2 summarizes the DOE test procedure and lists and characterizes the field studies which DOE used in its analyses. Section 3 discusses these studies and their implications for the UAF parameter used in Chapter 6, particularly regarding variation with season and climate, and efficiency degradation with unit age.

7-A.2 TEST PROCEDURE AND FIELD STUDIES

This section describes the DOE test procedure, then lists field studies of energy consumption by refrigerator-freezers and distills their results.

7A.2.1 DOE Test Procedure

"The DOE test is a compromise between realism and minimizing the costs of performing a reliable, repeatable laboratory test" (Meier, 1993). The DOE procedure for evaluating the annual energy consumption of refrigerator-freezers comprises the following features (10 CFR, Chapter II, Part 430, Appendix A1).

- The standard test temperature for the fresh food compartment is 45°F.
- The standard test temperature for the freezer compartment is 5°F.
- The test is performed in a chamber that is maintained at an ambient temperature of 90°F.
- The temperatures of the freezer and fresh food compartments are measured using three independent thermocouples, one for each compartment. Five thermocouples are used when the refrigerator height is over 40".
- The appliance's energy consumption is calculated by interpolating test results that bracket the standard freezer temperature (5°F). Interpolation is done around the 5°F temperature (freezer compartment) and the 45°F temperature (fresh food compartment).
- Ambient relative humidity is not specified.
- Doors are not opened during the test.
- The fresh food and freezer compartments are empty.
- Ice making capability, if present, is not powered on or evaluated by the test.

The DOE test procedure is currently undergoing a rulemaking process which may change some of the above details. In particular, changes have been proposed to the test temperatures for the refrigerator and freezer compartments.

The DOE test procedure does not measure the effects of door opening, cooling warm food, or ice making. However, this test procedure provides standardized results that can serve as the basis for comparing the performance of appliances. Although the DOE test does not precisely mirror any single unit's performance *in situ*, it serves as a foundation to which field measurements may be compared to develop estimates that account for a range of real-life circumstances (KEMA, 2004).

A summary of new refrigerator-freezer unit energy consumption values provided by manufacturers by year shows the annual variation of shipment-weighted refrigerator energy consumption from 1960s to the year 2006 (Table 2.1). These data are based on "nameplate" values. For the model years before the DOE energy standards (1989 and earlier), the test conditions are unknown in which energy consumption quantities were measured, although it is likely that manufacturers used the American Home Appliance Manufacturers (AHAM) test procedure or the test procedure prescribed by California state energy conservation standards.

Table 7-A.2.1 Refrigerator Energy Consumption Data by Year

Model Year	Shipment Weighted Average Use (kWh/yr)	Model Year	Shipment Weighted Average Use (kWh/yr)
2006	564	1990	988
2005	550	1989	1006
2004	559	1988	1049
2003	589	1987	1052
2002	576	1986	1165
2001	611	1985	1147
2000	779	1984	1139
1999	762	1983	1160
1998	738	1982	1191
1997	728	1981	1190
1996	708	1980	1278
1995	693	1975 – 1979	1530†
1994	693	1970 – 1974	1730†
1993	699	1965 – 1969	1540†
1992	877	1961 – 1964	1150†
1991	918		

Source: AHAM Fact Books
†: Approximate

7A.2.2 Field Studies

In situ conditions account for several important factors including: ambient air temperature; the number and duration of door openings; the temperature of food loaded into the unit; the placement of the unit in relation to walls, ovens, and stoves; the temperature setting in the field; and the ice maker setting in the field.

Since the early 1980s, utilities and government agencies have collected data on field-measured refrigerator-freezer energy consumption in order to evaluate the effects of refrigerator "early replacement" programs. The collected data varies tremendously by sample size, the type of refrigerator-freezer studied, the length of time each appliance was monitored, and their operating conditions. The studies summarized in Table 2.2 describe the performance of refrigerator-freezers as measured in various ways.

7A.2.2.1 KEMA-Xenergy Findings

The private consulting firm KEMA-Xenergy in 2002 reviewed numerous reports of *in situ* performance studies for Southern California Edison. Several reports were summarized by KEMA-Xenergy but are not available to be reviewed by DOE. These reports are indicated by a "#" in Table 2.2.

Table 7-A.2.2 Literature summary

Authors(s)	Year	Ratio Average[a]	Ratio Range	Comparison Type	Location	Refrigerator Type	Adjusted for climate or season	No. of Refrigerators
Arthur D. Little, Inc. [#]	1982	>1.2		C to A	Florida	unknown	No	unknown
Topping & Vineyard	1982		0.85 to 1.5[b]	C to A	Norfolk, VA	New	No[a]	47
Meier & Jansky	1993	0.85 is "typical"	0.56 to 1.17	C to A	Cold climates (many in Pacific Northwest)	Relatively new	No	209
Meier et al.	1993	B to A: 0.99, C to A: 0.87	B to A: 0.89 to 1.10	B and C to A	Rochester, NY	New, "energy efficient", frost-free	No	20
Bos [#]	1993	"considerably" > 1		B to A	Sacramento, CA	At replacement	N/A	79
Quantum Consulting	1994	0.87 for "high-efficiency", 1 for "super-efficiency"	95% between roughly 0.7 and 1.25	C to A	Southern CA (SCE)	1-3 years old	No	98
Proctor Engineering (Dutt et al.)	1994	Between 0.86 and 0.9[c]		C to A	Northern CA (PG&E)	New, "energy efficient"	Yes[d]	256
Goett [#]	1995	approx. 1		Unknown	CA (PG&E and SCE)	New	No	unknown
Barakat & Chamberlin [#]	1996	"significantly more" than 1		B to A	Unknown	At replacement	N/A	unknown
Miller & Pratt	1998	1.1	0.72 to 1.2[e]	C to A	New York City (multi-family public housing)	Some new, some older	No	324
Kinney & Belshe	2001	0.96 (new); 1.3 (mixture)		C to A	New York City (multi-family public housing)	220 old, 56 new	No	276
ICF Consulting	2003	approx. 0.5		C to statistical model of C	CA (Bay Area)	At replacement	No	40
Mowris [#]	2003	1.06	wide variation	C to A	Northern CA (6 cities)	At replacement	unknown	91
KEMA	2004	1.46 (median)	0.85 to > 3	B to A	California	At replacement	N/A	136
Peterson et al.	2007	median 1.4, mean 1.5		B to A	California	At replacement	N/A	193
ADM, Athens, et al.	2008	0.81 to 0.88, depending on weather model		C to B	California	At replacement	Yes	184

[a] A value greater than 1 for this ratio for a C to A comparison implies that energy use in the field (C) was greater than the labeled energy consumption (A).
[#] KEMA-Xenergy (2004) is DOE's only reference for the results of this study.
[b] Seasonal variation for a single model
[c] Ratio of average C to average A over sample
[d] Adjusted for typical meteorological year (TMY) at location
[e] Variation in the mean of various types of refrigerators in various use environments

7-A.3 LITERATURE ANALYSIS

DOE's interest in surveying the refrigerator-freezer energy use literature is to evaluate the range of possible appropriate values for the 'usage adjustment factor', or UAF. The UAF is a "(C) to (A)"-type measurement, relating energy use in situ to the DOE test result for a new appliance.

Studies of new appliances include Meier & Jansky (1993), Meier et al. (1993), Dutt et al. (1994), Quantum (1994), Goett (1995), Miller & Pratt (1998), and Kinney & Belshe (2001). The average (or typical) values of the ratio of (C) to (A) for these studies range from 0.85 to 1.1, and there is significant variation, with ratios ranging from 0.56 to 1.25. The majority of these studies are not adjusted for ambient temperature variations or climate (although several use year-long samples to eliminate seasonal effects). The only of these studies which is adjusted (Dutt et al.) is normalized to the climate of the particular location of the measurements, rather than to a national average climate model. Taken collectively, these studies do not allow DOE to draw conclusions regarding possible national variation in new-refrigerator energy use, particularly due to variations in climate. They do indicate that the labeled energy consumption of a new appliance is likely to be accurate *in situ* to within 40%, as suggested by Meier (1995).

Studies of refrigerators at the time of replacement by utility programs show higher energy use relative to the labeled energy consumption than do new refrigerators. For older refrigerators, studies predominantly take two forms: (B) to (A) or (C) to (A). (B) to (A) studies isolate the effects of age from any other effects (such as behavior or ambient temperature *in situ*), while (C) to (A) studies give a direct indication of the 'UAF' of old appliances. These studies are not necessarily representative of all older refrigerators, because they study only those units and households participating in utility refrigerator recycling programs.

Test-procedure-only comparison studies include Bos (1993), Barakat & Chamberlin (1996), KEMA (2004) and Peterson et al. (2007). All four of these studies show significant energy use increase in the DOE test procedure; KEMA and Peterson both indicate an energy use increase of close to 50%, with wide variation. Only 7% of the refrigerators measured by KEMA used less than their labeled consumption. 25% of the refrigerators measured by Peterson et al. used more than 70% more that their labeled consumption.

Miller & Pratt (1998), Kinney & Belshe (2001), and Mowris (2003) undertook direct evaluation of the ratio of *in situ* to labeled consumption for older refrigerators. The average ratio in all three studies was measured to be larger than one, although smaller than the test-procedure-based comparisons. Mowris indicated wide variation in energy use relative to the label, and Miller & Pratt's sub-categories show a range of energy consumptions from 28% below the label to 20% above.

Only one study reviewed by DOE compared *in situ* energy use to the DOE test on the same appliance (ADM, Athens, et al., 2008), a (C) to (B) comparison. Depending on the weather model used to adjust the *in situ* measurements, they found that on average the DOE test procedure overestimated the *in situ* use by 13 to 23%. This study does not include an indication of how the DOE test consumption compared with the labeled consumption.

Testing has confirmed that age, in combination with other refrigerator characteristics, accounts for the degradation of refrigerator energy efficiency (KEMA, 2004; Peterson, 2007). Therefore, energy efficiency degradation is a factor in calculating the savings between new and replacement units. Energy use increases when barriers to cabinet air and heat leakage degrade. For example, door seals no longer close tightly, damaged walls allow air flow, and wet or degraded insulation no longer performs its function.

Two studies (KEMA, 2004 and Miller & Pratt, 1998) used regression analysis to measure the average effect of annual degradation on appliance energy use. KEMA determined an energy use growth rate of roughly 40 kWh/year, depending on model characteristics. Miller & Pratt’s regression model predicts a 1.37% increase in energy use each year. Smit (2006) reports that Athens (1998) calculated a degradation rate of 0.6% per year.

7-A.4 SUMMARY

This appendix summarizes current literature pertaining to the difference between DOE-test based measurements (when new or at retirement) and field-based measurements of refrigerator-freezer energy consumption. *In situ* energy use was found to be close to labeled consumption for new refrigerators, but higher than labeled at the time of replacement. This appendix has examined the mean values and variability from the literature; the variability across a national sample is likely much greater than the range addressed here.

Degradation of the refrigerator unit contributes to the discrepancy between the DOE test and field measured energy consumption data. However, the precise rate of efficiency decrease (and particularly its variability) cannot be determined from the literature.

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APPENDIX 7-B. DATA FOR ESTIMATING DISTRIBUTION OF REFRIGERATOR AND FREEZER SIZE IN THE RECS SAMPLE

TABLE OF CONTENTS

LIST OF FIGURE

APPENDIX 7-B. DATA FOR ESTIMATING DISTRIBUTION OF REFRIGERATOR AND FREEZER SIZE IN THE RECS SAMPLE

7-B.1 INTRODUCTION

DOE used the California Energy Commission (CEC) appliance database[1] to determine the distribution of refrigerator and freezer volumes in the market. The Energy Information Administration's (EIA) Residential Energy Consumption Surveys (RECS)[2] provides the volumes of household refrigerators only within bins (ranges). In order to estimate the labeled energy consumption of a household's standard-sized appliance, DOE selected a volume from within the appropriate RECS bin. DOE then selected a more precise volume randomly from the distribution of volumes within the RECS bin, basing the probability of selecting each volume on the number of models in the CEC database having that volume. The figures in this appendix show the volume distributions by number of models in the CEC database (narrower, solid bars in figures) and the distributions of refrigerator volumes reported by RECS respondents (wider, empty bars in figures). For each standard-sized refrigeration product DOE first identified the appropriate RECS bin and product class, then chose a more precise volume from the relevant part of the CEC distribution.

For compact products (product classes 11 and 18), for which DOE did not use a household sample, DOE used the distribution of volumes from the CEC database to characterize the distribution of volumes sold in the market and determine the distribution of energy use.

7-B.2 RESULTS

Figures 7-B.2.1 through 7-B.2.7 depict the volume distributions on the number of models in the CEC database and the distribution of refrigerator and freezer volumes reported in RECS.

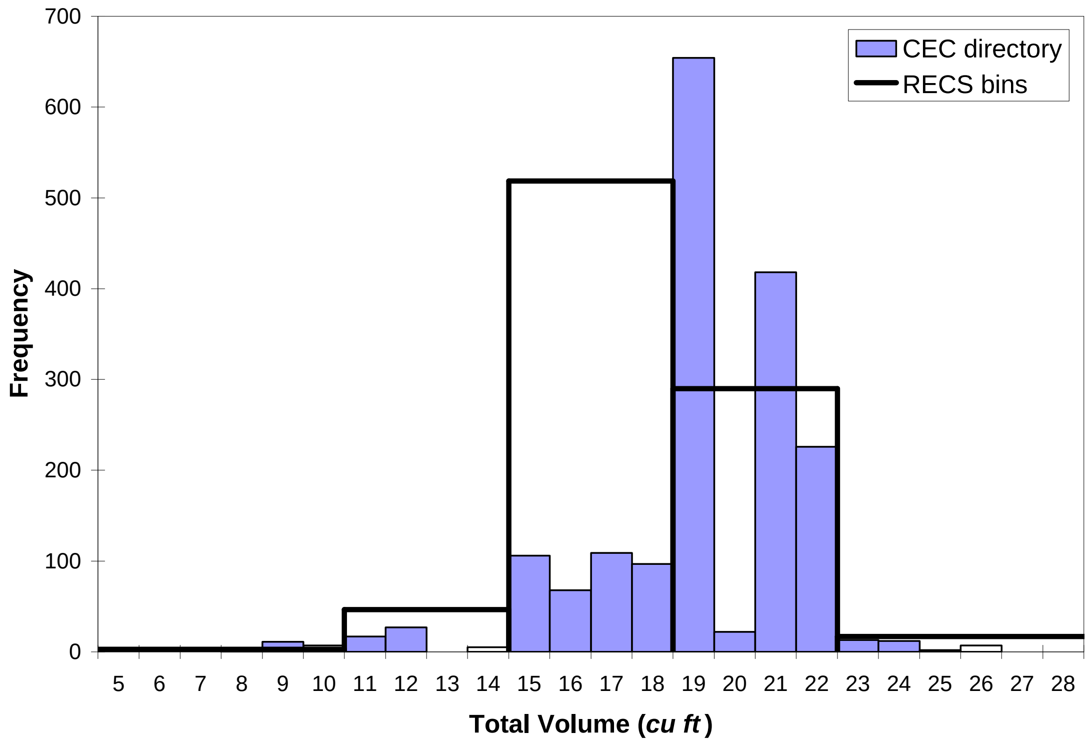

Figure 7-B.2.1 Models of Top Mount Freezer without through-the-door ice (Product Class 3)

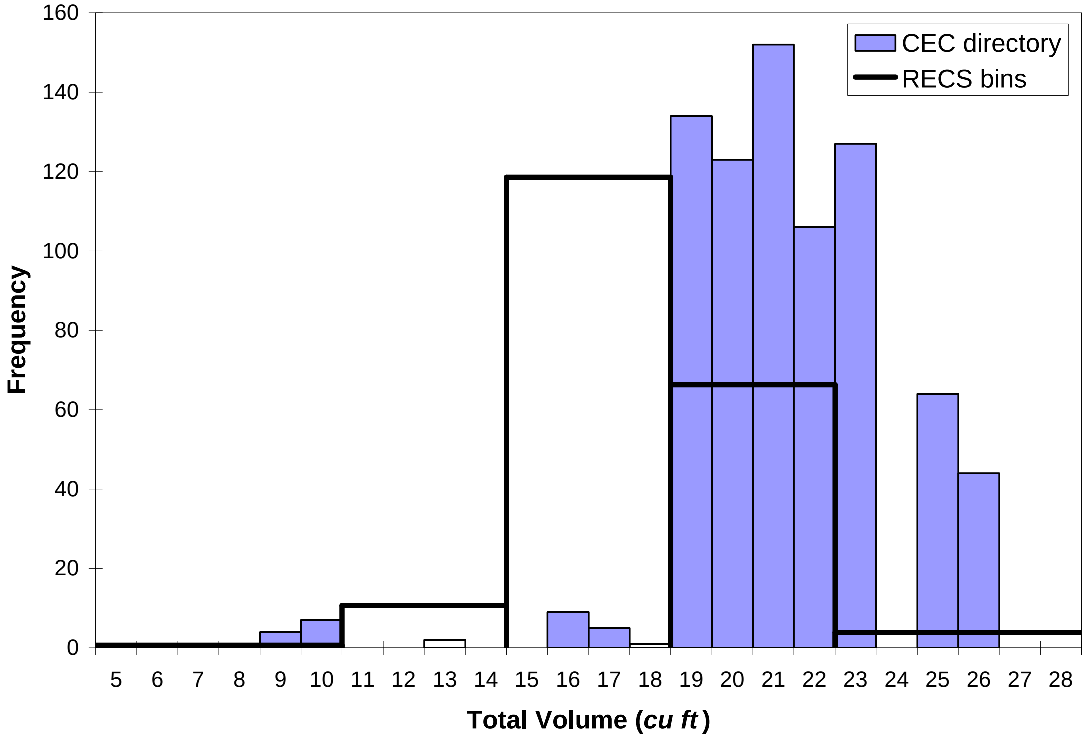

Figure 7-B.2.2 Models of Bottom Mount Freezer without through-the-door ice (Product Class 5)

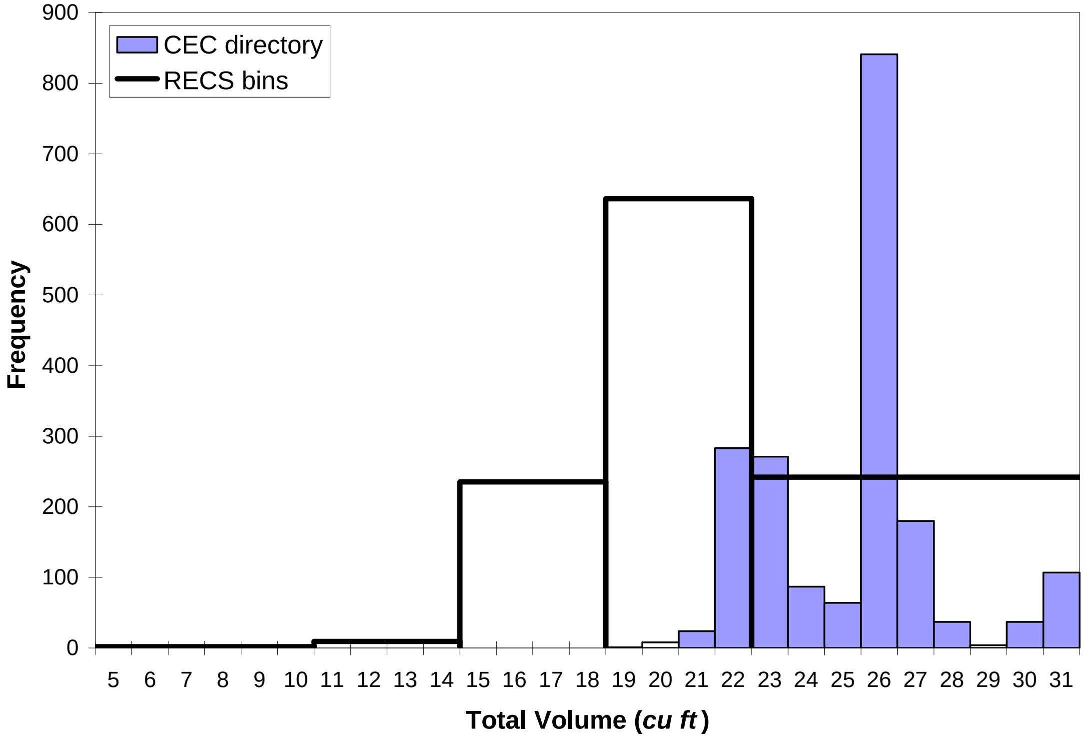

Figure 7-B.2.3 Models of Side Mount Freezer with through-the-door ice (Product Class 7)

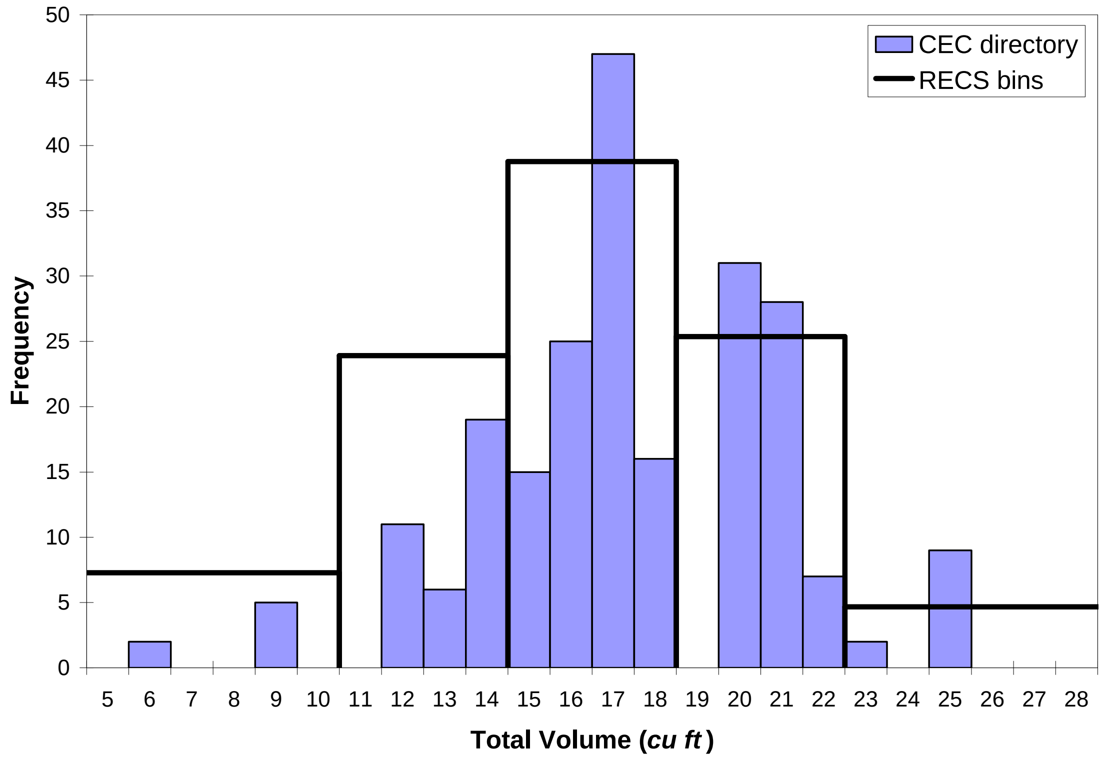

Figure 7-B.2.4 Models of Upright Freezer with automatic defrost (Product Class 9)

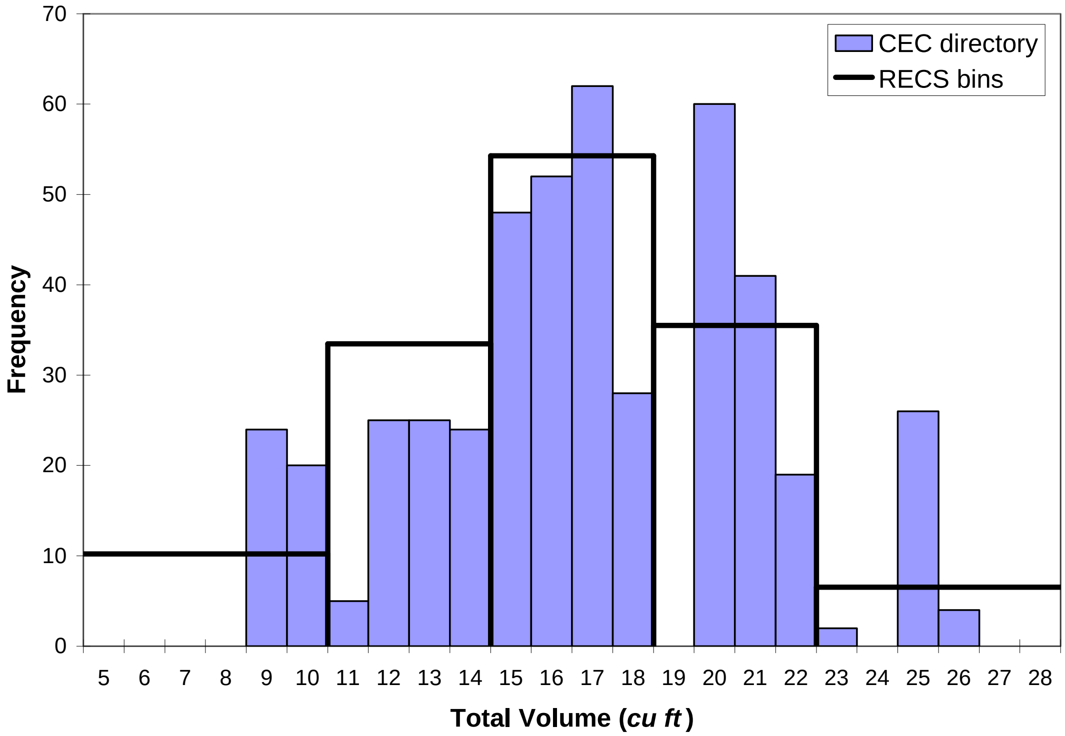

Figure 7-B.2.5 Models of Chest Freezers (Product Class 10)

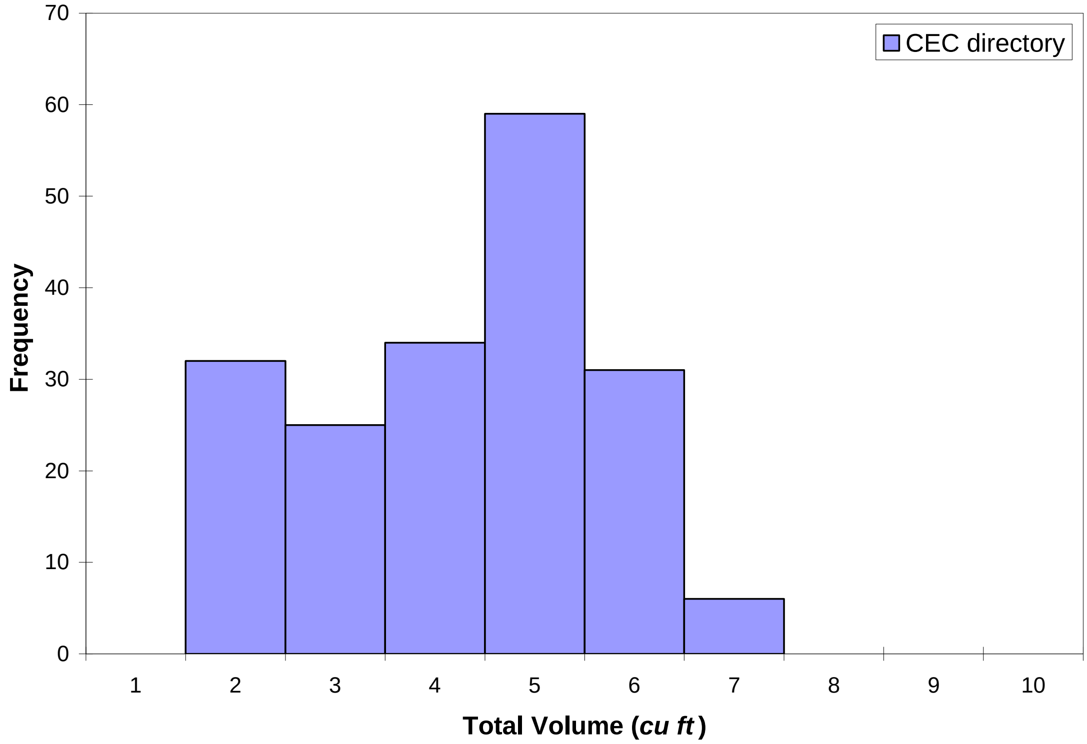

Figure 7-B.2.6 Models of Compact Refrigerator and Refrigerator-Freezer with manual defrost (Product Class 11)

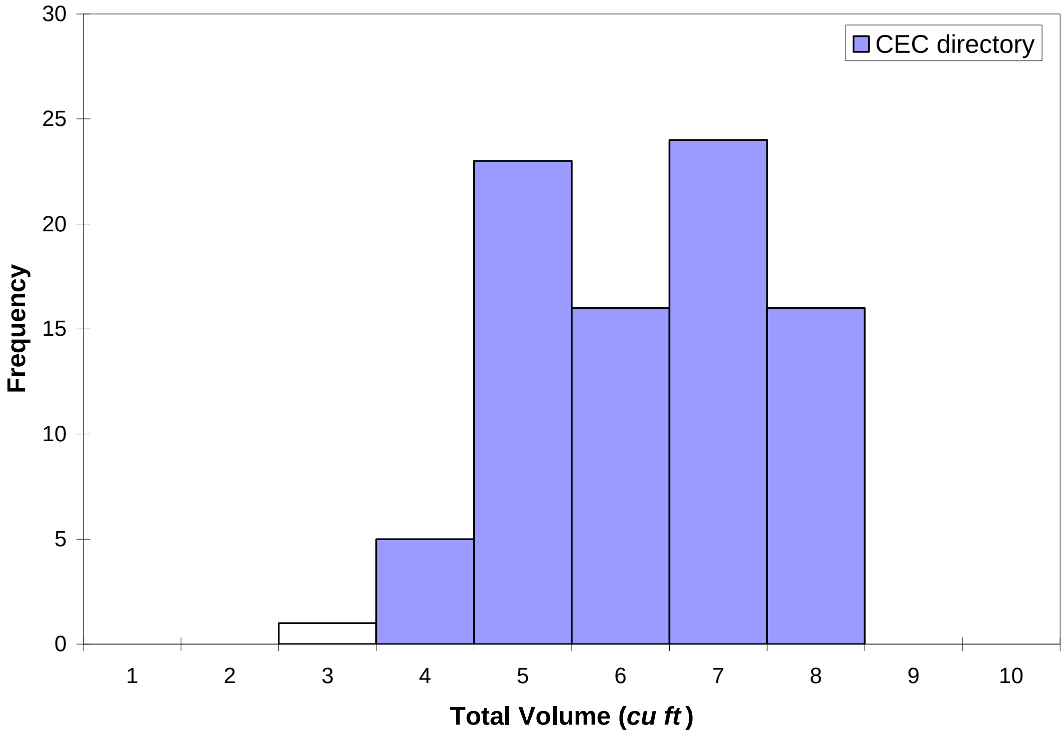

Figure 7-B.2.7 Models of Compact Chest Freezer (Product Class 18)

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[2] U.S. Department of Energy–Energy Information Administration. *Residential Energy Consumption Survey, 2005 Public Use Data Files.* 2009. U.S. Department of Energy: Washington, D.C. <www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html>

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

This chapter describes the Department of Energy (DOE)'s method and metrics for analyzing the economic impacts on individual consumers of potential energy efficiency standards for refrigeration products. The effects of standards on individual consumers include a change (usually a decrease) in operating cost and a change (usually an increase) in product cost. DOE analyzed the economic impacts related to potential new energy efficiency standards for standard-size refrigerator-freezers (top-mount, bottom-mount, and side-by-side); standard-size freezers (upright and chest); and compact refrigeration products (refrigerators and freezers), a total of 7 product classes. DOE examined the life-cycle cost, payback period, and rebuttable payback period of all potential efficiency standards on all product classes. The terms used in this analysis are defined below.

- *Life-cycle cost* (LCC) is the total cost consumers incur during the life of an appliance, including purchase and operating costs (including energy expenditures). DOE discounts future operating costs to the time of purchase, and sums them over the lifetime of a product.
- *Payback period* (PBP) measures the amount of time it takes consumers to recover the assumed higher purchase cost of more energy efficient products through lower operating costs.
- *Rebuttable payback period*, a special case of the payback period, is based on laboratory conditions (specifically, those that reflect the DOE test procedure) for energy use. Its other inputs (including electricity prices) reflect representative real-world operating conditions.

Inputs to the LCC and the PBP are discussed in sections 8.2 and 8.3, respectively, of this chapter. Results of the LCC and PBP analyses are presented in section 8.4. The rebuttable PBP is discussed in section 8.5. Key variables and calculations are presented for each of the three metrics listed above. DOE performed the calculations discussed here using a series of Microsoft Excel spreadsheets that are accessible on the Internet (www.eere.energy.gov/buildings/appliance_standards/). Details regarding and instructions for using the spreadsheets are discussed in appendix 8-A.

8.1.1 Approach

Recognizing that several inputs to the analysis of consumer LCC and PBP are either variable or uncertain, DOE used Monte Carlo simulation and probability distributions to model both the uncertainty and variability of inputs. Appendix 8-B provides a detailed explanation of Monte Carlo simulation and the use of probability distributions. DOE developed LCC and PBP spreadsheet models that incorporate both Monte Carlo simulation and probability distributions by using Microsoft Excel® spreadsheets combined with Crystal Ball®, a commercially available add-in program.

In addition to using probability distributions to characterize several of the inputs to the calculation, DOE developed samples of individual households that use standard-size refrigeration products. DOE performed the LCC and PBP calculations for each household in the sample to account for the variability in energy consumption and/or energy price associated with a range of households.

As described in chapter 7, DOE used the DOE Energy Information Administration (EIA)'s 2005 Residential Energy Consumption Survey (RECS) to develop household samples for standard-size refrigeration products.[1] EIA constructed the 2005 RECS to represent the range of households throughout the United States.

DOE used the 2005 RECS to establish the variability in the annual energy use of refrigeration products and in energy prices. DOE was able to assign a unique annual energy use and/or energy price to each household in the sample. Because of the large sample of households considered in the LCC and PBP analyses, annual energy use and/or energy prices vary greatly. Thus, although the annual energy use and/or energy prices are known for any particular household, their variability across all households contributes to the range of LCCs and PBPs calculated for any particular possible standard.

DOE did not develop a household sample for compact refrigeration products, because many such products are used in lodging, dormitories, and other commercial establishments. DOE estimated the fractions of shipments of compact refrigeration products used in the residential and commercial sectors, then used appropriate inputs for those fractions.

DOE displays LCC and PBP results as distributions of impacts compared to baseline conditions. Results, presented in section 8.4, were derived from 10,000 samples for each Monte Carlo simulation run. To illustrate the implications of the analysis, DOE generated a frequency chart that depicts the variation in LCC and PBP for each standard level considered for refrigeration products.

8.1.2 Summary of Inputs

The LCC represents the total consumer cost during the life of a product, including purchase and operating costs (including energy expenditures). DOE discounts future operating cost to the time of purchase, then sums them over the lifetime of each product. The PBP is the change in purchase cost due to an increased efficiency standard divided by the change in annual operating cost that results from the standard. The PBP represents the number of years it will take the customer to recover the increased purchase cost through decreased operating cost.

DOE uses two types of inputs to the calculation of LCC and PBP: (1) inputs for establishing the purchase cost, otherwise known as the consumer product cost, and (2) inputs for determining the operating cost.

The following are the primary inputs for establishing the consumer product cost.

- *Baseline selling price*: The price at which a manufacturer sells a product identified as a baseline-efficient model.
- *Increases in manufacturer selling price (MSP)*: The change in manufacturer selling price associated with producing a product that meets a particular efficiency level.
- *Markups and sales tax*: The costs associated with converting increases in the MSP into consumer product cost.

The following are the primary inputs for calculating the operating cost.

- *Product energy consumption*: The site energy use associated with operating a given product.
- *Product efficiency*: The energy consumption associated with a product that has an efficiency greater than that of the baseline product.
- *Energy prices*: The prices consumers paid for energy (electricity) in a recent year.
- *Energy price trends*. Energy prices forecasted into the future. DOE based these trends on the EIA's *Annual Energy Outlook (AEO) 2009*.[2]
- *Repair and maintenance costs*: Repair costs are associated with repairing or replacing components that fail. Maintenance costs are associated with maintaining the operation of a product.
- *Lifetime*: The age at which a product is retired from service.
- *Discount rate*: The rate at which DOE discounted future expenditures to establish their present value.

Figure 8.1.1 graphically depicts the relationships among the inputs for installed cost and operating cost used to calculate the LCC and PBP. The yellow boxes in Figure 8.1.1 indicate inputs; the green boxes indicate intermediate outputs; and the blue boxes indicate the final outputs of LCC and PBP.

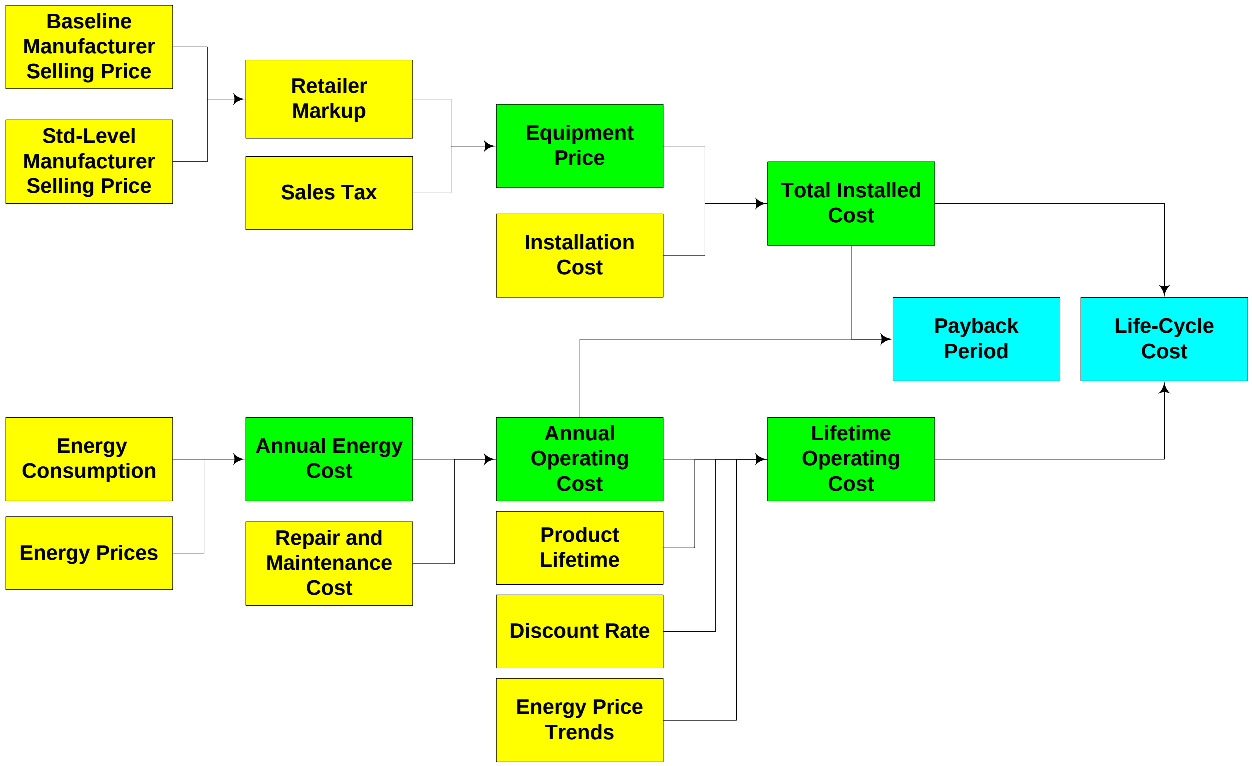


Figure 8.1.1 Flow Diagram of Inputs for Life-Cycle Cost and Payback Period Analyses

Tables 8.1.1 through 8.1.3 summarize the input values that DOE used to calculate the LCC and PBP for refrigeration products. The inputs for calculating total installed and operating costs included the product lifetime, discount rate, and energy price trends. DOE used single-point values to characterize all inputs to total cost, but used probability distributions to capture the uncertainty and/or variability of several inputs to operating cost. For those inputs characterized using probability distributions, the values in the following tables are average or typical values.

Table 8.1.1 Standard-Size Refrigerator-Freezers: Summary of Inputs to Calculations

Input	Product Class	Average or Typical Value	Characterization
Baseline retail price	Top-mount refrigerator-freezer	550 *2008$*	Custom distribution
	Bottom-mount refrigerator-freezer	1,615 *2008$*	Custom distribution
	Side-by-side refrigerator-freezer with TTD*	1,332 *2008$*	Custom distribution
Increase in manufacturer selling price†	All	Varies by efficiency level	Single-point value
Retailer markup	All	Baseline = 1.45 Incremental = 1.15	Single-point value
Sales tax	All	7.1%	Single-point value
Annual energy use	Top-mount refrigerator-freezer	Baseline use = 657 kWh‡	Varies depending on usage
	Bottom-mount refrigerator-freezer	Baseline use = 699 kWh	Varies depending on usage
	Side-by-side refrigerator-freezer with TTD	Baseline use = 1,087 kWh	Varies depending on usage
Energy prices	All	11.4 cents per kWh	Varies depending on region
Energy price trend	All	AEO 2009 reference case[2]	Two additional scenarios: AEO high and low growth**
Lifetime	All	16.2 years (median)	Weibull distribution
Discount rate	All	4.8%	Custom distribution

* Through-the-door ice service.
† Includes manufacturer markup.
‡ Kilowatt hours
** See section 8.2.2.3.

Table 8.1.2 Standard-Size Freezers: Summary of Inputs to Calculations

Input	Product Class	Average or Typical Value	Characterization
Baseline retail price	Upright	469 *2008$*	Custom distribution
	Chest	304 *2008$*	Custom distribution
Increase in manufacturer selling price*	All	Varies by efficiency level	Single-point value
Retailer markup	All	Baseline = 1.45 Incremental = 1.15	Single-point value
Sales tax	All	6.59%	Single-point value
Annual energy use	Upright	Baseline use = 980 kWh[†]	Varies depending on usage
	Chest	Baseline use = 623 kWh	Varies depending on usage
Energy prices	All	11.4 cents per kWh	Varies depending on region
Energy price trend	All	AEO 2009 reference case[2]	Two additional scenarios: AEO high and low growth[§]
Lifetime	All	21.7 years (median)	Weibull distribution
Discount rate	All	4.8%	Custom distribution

* Includes manufacturer markup.
[†] Kilowatt hours.
[§] See section 8.2.2.3.

Table 8.1.3 Compact Refrigeration Products: Summary of Inputs to Calculations

Input	Product Class	Average or Typical Value	Characterization
Baseline retail price	Refrigerator	153 *2008$*	Custom distribution
	Freezer	193 *2008$*	Custom distribution
Increase in manufacturer selling price*	All	Varies by efficiency level	Single-point value
Retailer markup	All	Baseline = 1.45 Incremental = 1.15	Single-point value
Sales tax	All	6.9%	Single-point value
Annual energy use	Refrigerator	Baseline use = 325 kWh[†]	Varies depending on usage
	Freezer	Baseline use = 313 kWh	Varies depending on usage
Energy prices	All	10.8 cents per kWh	Varies depending on region
Energy price trend	All	AEO 2009 reference case[2]	Two additional scenarios: AEO high- and low-growth[§]
Lifetime	Refrigerator	5.6 years (mean)	Weibull distribution
	Freezer	7.5 years (mean)	Weibull distribution
Energy prices	All	4.8% (residential users) 6.2% (commercial users)	Custom distribution

* Includes manufacturer markup
[†] Killowatt hours.
[§] See section 8.2.2.3.

8.2 INPUTS TO LIFE-CYCLE COST ANALYSIS

Life-cycle cost (LCC) is the total consumer cost during the life of an appliance, including purchase and operating costs (including energy costs). DOE discounted future operating costs to the time of purchase, then summed them over the lifetime of the product. DOE used the following equation to define LCC.

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

Where:

LCC = life-cycle cost in dollars;
PC = consumer product cost in dollars;
$\sum$ = sum over the lifetime, from year 1 to year *N*;
N = lifetime of appliance in years;
OC = operating cost in-dollars;

r = discount rate; and
t = year for which operating cost is being determined.

DOE expresses dollar values in 2008$ because it gathered most of its data for the LCC and PBP analysis in 2008.

8.2.1 Inputs to Product Cost

DOE calculated the cost consumers pay for baseline products based on the following equation.

$$PC_{BASE} = (RSP_{BASE}) \times (TAX)$$

Where:

PC_{BASE} = consumer cost for baseline product,
RSP_{BASE} = retail selling price for baseline product, and
TAX= sales tax.

DOE calculated the consumer cost for products having higher efficiency levels based on the following equation.

$$PC_{STD} = PC_{BASE} + (\Delta MSP_{STD} \times MU_{RETINCR} \times TAX)$$

Where:

PC_{STD} = consumer product cost for higher-efficiency products,
PC_{BASE} = consumer cost for baseline product
ΔMSP_{STD} = change in MSP for more efficient model,
MU_{RET_INCR} = incremental retailer markup,
TAX= sales tax.

8.2.1.1 Baseline Retail Prices

DOE's engineering analysis (see chapter 5) did not attempt to estimate the manufacturing sales price (MSP) for baseline models. Instead, it developed incremental increases in MSP associated with increases in efficiency level. This approach required DOE to estimate retail prices for the baseline model in each product class.

DOE drew upon proprietary retail price data collected by The NPD Group.[3] These data reflect prices and sales at many retail outlets in the United States, representing more than 50 percent of retail sales nationwide. The data include model number, refrigerated volume, configuration of doors and ice-making, and whether the unit is an ENERGY STAR product. Based on these data DOE developed a sales-weighted price distribution for non-ENERGY STAR appliances in each product class.[a] For the LCC and PBP analyses of standard-sized products, DOE assigned a baseline price from that distribution to each household sampled from the EIA's 2005 Residential Energy Consumption Survey (RECS).[1] For compact product classes, DOE assigned a baseline price from the distribution to each sampled product. Appendix 8-C presents the distribution histograms DOE developed for each product class. The average baseline retail prices before sales tax for each refrigeration product class are shown in Table 8.2.1.

Table 8.2.1 Residential Refrigeration Products: Average Baseline Retail Price

Product Class	**Baseline Retail Price** ***2008$***
Product class 3: Top-mount refrigerator-freezer	550
Product class 5: Bottom-mount refrigerator-freezer	1,615
Product class 7: Side-by-side refrigerator-freezer with TTD*	1,332
Product class 9: Upright freezer	469
Product class 10: Chest freezer	304
Product class 11: Compact refrigerator	153
Product class 18: Compact freezer	193

* Through-the-door ice service.

8.2.1.2 Increases in Manufacturer Selling Price

DOE used a combination of cost data submitted by the Association of Home Appliance Manufacturers (AHAM)[4] and a reverse engineering analysis to estimate increases to manufacturing cost associated with increases in efficiency levels for refrigeration products. Refer to Chapter 5, Engineering Analysis, for details. Adding the manufacturer markup described in chapter 6 yielded the MSP increases for each considered efficiency level and product class shown in Tables 8.2.2 through 8.2.4.

[a] DOE assumed that prices for non-ENERGY STAR models are a reasonable approximation of prices for the baseline models.

Table 8.2.2 Standard-Size Refrigerator-Freezers: Increases in Manufacturer Selling Prices

Efficiency Level *% less than baseline energy use*	Increase in MSP *2008$*		
	Product Class 3: Top-Mount Refrigerator-Freezer	**Product Class 5: Bottom-Mount Refrigerator-Freezer**	**Product Class 7: Side-by-Side Refrigerator-Freezer with-TTD Ice Service**
10	3.50	1.80	11.18
15	7.68	5.79	18.96
20	16.39	13.72	54.26
25	34.92	31.38	106.00
30	62.06	45.06	167.29
35	103.91	110.05	228.96
40	156.20	183.33	310.77
45	208.14	251.25	

* Through-the-door.

Table 8.2.3 Standard-Size Freezers: Increases in Manufacturer Selling Prices

Efficiency Level *% less than baseline energy use*	Increase in MSP *2008$*	
	Product Class 9: Upright Freezer	**Product Class 10: Chest Freezer**
10	6.41	2.35
15	11.45	6.05
20	13.57	24.08
25	27.51	29.26
30	46.58	34.84
35	76.82	74.35
40	124.06	77.12
45	196.78	136.90

Table 8.2.4 Compact Refrigeration Products: Increases in Manufacturer Selling Prices

Efficiency Level ***% less than baseline energy use***	**Increase in MSP *2008$***	
	Product Class 11: Compact Refrigerator or Refrigerator-Freezer	**Product Class 18: Compact Chest Freezer**
10	3.36	6.05
15	6.32	9.65
20	8.85	34.03
25	20.56	42.62
30	21.63	60.19
35	26.77	63.00
40	39.24	75.22
45	57.49	89.70

8.2.1.3 Markup and Sales Tax

To derive the incremental increase in consumer product cost for each efficiency level, DOE applied an incremental retail markup and sales tax to the MSP increases shown above. Refer to Chapter 6, Markups for Equipment Price Determination, for details. DOE also applied sales tax to the baseline retail prices.

8.2.1.4 Installation Cost

Because the cost to install refrigeration products does not change as efficiency increases, DOE did not incorporate installation costs in its analysis.

8.2.1.5 Consumer Product Cost

Tables 8.2.5 through 8.2.7 present the shipment-weighted consumer product cost at each considered efficiency standard level for the refrigeration product classes under consideration for new standards. These costs reflect the market efficiency distributions discussed in section 8.2.6.

Table 8.2.5 Standard-Size Refrigerator-Freezers: Average Consumer Cost

Efficiency Level *% less than baseline energy use*	**Product Class 3: Top-Mount** *2008$*	**Product Class 5: Bottom-Mount** *2008$*	**Product Class 7: Side-by-Side** *2008$*
Baseline	591	1,758	1,459
10	595	1,759	1,463
15	599	1,759	1,469
20	609	1,760	1,499
25	631	1,782	1,563
30	665	1,799	1,638
35	716	1,879	1,714
40	781	1,969	1,815
45	845	2,053	

Table 8.2.6 Standard-Size Freezers: Average Consumer Cost

Efficiency Level *% less than baseline energy use*	**Product Class 9: Upright** *2008$*	**Product Class 10: Chest** *2008$*
Baseline	505	325
10	511	328
15	517	332
20	520	355
25	537	361
30	561	368
35	598	416
40	656	420
45	745	493

Table 8.2.7 Compact Refrigeration Products: Average Consumer Cost

Efficiency Level ***% less than baseline energy use***	**Product Class 11: Compact Refrigerator** ***2008$***	**Product Class 18: Compact Freezer** ***2008$***
Baseline	166	207
10	170	214
15	173	218
20	176	248
25	191	259
30	192	281
35	198	284
40	214	299
45	236	317

8.2.2 Inputs to Operating Cost

DOE defines operating cost (*OC*) by the following equation.

$$OC = EC + RC + MC$$

Where:

EC = energy cost associated with operating the product,
RC = repair cost associated with component failure, and
MC = cost for maintaining appliance operation.

DOE used the following equation to calculate the annual operating cost for baseline products.

$$OC_{BASE} = (AEC_{BASE} \times PRICE_{ENERGY}) + RC_{BASE} + MC_{BASE}$$

Where:

OC_{BASE} = operating cost for baseline product,
AEC_{BASE} = annual energy consumption for baseline product,
$PRICE_{ENERGY}$ = energy price,
RC_{BASE} = repair costs associated with component failure for baseline product, and
MC_{BASE} = maintenance costs for baseline product.

DOE used the following equation to calculate the annual operating cost for higher efficiency products.

$$OC_{STD} = (AEC_{STD} \times PRICE_{ENERGY}) + RC_{STD} + MC_{STD}$$

Where:

OC_{STD} =	operating cost of higher efficiency product,
AEC_{STD} =	annual energy consumption of higher efficiency product,
$PRICE_{ENERGY}$ =	energy price in each year,
RC_{STD} =	repair costs associated with component failure for higher efficiency product, and
MC_{STD} =	maintenance costs for higher efficiency product.

8.2.2.1 Annual Energy Consumption

As described in Chapter 7, Energy Use Determination, DOE developed samples of individual households that use each of the standard-sized refrigeration products considered herein. By developing the samples, DOE was able to calculate the LCC and PBP for each household to account for the variability in both energy use and energy price associated with that household.

Tables 8.2.8 through 8.2.10 are derived from the analysis described in chapter 7. The values shown for annual energy consumption are averages in the field. For compact products, DOE did not use the RECS sample, and the energy consumption is as measured using the DOE test procedure. DOE captured the variability in energy consumption by using a range of values in its LCC and PBP analyses.

Table 8.2.8 Standard-Size Refrigerator-Freezers: Average Annual Energy Use by Efficiency Level

Product Class 3: Top-Mount Refrigerator-Freezer		**Product Class 5: Bottom-Mount Refrigerator-Freezer**		**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD†**	
Efficiency Level ***% less than baseline energy use***	**Energy Use** ***kWh****	**Efficiency Level** ***% less than baseline energy use***	**Energy Use** ***kWh***	**Efficiency Level** ***% less than baseline energy use***	**Energy Use** ***kWh***
Baseline	657	Baseline	699	Baseline	1,087
10	591	10	629	10	979
15	558	15	594	15	924
20	526	20	559	20	870
25	493	25	524	25	815
30	460	30	489	30	761
35	427	35	454	35	707
40	394	40	419	40	652
45	361	45	384	-	-

* Kilowatt hours.
†Through-the-door ice service.

Table 8.2.9 Standard-Size Freezers: Average Annual Energy Use by Efficiency Level

Product Class 9: Upright Freezer		**Product Class 10: Chest Freezer**	
Efficiency Level ***% less than baseline energy use***	**Energy Use** ***kWh****	**Efficiency Level** ***% less than baseline energy use***	**Energy Use** ***kWh***
Baseline	980	Baseline	623
10	882	10	561
15	833	15	530
20	784	20	498
25	735	25	467
30	686	30	436
35	637	35	405
40	588	40	374
45	539	45	343

* Kilowatt hours.

Table 8.2.10 Compact Refrigeration Products: Average Annual Energy Use by Efficiency Level

Product Class 11: Compact Refrigerator		**Product Class 18: Compact Freezer**	
Efficiency Level ***% less than baseline energy use***	**Energy Use** ***kWh****	**Efficiency Level** ***% less than baseline energy use***	**Energy Use** ***kWh***
Baseline	325	Baseline	313
10	292	10	282
15	276	15	266
20	260	20	250
25	244	25	235
30	227	30	219
35	211	35	203
40	195	40	188
45	179	45	172

* Kilowatt hours.

8.2.2.2 Energy Prices

Using data from EIA Form 861[5], DOE derived average energy prices for 13 geographic areas in the United States: the nine U.S. Census divisions, plus four large states (New York, Florida, Texas, and California) considered individually. For Census divisions containing one of those large states, DOE left out data for the large state when calculating average regional values.

For example, the Pacific region average excludes California, and the West South Central region excludes Texas. Using the modified regional data, DOE assigned an appropriate energy price to each household in the sample.

DOE used data from EIA to estimate electricity prices for residential consumers in each of the 13 geographic areas These data, which are published annually, include annual electricity sales in kilowatt hours (kWh), revenues from electricity sales, and number of consumers by sector for every utility that serves final consumers. The calculation of an area-average residential or commercial electricity price proceeds in two steps.

1. For each utility, an average sector (residential or commercial) price is estimated by dividing sector revenues by sector sales.
2. An average regional price is calculated, whereby each utility having customers in a region is weighted by the number of residential consumers served in that region.

The calculation used the most recent EIA data available at the time the analysis was conducted. Table 8.2.11 shows the average residential and commercial electricity price in 2007 for each Census division and large state.

Table 8.2.11 Average Electricity Prices in 2007

Geographic Area	**Average Residential Price** ***2008$/kWh***	**Average Commercial Price** ***2008$/kWh***
New England	0.162	0.153
Middle Atlantic	0.127	0.111
East North Central	0.102	0.091
West North Central	0.088	0.075
South Atlantic	0.099	0.085
East South Central	0.087	0.086
West South Central	0.093	0.085
Mountain	0.097	0.084
Pacific	0.099	0.094
New York State	0.178	0.169
California	0.150	0.136
Texas	0.128	0.119
Florida	0.117	0.102

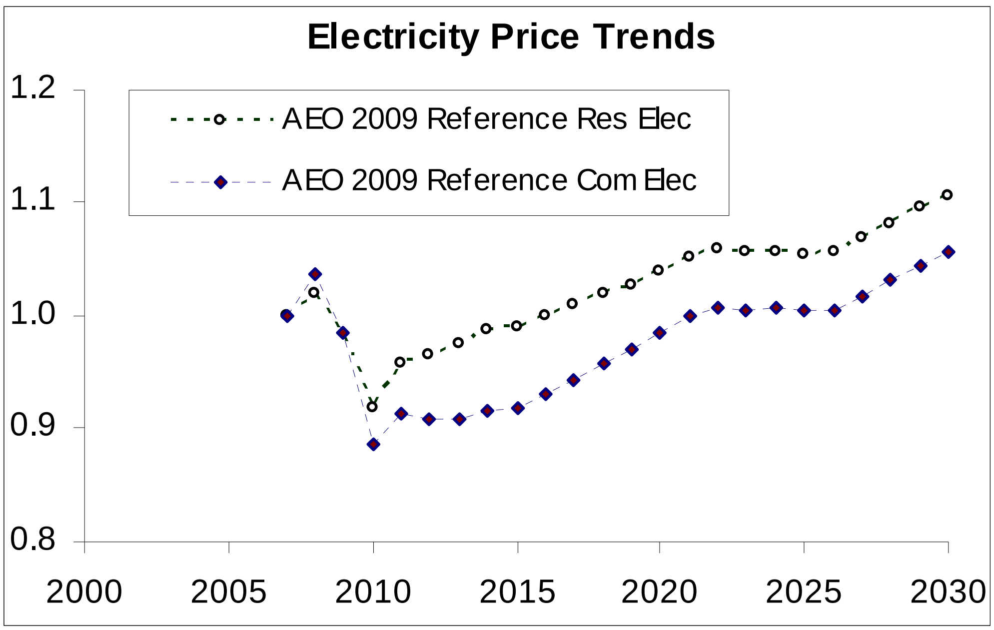
Source: U.S. Department of Energy–Energy Information Administration EIA Form 861.

8.2.2.3 Energy Price Trends

To estimate energy prices in future years, DOE multiplied the average prices listed in Table 8.2.11 by the forecast of annual average price changes in the EIA's AEO 2009.[2] To estimate the trend after 2030, DOE followed guidelines that the EIA had provided to the Federal

Energy Management Program, which called for using the average rate of change for electricity during 2020–2030.

The Department calculated LCC and PBP for each class of refrigeration products using three separate projections from AEO 2009: reference, low, and high economic growth. Alternative assumptions regarding the future growth in energy markets reflects the uncertainty regarding economic conditions during the forecast period. Figure 8.2.1 shows the projected trends in residential and commercial electricity prices based on the AEO 2009 reference case. For the LCC results presented in this chapter, DOE used only the energy price forecasts from the AEO reference case.



Source: Energy Information Administration, Annual Energy Outlook. 2009.

Figure 8.2.1 Residential and Commercial Electricity Price Trends (2007 = 1)

8.2.2.4 Repair and Maintenance Costs

Because DOE found no evidence that repair or maintenance costs change as the efficiency of refrigeration products increases, it excluded those costs from its analysis.

8.2.3 Product Lifetimes

8.2.3.1 Estimated Survival Function

The Energy Information Agency (EIA)'s Residential Energy Consumption Survey (RECS)[1] of occupied primary housing units records the presence of various appliances in each household, and places the age of each appliance into bins comprising several years. Data from the U.S. Census's *American Housing Survey* (AHS),[6] which surveys all housing including vacant and second homes, enabled DOE to adjust the RECS data to reflect some appliance use outside of primary residences. By combining the results of both surveys with the known history of appliance shipments (collected from *Appliance* magazine or directly from manufacturer trade associations), DOE estimated the percentage of appliances of a given age still in operation. This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an average and a median appliance lifetime.

The Weibull distribution is a probability distribution commonly used to measure failure rates.[b] Its form is similar to an exponential distribution, which models a fixed failure rate, except that a Weibull distribution allows for a failure rate that changes over time in a particular fashion. The cumulative Weibull distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \text{ for } x > \theta \text{ and}$$
$$P(x) = 1 \text{ for } x \le \theta$$

Where:

$P(x)$ = probability that the appliance is still in use at age x;
x = appliance age;
α = scale parameter, which would be the decay length in an exponential distribution;
β = shape parameter, which determines the way in which the failure rate changes through time; and
θ = delay parameter, which allows for a delay before any failures occur.

When $\beta = 1$, the failure rate is constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, β commonly is greater than 1, reflecting an increasing failure rate as appliances age.

The RECS survey is DOE's primary resource for appliance ages. For several appliances, including refrigerators and freezers, the survey asks respondents to identify the appliance's age as:

- less than 2 years old,
- 2 to 4 years old,
- 5 to 9 years old,

[b] For reference on the Weibull distribution, see sections 1.3.6.6.8 and 8.4.1.3 of the *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

- 10 to19 years old, or
- more than 20 years old.

The RECS survey has been conducted every three or four years for the past several decades. For this analysis, DOE used the surveys conducted in 1990, 1993, 1997, 2001, and 2005. DOE used the AHS count of housing units that contain refrigerators to scale the RECS data to better match the total installed stock. The U.S. Census AHS does not include data on freezers. DOE used the RECS micro-data to exclude from this analysis refrigerators that are both "half-height" and less than 10 cubic feet in capacity, because such refrigerators are not standard-sized. To determine overall refrigerator lifetime, DOE included all appropriately sized refrigerators, whether the household's first (primary) or second refrigerator. Households that did not know the age of their appliance were allocated among the remaining age bins according to the distribution of respondents who did report the appliance age.

Refrigerator ownership exhibits complex consumer behavior, which is not adequately reflected in AHS. In particular, AHS records only whether a housing unit contains a refrigerator, not the number of refrigerators. In addition, AHS may record a unit as containing a refrigerator when it contains a compact, rather than standard-size, appliance. Therefore, DOE used AHS only to scale the number of first refrigerators recorded by RECS. The baseline number of refrigerators reported in each RECS age bin is the sum of the AHS-scaled first refrigerators and the un-scaled, standard-size second refrigerators.

DOE adjusted the RECS survey data to account for the fact that the RECS survey begins its reference year with July, whereas shipments data are provided for each calendar year. DOE adjusted the data by using the survival function to model the additional retirement and replacement of appliances that takes place in the latter half of a survey year (after a given respondent is surveyed).

DOE used the RECS data on appliance ages, combined with the history of appliance shipments, to develop survival functions for refrigeration products. For example, DOE summed the total shipments from 5 to 9 years before each RECS survey, then compared this number with the number of units still in use at the time of the survey to approximate the percentage of surviving appliances within that age bin. By combining the age bins from the five RECS surveys with shipments data, DOE had enough data to use a least-squares method to build a fit to a Weibull distribution and find the parameters (α, β, θ) that best approximate the number of surviving units. Because the first two (youngest) RECS bins tend to have a large scatter relative to the shipments in those years, DOE combined the RECS and shipments data in the first two bins. Refrigerators and freezers generally do not fail during their first four years, so combining bins did not lower appreciably the accuracy of the distribution. DOE weighted each bin's contribution to the sum of squares by the inverse of the variance in RECS survey results, which controls for the changes in sample size between bins and through time.[c] RECS has a complex

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[c] See sections 4.1.4.3, 4.4.3.2, and 4.4.5.2 of *NIST/SEMATECH e-Handbook of Statistical Methods*, <www.itl.nist.gov/div898/handbook/>.

error model. DOE used only the error due to finite sample size to determine the variance for weighting the age bins. The equation for the sum of squares that DOE minimized is:

$$\sum_i \frac{\left(RECS_i - Surv_i\right)^2}{\sigma^2_{i,RECS}},$$

Where:

i =	the identifier for a bin from a single RECS;
$RECS_i$ =	the number of appliances reported by RECS in bin *I*;
$Surv_i$ =	the number of surviving appliances in bin *i* predicted by the Weibull distribution applied to the number of appliances shipped (a function of α, β, and θ); and
$\sigma_{i,RECS}$ =	the standard error (square root of the variance) of the RECS data point for bin *i*.

Table 8.2.13 shows the RECS data for refrigerators, the associated total shipments, and the best-fit Weibull calculation of stock by age bin. Figure 8.2.2 plots the data from the third and fourth columns of Table 8.2.12 against each other to show the quality of the fit. DOE allowed the delay parameter, θ, to vary only between 1 and 5 years, which corresponds to common warranty periods (see discussion below). For refrigerators and freezers, the best fit within this range is 5 years.

The Weibull distribution, shown in Figure 8.2.3, is characterized by the parameters α = 13.91, β = 1.68, and θ = 5.0. This distribution has a mean refrigerator lifetime of 17.43 years and a median lifetime of 16.18 years.

Table 8.2.12 Standard-Size Refrigerator-Freezers: Comparison of Survey and Shipments Data with Modeled Stock

		RECS 2005			
		All Refrigerators		**Second Refrigerators**	
Age Bin ***years***	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	51,119,128	56,880,896	51,119,128	5,311,005	3,041,016
5 to 9	42,988,500	40,150,841	41,031,292	4,983,112	3,524,129
10 to 19	68,088,000	36,771,769	40,997,548	8,672,157	6,942,353
20 or more	165,800,000	10,337,608	12,039,872	4,139,841	4,628,220
		RECS 2001			
		All Refrigerators		**Second Refrigerators**	
Age Bin ***years***	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	44,319,100	46,312,479	44,319,100	2,460,510	2,637,703
5 to 9	36,982,000	39,491,335	35,298,172	3,868,224	3,031,985
10 to 19	60,556,000	35,970,898	36,813,807	6,572,685	6,198,453
20 or more	144,325,000	11,301,203	11,920,574	3,955,496	4,580,842
		RECS 1997			
		All Refrigerators		**Second Refrigerators**	
Age Bin ***years***	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	38,185,000	44,356,564	38,185,000	2,047,982	2,274,485
5 to 9	32,698,000	36,760,359	31,123,487	2,782,204	2,695,071
10 to 19	56,244,000	31,056,224	33,972,064	5,078,190	5,724,270
20 or more	122,660,000	10,989,427	11,832,244	3,879,197	4,475,841
		RECS 1993			
		All Refrigerators		**Second Refrigerators**	
Age Bin ***years***	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	33,088,000	37,322,759	33,088,000	1,605,544	1,972,965
5 to 9	31,584,000	35,001,768	30,138,108	2,289,052	2,591,010
10 to 19	52,400,000	32,735,032	30,891,143	4,695,960	5,348,774
20 or more	101,577,000	13,119,858	11,723,329	5,708,862	4,296,210
		RECS 1990			
		All Refrigerators		**Second Refrigerators**	
Age Bin ***years***	**Shipments**	**RECS Stock**	**Modeled Stock**	**RECS Stock**	**Modeled Stock**
0 to 4	32,670,000	38,098,670	32,670,000	1,784,095	1,950,717
5 to 9	26,419,000	30,724,176	25,249,353	2,227,766	2,158,527
10 to 19	56,584,000	34,088,557	33,242,186	5,316,297	5,767,417
20 or more	82,797,000	12,571,836	10,159,632	4,869,236	3,737,018

Source: U.S. Department of Energy–Energy Information Agency. Residential Energy Consumption Survey. 1990, 1993, 1997, 2001, and 2005.

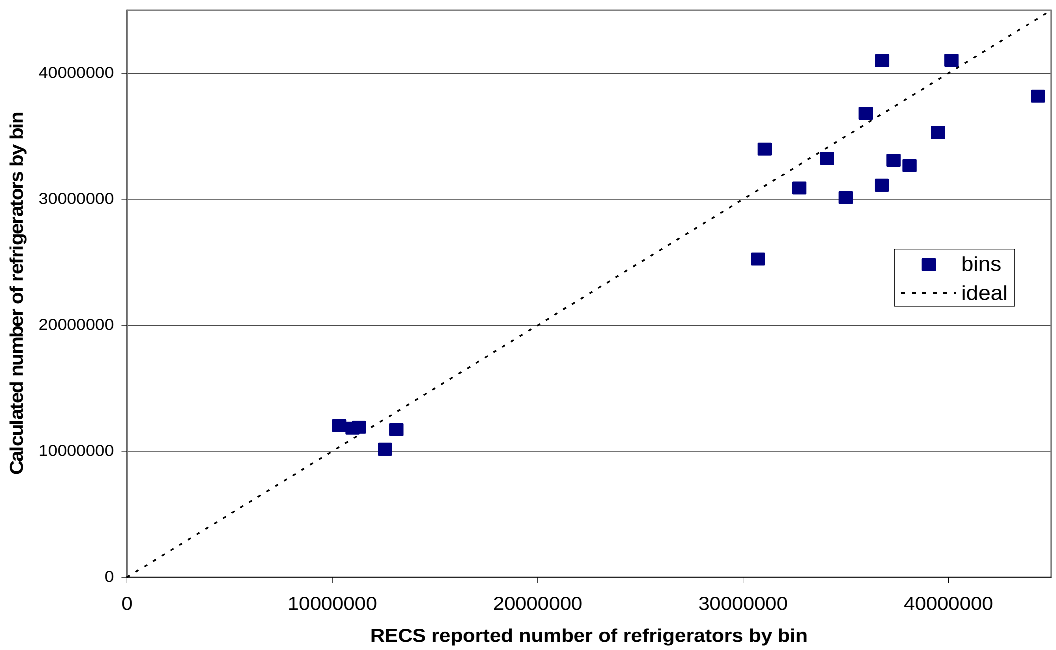

Figure 8.2.2 Comparison of Modeled Refrigerator Age Distribution with Data from Residential Energy Consumption Surveys

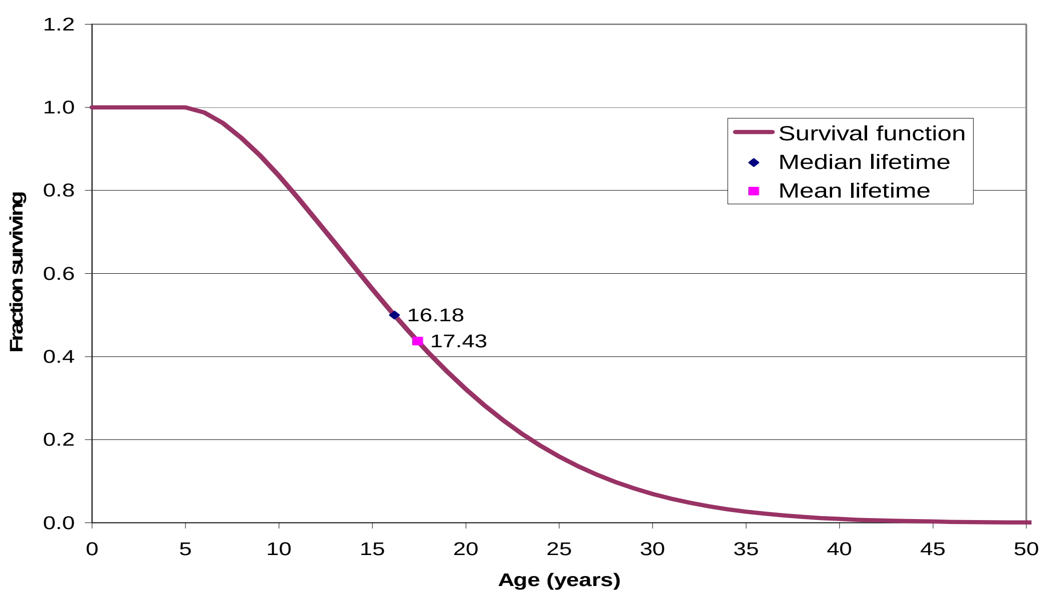

Figure 8.2.3 Survival Function for Standard-Size Refrigerator-Freezers

The method DOE used to calculate product lifetimes incorporates several assumptions:

- Appliance lifetime can be modeled by a survival function. In particular, a Weibull distribution is an appropriate survival function.
- The appliance survival function does not change through time.
- The survival function is independent of other household factors (such as household size or geographic region) as well as product class (within standard-size refrigerators or freezers).
- RECS respondents neither systematically overestimated nor underestimated the current age of their appliance.
- The historical shipment data are accurate.
- The shipped appliances are installed exclusively (or almost exclusively) in residences.
- The Weibull delay parameter, θ, is limited to between 1 and 5 years.

Three of these assumptions reflect analytical choices made by DOE. The first is the assumption that a Weibull distribution is the appropriate distribution to use for rates of appliance retirement. This distribution is the standard one used in lifetime analyses, but it is not guaranteed to reflect actual real-world experience. The second assumption is that consumer behavior and mechanical appliance lifetime have not changed over time. This assumption required DOE to treat equally all data from the several RECS surveys. Using only recent surveys (which may better reflect recent consumer behavior and appliance lifetime) would provide only a few data points for attempting least-squares fits, producing large statistical uncertainty.

The third assumption concerns the Weibull delay parameter. DOE limited the delay parameter to between 1 and 5 years to reflect the range of common appliance warranties. A delay of less than 1 year would imply that some appliances fail or are replaced within their first year of use. A delay of more than 5 years would imply that no appliances are replaced for some time after the end of the longest standard warranty. Fits using $\theta > 5$ also commonly show nonsensical behavior, with sharp changes in consumer behavior or appliance survival immediately following the delay period.

8.2.3.2 Conversion of First to Second Refrigerators

When a household purchases a new refrigerator, sometimes it uses its original unit as a secondary appliance in the basement or garage. DOE modeled the process by which first refrigerators are converted to second refrigerators as a Weibull process having a cumulative distribution of the form:

$$P(x) = \delta + (1-\delta) \times \left(1 - e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}}\right) \text{ for } x > \theta \text{ and}$$

$$P(x) = \delta \text{ for } x \leq \theta$$

Where:

$P(x)$ =	probability that the appliance has been converted at age x;
x =	appliance age;
α =	the scale parameter, which would be the decay length in an exponential distribution;
β =	the shape parameter, which determines the way in which the conversion rate changes through time;
δ =	the percentage of shipments that are used immediately as second refrigerators; and
θ =	the delay parameter, which allows for a delay before any conversions occur.

Rather than comparing second refrigerators to shipments, DOE compared them with the existing total installed base of refrigerators of a certain age, as measured by RECS. As with calculating appliance lifetime, the RECS data were adjusted with AHS data. In essence, DOE constructed a Weibull distribution to model a conversion function rather than a survival function. In addition, the model allows for the direct purchase of a new second refrigerator. A refrigerator bought to be a second refrigerator is modeled as being converted from first to second immediately at purchase; the offset parameter δ represents those units. Refrigerators commonly are bought to be second units, as indicated by the relatively large number of young second refrigerators reported by in RECS surveys.

DOE fit the conversion function using results from the 1990, 1993, 1997, 2001, and 2005 RECS. The RECS micro-data again enabled removing refrigerators that are not standard size, which has a significant effect given that many compact refrigerators are used as second units. In Table 8.2.12 the fifth column shows the RECS-derived stock of second refrigerators by age bin, and the sixth column shows the best fit from a Weibull distribution. Figure 8.2.4 shows the Weibull distribution. The best-fit Weibull parameters for the conversion function are $\alpha = 38.12$, $\beta = 2.03$, and $\theta = 0.0$, with an offset of 5.6 percent (meaning that 5.6 percent of shipments are sold as new second refrigerators). Roughly 1.5 percent of surviving refrigerators are converted from first to second refrigerator status each year, and roughly 20 percent of surviving refrigerators are converted to second refrigerators before they reach 15 years of age.

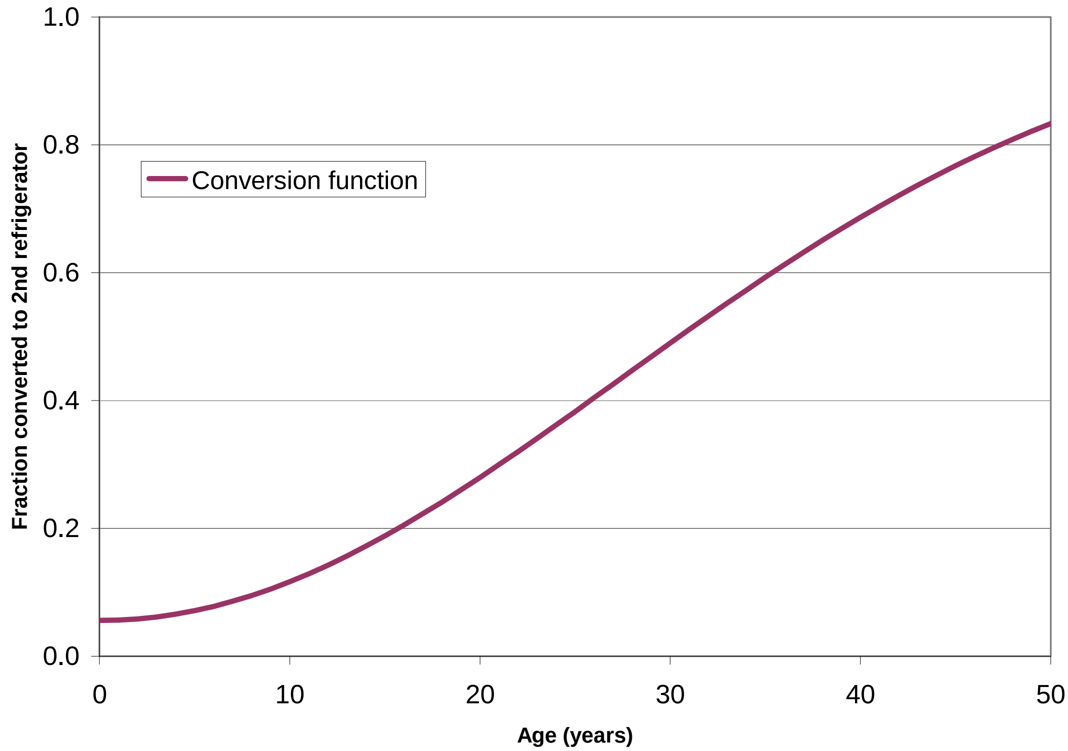

Figure 8.2.4 Function for Conversion of First to Second Refrigerator-Freezers

8.2.3.3 Standard-Size Freezers

DOE assumed relatively simple consumer behavior related to freezers. DOE did not model the conversion from first to second freezer for households having more than one freezer, but simply used all freezer data from RECS. Standard-sized freezers were assumed to have a capacity greater than 10 cubic feet. As with refrigerators, RECS bins were adjusted for units replaced in the second half of a year to synchronize the RECS and shipments data. RECS did not collect freezer lifetime data in 1990, so DOE used results from only the 1993, 1997, 2001, and 2005 surveys. The U.S. Census AHS survey does not report data on freezers, so the RECS bins were not scaled by the AHS total as for refrigerators. Before 2005, RECS reported the age distribution only for a household's first freezer, so DOE assumed that second and third freezers have the same age distribution as first freezers.

The best-fit Weibull parameters for freezer lifetime are $\alpha = 19.49$, $\beta = 2.40$, and $\theta = 5.0$. The resulting calculated mean freezer lifetime is 22.28 years; the median is 21.73 years. Table 8.2.13 lists the (adjusted) number of freezers reported in each RECS age bin, along with the modeled stock based on the best-fit Weibull survival function and the manufacturer-provided shipments history. Figure 8.2.5 shows the survival function used for standard-size freezers in the LCC and national impact analyses.

Table 8.2.13 Standard-Size Freezers: Comparison of Survey and Shipments Stock to Modeled Stock

RECS 2005			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	12,003,000	9,378,328	12,003,000
5–9	8,617,000	8,118,709	8,557,502
10–19	13,571,000	9,886,011	11,269,325
20 or more	47,672,000	7,607,227	6,973,305
RECS 2001			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	9,284,000	8,462,128	9,284,000
5–9	7,615,000	6,939,187	7,557,289
10–19	12,648,000	12,144,649	10,366,534
20 or more	42,528,000	7,494,606	7,817,703
RECS 1997			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	7,580,000	7,192,449	7,580,000
5–9	6,578,000	7,527,447	6,529,381
10–19	13,920,000	12,591,552	11,241,688
20 or more	36,203,000	6,561,157	8,045,004
RECS 1993			
Age Bin *years*	**Shipments**	**RECS Stock**	**Modeled Stock**
0–4	6,700,000	6,018,630	6,700,000
5–9	6,250,000	6,924,204	6,202,243
10–19	17,801,000	13,279,168	14,110,780
20 or more	27,388,000	8,277,900	6,374,921

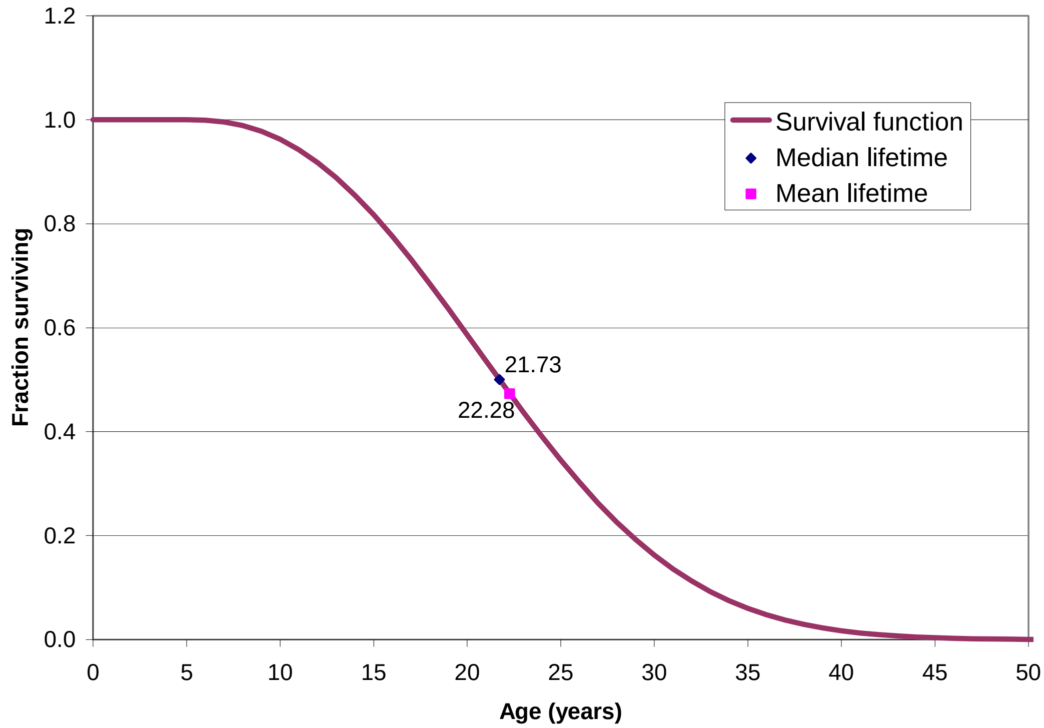

Figure 8.2.5 Survival Function for Standard-Size Freezers

8.2.3.4 Compact Refrigeration Products

As mentioned previously, compact refrigeration products are used in the residential and commercial sectors. RECS micro-data identify households that have refrigerators that are "half-height" and less than 10 cubic feet in capacity. DOE considered those households as potentially using compact refrigerators. EIA's *Commercial Building Energy Consumption Survey* (CBECS) survey of 2003[7] notes the presence of a residential-style refrigerator in an establishment. However, CBECS provides no further detail regarding the size of the refrigerator. Thus, RECS and CBECS data together do not provide enough detail on compact refrigerators to develop a survival function similar to the ones developed for standard-sized refrigerator-freezers and freezers.

DOE assumed that a Weibull distribution remains the appropriate functional form to represent retirement rates of compact refrigeration products. DOE initially used the average value of lifetime and historical shipments data from *Appliance* magazine to estimate Weibull parameters for compact refrigerators. When DOE applied the average lifetime of 10 years, given in *Appliance* magazine, to historical shipments, the model yielded a stock of compact refrigerators that was more than double the stock indicated by RECS and CBECS. DOE therefore calibrated the average lifetime to match the stock of compact refrigerators as reported by the surveys.

The estimated Weibull parameters for compact refrigerator lifetime are $\alpha = 5.75$ and $\beta = 1.75$. The resulting calculated mean lifetime is 5.62 years. For determining the lifetime of compact freezers, DOE used a scaling factor proportional to the ratio of the lifetimes of standard-sized refrigerators and standard-sized freezers. The calculated mean lifetime of a compact freezer is 7.46 years.

8.2.4 Discount Rates

The discount rate is the rate at which DOE discounts future expenditures to establish their present value. DOE derived discount rates for the LCC and PBP analyses from estimates of the cost to finance the purchase of the considered products. Following financial theory, the financal cost of raising funds to purchase appliances can be interpreted as: (1) the financial cost of any debt incurred to purchase a product, or (2) the opportunity cost of any equity used to purchase a product. In addition to estimating discount rates for appliances bought directly by consumers, DOE also estimated discount rates for purchasers of compact refrigerators and freezers in the commercial sector.

8.2.4.1 Discount Rates for Residential Consumers

Households use various methods to finance the purchase of major appliances. In principle, one could estimate the interest rates on the actual financing vehicles used to purchase appliances. The frequency with which each financing vehicle is used to purchase an appliance is unknown, however.

DOE's approach involved identifying all possible debt or asset classes that might be used to purchase the considered appliances, including household assets that might be affected indirectly.[d] DOE excluded debt from primary mortgages and the equity of assets considered non-liquid (such as retirement accounts), because those are unlikely to be used to purchase appliances. DOE estimated the average percentage shares of the various types of debt and equity in the average U.S. household using data from the Federal Reserve Board's *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[8] Table 8.2.15 shows the average percentages of each considered type of debt or equity. DOE derived the mean percentages of each source of financing throughout the 7 years surveyed.

[d] An indirect effect would arise if a household sold assets in order to pay off a loan or credit card debt that might have been used to finance the appliance purchase.

Table 8.2.14 Types of Household Debt and Equity by Percentage Shares

Type of Debt or Equity	1989 %	1992 %	1995 %	1998 %	2001 %	2004 %	2007 %	Mean %
Home equity loan	4.3	4.5	2.7	2.8	2.8	4.4	4.6	3.7
Credit card	1.6	2.1	2.6	2.2	1.7	2.0	2.4	2.1
Other installment loan	2.8	1.7	1.4	1.7	1.1	1.3	1.1	1.6
Other residential loan	4.4	6.9	5.2	4.3	3.1	5.8	7.1	5.3
Other line of credit	1.1	0.6	0.4	0.2	0.3	0.5	0.3	0.5
Checking account	5.8	4.7	4.9	3.9	3.6	4.2	3.4	4.4
Savings or money market account	19.2	18.8	14.0	12.8	14.2	15.1	13.0	15.3
Certificate of deposit	14.5	11.7	9.4	7.0	5.4	5.9	6.5	8.6
Savings bond	2.2	1.7	2.2	1.1	1.2	0.9	0.7	1.4
Bonds	13.8	12.3	10.5	7.0	7.9	8.4	6.7	9.5
Stocks	22.4	24.0	25.9	36.9	37.5	28.0	28.6	29.0
Mutual funds	8.0	11.1	20.9	20.1	21.3	23.4	25.5	18.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.

DOE estimated interest or return rates associated with each type of equity and debt. The source for interest rates for loans, credit cards, and lines of credit was the Federal Reserve Board's SCF for 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Table 8.2.16 shows the average nominal rates in each year and the inflation factors used to calculate real rates. DOE calculated effective interest rates for home equity loans in a similar manner as for mortgage rates, because interest on both such loans is tax deductible. Table 8.2.17 shows the average effective real rates in each year and the mean rate across years. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2014.

Table 8.2.15 Average Nominal Interest Rates for Household Debt

Type of Debt	1989 %	1992 %	1995 %	1998 %	2001 %	2004 %	2007 %	Mean %
Home equity loan	11.5	9.6	9.6	9.8	8.7	5.7	6.3	7.9
Credit card*	-	-	14.2	14.5	14.2	11.7	7.9	9.0
Other installment loan	9.0	7.8	9.3	7.8	8.7	7.4	12.6	13.4
Other residential loan	8.8	7.6	7.7	7.7	7.5	6.0	10.4	8.6
Other line of credit	14.8	12.7	12.4	11.9	14.7	8.8	6.3	7.4
Inflation rate	4.82	3.01	2.83	1.56	2.85	2.66	2.85	

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.
* No data on interest rates available for credit cards in 1989 or 1992.

Table 8.2.16 Average Real Effective Interest Rates for Household Debt

Type of Debt	1989 %	1992 %	1995 %	1998 %	2001 %	2004 %	2007 %	Mean %
Home equity loan	3.8	4.3	4.4	5.8	3.8	1.9	2.1	3.0
Credit card*	-	-	11.0	12.7	11.1	9.1	3.3	3.9
Other installment loan	4.9	5.8	7.0	6.6	6.1	5.4	9.7	10.7
Other residential loan	4.0	4.7	4.8	6.0	4.6	3.3	5.8	6.0
Other line of credit	9.6	9.4	9.3	10.2	7.3	6.0	3.4	4.4

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, and 2007.
* No data on interest rates available for credit cards in 1989 or 1992.

No similar rate data are available from the *SCF* for classes of assets, so the Department derived that information from national historical data. The interest rates associated with certificates of deposit,[9] savings bonds,[10] and bonds (AAA corporate bonds)[11] were collected from Federal Reserve Board time-series data for 1977–2008. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts came from Cost of Savings Index data covering 1984–2008. [12] The rates for stocks are the annual returns on the Standard and Poor's 500 for 1977–2008. [13] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year for 1977–2008. DOE adjusted the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.18. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2014.

Table 8.2.17 Average Nominal and Real Interest Rates for Household Equity

Type of Equity	Average Nominal Rate %	Average Real Rate %
Checking account	-	0.0
Savings and money market accounts	5.4	2.2
Certificate of deposit	6.6	2.3
Savings bond	7.7	3.3
Bonds	8.5	4.1
Stocks	11.6	7.1
Mutual funds	10.3	5.8

Table 8.2.19 summarizes the mean real effective rates of each type of equity or debt. DOE determined the average percentage of each type of debt and asset using *SCF* data for 1989, 1992, 1995, 1998, 2001, 2004, and 2007. Each year of SCF data provides the percents of debts and assets for U.S. households. DOE averaged those percentages for the 7 years of survey data to arrive at the percentages shown in Table 8.2.19. The average rate across all types of household debt and equity, weighted by the percentages of each type, is 4.8 percent.

Table 8.2.18 Average Interest on Household Debt and Equity

Type of Debt or Equity	Average % of Household Debt plus Equity*	Mean Effective Real Rate %**
Home equity loan	3.7	3.9
Credit card	2.1	10.7
Other installment loan	1.6	6.0
Other residential loan	5.3	4.4
Other line of credit	0.5	8.8
Checking account	4.4	0.0
Savings and money market account	15.3	2.2
Certificate of deposit	8.6	2.3
Savings bond	1.4	3.3
Bonds	9.5	4.1
Stocks	29.0	7.1
Mutual funds	18.6	5.8
Total/weighted-average discount rate	100.0	4.8

* Not including primary mortgage or retirement accounts.

** Adjusted for inflation and, for home equity loans, tax deduction of interest.

8.2.4.2 Assignment of Discount Rates to Sample Households

To account for variations among households, DOE assigned each sampled RECS household a rate from a distribution of rates for each type of debt and equity. DOE developed a probability distribution of interest rates based on SCF data. Appendix 8-C presents the probability distribution of interest rates that DOE used in the LCC and PBP analyses.

8.2.4.3 Discount Rates for Commercial Purchasers

DOE derived the discount rate for commercial owners of compact refrigeration products from the cost of capital of publicly traded firms in the sectors that purchase those products. The firms typically finance equipment purchases through debt and/or equity capital. DOE estimated the cost of the firms' capital as the weighted average of the cost of equity financing and the cost of debt financing for each year between 2001 and 2008.

The costs of debt and equity financing usually are publicly available for firms in the lodging and other commercial sectors[e] that may purchase compact refrigeration products.

DOE estimated the cost of equity using the capital asset pricing model (CAPM).[14] The CAPM assumes that the cost of equity (k_e) for a given company is proportional to the systematic risk faced by that company, whereby high risk is associated with a high cost of equity and low

[e] The "other commercial" sector includes financial institutions and all services other than lodging (SIC 6-8).

risk is associated with a low cost of equity. The systematic risk facing a firm is determined by several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (*ERP*). The risk coefficient of a firm describes the risk associated with that firm represented by standard deviations in the firm's stock price. The expected return on risk-free assets is defined by the yield on long-term government bonds. The *ERP* represents the difference between the expected stock market return and the risk-free rate. To estimate the expected return on risk-free assets and the equity risk premium, DOE used stock and bond data from Damodaran Online, a widely used source of information about debt and equity financing for most types of firms.[15,16] The Damodaran Online data were adjusted for annual inflation using deflator data for the gross domestic product from the Bureau of Economic Analysis' *National Income and Product Accounts Tables*.[17]

The cost of equity financing is estimated using the following equation:

$$k_e = R_f + (\beta \times ERP)$$

Where:

k_e = cost of equity,
R_f = inflation-adjusted expected return on risk-free assets,[f]
β = risk coefficient of the firm, and
ERP = equity risk premium.

The cost of debt financing (k_d) is the interest rate paid on money a company borrows. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate. This risk adjustment factor depends on the variability of stock returns represented by standard deviations in the firm's stock price. Thus for firm *i*, the cost of debt financing is:

$$k_{di} = R_f + R_{ai}$$

Where:

k_d = cost of debt financing for firm *i*,
R_f = expected return on risk-free assets, and
R_{ai} = risk adjustment factor to risk-free rate for firm *i*.

DOE estimates the weighted-average cost of capital using the following equation.

$$WACC = k_e \times w_e + k_d \times w_d$$

Where:

$WACC$ = weighted average cost of capital,

[f] Ibbotson Associates argues that the arithmetic mean equates the expected future value with the present value and should be used in calculating the risk-free rate and equity risk premium when using CAPM to estimate discount rates (*Stocks, Bonds, Bills, and Inflation 2009 Yearbook*, Ibbotson Associates, p. 60).

w_e = proportion of equity financing, and
w_d = proportion of debt financing.

The values of the parameters used in the calculations are shown in Table 8.2.20.

Table 8.2.19 Data for Calculating Weighted-Average Cost of Capital for Commercial Sectors

Sector	Year	β	R_f %	ERP %	R_a %	w_e %	w_d %
Lodging	2001	1.18	3.25	5.17	1.50	88	12
	2002	1.27	3.55	3.66	1.50	89	11
	2003	1.71	3.40	4.70	1.25	93	7
	2004	0.98	3.43	4.34	1.00	89	11
	2005	1.45	3.36	4.08	1.25	93	7
	2006	1.24	3.36	4.13	1.25	93	7
	2007	1.25	3.54	4.33	1.00	96	4
	2008	1.23	4.10	2.33	2.00	86	14
Other Commercial	2001	0.87	3.25	5.17	3.50	77	23
	2002	0.92	3.55	3.66	3.50	77	23
	2003	0.87	3.40	4.70	1.50	81	19
	2004	0.90	3.43	4.34	1.25	84	16
	2005	0.88	3.36	4.08	1.50	82	18
	2006	0.91	3.36	4.13	2.00	84	16
	2007	0.87	3.54	4.33	1.25	79	21
	2008	0.93	4.10	2.33	3.00	68	32

Note: Parameters are defined on the preceding two pages.

Using the procedure described above and the data in Table 8.2.20, DOE developed the real weighted-average cost of capital for the two commercial sectors that purchase compact refrigeration products. Those costs are listed in Table 8.2.21.

Table 8.2.20 Weighted-Average Cost of Capital for Commercial Sectors

Year	Lodging %	Other Commercial %
2001	5.69	6.75
2002	5.11	6.21
2003	5.49	6.64
2004	5.82	6.62
2005	5.95	6.24
2006	6.04	6.46
2007	6.42	6.40
2008	5.74	5.60
Sector average	5.78	6.37

In calculating the discount rate for companies that typically purchase compact refrigeration products, DOE generated a distribution of discount rates within each sector. The standard deviation of the distribution for each sector is provided in Table 8.2.22. Weighting each sector's discount rate by its share of compact refrigerator purchases,[g] DOE estimated that the average discount rate for companies that purchase compact refrigeration products is 6.20 percent.

Table 8.2.21 Discount Rates for Commercial Sectors

Sector	Discount Rate				% of Purchases
	Average %	Max. %	Min. %	Standard Deviation %	
Lodging	5.78	11.98	2.35	1.26	29
Other commercial	6.37	15.65	2.48	1.72	71
Weighted average	6.20	-	-	-	100

To account for variations in discount rates within each sector, DOE applied a normal probability distribution to the average values and standard deviations in Table 8.2.22. DOE truncated the normal distribution using the maximum and minimum values presented in Table 8.2.22.

8.2.5 Effective Date of Standard

The effective date of a potential new standard is the future date when it would become operative. Based on DOE's implementation report for energy conservation standards activities submitted pursuant to section 141 of the Energy Policy Act of 2005, a final rule pertaining to the appliances being considered for this rulemaking is scheduled for December 2010.[18] The effective date of any new energy efficiency standards for the products is 3 years after the final rule is

[g] The approach for estimating the share of total purchases by each of the two commercial sectors is described in chapter 9.

published, or January 2014. The Department calculated the life-cycle cost (LCC) for all consumers as if each would purchase a new appliance in the year the standard is to take effect.

8.2.6 Base-Case Energy Efficiencies

To estimate the percentage of consumers who would be affected by a standard at any of the potential efficiency levels, in its LCC analysis DOE considered the projected distribution of efficiencies for products that consumers purchase under the base case (the case without new energy efficiency standards). DOE refers to this distribution of product energy efficiencies as the base-case efficiency distribution. Using the projected distribution of efficiencies for each product class, DOE randomly assigned a product efficiency to each sample household. If a household was assigned a product efficiency that was greater than or equal to the efficiency of the standard level under consideration, the LCC calculation would show that this household would not be affected by that standard level.

DOE began with the energy efficiency distribution (market shares) for refrigeration products in 2007 based on data provided by AHAM[19]. In 2007, efficiency level 2 for refrigerator-freezers corresponded to the efficiency required for ENERGY STAR certification. In 2008, the criteria changed so that efficiency level 3 corresponded to the efficiency required for ENERGY STAR certification. If the market shares of refrigeration products by efficiency were the same in 2008 as in 2007, the ENERGY STAR market share would be 0 percent for top-mount refrigerators, 18 percent for bottom-mount refrigerators, and 2 percent for side-by-side refrigerators.

Efforts to promote ENERGY STAR products through various means, including consumer rebates, are expected to increase their market shares by 2014. Although it is difficult to predict appliance sales in 2014, it is reasonable to assume that the increase in market shares of ENERGY STAR products will follow the same pattern as they did between 2001 (the year in which the current DOE standards took effect and caused a shift in ENERGY STAR requirements) and 2007. The projected market shares of efficiency levels are shown in Table 8.2.23. As shown, the assumed market share of ENERGY STAR models in 2014 (under current requirements) is equal to the market share of ENERGY STAR models in 2007 (under the old requirements). For example, because 32 percent of side-by-side refrigerator-freezers qualified for ENERGY STAR (efficiency level 2 and higher) under the pre-2008 requirements, DOE assumed that 32 percent would meet ENERGY STAR requirements (efficiency level 3) in 2014. DOE also assumed that the market shares of lower-efficiency models (*i.e.,* baseline and 10 percent below baseline) would stay the same between 2007 and 2014.

Table 8.2.22 Standard-Size Refrigerator-Freezers: Base-Case Efficiency Distributions

Efficiency Level (*% less than baseline energy use)*	Product Class 3: Top-Mount Refrigerator-Freezer		Product Class 5: Bottom-Mount Refrigerator-Freezer		Product Class 7: Side-by-Side Refrigerator-Freezer with TTD*	
	Market Share %		Market Share %		Market Share %	
	2007	2014	2007	2014	2007	2014
Baseline	81	81	12	12	25	25
1 (10)	6	6	0	0	43	43
2 (15)	13	0	70	0	30	0
3 (20)†	0	13	18	88	2	32
4 (25)	0	0	0	0	0	0
5 (30)	0	0	0	0	0	0

* Through-the-door ice service.
† Meets 2008 ENERGY STAR criteria.

ENERGY STAR requirements for standard-size freezers and compact products have not changed since 2001. Those ENERGY STAR requirements correspond to efficiency level 1 for standard-size freezers and level 3 for compact products. DOE assumed that the market shares of those ENERGY STAR products would remain the same between 2007 and 2014 (Tables 8.2.24 and 8.2.25).

Table 8.2.23 Standard-Size Freezers: Base-Case Efficiency Distributions

Efficiency Level *(% less than baseline energy use)*	Product Class 9: Upright Freezer		Product Class 10: Chest Freezer	
	Market Share %		Market Share %	
	2007	2014	2007	2014
Baseline	82	82	85	85
1 (10)*	17	17	14	14
2 (15)	1	1	1	1
3 (20)	0	0	0	0
4 (25)	0	0	2	2
5 (30)	0	0	0	0

* Meets 2008 ENERGY STAR criteria.

Table 8.2.24 Compact Refrigeration Products: Base-Case Efficiency Distributions

Efficiency Level *(% less than baseline energy use)*	Product Class 11: Compact Refrigerator		Product Class 18: Compact Freezer	
	Market Share %		Market Share %	
	2007	2014	2007	2014
Baseline	97	97	95	95
1 (10)	0	0	5	5
2 (15)	0	0	0	0
3 (20)*	1	1	0	0
4 (25)	2	2	0	0
5 (30)	0	0	0	0

* Meets 2008 ENERGY STAR criteria.

8.3 INPUTS TO PAYBACK PERIOD ANALYSIS

The payback period (PBP) refers to the time it takes a consumer to recover, through lower operating costs, the assumed higher purchase cost of more energy efficient products. Numerically, the PBP is the ratio of the increase in purchase cost (from a less to a more efficient design) to the decrease in annual operating cost. This type of calculation is known as a simple payback period, because it does not account for changes in operating cost over time or the time value of money. That is, the calculation is performed at an effective discount rate of 0 percent.

The equation for determining PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Where:

ΔIC = the difference in total installed cost between the more efficient design based on the new standard level and the baseline design, and

ΔOC = the difference in annual operating cost between the two units.

Payback periods are expressed in years. Payback periods greater than the life of a product mean that the increased total installed cost is not recovered through reduced operating cost.

The data inputs to calculating PBP are the total installed cost to the consumer for each product at each efficiency level and the annual (first-year) operating cost for each efficiency level. The inputs to calculating total installed cost are the product and installation costs. The inputs to calculating operating cost are the annual energy, repair, and maintenance costs. The PBP uses the same inputs as the LCC analysis described in section 8.2, except that no energy price trends, product lifetimes, or discount rates are required. Because the PBP is a simple payback, the only energy price required is for the year in which a new standard takes effect—in this case, the price projected for 2014.

8.4 RESULTS OF ANALYSES

This section presents the results of the life-cycle cost (LCC) and payback period (PBP) analyses for the considered efficiency levels for refrigeration products. As discussed in section 8.1.1, DOE's approach to the LCC analysis involved developing a sample of consumers who use each product. DOE also used probability distributions to characterize the uncertainty in many of the analytical inputs. DOE used a Monte Carlo simulation technique to perform the LCC calculations on data pertaining to the consumers in each sample. For each set of sample consumers who use the appliance in each product class, DOE calculated the average LCC, the LCC savings, and the median and average PBP for each standard level.

DOE calculated LCC savings and PBPs relative to the base-case product that it assigned to the sampled consumers. As discussed in section 8.2.6, DOE assigned some consumers a base-case product that is more efficient than the baseline product. For that reason, average LCC impacts are not equal to the difference between the LCC of a specific possible standard level and the LCC of the baseline product.

In the following subsections, DOE presents figures showing the distribution of LCCs in the base case for each product class. Also presented are figures showing the distribution of LCC impacts and the distribution of PBPs for specific possible standard levels. The figures represent frequency charts that include probabilities of occurrence for the distributions of LCC impacts and PBPs. DOE generated the figures for the distributions from a Monte Carlo simulation that utilized 10,000 samples.

LCC and PBP calculations were performed 10,000 times on the sample of consumers developed for each product. Each calculation was performed on a single consumer who was selected from the sample. The selection was based on weight, that is on how representative a particular consumer was of other consumers in the national distribution. Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

Based on the Monte Carlo simulations that DOE performed, for each efficiency level, DOE calculated the percentage of consumers who would experience a net LCC benefit, a net LCC cost, or no impact. DOE considered a consumer to receive no impact at a given efficiency level if the base-case product DOE assigned to that consumer had the same or higher efficiency than that of the new standard being evaluated. Note that the average LCC savings at each efficiency level are relative to the base-case efficiency distribution, not the baseline efficiency level.

8.4.1 Standard-Size Refrigerator-Freezers

The following subsections summarize results of LCC and PBP analyses for standard-size refrigerator-freezers and present figures showing the distribution of LCCs in the base case for each product class. Also presented are figures showing the distribution of LCC impacts and the distribution of PBPs for specific efficiency levels.

8.4.1.1 Summary of Results

Tables 8.4.1 through 8.4.3 show the LCC and PBP results for each refrigerator-freezer product class considered for new standards. DOE determined the median and average values for PBPs at each efficiency level by excluding those households that would not be affected by the standard.

Table 8.4.1 Product Class 3, Top-Mount Refrigerator-Freezers: Analytical Results

Efficiency Level *(% less than baseline energy use)*	**Life-Cycle Cost *2008$***			**Life-Cycle Cost Savings**				**Payback Period (years)**	
					% of Households that Experience				
	Average Product Cost	**Average Annual Operating Cost**	**Average LCC**	**Average Savings *2008$***	**Net Cost**	**No Impact**	**Net Benefit**	**Median**	**Average**
Baseline	591	77	1,505						
1 (10)	595	71	1,434	71	0.0	18.5	81.5	0.6	0.7
2 (15)	599	67	1,398	106	0.0	13.0	86.9	0.9	1.1
3 (20)	609	64	1,368	137	0.1	13.0	86.8	1.5	1.7
4 (25)	631	60	1,343	162	2.6	0.0	97.4	2.8	3.2
5 (30)	665	56	1,329	176	7.0	0.0	93.0	4.0	4.6
6 (35)	716	52	1,333	172	16.5	0.0	83.5	5.6	6.4
7 (40)	781	48	1,350	155	28.2	0.0	71.8	7.3	8.3
8 (45)	845	44	1,367	138	36.3	0.0	63.7	8.5	9.7

Table 8.4.2 Product Class 5, Bottom-Mount Refrigerator-Freezers: Analytical Results

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2008$*			Life-Cycle Cost Savings				Payback Period *years*	
	Average Product Cost	Average Annual Operating Cost	Average LCC	Average Savings *2008$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median	Average
Baseline	1,758	70	2,591						
1 (10)	1,759	69	2,581	11	0.0	88.5	11.5	0.3	0.4
2 (15)	1,759	69	2,576	16	0.0	88.4	11.6	0.7	0.8
3 (20)	1,760	68	2,571	20	0.0	88.4	11.6	1.2	1.4
4 (25)	1,782	64	2,542	49	14.8	0.0	85.2	5.1	6.0
5 (30)	1,799	60	2,508	83	11.2	0.0	88.8	4.6	5.4
6 (35)	1,879	55	2,538	54	44.1	0.0	55.9	9.5	11.0
7 (40)	1,969	51	2,577	14	60.5	0.0	39.5	12.6	14.7
8 (45)	2,053	47	2,610	-19	67.0	0.0	33.0	14.3	16.6

Table 8.4.3 Product Class 7, Side-by-Side Refrigerator-Freezers with Through-the-Door Ice Service: Analytical Results

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2008$*			Life-Cycle Cost Savings				Payback Period *years*	
	Average Product Cost	Average Annual Operating Cost	Average LCC	Average Savings *2008$*	% of Households that Experience: Net Cost	No Impact	Net Benefit	Median	Average
Baseline	1,459	116	2,840						
1 (10)	1,463	113	2,804	35	0.0	74.3	25.7	1.1	1.3
2 (15)	1,469	108	2,759	80	0.1	31.6	68.4	1.5	1.6
3 (20)	1,499	104	2,738	102	3.1	31.6	65.4	3.8	4.2
4 (25)	1,563	97	2,724	116	23.8	0.0	76.2	6.7	7.6
5 (30)	1,638	91	2,722	117	32.7	0.0	67.3	8.1	9.0
6 (35)	1,714	84	2,721	119	38.5	0.0	61.5	8.9	9.9
7 (40)	1,815	78	2,744	95	46.2	0.0	53.9	10.1	11.2

8.4.1.2 Distributions of Impacts

Figure 8.4.1 presents a frequency chart that shows the distribution of LCC impacts for the case of efficiency level 5 for top-mount refrigerator-freezers. The note, "Certainty is 93.01% from $0 to +Infinity," means that 93.01 percent of households owning top-mount refrigerator-freezers either will not be affected or will have LCC savings under the standard compared to the base case. DOE could generate a similar frequency chart for every efficiency level.

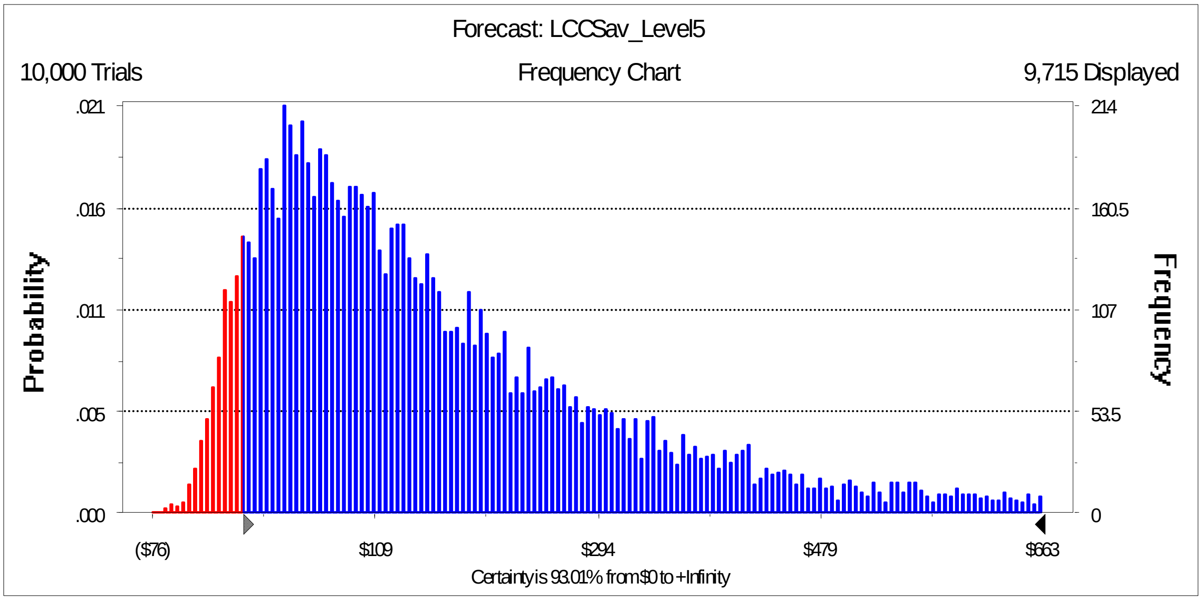

Figure 8.4.1 Product Class 3, Top-Mount Refrigerator-Freezers: Distribution of Life-Cycle Cost Impacts for Efficiency Level 5

Figure 8.4.2 is an example of a frequency chart showing the distribution of payback periods for efficiency level 5 for top-mount refrigerator-freezers. DOE could generate a similar frequency chart for every efficiency level.

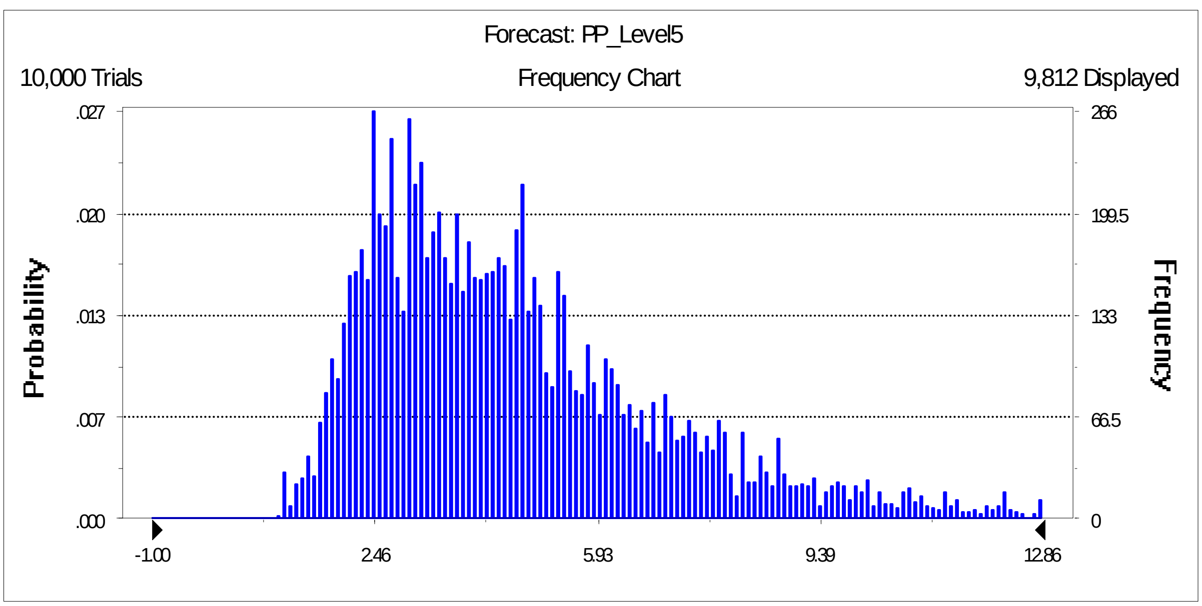

Figure 8.4.2 Product Class 3, Top-Mount Refrigerator-Freezers: Distribution of Payback Periods for Efficiency Level 5

Figures 8.4.3 through 8.4.5 show the range of LCC savings for all the efficiency levels considered for each refrigerator-freezer product class. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of households have LCC savings that exceed this value. The-horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average LCC savings for each efficiency level.

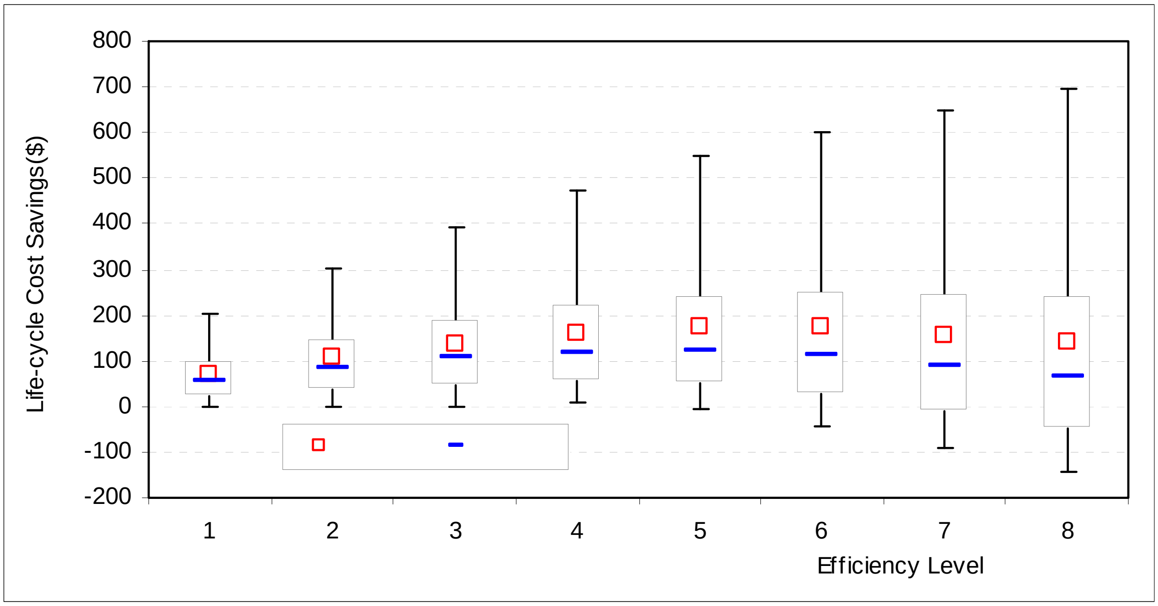

Figure 8.4.3 Product Class 3, Top-Mount Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

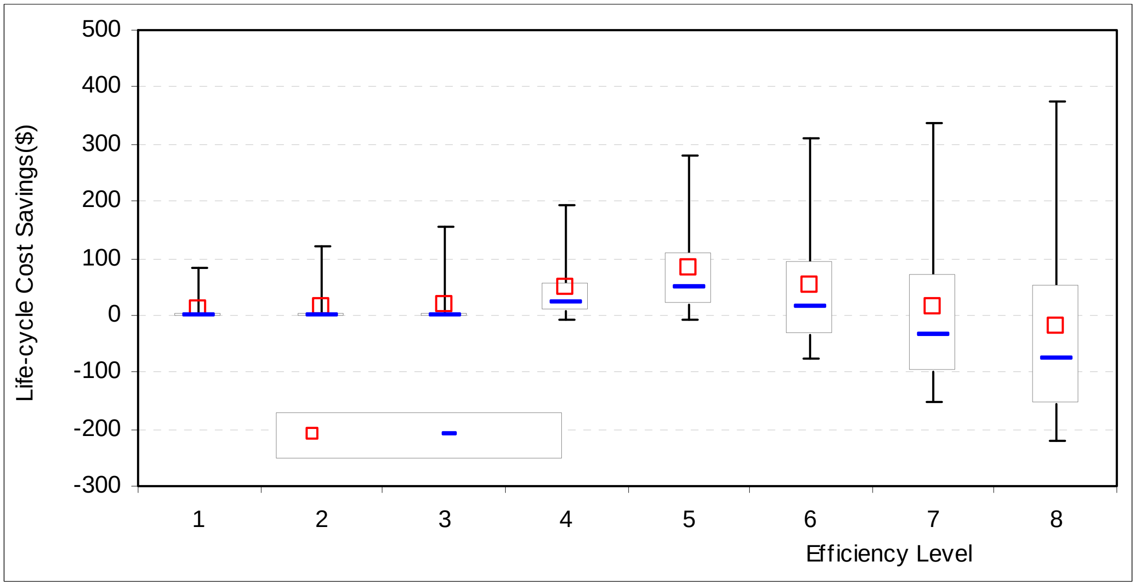

Figure 8.4.4 Product Class 5, Bottom-Mount Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

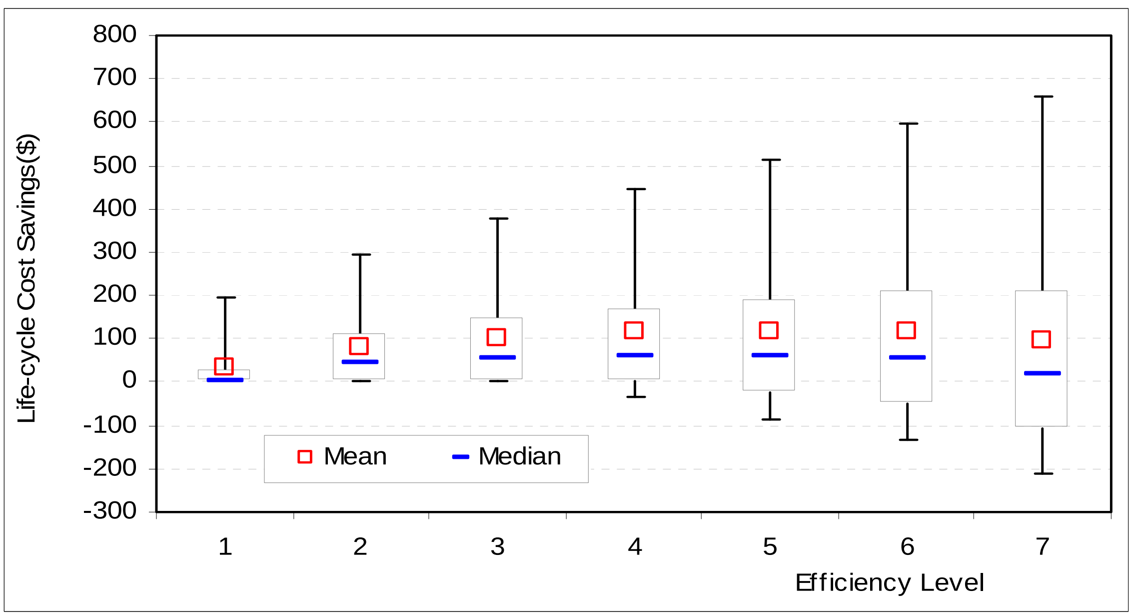

Figure 8.4.5 Product Class 7, Side-by-Side Refrigerator-Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

Figures 8.4.6 through 8.4.8 show the range of PBPs for all efficiency levels considered for each analyzed refrigerator-freezer product class. For each efficiency level, the top and bottom of the box in the figure indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have a PBP above this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively. The small box indicates the average PBP for each efficiency level.

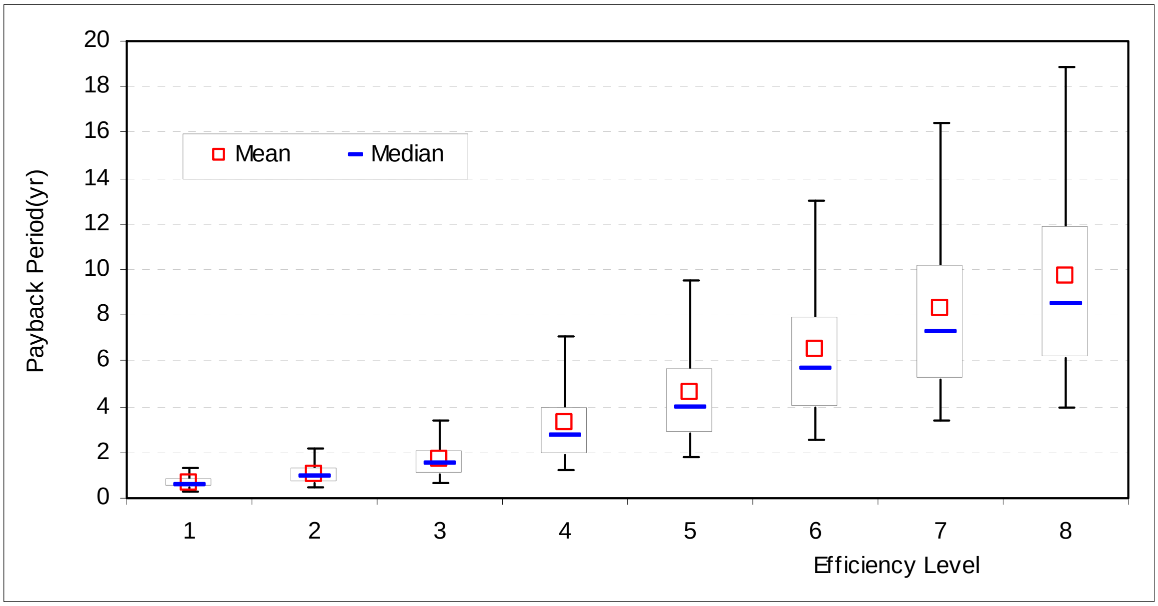

Figure 8.4.6 Product Class 3, Top-Mount Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

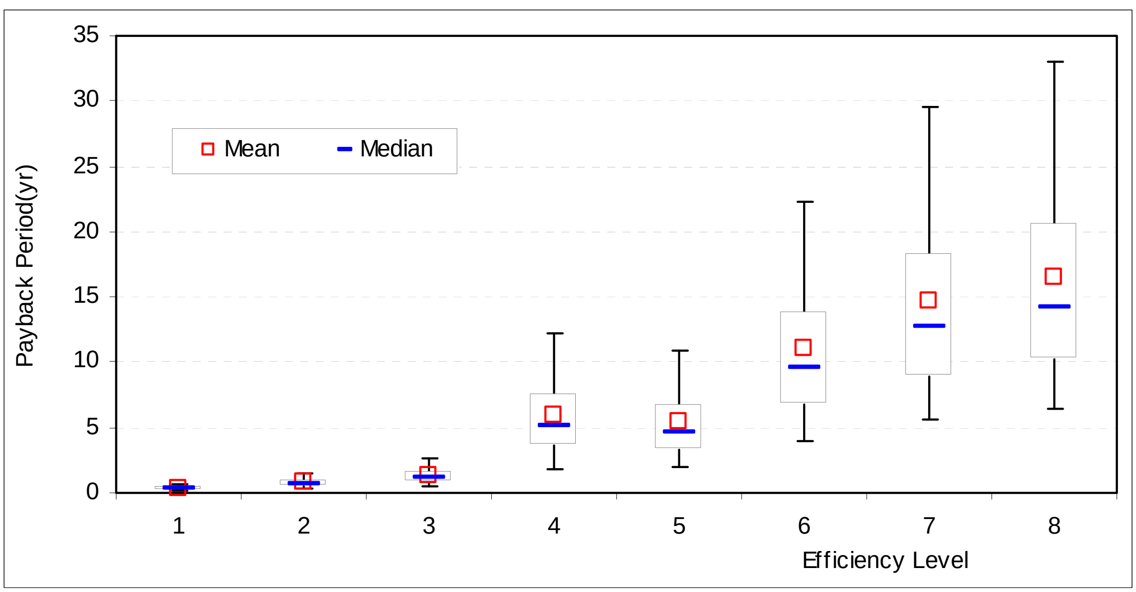

Figure 8.4.7 Product Class 5, Bottom-Mount Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

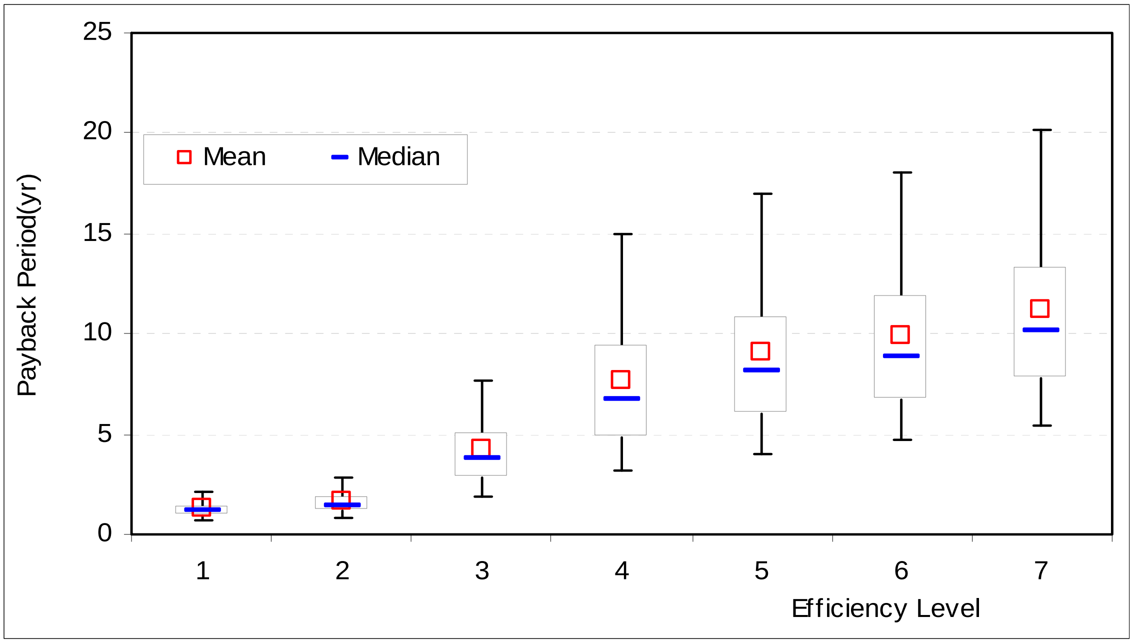

Figure 8.4.8 Product Class 7, Side-by-Side Refrigerator-Freezers: Range of Payback Periods by Efficiency Level

8.4.2 Standard-Size Freezers

The following subsections summarize results of LCC and PBP analyses for standard-size freezers and present figures showing the distribution of LCCs in the base case for both product classes. Also presented are figures showing the distribution of LCC impacts and the distribution of PBPs for specific efficiency levels.

8.4.2.1 Summary of Results

Tables 8.4.4 and 8.4.5 show the LCC and PBP results for each freezer product class considered for new standards. DOE determined the median and average values for PBPs at each efficiency level by excluding those households not affected by a standard.

Table 8.4.4 Product Class 9, Upright Freezers: Analytical Results

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2008$*			Life-Cycle Cost Savings				Payback Period *years*	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings *2008$*	% of Households that Experience			Median	Average
					Net Cost	No Impact	Net Benefit		
Baseline	505	113	2,064						
1 (10)	511	104	1,942	122	0.0	19.4	80.6	0.7	0.8
2 (15)	517	98	1,870	194	0.0	1.6	98.4	0.9	1.1
3 (20)	520	92	1,793	271	0.0	0.5	99.5	0.7	0.9
4 (25)	537	87	1,731	333	0.0	0.4	99.6	1.3	1.5
5 (30)	561	81	1,675	389	0.3	0.2	99.6	1.8	2.1
6 (35)	598	75	1,633	432	1.2	0.0	98.8	2.5	3.0
7 (40)	656	69	1,611	453	4.0	0.0	96.0	3.5	4.3
8 (45)	745	63	1,621	443	9.9	0.0	90.1	5.0	6.0

Table 8.4.5 Product Class 10, Chest Freezer: Analytical Results

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *2008$*			Life-Cycle Cost Savings				Payback Period *years*	
	Average Equipment Cost	Average Annual Operating Cost	Average LCC	Average Savings *2008$*	% of Households that Experience			Median	Average
					Net Cost	No Impact	Net Benefit		
Baseline	325	69	1,275						
1 (10)	328	63	1,196	79	0.0	15.3	84.8	0.4	0.5
2 (15)	332	60	1,153	122	0.0	1.1	98.9	0.8	1.0
3 (20)	355	56	1,127	148	1.2	0.2	98.6	2.5	3.0
4 (25)	361	53	1,085	190	0.7	0.2	99.2	2.4	2.8
5 (30)	368	49	1,044	231	0.4	0.2	99.4	2.3	2.7
6 (35)	416	46	1,044	231	5.3	0.0	94.7	4.2	4.9
7 (40)	420	42	999	276	3.7	0.0	96.3	3.8	4.4
8 (45)	493	39	1,024	251	13.8	0.0	86.2	6.0	6.9

8.4.2.2 Distributions of Impacts

Figure 8.4.9 presents a frequency chart showing the distribution of LCCs for the case of standard level 5 for upright freezers. The note, “Certainty is 99.67 % from $0 to +Infinity,” means that 99.67 percent of households owning upright freezers either will not be affected or will have LCC savings under the standard level compared to the base case. DOE could generate a similar frequency chart for every efficiency level.

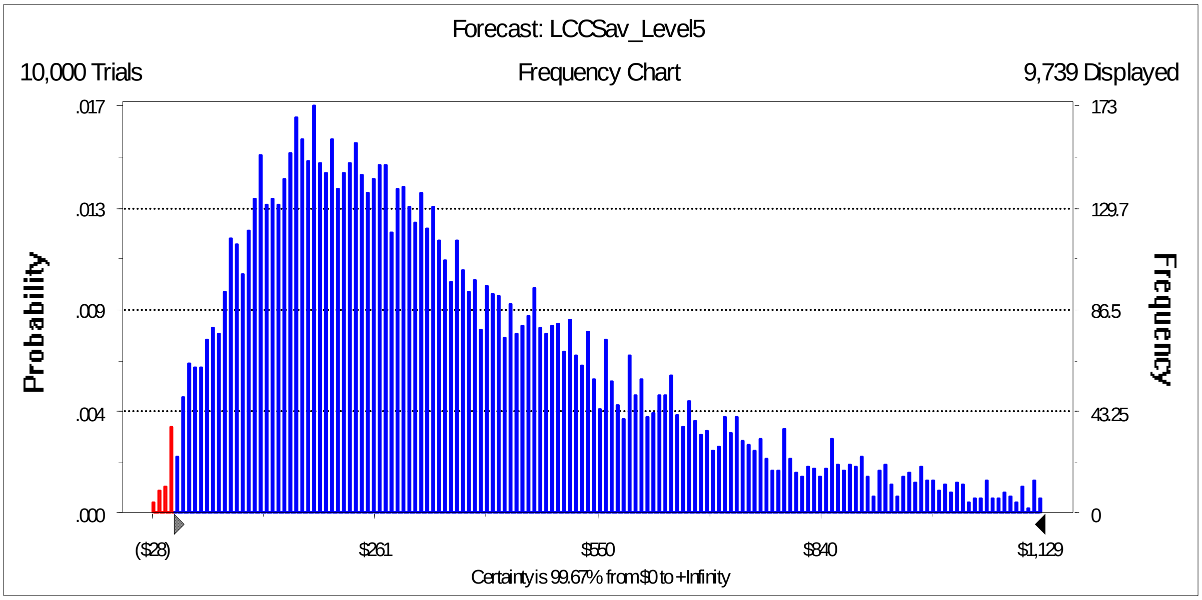

Figure 8.4.9 Product Class 9, Upright Freezers: Distribution of Life-Cycle Cost Impacts for Efficiency Level 5

Figure 8.4.10 presents a frequency chart showing the distribution of payback periods for standard level 5 for upright freezers. DOE could generate a similar frequency chart for every efficiency level within each product class.

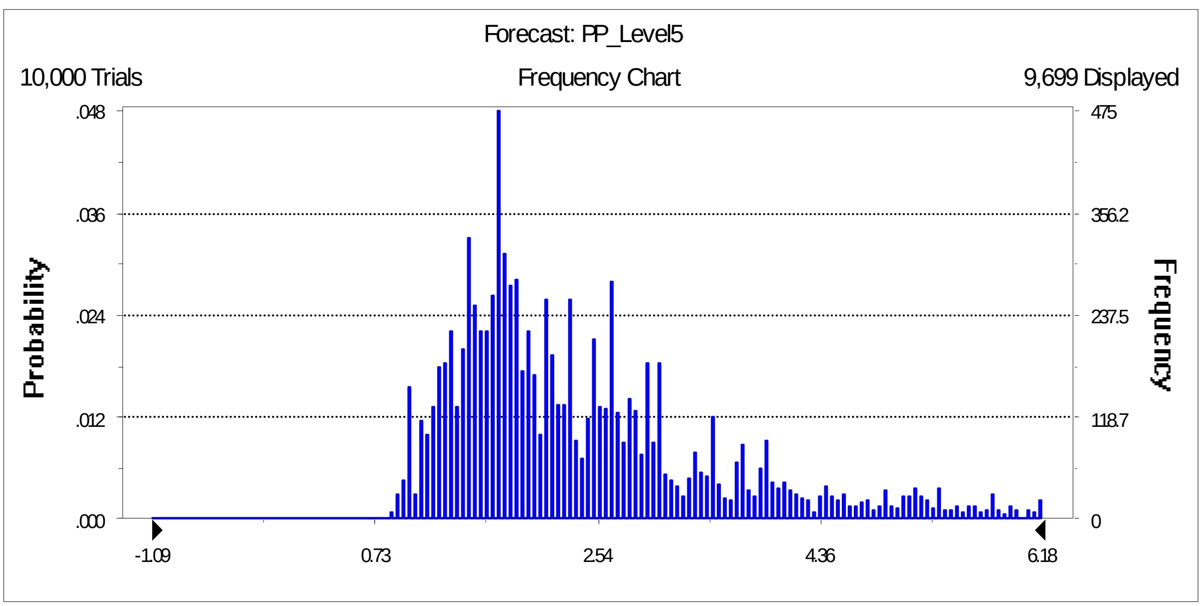

Figure 8.4.10 Product Class 9, Upright Freezers: Distribution of Payback Periods for Efficiency Level 5

Figures 8.4.11 and 8.4.12 show the range of LCC savings for the efficiency levels considered for each freezer product class. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have LCC savings that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average LCC savings for each efficiency level.

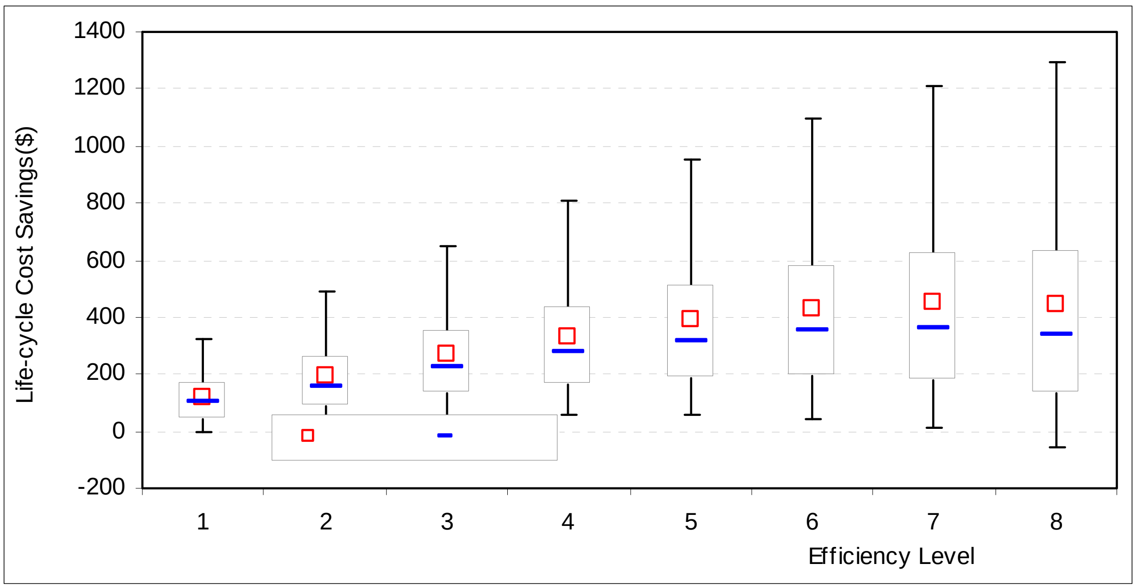

Figure 8.4.11 Product Class 9, Upright Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

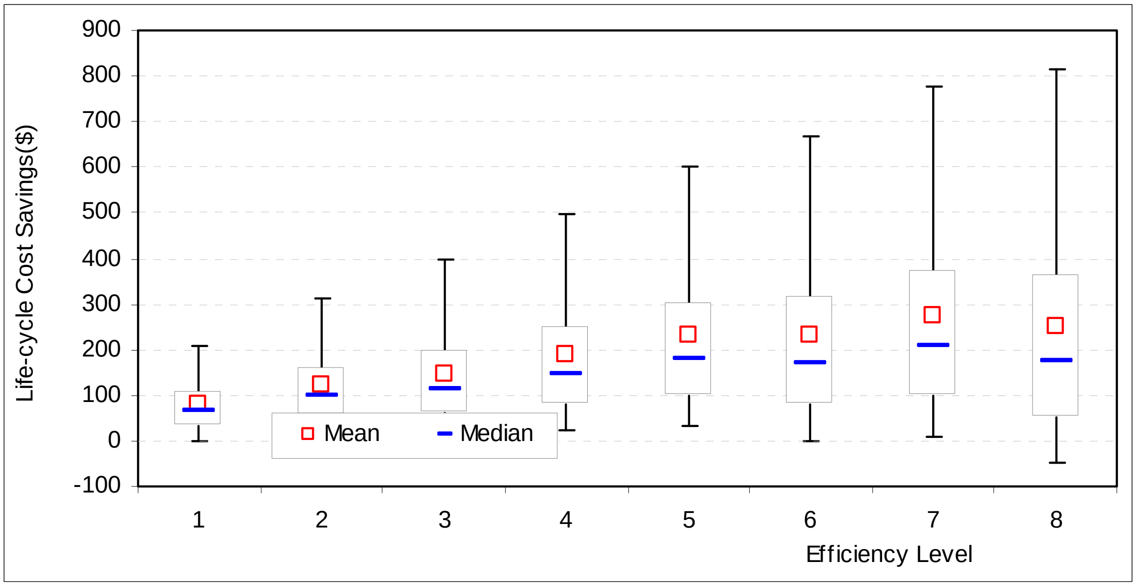

Figure 8.4.12 Product Class 10, Chest Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

Figures 8.4.13 and 8.4.14 show the range of PBPs for the efficiency levels considered for each freezer product class. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have PBPs that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average PBP for each efficiency level.

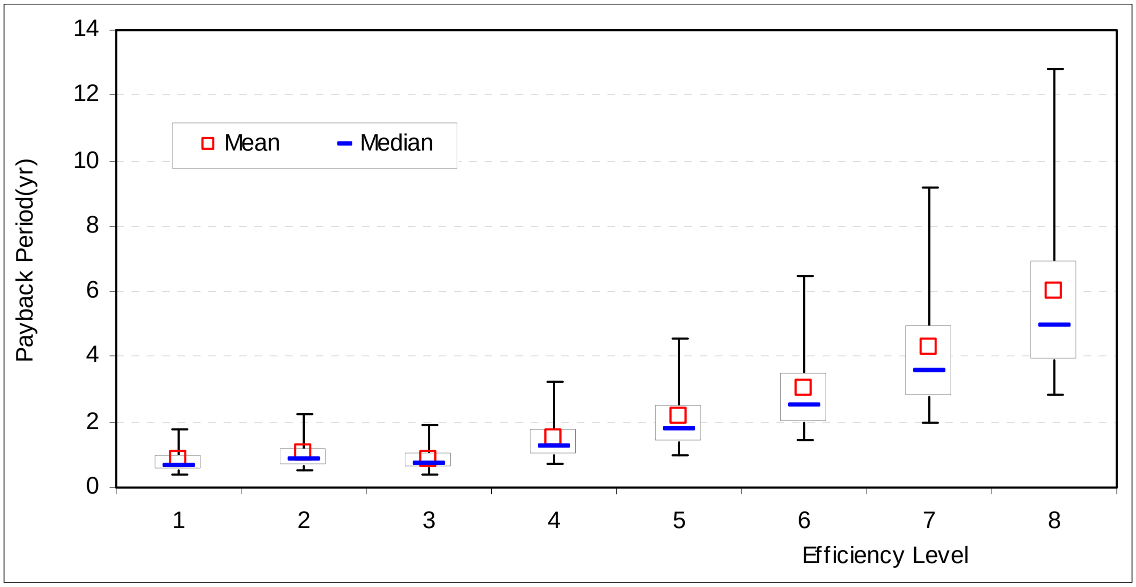

Figure 8.4.13 Product Class 9, Upright Freezers: Range of Payback Periods by Efficiency Level

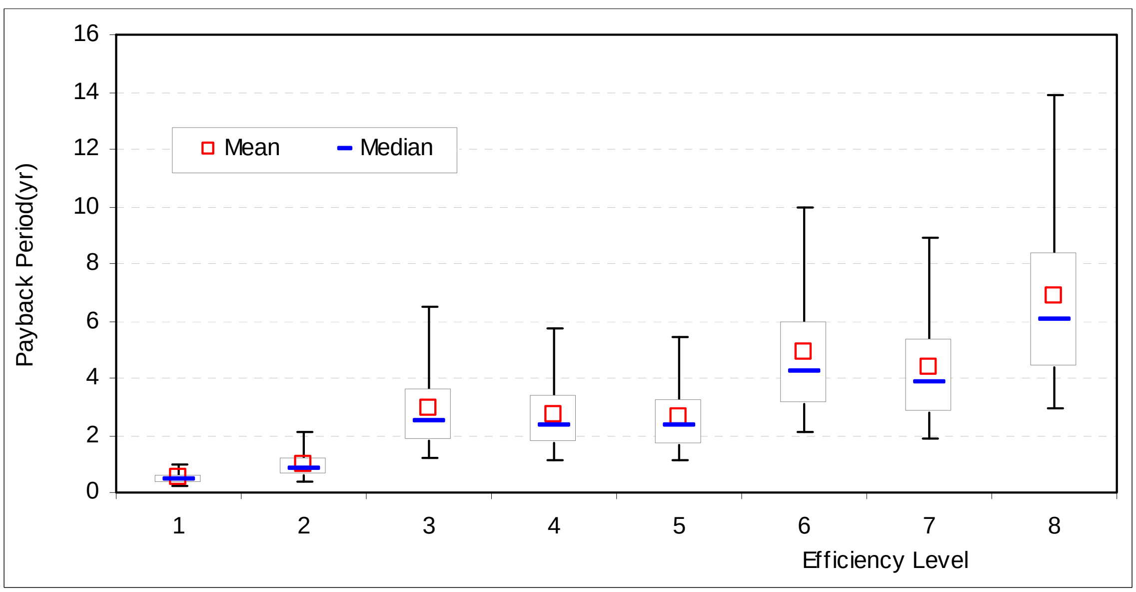

Figure 8.4.14 Product Class 10, Chest Freezers: Range of Payback Periods by Efficiency Level

8.4.3 Compact Refrigeration Products

The following subsections summarize results of LCC and PBP analyses for compact refrigeration products and present figures showing the distribution of LCCs in the base case for both product classes. Also presented are figures showing the distribution of LCC impacts and the distribution of PBPs for specific efficiency levels.

8.4.3.1 Summary of Results

Tables 8.4.6 and 8.4.7 show the results of LCC and PBP analyses for compact refrigerators and freezers. DOE determined the median and average values of PBPs by excluding those households not affected by a standard at each efficiency level.

Table 8.4.6 Product Class 11, Compact Refrigerators: Analytical Results

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *$2008*			Life-Cycle Cost Savings				Payback Period *years*	
	Average Product Cost	Average Annual Operating Cost	Average LCC	Average Savings *$2008*	% of Consumers who Experience			Median	Average
					Net Cost	No Impact	Net Benefit		
Baseline	166	33	325						
1 (10)	170	30	314	12	4.2	2.9	92.8	1.4	1.3
2 (15)	173	28	309	16	8.1	2.6	89.4	1.7	1.7
3 (20)	176	26	305	21	9.3	2.6	88.1	1.8	1.8
4 (25)	191	25	311	14	34.1	1.7	64.2	3.4	3.3
5 (30)	192	23	304	21	26.9	0.0	73.2	2.9	2.8
6 (35)	198	21	303	23	30.5	0.0	69.6	3.1	3.0
7 (40)	214	20	310	15	44.6	0.0	55.4	4.0	3.9
8 (45)	236	18	324	1	62.2	0.0	37.8	5.3	5.1

Table 8.4.7 Product Class 18, Compact Freezers: Analytical Results

Efficiency Level (*% less than baseline energy use*)	Life-Cycle Cost *$2008*			Life-Cycle Cost Savings				Payback Period *years*	
	Average Product Cost	Average Annual Operating Cost	Average LCC	Average Savings *$2008*	% of Consumers who Experience			Median	Average
					Net Cost	No Impact	Net Benefit		
Baseline	207	34	399						
1 (10)	214	30	388	11	9.6	5.0	85.4	2.4	2.3
2 (15)	218	29	382	16	11.7	0.0	88.3	2.5	2.5
3 (20)	248	27	403	-4	65.8	0.0	34.2	6.7	6.8
4 (25)	259	25	404	-5	65.6	0.0	34.4	6.7	6.7
5 (30)	281	24	416	-17	76.5	0.0	23.5	7.9	7.9
6 (35)	284	22	410	-11	69.3	0.0	30.7	7.1	7.1
7 (40)	299	20	415	-16	72.0	0.0	28.0	7.4	7.4
8 (45)	317	19	423	-24	75.9	0.0	24.1	7.8	7.8

8.4.3.2 Distributions of Impacts

Figure 8.4.15 presents a frequency chart showing the distribution of LCCs for the case of efficiency level 5 for compact refrigerators. The note, “Certainty is 71.04% from $0 to +Infinity,” means that 71.04 percent of households owning compact refrigerators either will not be affected or will have LCC savings under the standard level compared to the base case. DOE could generate a similar frequency chart for every efficiency level.

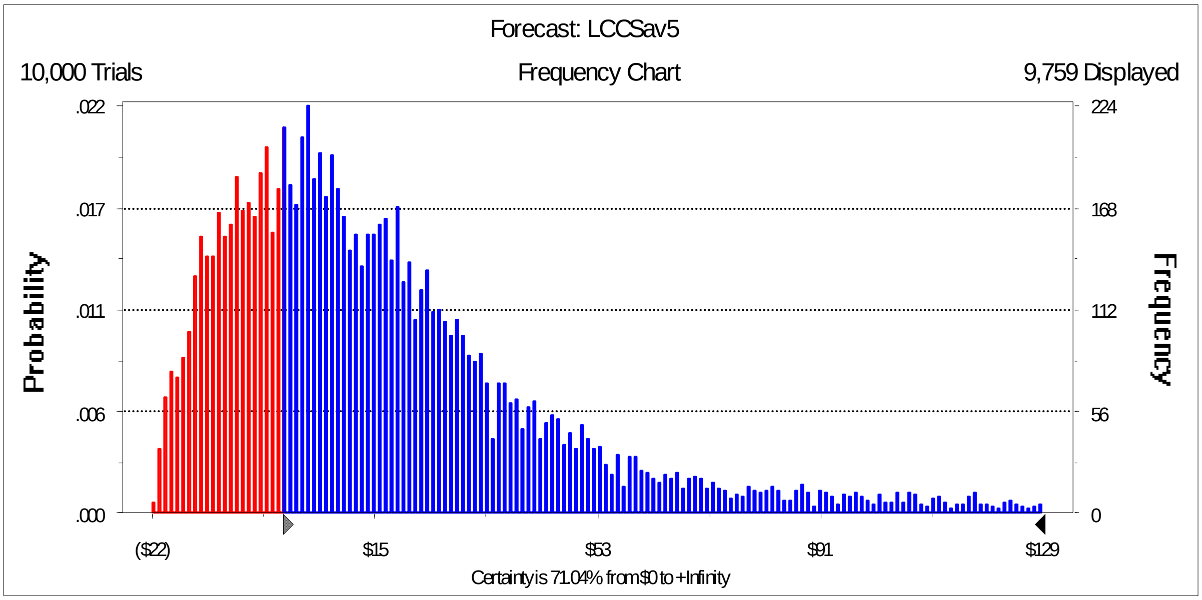

Figure 8.4.15 Product Class 11, Compact Refrigerators: Distribution of Life-Cycle Cost Impacts for Efficiency Level 5

Figure 8.4.16 presents a frequency chart showing the distribution of payback periods for efficiency level 5 for compact refrigerators. DOE could generate a similar frequency chart for every efficiency level within each product class.

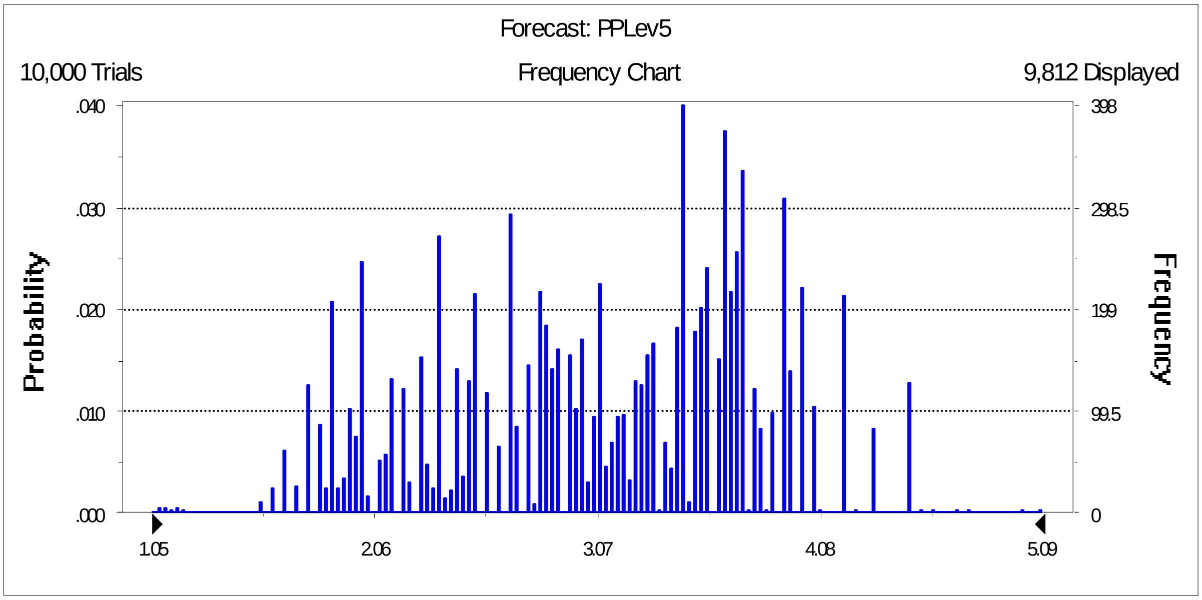

Figure 8.4.16 Product Class 11, Compact Refrigerators: Distribution of Payback Period for Efficiency Level 5

Figures 8.4.17 and 8.4.18 show the range of LCC savings for the standard levels considered for compact refrigerators and freezers. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have LCC savings that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average LCC savings for each efficiency level. Figures 8.4.19 and 8.4.20 show the range of PBPs for each efficiency level considered.

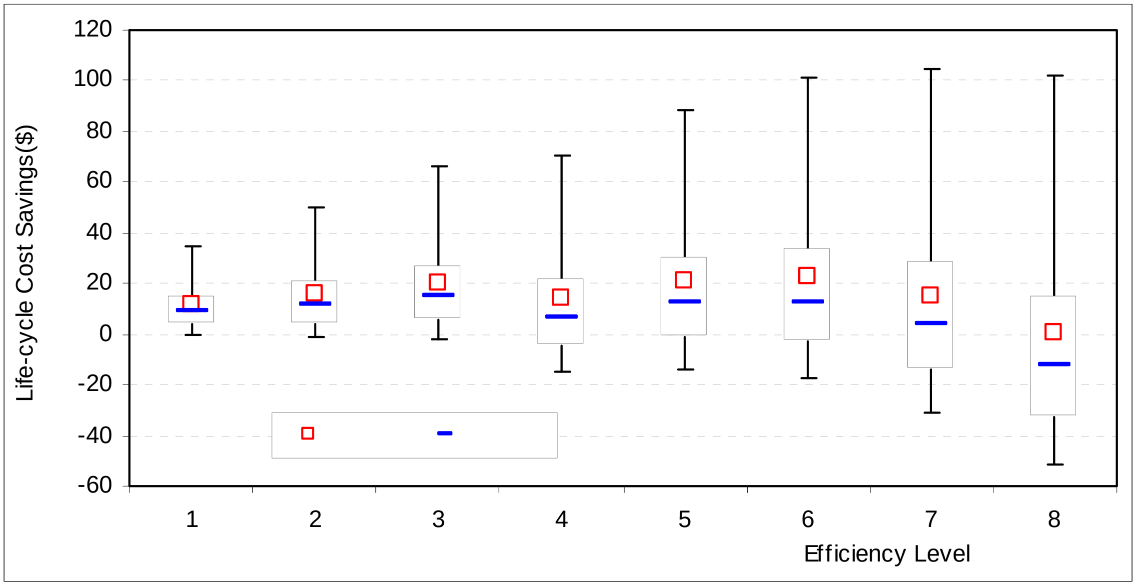

Figure 8.4.17 Product Class 11, Compact Refrigerators: Range of Life-Cycle Cost Savings by Efficiency Level

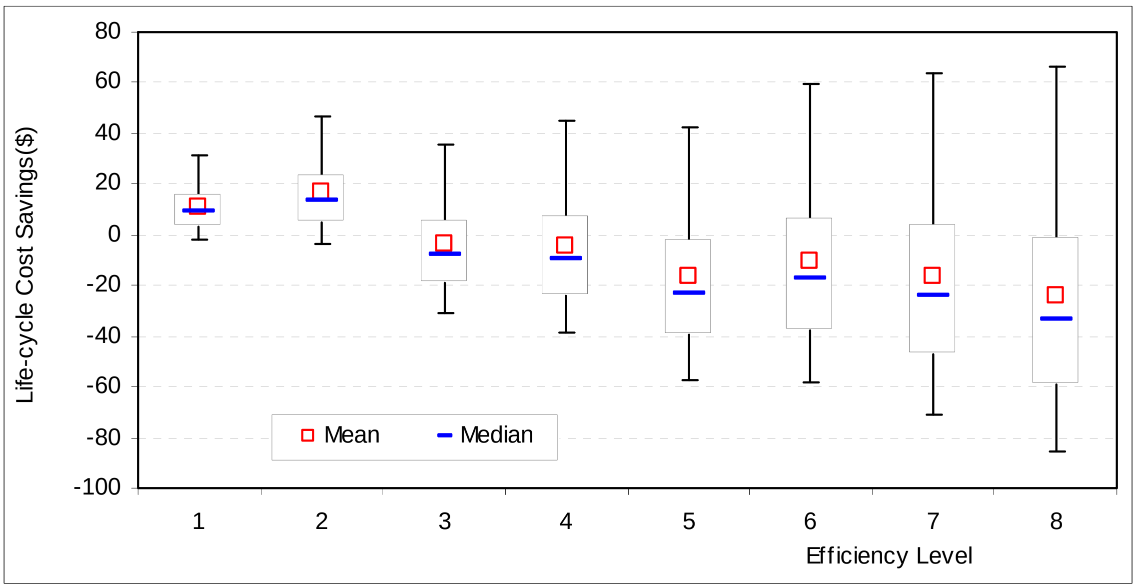

Figure 8.4.18 Product Class 18, Compact Freezers: Range of Life-Cycle Cost Savings by Efficiency Level

Figures 8.4.19 and 8.4.20 show the range of PBPs for the standard levels considered for compact refrigerators and freezers. For each standard level, the top and bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median: 50 percent of the households have PBPs that exceed this value. The horizontal lines above and below the box indicate the 95th and 5th percentiles, respectively. The small box shows the average PBP for each efficiency level.

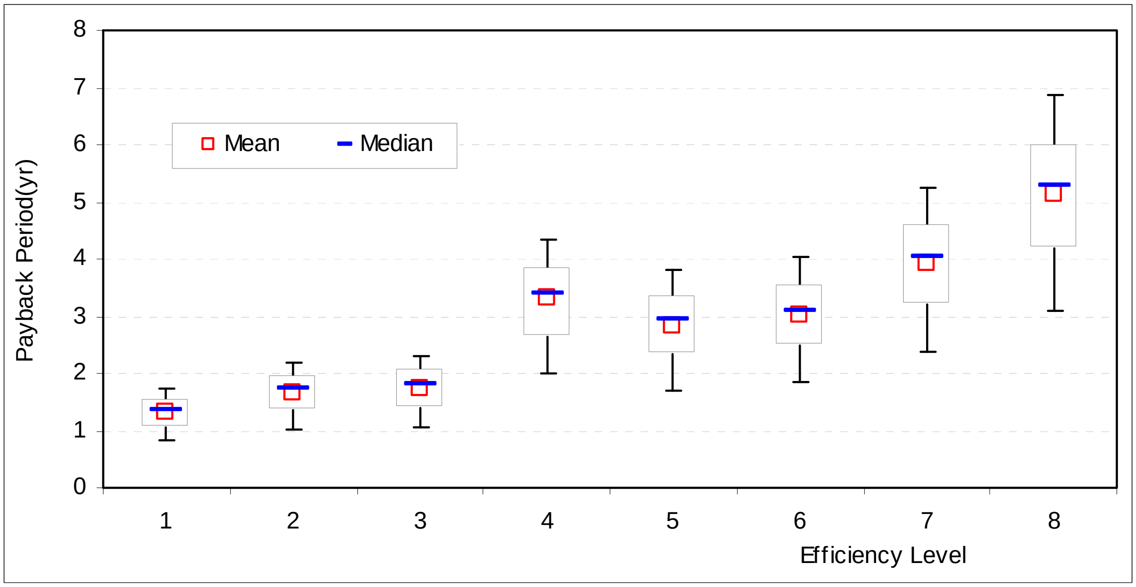

Figure 8.4.19 Product Class 11, Compact Refrigerators: Range of Payback Periods by Efficiency Level

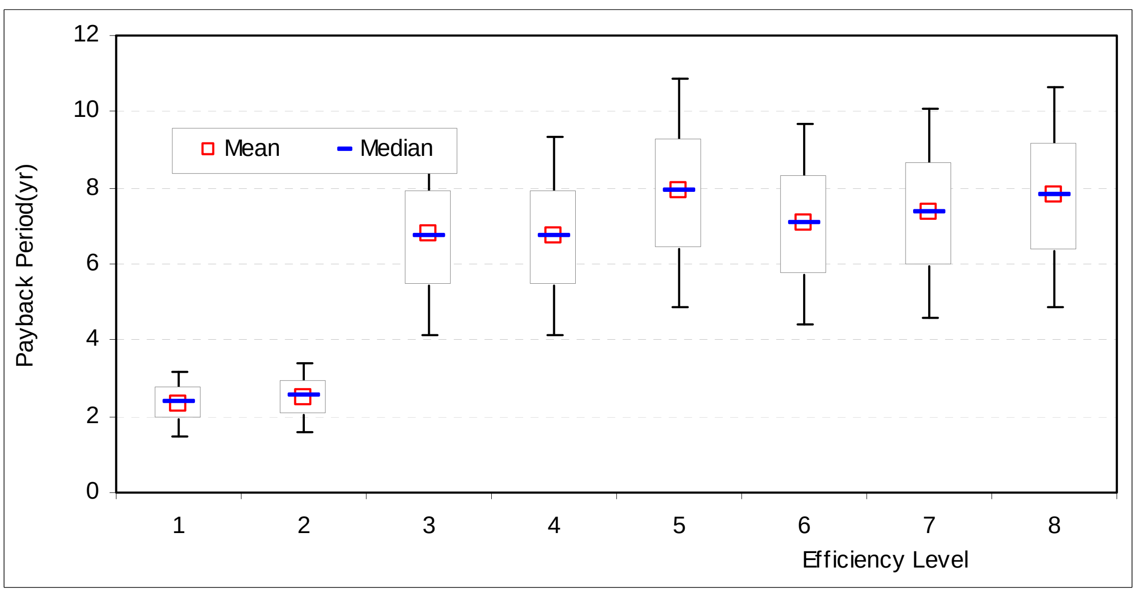

Figure 8.4.20 Product Class 18, Compact Freezers: Range of Payback Periods by Efficiency Level

8.5 REBUTTABLE PAYBACK PERIOD

DOE presents rebuttable PBPs to provide information for considering the legally established rebuttable presumption that an energy efficiency standard is economically justified if the additional product costs attributed to the standard are less than three times the value of the first-year savings in energy costs. (42 U.S.C. §6295 (o)(2)(B)(iii))

8.5.1 Metric

The basic equation for rebuttable PBP is the same as that shown in section 8.3, Inputs to Analysis of Payback Period. Unlike the analyses described in sections 8.2 and 8.3, however, the rebuttable PBP is not based on the use of household samples and probability distributions. Rather, it is based on discrete, single-point values. For example, although DOE uses a probability distribution of regional energy prices in the analysis of payback period, it uses only the national average energy price from the probability distribution to determine the rebuttable PBP.

Other than the use of single-point values, the most notable difference between the distribution PBP and the rebuttable PBP is the latter's reliance on the DOE test procedure to determine a product's annual energy consumption.

8.5.2 Inputs to Rebuttable Payback Period Analysis

The following were the key inputs that DOE used in determining rebuttable PBP.

- Incremental manufacturing costs, markup, baseline retail price, sales tax, and installation costs were all based on single-point values derived from, or used as inputs to, the distributional LCC and PBP analysis.
- Annual energy consumption was based on results of the proposed DOE test procedure for a product with the average adjusted volume from the LCC and PBP analysis.
- Energy prices were based on average values for the year that new standards are assumed to take effect (2014).

An average discount rate or lifetime is not required in calculating the rebuttable PBP.

8.5.3 Results of Analysis

DOE calculated rebuttable PBPs for each standard level relative to the purchase and operating costs of an average baseline product.

Table 8.5.1 presents the rebuttable PBPs for each standard-size refrigerator product class that DOE analyzed for the LCC and PBP analysis.

Table 8.5.1 Standard-Size Refrigerator-Freezers: Rebuttable Payback Periods

Product Class 3: Top-Mount Refrigerator-Freezer		**Product Class 5: Bottom-Mount Refrigerator-Freezer**		**Product Class 7: Side-by-Side Refrigerator-Freezer with TTD***	
Efficiency Level (*% less than baseline energy use*)	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***
Baseline	-	Baseline	-	Baseline	-
1 (10)	0.7	1 (10)	0.3	1 (10)	1.4
2 (15)	1.0	2 (15)	0.6	2 (15)	1.6
3 (20)	1.6	3 (20)	1.0	3 (20)	3.4
4 (25)	2.6	4 (25)	1.8	4 (25)	5.4
5 (30)	3.9	5 (30)	2.2	5 (30)	7.1
6 (35)	5.6	6 (35)	4.6	6 (35)	8.3
7 (40)	7.4	7 (40)	6.6	7 (40)	9.9
8 (45)	8.7	8 (45)	8.1	-	-

*Through-the-door ice service.

Table 8.5.2 presents the rebuttable PBPs for each standard-size freezer product class that DOE analyzed for the LCC and PBP analysis.

Table 8.5.2 Standard-Size Freezers: Rebuttable Payback Periods

Product Class 9: Upright Freezer		**Product Class 10: Chest Freezer**	
Efficiency Level (*% less than baseline energy use*)	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***
Baseline	-	Baseline	-
1 (10)	1.0	1 (10)	0.6
2 (15)	1.2	2 (15)	1.0
3 (20)	1.1	3 (20)	3.0
4 (25)	1.8	4 (25)	3.0
5 (30)	2.5	5 (30)	2.9
6 (35)	3.5	6 (35)	5.4
7 (40)	5.0	7 (40)	4.9
8 (45)	7.0	8 (45)	7.7

Table 8.5.3 presents the rebuttable PBPs for each compact refrigeration product class that DOE analyzed for the LCC and PBP analysis.

Table 8.5.3 Compact Refrigerators and Freezers: Rebuttable Payback Periods

Product Class 11: Compact Refrigerator		**Product Class 18: Compact Freezer**	
Efficiency Level (*% less than baseline energy use*)	**PBP *years***	**Efficiency Level (*% less than baseline energy use*)**	**PBP *years***
Baseline	-	Baseline	-
1 (10)	1.3	1 (10)	2.1
2 (15)	1.7	2 (15)	2.3
3 (20)	1.8	3 (20)	6.0
4 (25)	3.3	4 (25)	6.0
5 (30)	2.9	5 (30)	7.0
6 (35)	3.0	6 (35)	6.3
7 (40)	3.9	7 (40)	6.6
8 (45)	5.1	8 (45)	7.0

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APPENDIX 8-A. USER INSTRUCTIONS FOR LCC AND PBP SPREADSHEETS

TABLE OF CONTENTS

APPENDIX 8-A. USER INSTRUCTIONS FOR LCC AND PBP SPREADSHEETS

8-A.1 INTRODUCTION

It is possible to examine and reproduce the detailed results of the life-cycle cost (LCC) and payback period (PBP) analyses using Microsoft Excel spreadsheets available on the U.S. Department of Energy's website at: http://www.eere.energy.gov/buildings/appliance_standards/. To fully execute the spreadsheets requires both Microsoft Excel and Crystal Ball software. Both applications are commercially available. Crystal Ball is available at: http://www.decisioneering.com.

The seven spreadsheets posted on the DOE website represent the latest versions and have been tested with Microsoft Excel 2003.

8-A.1.1 Standard Size Refrigerator-Freezers and Freezers

The Standard Size Refrigerator-Freezers and Freezers LCC and PBP spreadsheets or workbooks consist of the following worksheets:

LCC Summary	Contains the input selections and a summary table of energy use, operating costs, LCC, and Payback. This worksheet also works as an interface between user inputs and the rest of the worksheets — do not modify this sheet.
RECS Households	For each RECS household being sampled, contains the equipment usage data, along with product characteristics (i.e., size, volume, product age) and household characteristics (e.g., Census division, income).
RECS UAF	Contains the unit adjustment factor calculation which converts tested energy consumption into field energy consumption
Base Case Eff Dist	Contains market efficiency distribution in the year the standard takes effect
Equipment Price	Contains manufacturer price data for the considered design options. Also includes the manufacturer and retail mark-ups, sales tax.
Energy Use	Contains unit energy use data (tested and field)
Energy Price	Contains regional electricity prices for the reference year.

Energy Price Trend	Contains the electricity price trends for the reference, high, and low economic growth scenarios based on AEO 2009.
Discount Rate	Contains data from which an average discount rate and a distribution of discount rates are determined.
Lifetime	Contains the survival function and average lifetime in years.
Standards	Contains past and existing standards by product class along with historical trends of energy consumption prior to first standards.
AV Equations	Contains average relation between volume and adjusted volume by product class.
ESAF	Contains efficiency standard adjustment factor.
UAF Range	Contains parameters allowing for the sample selection, and minimum and maximum UAF assignments.
EStarModel	Contains Energy Star model assigning energy star to households based on income.

8-A.1.2 Compact Refrigerators and Compact Freezers

The Compact Refrigerators and Compact Freezers LCC and PBP spreadsheet or workbook consists of the following worksheets:

LCC Summary	Contains the input selections and a summary table of energy use, operating costs, LCC, and Payback. This worksheet also works as an interface between user inputs and the rest of the worksheets — do not modify this sheet.
Base Case Eff Dist	Contains market efficiency distribution in the year the standard takes effect.
Division	Contains number of customers for residential and commercial sector by region.
Equipment Price	Contains manufacturer price data for the considered design options. Also includes the manufacturer and retail mark-ups, sales tax.
Energy Use	Contains unit energy use data (tested and field)
Energy Price	Contains regional electricity prices for the reference year.

Energy Price Trend	Contains the electricity price trends for the reference, high, and low economic growth scenarios based on AEO 2009.
Discount Rate	Contains data from which an average discount rate and a distribution of discount rates are determined.
Lifetime	Contains the survival function and average lifetime in years.
AV Equations	Contains average relation between volume and adjusted volume by product class.

8-A.2 BASIC INSTRUCTIONS

Basic instructions for operating the LCC spreadsheets are as follows:

1. Once you have downloaded the LCC file from the Web, open the file using Excel. At the bottom, click on the tab for sheet ‘LCC Summary’.

2. Use Excel’s “View/Zoom” commands at the top menu bar to change the size of the display to make it fit your monitor.

3. The user interacts with the spreadsheet by clicking choices or entering data using the graphical interface that comes with the spreadsheet. Select choices from the various inputs listed under "User Options" heading.

4. Under the "User Options" heading, select choices from the selection buttons and boxes for the following: (1) type of calculation (Sample or Crystal Ball®), (2) energy price Trend, (3) start year, and (4) efficiency market share scenario. By overwriting the code in the LCC summary sheet, a new discount rate or lifetime can be entered if a value other than the default value is wanted . The Department does not recommend saving the spreadsheet after the code is changed.

5. To change inputs listed under "User Input", select the input you wish to change by either clicking on the appropriate button or selecting the appropriate input from the input box.

6. This spreadsheet gives the user two types of calculation methods:
   a. If the "Sample Calc" is selected, then all calculations are performed for single input values, usually an average. The new results are shown on the same sheet as soon as the new values are entered.

   b. Alternately, if the "CB Calculation" is selected, the spreadsheet generates results that are distributions. Some of the inputs are also distributions. The results from the LCC distribution are shown as single values and refer only to the results from the last

Monte Carlo sample and are therefore not meaningful. To run the distribution version of the spreadsheet, the Microsoft Excel® add-in software called Crystal Ball® must be enabled.

To produce sensitivity results using Crystal Ball, simply select Run from the Run menu (on the menu bar). To make basic changes in the run sequence, including altering the number of trials, select Run Preferences from the Run menu. After each simulation run, the user needs to select Reset (also from the Run menu) before Run can be selected again. Once Crystal Ball has completed its run sequence it will produce a series of distributions. Using the menu bars on the distribution results, it is possible to obtain further statistical information. The time taken to complete a run sequence can be reduced by minimizing the Crystal Ball window in Microsoft Excel. A step-by-step summary of the procedure for running a distribution analysis is outlined below:

1. Find the Crystal Ball toolbar (at top of screen)

2. Click on Run from the menu bar

3. Select Run Preferences and choose from the following choices:
   a. Monte Carlo[a]
   b. Latin Hypercube (recommended)
   c. Initial seed choices and whether you want it to be constant between runs
   d. Select number of Monte Carlo Trials (DOE suggests 10,000).

4. To run the simulation, follow the following sequence (on the Crystal Ball toolbar)

   Run
   Reset
   Run

5. Now wait until the program informs you that the simulation is completed.

The following instructions are provided to view the output generated by Crystal Ball.

1. After the simulation has finished, to see the distribution charts generated, click on the Windows tab bar that is labeled Crystal Ball.

2. The life-cycle cost savings and payback periods are defined as Forecast cells. The frequency charts display the results of the simulations, or trials, performed by Crystal Ball. Click on any chart to bring it into view. The charts show the low and high endpoints of the forecasts. The View selection on the Crystal Ball toolbar can be used to specify whether you want cumulative or frequency plots shown.

[a] Because of the nature of the program, there is some variation in results due to random sampling when Monte Carlo or Latin Hypercube sampling is used.

3. To calculate the probability that a particular value of LCC savings will occur, either type 0 in the box by the left arrow, or move the arrow key with the cursor to 0 on the scale. The value in the Certainty box shows the likelihood that the LCC savings will occur. To calculate the certainty of payback period being below a certain number of years, choose that value as the high endpoint.
4. To generate a printout report, select Create Report from the Run menu. The toolbar choice of Forecast Windows allows you to select the charts and statistics in which you are interested. For further information on Crystal Ball outputs, please refer to Understanding the Forecast Chart in the Crystal Ball manual.

APPENDIX 8-B. UNCERTAINTY AND VARIABILITY

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX 8-B. UNCERTAINTY AND VARIABILITY

8-B.1 INTRODUCTION

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

Thorough analysis involves accounting for uncertainty and variability. While the simplest analysis involves a single numerical value for each quantity in a calculation, arguments can arise about what the appropriate value is for each quantity. Explicit analysis of uncertainty and variability is intended to provide more complete information to the decision-making process.

8-B.2 UNCERTAINTY

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

8-B.3 VARIABILITY

Variability means that different applications or situations produce different numerical values when calculating a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, the number of hours an air conditioner is operated by a household depends upon the specific circumstances and behaviors of the occupants (e.g., number of persons, personal habits about how comfortable the person wants to be, etc.). Variability makes specifying an appropriate population value more difficult in as much as any one value may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., hours of use) to other variables that are better known or easier to forecast (e.g., persons per household).

8-B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to uncertainty and variability:

- scenario analysis, and
- probability analysis.

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

The advantages of scenario analysis are that each calculation is simple; a range of estimates is used; and crossover points can be identified. (An example of a crossover point is the energy rate above which the life-cycle cost is reduced, holding all other inputs constant. That is, the crossover point is the energy rate at which the consumer achieves savings in operating expense that more than compensate for the increased purchase expense.) The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

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

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

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

8-B.5 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and payback period (PBP) analyses, the Department used Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in, to conduct probability analyses. The probability analyses used Monte Carlo simulation and probability distributions.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a model. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that either a 1, 2, 3, 4, 5, or 6 will come up, but you do not know which for any particular roll. It's the same with the variables that have a known range of values but an uncertain value for any particular time or event (e.g., equipment lifetime, discount rate, and installation cost).

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include:

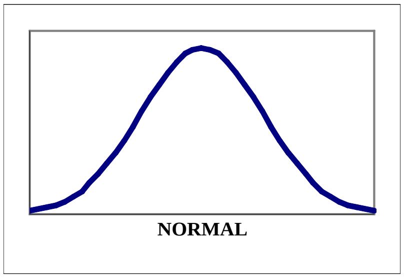

Figure 8-B.5.1 Normal Probability Distribution

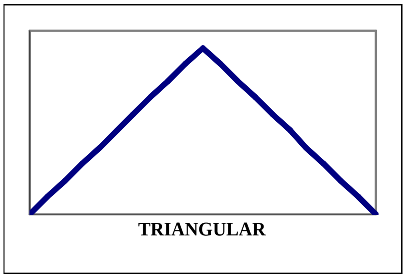

Figure 8-B.5.2 Triangular Probability Distribution

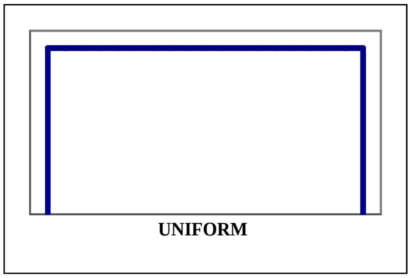

Figure 8-B.5.3 Uniform Probability Distribution

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. Crystal Ball simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. During a single trial, Crystal Ball randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the spreadsheet.

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include:

APPENDIX 8-C. CONSUMER RETAIL PRICE DISTRIBUTIONS FOR BASELINE REFRIGERATOR-FREEZERS AND FREEZERS

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX 8-C. CONSUMER RETAIL PRICE DISTRIBUTIONS FOR BASELINE REFRIGERATOR-FREEZERS AND FREEZERS

8-C.1 INTRODUCTION

DOE's engineering analysis did not attempt to estimate the manufacturing cost for baseline models. Instead, it developed incremental increases in manufacturer selling price associated with increases in efficiency levels. This approach required DOE to estimate retail prices for the baseline model in each product class.

DOE drew upon proprietary retail price data collected by The NPD Group.[1] These data reflect retail prices and sales at a large number of retail outlets in the United States (including over 50 percent of retail sales), and include information regarding model number, refrigerated volume, configuration of doors and ice-making, and whether the unit is an ENERGY STAR product. The data include enough information to assign each model to the correct product class. DOE developed a sales-weighted price distribution for non-ENERGY STAR appliances in each product class from this data. DOE grouped models by selling price in bins of varying width (generally $25 for compact products and $50 to $100 for standard-sized products) in order to balance the accuracy and usability of the distributions. These distributions are shown in the following section.

DOE assumed that prices for non-ENERGY STAR models are a reasonable approximation of prices for the baseline models. These models may be "baseline" in efficiency, but span a wide range of other features and materials, and therefore have a broad distribution of prices. DOE chose not to develop volume-dependent baseline retail prices because the data did not show a strong relationship between volume and retail price. The price distributions within most volume ranges and product classes are almost as broad as the volume-independent distributions DOE chose to use, and regression analysis indicated very weak dependence of average price on volume.

8-C.2 DISTRIBUTION HISTOGRAMS

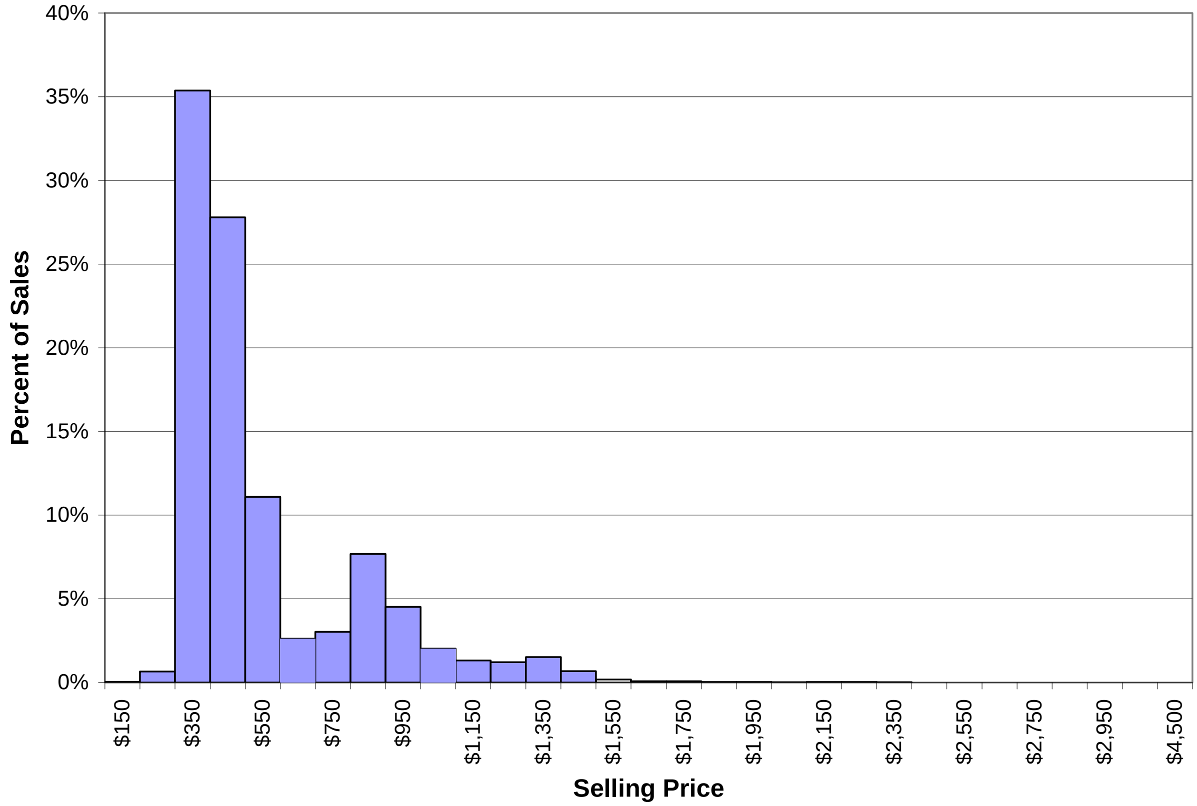

Figure 8-C.2.1 Baseline Retail Price Distribution for Product Class 3 (Standard-sized Top-mount Refrigerator-Freezers without Through-the-door Service)

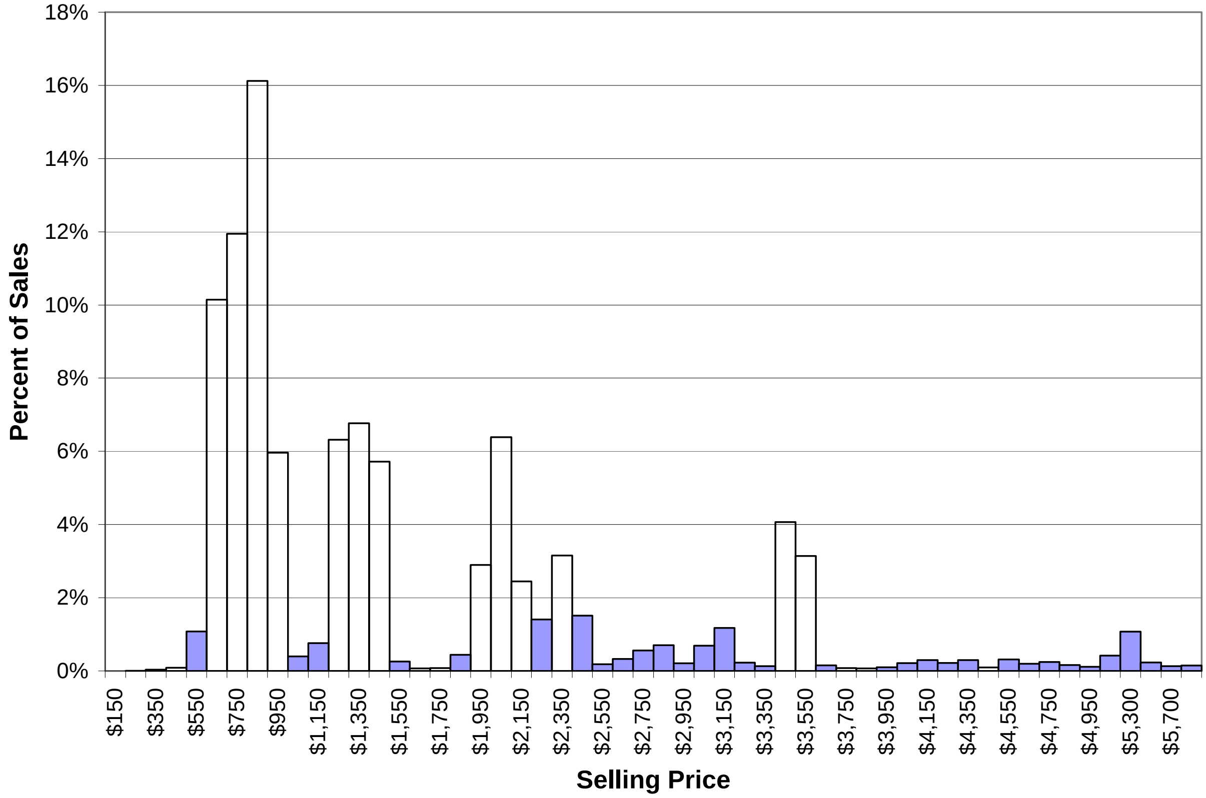

Figure 8-C.2.2 Baseline Retail Price Distribution for Product Class 5 (Standard-sized Bottom-mount Refrigerator-Freezers without Through-the-door Service)

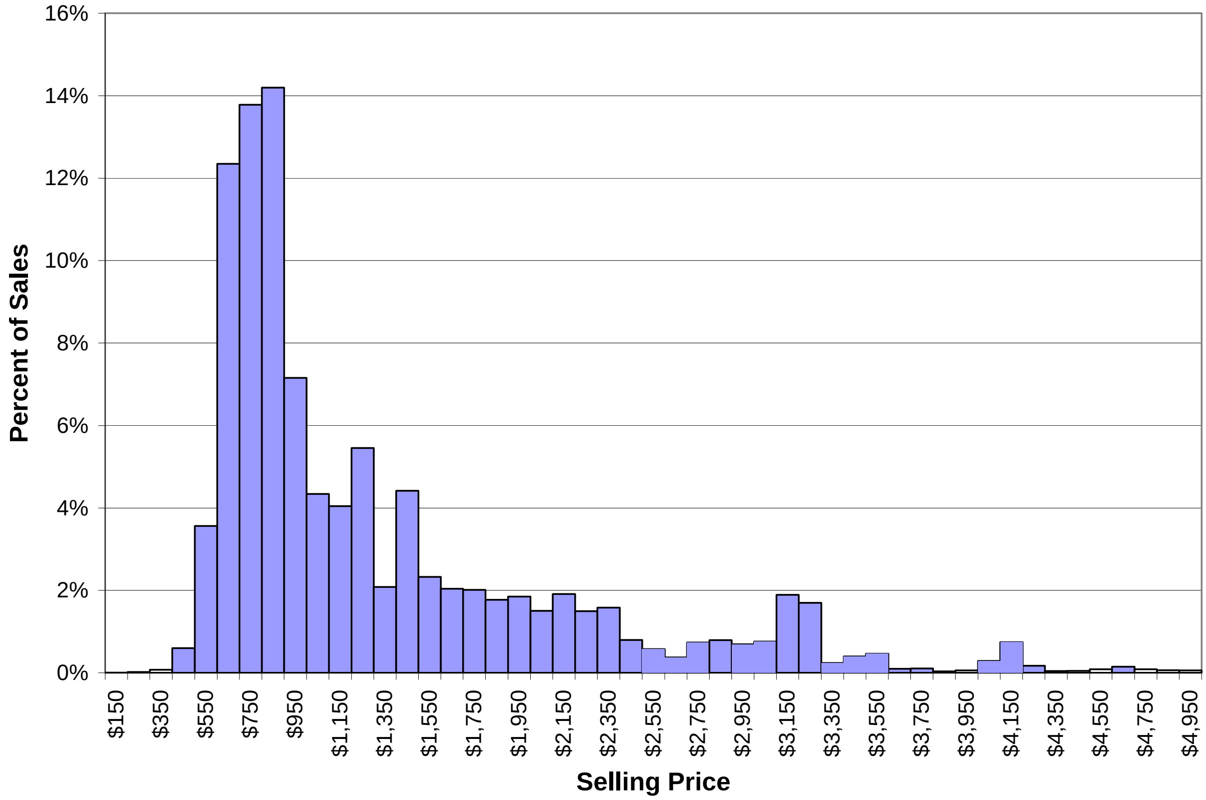

Figure 8-C.2.3 Baseline Retail Price Distribution for Product Class 7 (Standard-sized Side-mount Refrigerator-Freezers with Through-the-door Service)

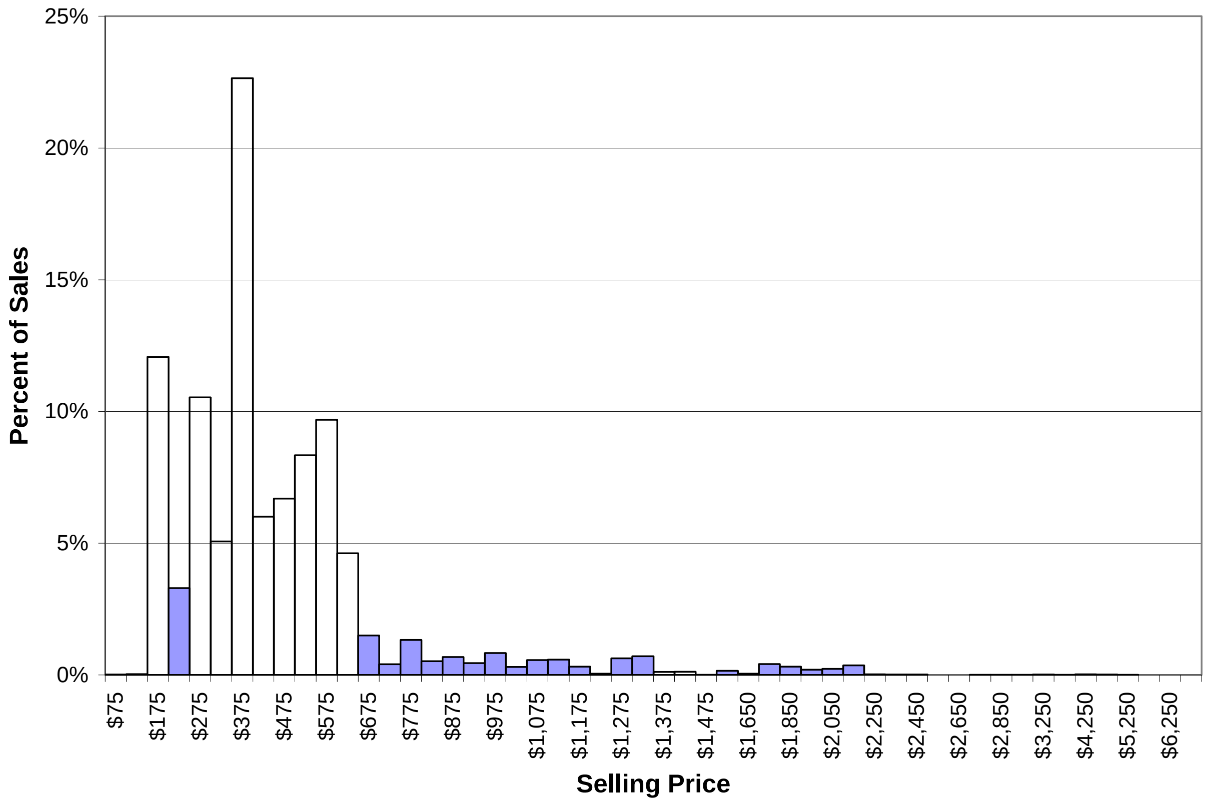

Figure 8-C.2.4 Baseline Retail Price Distribution for Product Class 9 (Standard-sized Upright Freezers)

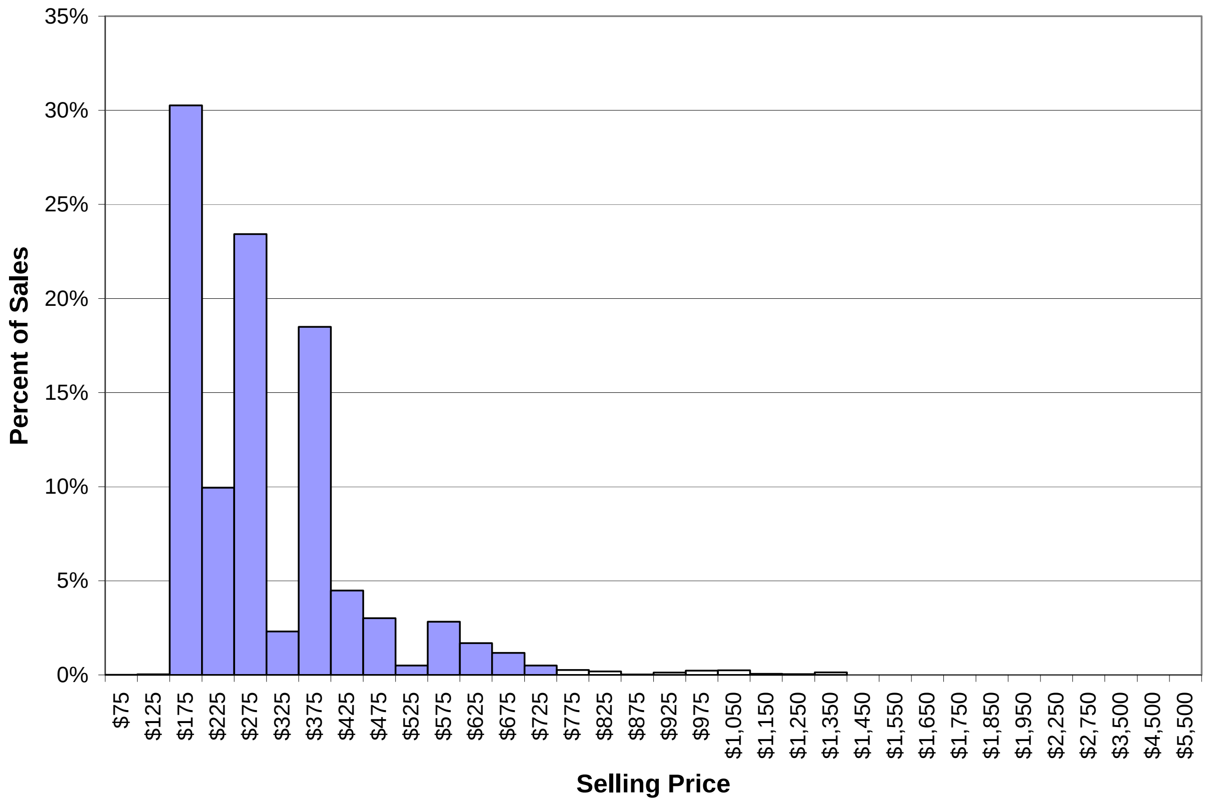

Figure 8-C.2.5 Baseline Retail Price Distribution for Product Class 10 (Standard-sized Chest Freezers)

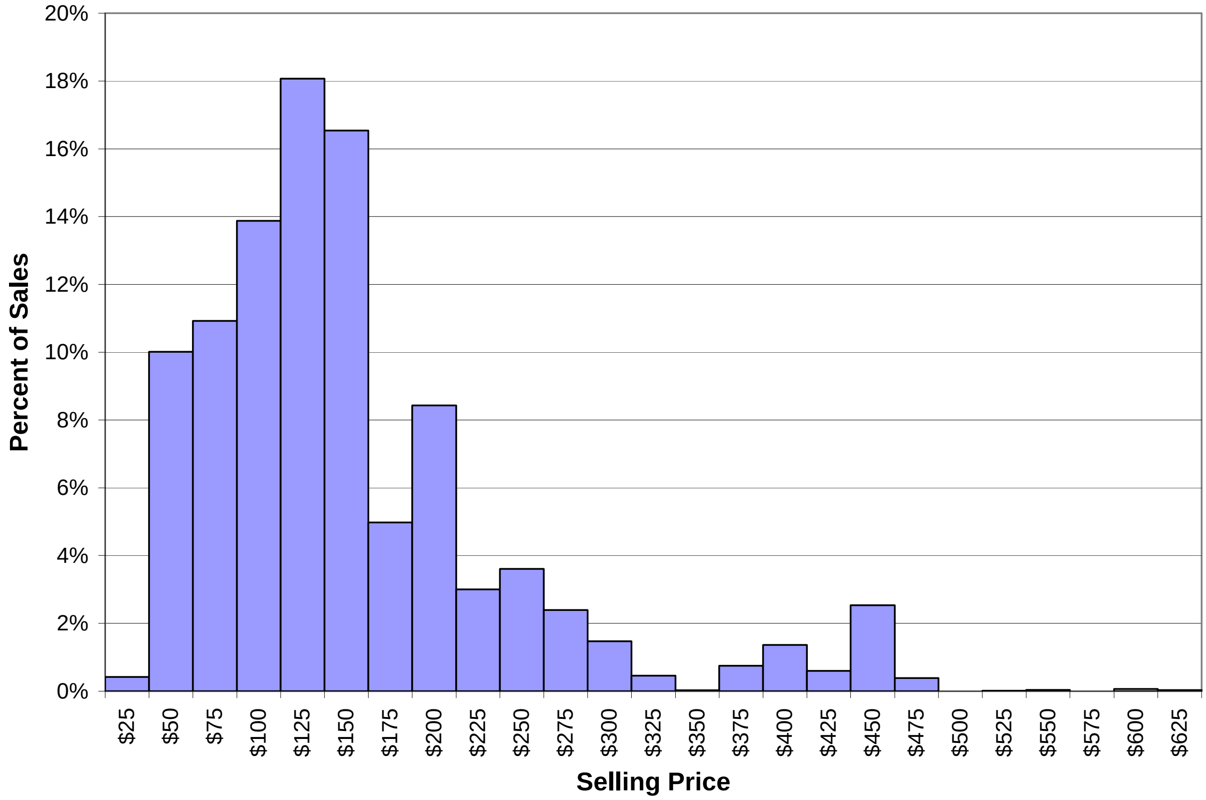

Figure 8-C.2.6 Baseline Retail Price Distribution for Product Class 11 (Compact Refrigerators)

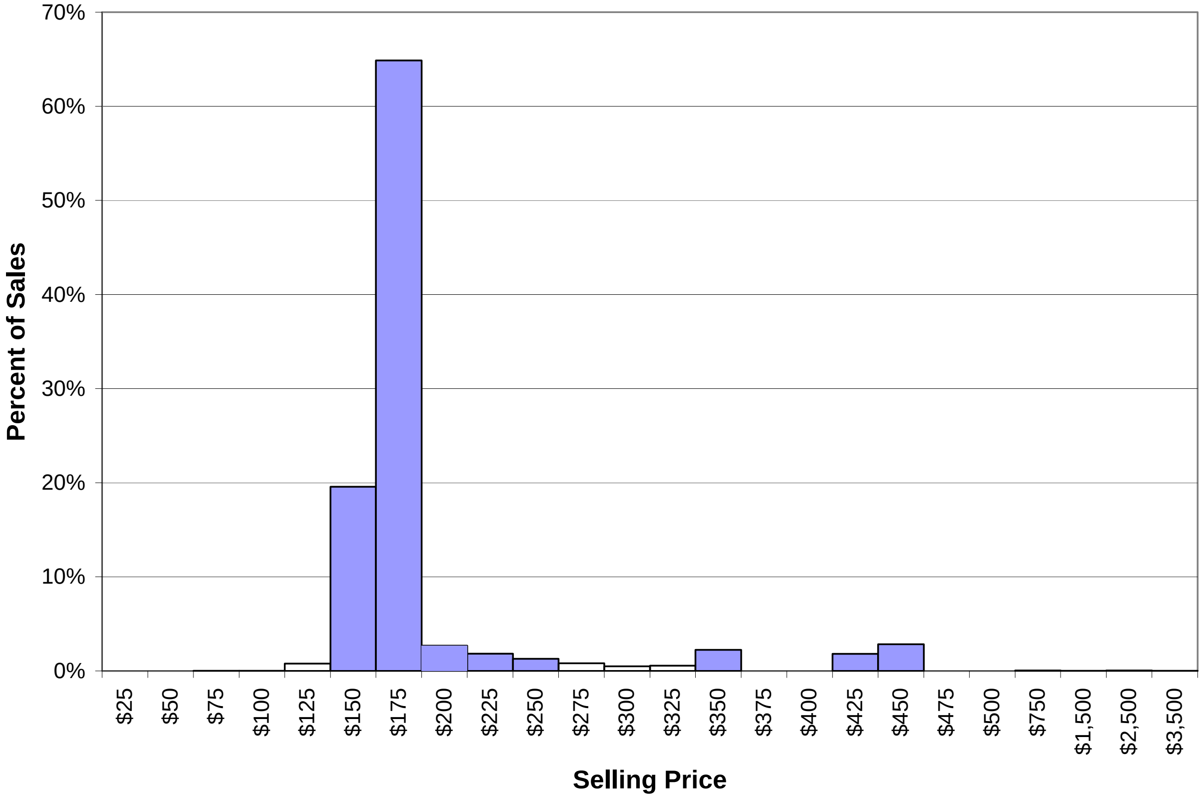

Figure 8-C.2.7 Baseline Retail Price Distribution for Product Class 18 (Compact Freezers)

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APPENDIX 8-D. HOUSEHOLD DISCOUNT RATE DISTRIBUTIONS

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX 8-D. HOUSEHOLD DISCOUNT RATE DISTRIBUTIONS

8-D.1 INTRODUCTION

DOE derived discount rates for the LCC analysis using data on interest or return rates for various types of debt and equity. To account for variation among households in rates for each of the types, DOE sampled a rate for each household from a distribution of rates for each debt and equity type. This appendix describes the distributions used.

8-D.2 DISTRIBUTION OF MORTGAGE INTEREST RATES

Figure 8-D.2.1 shows the distribution of real interest rates for new home mortgages. The data source DOE used for mortgage interest rates is the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1989, 1992, 1995, 1998, 2001, 2004 and 2007.[1] Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

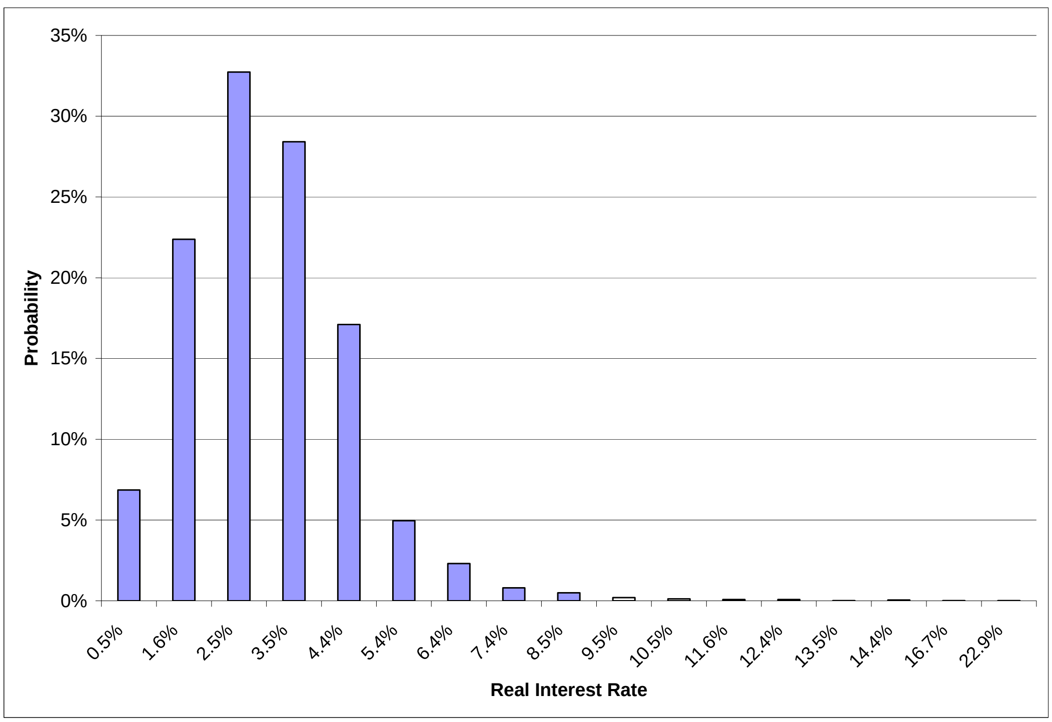

Figure 8-D.2.1 Distribution of New Home Mortgage Interest Rates

8-D.3 DISTRIBUTION OF RATES FOR TYPES OF DEBT AND EQUITY USED TO FINANCE REPLACEMENT FURNACES

Figure 8-D.3.1 through Figure 8-D.3.5 show the distribution of real interest rates for different types of debt used to finance replacement furnaces. The data source for the interest rates for home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1989, 1992, 1995, 1998, 2001, 2004, and 2007.[1] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year. For home equity loans, DOE calculated effective interest rates in a similar manner as for mortgage rates, since interest on such loans is tax deductible.

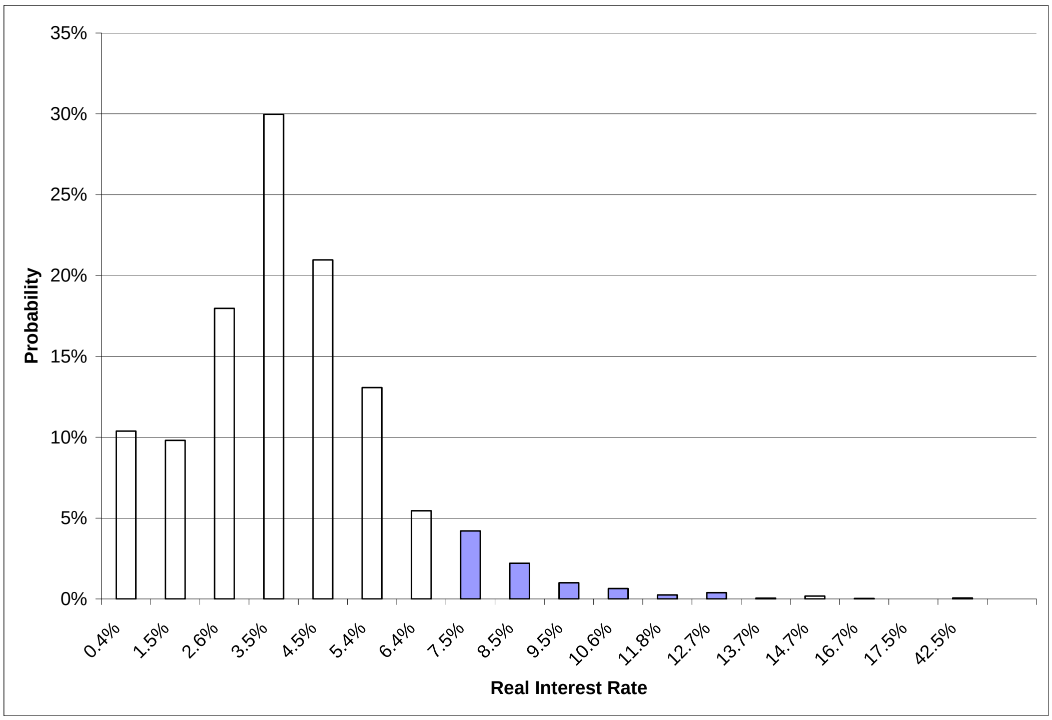

Figure 8-D.3.1 Distribution of Home Equity Loan Interest Rates

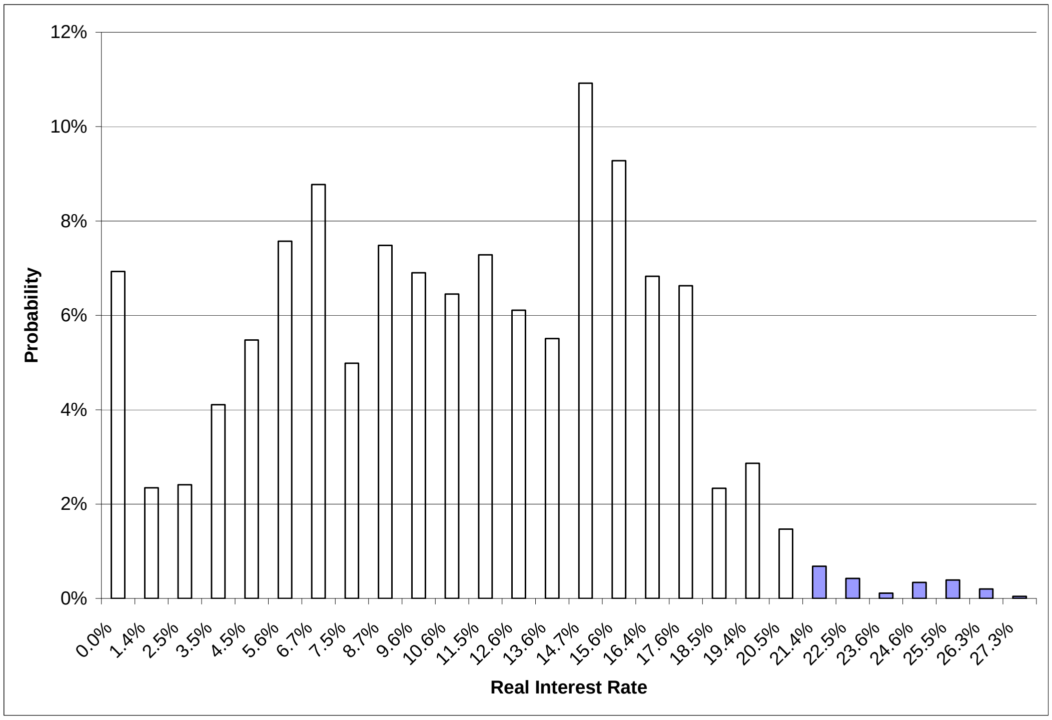

Figure 8-D.3.2 Distribution of Credit Card Interest Rates

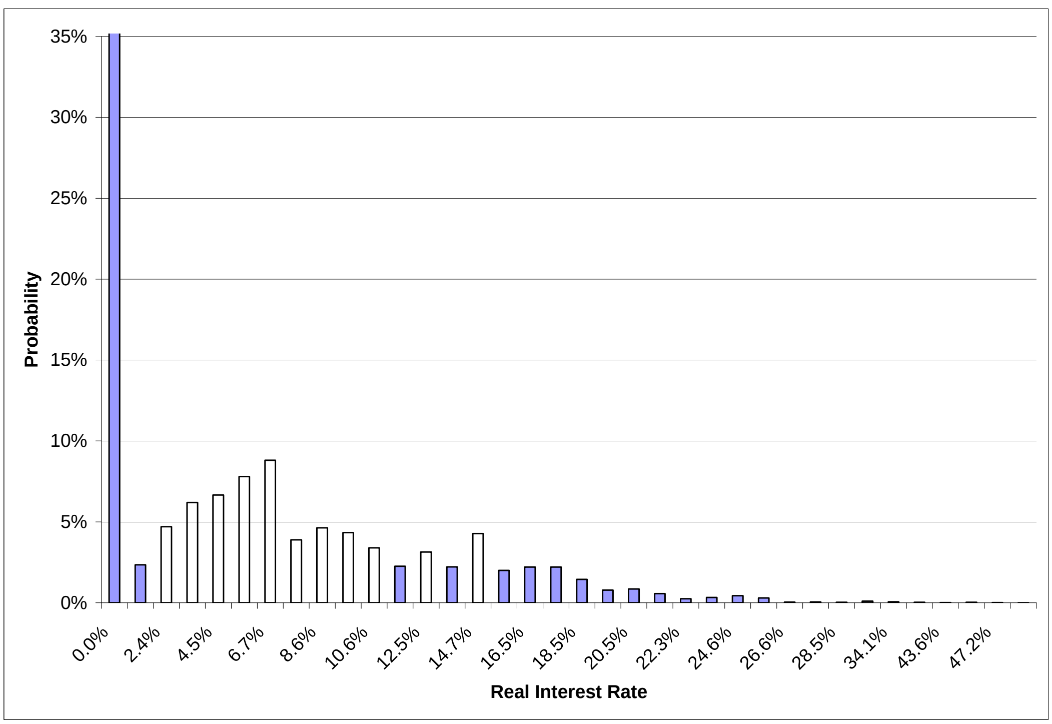

Figure 8-D.3.3 Distribution of Installment Loan Interest Rates

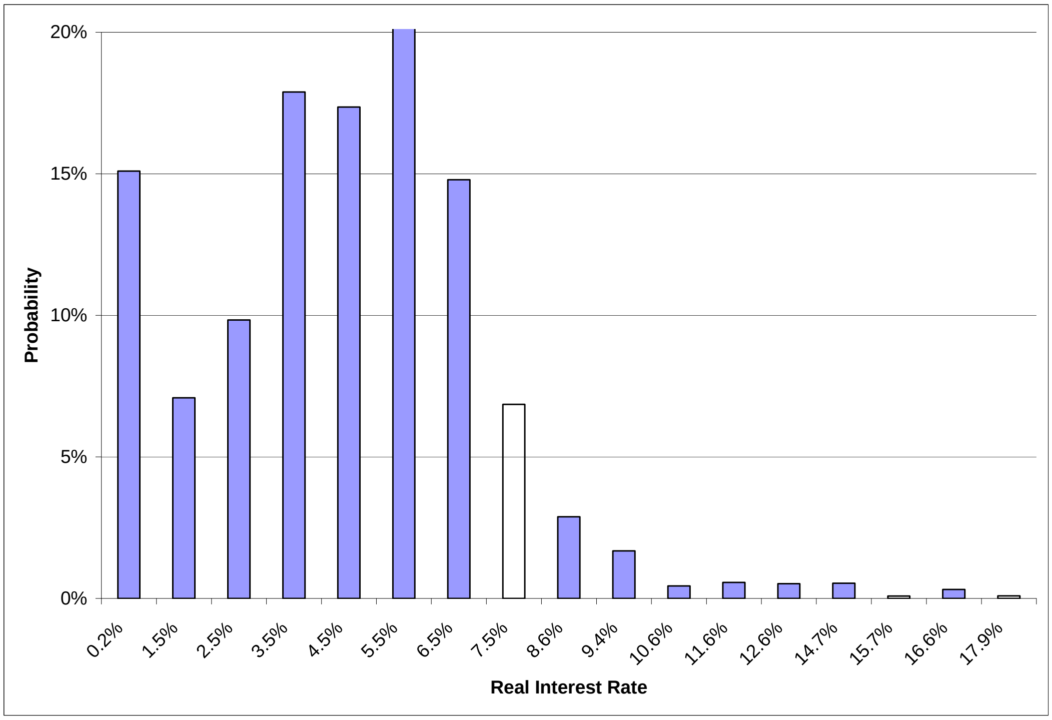

Figure 8-D.3.4 Distribution of Other Residence Loan Interest Rates

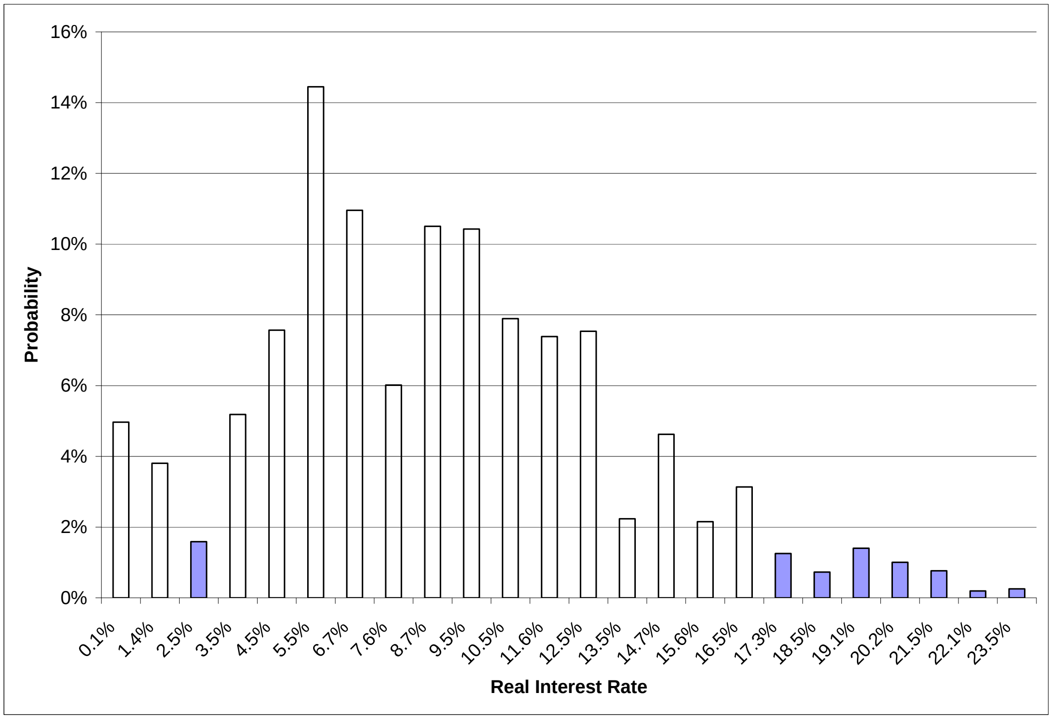

Figure 8-D.3.5 Distribution of Other Lines of Credit Loan Interest Rates

8-D.4 DISTRIBUTION OF RATES FOR TYPES OF EQUITY USED TO FINANCE REPLACEMENT FURNACES

Figure 8-D.4.1 through Figure 8-D.4.6 show the distribution of real interest rates for different types of equity used to finance replacement furnaces. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so the Department derived data for these classes from national-level historical data. The interest rates associated with certificates of deposit (CDs),[2] savings bonds,[3] and bonds (AAA corporate bonds)[4] are from Federal Reserve Board time-series data covering 1977–2007. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data covering 1984–2007.[5] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500 in the 1977–2007 period.[6] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year of the 1977–2007 period. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

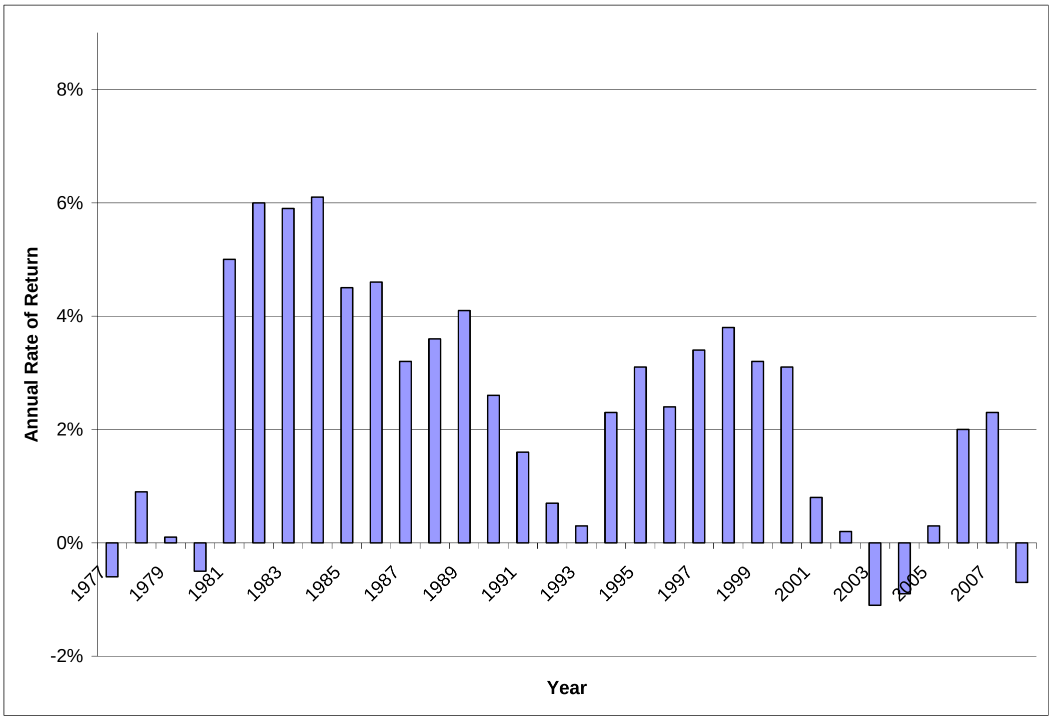

Figure 8-D.4.1 Distribution of Annual Rate of Return on CD's

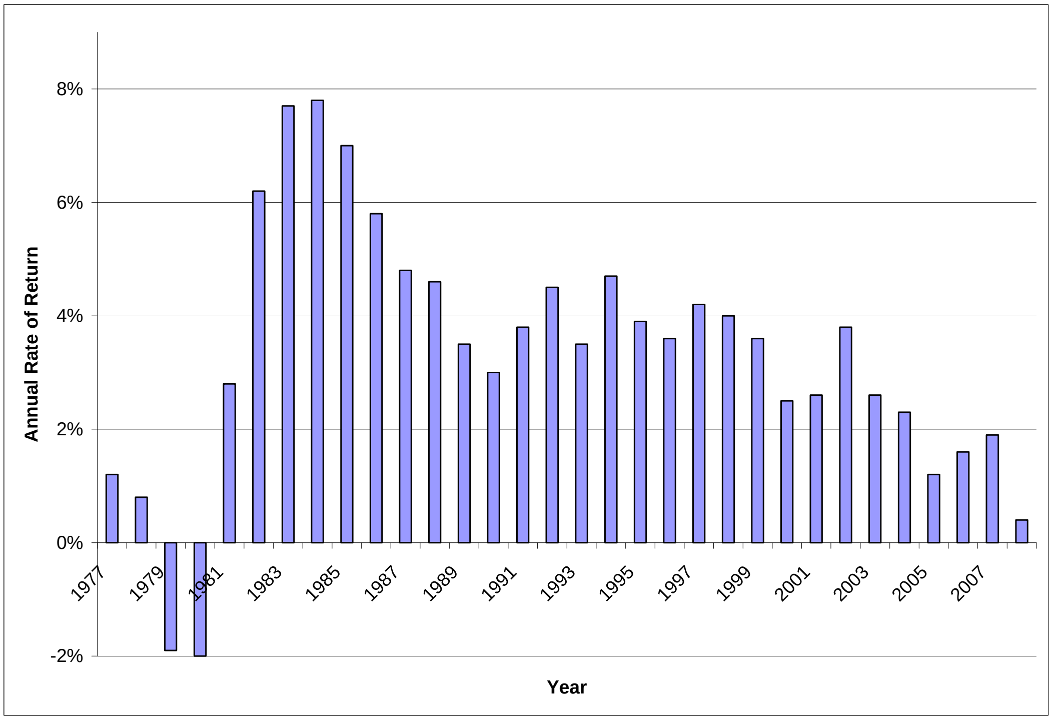

Figure 8-D.4.2 Distribution of Annual Rate of Return on Savings Bonds

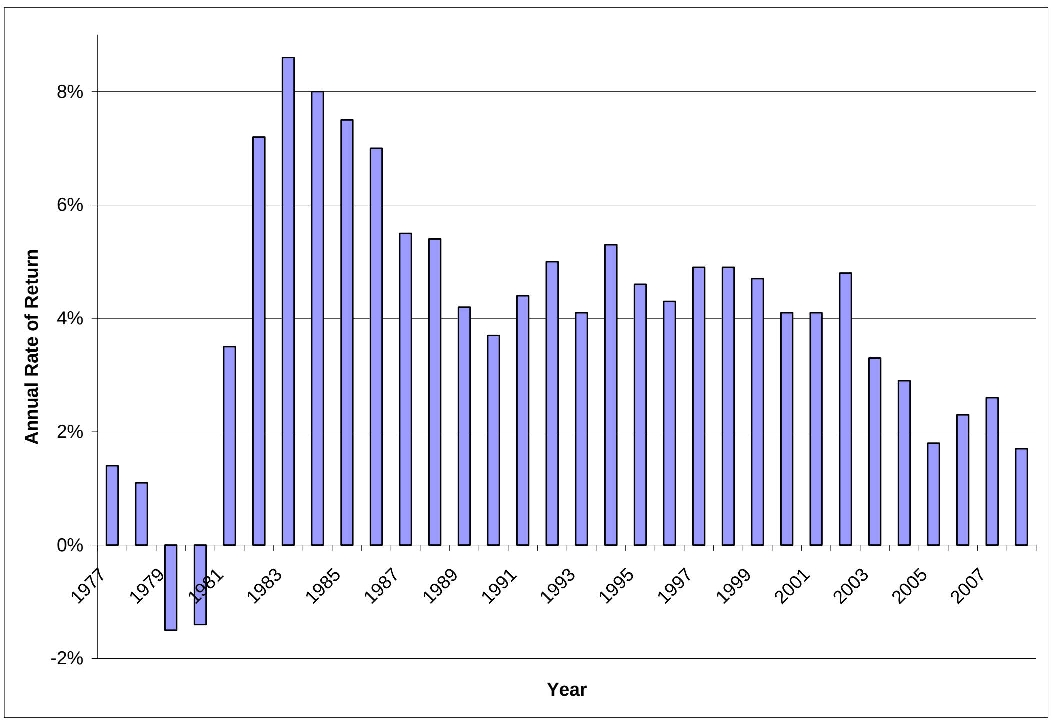

Figure 8-D.4.3 Distribution of Annual Rate of Return on Corporate AAA Bonds

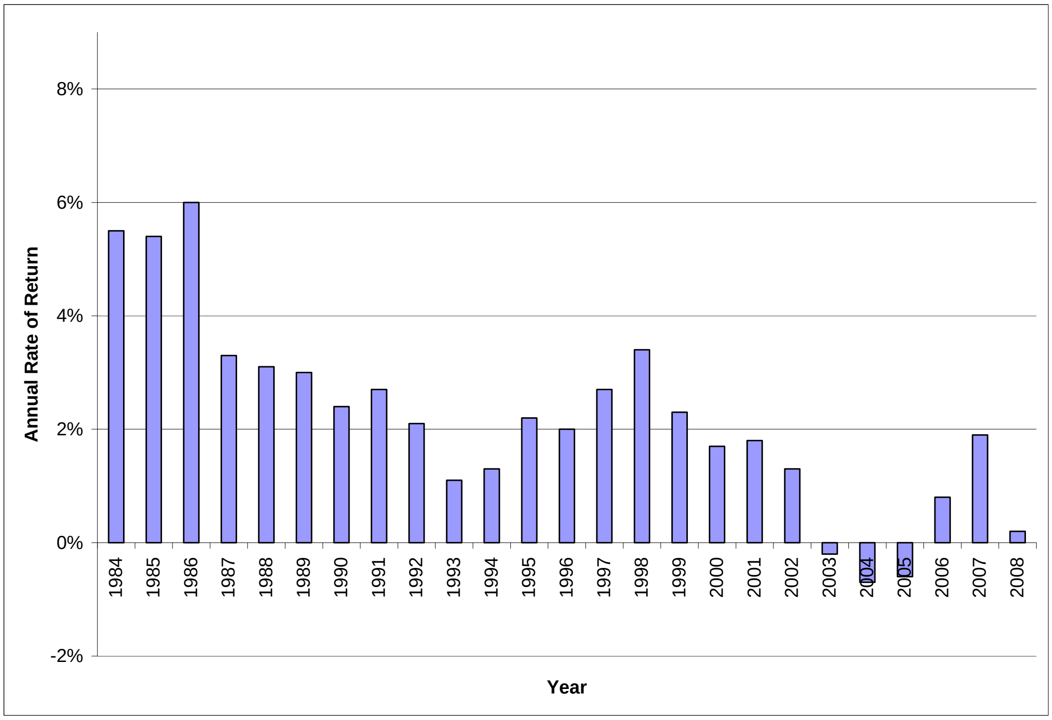

Figure 8-D.4.4 Distribution of Annual Rate of Savings Accounts

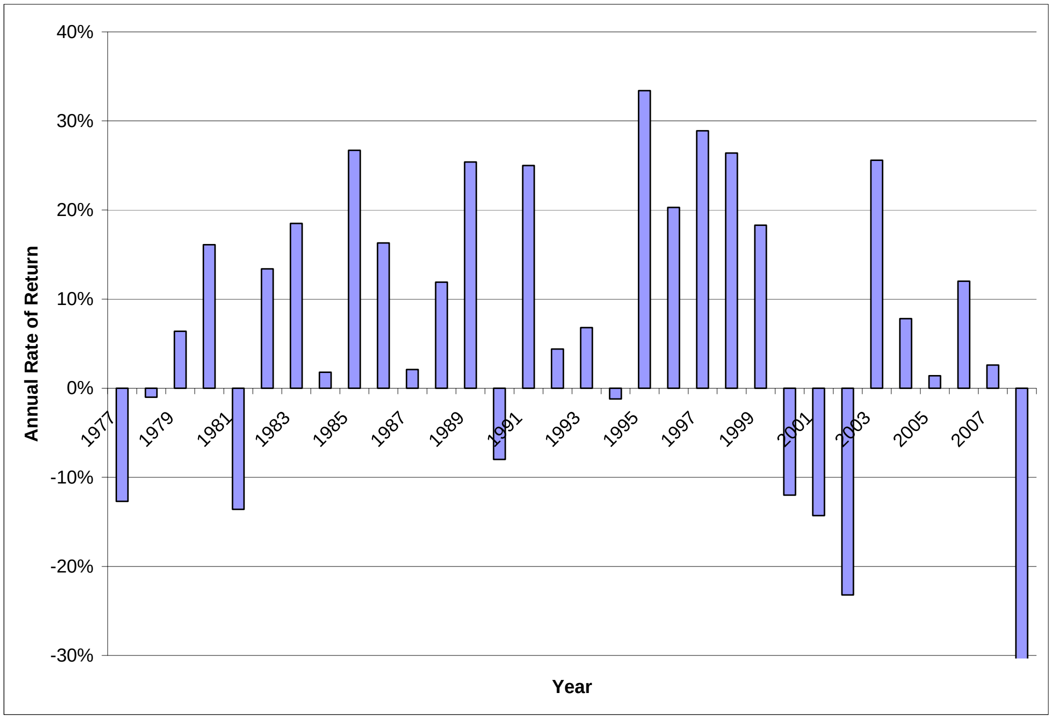

Figure 8-D.4.5 Distribution of Annual Rate of Return on S&P 500

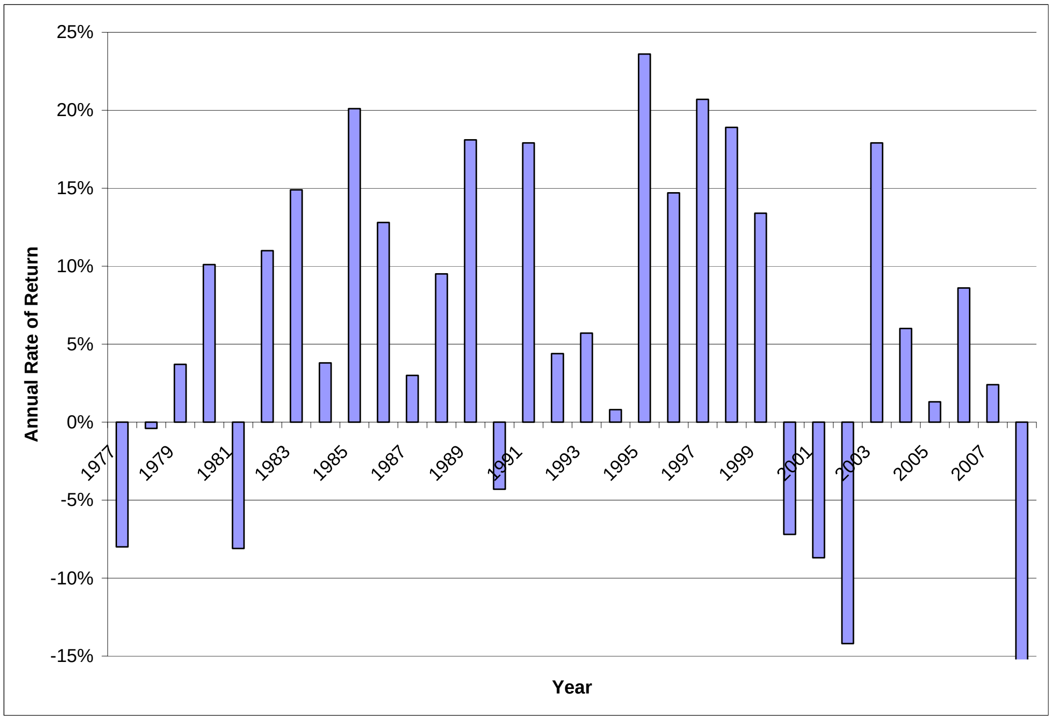

Figure 8-D.4.6 Distribution of Annual Rate of Return on Mutual Funds

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5. Wachovia, *Cost of Savings Index (COSI) Index History*, 2008. (Last accessed March 10, 2008.) <http://mortgage-x.com/general/indexes/default.asp>

6. Damodaran Online, *Damodaran Online:The Data Page (Historical Returns on Stocks, Bonds, and Bills - United States)*, 2008. Stern School of Business, New York University. (Last accessed March 10, 2008.) <http://pages.stern.nyu.edu/~adamodar/>

CHAPTER 9. SHIPMENTS ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to forecast annual product shipments and presents results for each of the refrigeration product classes being considered in this analysis.

DOE defined four refrigeration product types, and developed models to estimate shipments for each type. The four types are: (1) standard-size refrigerator-freezers, (2) standard-size freezers, (3) compact refrigerators, and (4) compact freezers. DOE calibrated each model against historical shipments. To estimate the effects of potential standard levels on shipments of each product class, each model was structured to account for the combined effects on consumer purchase decisions of changes in product cost, annual operating cost, and household income.

Each model considers specific market segments to estimate shipments of individual product classes within each segment. The analytical results from these segments then are aggregated to estimate total shipments for each product class and type. For the product types included in this analysis, DOE considered three market segments: (1) new construction or new owners; (2) replacements for failed products; and (3) for standard-size refrigerators, the purchase of an additional refrigerator.

The shipments models were developed as Microsoft Excel spreadsheets that are accessible on the Internet (www.eere.energy.gov/buildings/appliance_standards/). Appendix 10-A discusses how to access and utilize the shipments model spreadsheets, which are integrated into spreadsheets for the National Impact Analysis. The rest of this chapter explains the shipments models in more detail. Section 9.2 presents methodology behind the models; section 9.3 describes the data inputs and calibration of each model; section 9.4 discusses impacts on shipments from changes in product cost, operating cost, and household income; section 9.5 discusses the affected stock; and section 9.6 presents the shipments forecast for different energy conservation standard-level scenarios.

9.2 SHIPMENTS MODEL METHODOLOGY

DOE developed a model of the national stock of in-service appliances for estimating annual shipments for each of the four product types considered for this standards rulemaking. The model considers market segments as distinct inputs to the shipments forecast. As represented by the following equation, the two primary market segments for standard-size products are new installations and replacements.

$$Ship_p(j) = Rpl_p(j) + NI_p(j)$$

Where:

$Ship_p(j)$ = total shipments of product p in year j,
$Rpl_p(j)$ = units of product p retired and replaced in year j, and
$NI_p(j)$ = number of new installations of product p in year j.

DOE's shipments models take an accounting approach, tracking market shares of each product class, the vintage of units in the existing stock, and expected construction trends. Rather than simply extrapolating a current shipments trend, the analysis of the base case for each type (i.e., the case without new standards) uses input variables as drivers, including construction forecasts and product lifetime distributions, to forecast sales in each market segment. As a result, DOE's shipments models assume that new construction drives shipments.

To estimate shipments of replacement units, the models utilize shipments data from previous years and assumptions about the lifetime of each product. Estimated shipments of replacement units in a given year are equal to the total stock of the appliance minus those units shipped in previous years that remain in the stock. DOE determined the useful service life of each product class to estimate how many years it is likely to remain in stock. The following equation shows how DOE estimated shipments of replacement units.

$$Rpl_p(j) = Stock_p(j-1) - \sum_{age=0}^{ageMax} \sum_{j=N}^{j-1} Ship_j \times prob_{Rtr}(age)$$

Where:

$Stock_p(j-1)$ = total stock of appliances in year $j-1$,
$prob_{Rtr}(age)$ = probability that an appliance of a particular *age* will be retired, and
N = year in which the model begins its stock accounting (start year is specific to each product type, and is based on available historical shipments data).

Stock accounting provides an estimate of the age distribution of product stocks for all years, using product shipments, a retirement function, and initial product stock as inputs. The age distribution of product stocks is a key input to both the NES and NPV calculations because the operating costs for any year depend on the age distribution of the stock. Operating cost is dependent on the product age distribution under a standards case scenario that produces increasing efficiency over time, where older, less efficient units may have higher operating costs, while younger, more-efficient units will have lower operating costs.

DOE calculated total stock of each product by integrating historical shipments data beginning with a specific year. The start year depended on the historical data available for the product. As units are added to the stock, some of the older ones retire and exit the stock. To estimate future shipments, DOE developed a series of equations that define the dynamics and accounting of stocks. For new units, the equation is:

$$\boldsymbol{Stock(\,j, age} = 1\boldsymbol{)} = \boldsymbol{Ship(\,j} - 1\boldsymbol{)}$$

Where:

Stock(j, age) = number of units of a particular age,
j = year for which the stock is being estimated, and
Ship (j) = number of units purchased in year *j*.

The above equation states that the number of one-year-old units is simply equal to the number of new units purchased the previous year. Slightly more complicated equations, such as the following equation, describe how the model accounts for the existing stock of units.

$$\boldsymbol{Stock(\,j} + 1\boldsymbol{, age} + 1\boldsymbol{)} = \boldsymbol{Stock(\,j, age\,)} \times \left[1 - \boldsymbol{prob}_{\boldsymbol{Rtr}}\boldsymbol{(\,age\,)}\right]$$

In this equation, as the year is incremented from *j* to *j+1*, the age is also incremented from *age* to *age+1*. Over time, a fraction of the stock is removed; that fraction is determined by a retirement probability function, $prob_{Rtr}(age)$, which is described in section 9.3. Because the products considered in this rulemaking are common appliances that have been used by U.S. consumers for a long time, replacements typically constitute the majority of shipments.

9.3 DATA INPUTS AND MODEL CALIBRATION

For standard-size products designed for residential application, DOE used two inputs to estimate shipments driven by new construction: new housing forecasts and saturation of the product in new housing. New housing includes newly constructed single- and multi-family units, termed “new housing completions,” and mobile home placements. For new housing completions and mobile home placements, DOE used recorded data through 2007, and adopted the projections from the DOE Energy Information Administration (EIA)’s *Annual Energy Outlook 2009* (*AEO2009*) for the period 2008–2030.[1] To determine new construction shipments for standard-size products, DOE used forecasts of market saturations combined with forecasts of housing starts. For compact products, which are used in both residential and commercial applications, DOE used market saturations in combination with forecasts of housing starts and new commercial construction.

DOE estimated replacements using product retirement functions that it developed based on product lifetimes. The retirement functions for all product types are described in detail in chapter 8. The retirement functions use the following equation to determine the probability of retirement at a certain age for the considered products:

$$Rpl_p(j) = Stock_p(j-1) - \sum_{age=0}^{ageMax} \sum_{j=N}^{j-1} Ship_j \times prob_{Rtr}(age)$$

Where:

$Stock_p$ *(j-1)* =	total stock of appliances in year *j-1*,
Shipj =	shipments in year *j*,
$prob_{Rtr}$ *(age)* =	probability that an appliance of a particular *age* will be retired, and
N =	year in which the model begins its stock accounting (start year is specific to each product type, and is based on available historical shipments data).

DOE used historical shipments data to calibrate its shipments models. For standard-size refrigerator-freezers and standard-size freezers, modeled new construction shipments and replacements were insufficient to account for all product shipments. DOE therefore developed two additional market segments to calibrate its model: "additional refrigerator purchase" for refrigerators and "existing homes without the appliance" for freezers. The "additional refrigerator purchase" segment represents those purchases that are meant to be used as a new primary refrigerator while the former primary refrigerator is converted to a second refrigerator, as well as a small number of direct purchases of second refrigerators. Chapter 8 describes in detail how DOE estimated the probability that a primary refrigerator will be converted to a second refrigerator.

The following sections explain in detail each of the data inputs for each product type.

9.3.1 Standard-size Refrigerator-Freezers

DOE considered seven product classes of standard-size refrigerator-freezers for this rulemaking. DOE's shipments model for these product classes used the aggregate shipments, that is, the shipments for all seven product classes, as the basis for its forecasts. DOE did not develop a separate shipments model for each refrigerator-freezer product class. Instead, DOE disaggregated total shipments into product classes using various data and assumptions.

9.3.1.1 Historical Shipments

DOE used historical shipments data (i.e., domestic shipments and imports) to populate and calibrate its shipments model for standard-size refrigerator-freezers. It used the following sources to establish historical shipments: *Appliance* magazine's Statistical Review,[2,3,4] AHAM Factbooks,[5,6] and an AHAM data submittal related to this rulemaking.[7] Table 9.3.1 summarizes the historical shipments data. DOE developed a total stock estimate by integrating historical shipments. Over time, some of the units are retired and removed from the stock, triggering the purchase of a new unit. Because of the relationship between retirements and total stock, there is a strong correlation between past and future shipments, independent of conservation standards.

Table 9.3.1 Standard-size Refrigerator-Freezers: Historical Shipments

Year	Shipments *millions*	Year	Shipments *millions*
1951	4.075	1980	5.124
1952	3.570	1981	4.944
1953	3.650	1982	4.364
1954	3.600	1983	5.340
1955	4.200	1984	5.882
1956	3.700	1985	6.002
1957	3.350	1986	6.410
1958	3.117	1987	6.748
1959	3.785	1988	6.733
1960	3.475	1989	6.453
1961	3.480	1990	6.456
1962	3.775	1991	6.411
1963	4.125	1992	6.721
1964	4.545	1993	7.047
1965	4.931	1994	7.589
1966	4.974	1995	7.650
1967	4.713	1996	7.975
1968	5.150	1997	7.924
1969	5.296	1998	8.774
1970	5.286	1999	9.099
1971	5.691	2000	9.217
1972	6.315	2001	9.305
1973	6.774	2002	9.744
1974	5.982	2003	10.021
1975	4.577	2004	10.913
1976	4.817	2005	11.134
1977	5.707	2006	11.078
1978	5.890	2007	10.402
1979	5.707	2008	9.314

Sources: 2005–2007: AHAM Data Submittal, 2009; 1995–2004: AHAM *Fact Book* 2005; 1992–1994: AHAM *Factbook* 2003; 1951–1992: *Appliance* Magazine, "Statistical Review," various issues.

9.3.1.2 Markets and Model Calibration

The market for standard-size refrigerator-freezers is primarily comprised of units for new construction, replacement units for products that have been retired, and purchases driven by the conversion of an existing unit from first to second refrigerator. Total shipments are represented by the following equation:

$$Ship_{SRRF}(j) = Rpl_{SRRF}(j) + NH_{SRRF}(j) + Conv_{SRRF}(j)$$

Where:

$Ship_{SRRF}(j)$ = total shipments of standard-size refrigerator-freezers in year j,
$Rpl_{SRRF}(j)$ = replacement shipments in year j,
$NH_{SRRF}(j)$ = shipments to new households in year j, and
$Conv_{SRRF}(j)$= shipments due to additional refrigerator purchase (conversion of first to second refrigerator) in year j.

The following sections discuss these three markets in further detail.

New Construction. To estimate shipments driven by new residential construction, DOE multiplied the housing starts forecast for each year by the estimated saturation of standard-size refrigerator-freezers in new housing. DOE based saturation for a given year on the calculated saturation in the previous year. DOE froze the saturation at the level corresponding to year 2008 (1.3 per new home), the last year for which shipments data are available. The following equation describes the method used for calculating saturation for new construction:

$$Sat_{NC}(j-1) = Stock(j) / HStock(j)$$

$$Sat_{NC}(j) = Sat_{NC}(2008) \forall j > 2008$$

Where:

$Sat_{NC}(j)$ = market saturation of standard-size refrigerator-freezers in the new housing market segment in year j,
$Stock(j)$ = total stock of standard-size refrigerator-freezers in year j,
$HStock(j)$ = total number of housing units in year j, and
$Sat_{NC}(2008)$ = market saturation of standard-size refrigerator-freezers in the new housing market segment in 2008.

Table 9.3.2 presents historical and forecasted new housing starts based on EIA's *AEO2009* for the period 1990–2030. *AEO2009* provides three sets of housing starts forecasts, based on economic growth scenarios: a Reference case, a High Economic Growth case, and a Low Economic Growth case. DOE used the Reference Case that incorporates the effects from the American Recovery and Reinvestment Act.[1] DOE used the high and low growth scenarios from the March 2009 release of the *AEO2009*.[8] DOE used the forecasts from the Reference case to estimate its shipments to new housing, which is comprised of single- and multi-family units (new housing completions) and mobile home placements. For 2031−2043, DOE froze completions at the 2030 level for all three economic scenarios.

Replacements. DOE determined refrigerator-freezer shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. DOE estimated a stock by vintage by integrating historical shipments. Over time, some units are retired and removed from the stock, thereby triggering the shipment of replacement units. A certain percentage (depending on the age) of units will fail each year and need to be replaced. To determine when a unit fails, DOE used a survival function based on a product lifetime distribution with an average value of 17.1 years. Chapter 8 provides a more thorough discussion of product lifetimes. Figure 9.3.1 shows the survival and retirement functions that DOE used to estimate replacement shipments for all product classes of standard-size refrigerator-freezers.

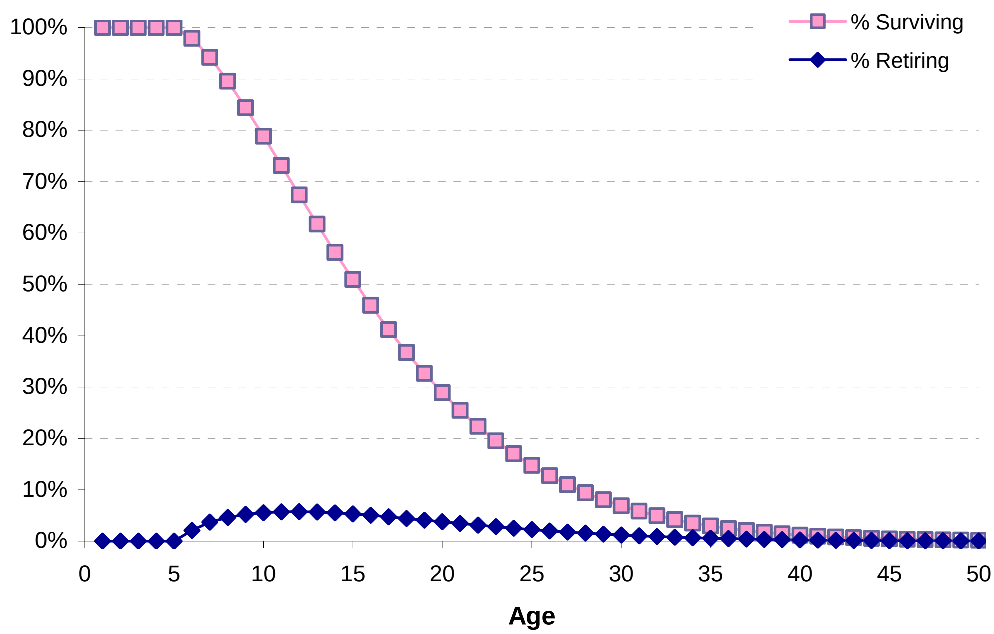

Figure 9.3.1 Standard-size Refrigerator-Freezers: Survival and Retirement Functions

Table 9.3.2 Historical and Forecasted Housing Starts (millions)

Year	Reference Case	High Growth	Low Growth	Year	Reference Case	High Growth	Low Growth
1990	1.38	1.38	1.38	2017	1.99	2.40	1.60
1991	1.18	1.18	1.18	2018	2.00	2.42	1.59
1992	1.41	1.41	1.41	2019	2.01	2.34	1.53
1993	1.54	1.54	1.54	2020	1.99	2.16	1.39
1994	1.76	1.76	1.76	2021	1.93	2.11	1.33
1995	1.69	1.69	1.69	2022	1.89	2.10	1.30
1996	1.82	1.82	1.82	2023	1.87	2.11	1.27
1997	1.49	1.49	1.49	2024	1.87	2.15	1.26
1998	1.54	1.54	1.54	2025	1.89	2.21	1.27
1999	1.64	1.64	1.64	2026	1.88	2.27	1.25
2000	1.70	1.70	1.70	2027	1.84	2.28	1.22
2001	1.72	1.72	1.72	2028	1.79	2.26	1.19
2002	1.75	1.75	1.75	2029	1.76	2.27	1.17
2003	1.79	1.79	1.79	2030	1.77	2.30	1.18
2004	1.80	1.80	1.80	2031	1.77	2.30	1.18
2005	2.22	2.22	2.22	2032	1.77	2.30	1.18
2006	1.92	1.92	1.92	2033	1.77	2.30	1.18
2007	1.75	1.75	1.75	2034	1.77	2.30	1.18
2008	1.48	1.61	1.28	2035	1.77	2.30	1.18
2009	1.30	1.70	1.28	2036	1.77	2.30	1.18
2010	1.08	1.38	1.02	2037	1.77	2.30	1.18
2011	1.51	1.82	1.31	2038	1.77	2.30	1.18
2012	1.73	2.06	1.47	2039	1.77	2.30	1.18
2013	1.86	2.23	1.56	2040	1.77	2.30	1.18
2014	1.89	2.30	1.59	2041	1.77	2.30	1.18
2015	1.93	2.39	1.59	2042	1.77	2.30	1.18
2016	1.98	2.42	1.60	2043	1.77	2.30	1.18

Source: EIA, *AEO2009*.

Shipments Due to Additional Refrigerator Purchase. To calibrate estimated shipments with historical data, DOE introduced into the model a market segment corresponding to purchases of additional standard-size refrigerator-freezers that are not intended as replacements. Because such purchases involve converting a first unit to a second refrigerator, DOE estimated shipments to this market segment by applying the probability of conversion (developed in chapter 8) to the stock of surviving refrigerators. To determine when a household converts a first refrigerator to a second one, DOE used a conversion function based on the total installed stock of refrigerators of a certain age. Chapter 8 provides a detailed discussion of the conversion function. The following equation shows how DOE calculated shipments to this market segment.

$$SNew_{SRRF}(j) = C_j \times \sum_{age=0}^{ageMax} \sum_{j=N}^{j-1} Stock(age)_j \times prob_{conv}(age)$$

Where:

$SNew_{SRRF}(j)$ = shipments due to additional refrigerator purchase (conversion of first to second refrigerator) in year *j*,
C_j = a calibration factor, equal to the ratio of new shipments in year *j* to the installed stock in that year, and
$Prob_{conv}(age)$ = probability that the refrigerator has been converted at a given *age*

9.3.1.3 Disaggregation into Separate Refrigerator-Freezer Product Classes

DOE examined the historical trends in the market shares of various refrigerator-freezer configurations to disaggregate the total shipments of refrigerator-freezers into shipments to each of the three considered refrigerator-freezer product categories (top-mount, bottom-mount and side-by-side configurations). The market share of side-by-side refrigerator-freezers models has grown significantly during the past two decades. Bottom-freezer models historically have had a small market share, but that share has grown in recent years. To forecast the market share for these three configurations throughout the 30-year analysis period (beginning in 2014), DOE built a simple model of aggregate consumer behavior, fit its model to the historical growth in side-by-side market share, and then used its model to estimate future market shares for all three configurations.

DOE assumed that bottom-freezer models were an insignificant portion of the market prior to 2005, and that consumer behavior related to these classes in the future would mirror behavior regarding side-by-side models. Therefore, DOE forecast the combined market share for side-by-side and bottom-freezer products. DOE assumed that the ratio between the market share of bottom-mount and the market share of side-mount products would remain fixed at its 2008 value.

DOE based its model on the market share of each product category as reported by households in the Energy Information Administration's Residential Energy Consumption Survey[9] (RECS) and as reported by the Association of Home Appliance Manufacturers (AHAM).[7] RECS reports whether a household owns a side-by-side refrigerator, but does not distinguish between top- and bottom-mount units. For the purpose of this model, DOE assumed that all recently-purchased top-or-bottom-mount refrigerators reported in the RECS surveys conducted in 1990, 1993, 1997, 2001, and 2005 are top-mount units.

DOE used RECS data first to estimate the maximum ("limiting") market share that side-by-side and bottom-mount product classes would attain in the future. RECS reports the income of each household in its sample. DOE assumed that households that have annual incomes greater than $100,000 and that own their own homes are able to select the appliance that best meets their needs and preferences. The market share of side-by-side units in these households is significantly higher than the current overall market share of side-by-side products. DOE determined market shares for recent purchases from RECS by considering only households which reported purchasing their appliance within two years prior to the survey. The market share of side-by-side refrigerator purchases in the selected household group from each RECS survey is shown in Table 9.3.3. Over time, DOE assumed that all homeowners will be free to choose the product of their choice, as DOE assumed high-income homeowners can today. As a result, DOE assumed that market share of side-by-side units among all homeowners will increase until it equals the mean market share among high-income home-owning households, 66.4 percent.

Table 9.3.3 Market Shares of Side-by-Side Refrigerator-Freezers

RECS Survey Year	Market Share of Side-by-Side Units for High-Income Homeowners %
1990	57.7
1993	71.7
1997	73.4
2001	61.6
2005	67.5
Mean	**66.4**

Source: EIA, Residential Energy Consumption Survey, for the years listed.

DOE used RECS to determine what percent of side-by-side units is sold to home-owners in order to convert a limiting market share among home-owning households into a market share for all shipments. This pecentage was roughly constant in the five most recent RECS surveys, and DOE assumed that it would remain equal to their mean, 90.9 percent, throughout the forecast period. DOE also assumed that the percent of American households that own their home would return to its historical level of roughly 65 percent by 2025. (American home ownership was between 63 percent and 66 percent from 1962 to 1997, peaked at 69 percent in 2004, and fell to 67.8 percent in 2008.)

DOE combined the three factors (the observed preference of high-income consumers, percent of side-by-side refrigerator-freezers purchased by homeowners, and homeownership) to predict the limiting market share for the side- and bottom-freezer product classes. This limit is

$$MS_{SF-LIM} = \frac{MS_{HO-LIM} \times HO_{LIM}}{SF_{HO}} = 47.45\%$$

Where:

MS_{SF-LIM} = limiting market share for side-by-side and bottom-mount product classes,
MS_{HO-LIM} = limiting market share for side-by-side and bottom- mount product classes among homeowners (66.4 percent),
HO_{LIM} = DOE’s assumed value for the eventual percentage of households that will own their own home (65 percent), and

SF_{HO} = the percentage of side-by-side and bottom-mount products sold to homeowners (90.9 percent).

DOE modeled the approach to this limiting value as an exponential curve, and fit the model parameters to data from RECS and AHAM in order to determine the rate at which the market will approach the limit. RECS micro-data enabled DOE to determine the approximate market share of side-by-side products among all homeowners in the years preceding each RECS survey (1989, 1992, 1996, 2000, and 2004). DOE also calculated the market share among homeowners from the AHAM data by multiplying by 90.9 percent (SF_{HO}) and dividing by the homeownership (HO) for each year. The resulting estimates for market shares of side-by-side products among homeowners are shown in Table 9.3.4.

Table 9.3.4 Modeled Homeowner Side-by-Side Market Share

Survey	Year	Homeowner Side-freezer Market Share
AHAM	1998	41.0%
	1999	41.9%
	2000	42.2%
	2001	43.0%
	2002	43.9%
	2003	45.9%
	2004	46.2%
	2005	49.1%
	2006	59.8%
	2007	61.4%
RECS	1989	32.5%
	1992	31.9%
	1996	41.1%
	2000	48.9%
	2004	53.0%

DOE fit an exponential curve to the data in Table 9.3.4, approaching the limiting value $MS_{SF\text{-}LIM}$:

$$MS_{HO-year} = MS_{HO-LIM} - e^{\alpha(\beta - year)},$$

Where:

$MS_{HO\text{-}year}$ = market share of side-by-side and bottom-mount refrigerator-freezers among all homeowners in a given *year*,
α, β = fit parameters, and
$MS_{HO\text{-}LIM}$ = limiting market share for side- and bottom-freezer product classes among homeowners (66.4 percent).

The best fit parameters are: α = 0.05555 and β = 1971.62.

The R-squared value for the fit is 0.924, indicating that the model is a relatively good fit. DOE multiplied the best-fit estimate of $MS_{HO\text{-}year}$ by homeownership in each year, then divided by SF_{HO} to account for side- and bottom-mount refrigerators sold to non-homeowners. The results are estimated market shares of side-by-side or bottom-mount products throughout the analysis period. This estimate, along with the markets shares derived from the RECS and AHAM data, is shown in Figure 9.3.2.

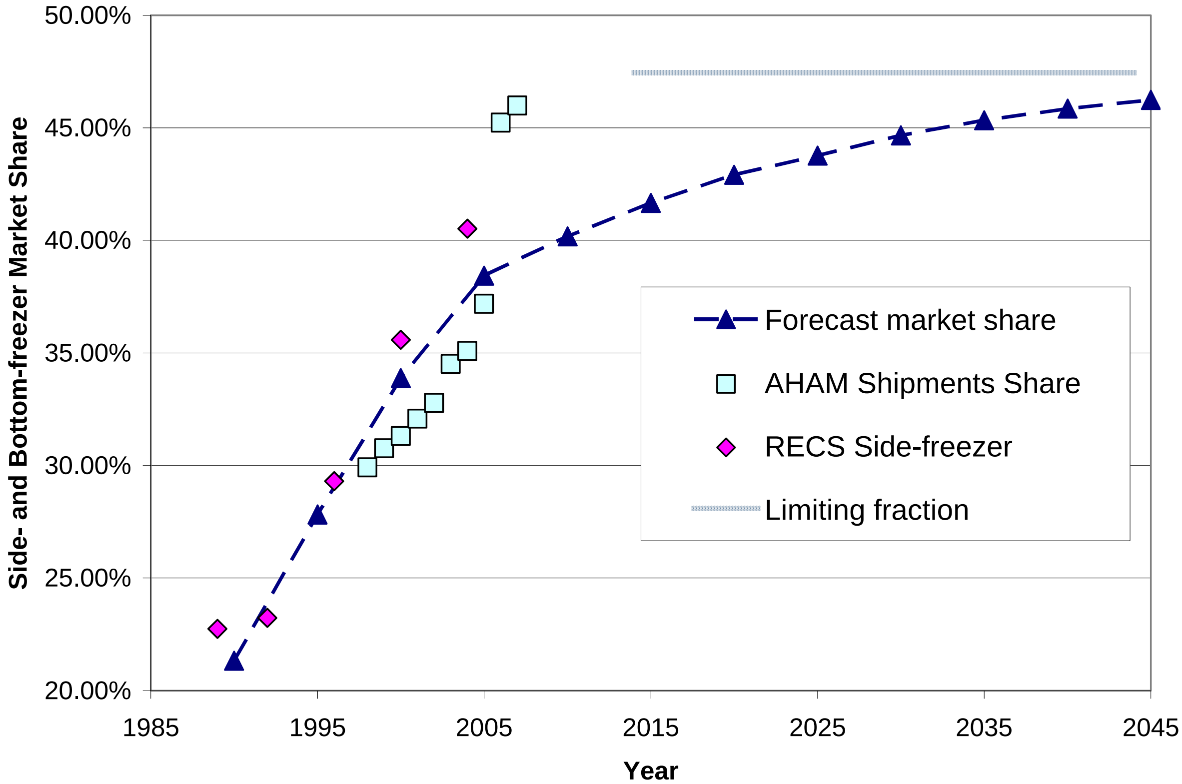

Figure 9.3.2 Projected Market Share of Side- And Bottom-Freezer Product Classes

DOE disaggregated the side and bottom-mount freezer classes into their respective product classes based on the AHAM data submittal for the years 2005-2008. For future years, DOE maintained the market shares of the product classes within each considered category of side-by-side and bottom-mount, and top-mount refrigerator-freezer as they existed in 2008. Table 9.3.5 presents the resulting market share forecast DOE used to disaggregate total modeled shipments.

Table 9.3.5 Product Class Market Shares of Standard-size Refrigerator-Freezers

Year	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC5A
2005	0.2%	0.1%	62.4%	1.0%	1.6%	0.1%	34.1%	0.4%
2006	0.2%	0.1%	54.4%	1.0%	8.4%	0.1%	33.6%	2.2%
2007	0.1%	0.0%	53.8%	0.8%	10.7%	0.1%	31.6%	2.9%
2008	0.1%	0.0%	55.8%	0.8%	10.3%	0.1%	30.2%	2.7%
2009	0.1%	0.0%	57.7%	0.7%	9.8%	0.1%	28.8%	2.6%
2010	0.1%	0.0%	59.6%	0.7%	9.4%	0.1%	27.6%	2.5%
2011	0.1%	0.0%	59.3%	0.7%	9.5%	0.1%	27.8%	2.5%
2012	0.1%	0.0%	59.0%	0.7%	9.5%	0.1%	28.0%	2.5%
2013	0.1%	0.0%	58.7%	0.7%	9.6%	0.1%	28.2%	2.6%
2014	0.1%	0.0%	58.4%	0.7%	9.7%	0.1%	28.4%	2.6%
2015	0.1%	0.0%	58.1%	0.7%	9.7%	0.1%	28.6%	2.6%
2016	0.1%	0.0%	57.8%	0.7%	9.8%	0.1%	28.8%	2.6%
2017	0.1%	0.0%	57.6%	0.7%	9.9%	0.1%	28.9%	2.6%
2018	0.1%	0.0%	57.3%	0.8%	9.9%	0.1%	29.1%	2.6%
2019	0.1%	0.0%	57.1%	0.8%	10.0%	0.1%	29.3%	2.7%
2020	0.1%	0.0%	56.8%	0.8%	10.0%	0.1%	29.5%	2.7%
2021	0.1%	0.0%	56.7%	0.8%	10.1%	0.1%	29.6%	2.7%
2022	0.1%	0.0%	56.5%	0.8%	10.1%	0.1%	29.7%	2.7%
2023	0.1%	0.0%	56.3%	0.8%	10.2%	0.1%	29.8%	2.7%
2024	0.1%	0.0%	56.1%	0.8%	10.2%	0.1%	29.9%	2.7%
2025	0.1%	0.0%	56.0%	0.8%	10.2%	0.1%	30.0%	2.7%
2026	0.1%	0.0%	55.8%	0.8%	10.3%	0.1%	30.2%	2.7%
2027	0.1%	0.0%	55.6%	0.8%	10.3%	0.1%	30.3%	2.7%
2028	0.1%	0.0%	55.4%	0.8%	10.4%	0.1%	30.4%	2.8%
2029	0.1%	0.0%	55.3%	0.8%	10.4%	0.1%	30.5%	2.8%
2030	0.1%	0.0%	55.1%	0.8%	10.4%	0.1%	30.7%	2.8%
2031	0.1%	0.0%	55.0%	0.8%	10.5%	0.1%	30.7%	2.8%
2032	0.1%	0.0%	54.8%	0.8%	10.5%	0.1%	30.8%	2.8%
2033	0.1%	0.0%	54.7%	0.8%	10.5%	0.1%	30.9%	2.8%
2034	0.1%	0.0%	54.5%	0.8%	10.6%	0.1%	31.0%	2.8%
2035	0.1%	0.0%	54.4%	0.8%	10.6%	0.1%	31.1%	2.8%
2036	0.1%	0.0%	54.3%	0.8%	10.6%	0.1%	31.2%	2.8%
2037	0.1%	0.0%	54.2%	0.8%	10.6%	0.1%	31.3%	2.8%
2038	0.1%	0.0%	54.1%	0.8%	10.7%	0.1%	31.3%	2.8%
2039	0.1%	0.0%	54.0%	0.8%	10.7%	0.1%	31.4%	2.8%
2040	0.1%	0.0%	53.9%	0.8%	10.7%	0.1%	31.5%	2.8%
2041	0.1%	0.0%	53.8%	0.8%	10.7%	0.1%	31.6%	2.9%
2042	0.1%	0.0%	53.5%	0.8%	10.8%	0.1%	31.7%	2.9%
2043	0.1%	0.0%	53.4%	0.8%	10.8%	0.1%	31.8%	2.9%

9.3.1.4 Base Case Shipments

Figure 9.3.3 shows the forecasted shipments in the base case (without new energy conservation standards) and the historical shipments DOE used to calibrate the forecast. The figure also presents shipments due to retirements, shipments to new housing, and shipments due to conversion from first to second unit. Figure 9.3.4 presents forecasted refrigerator-freezer shipments disaggregated by product category.

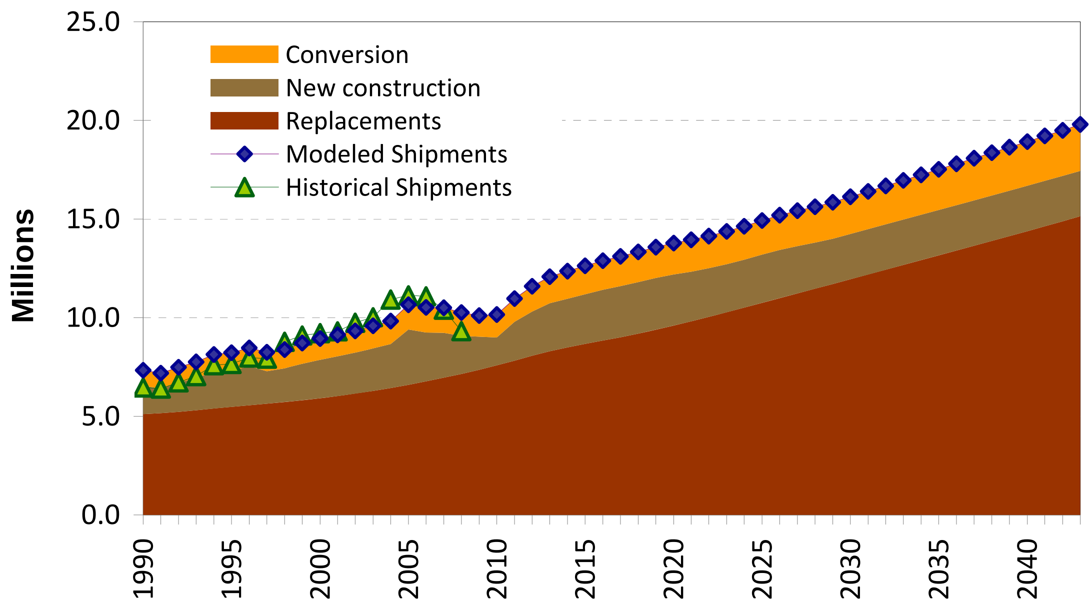

Figure 9.3.3 Standard-Size Refrigerator-Freezers: Historical and Base Case Shipments Forecast by Market Segment

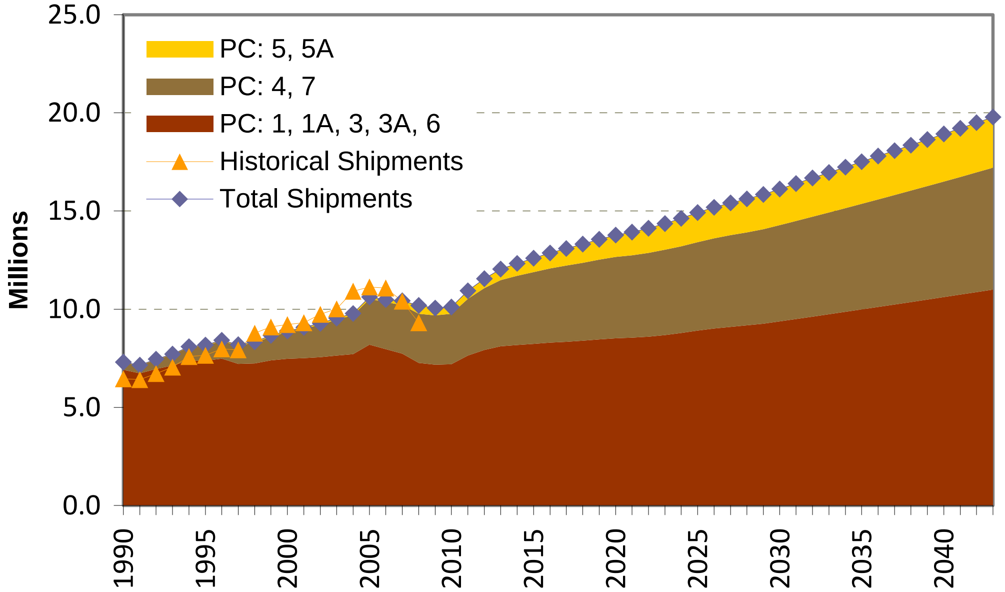

Figure 9.3.4 Standard-size Refrigerator-Freezers: Base Case Shipments Forecast by Product Class Group

9.3.2 Standard-size Freezers

DOE considered four product classes of standard-size freezers in its analysis. DOE's shipments model for these classes uses the aggregate shipments for all four product classes as the basis for its forecasts. In other words, DOE did not develop a separate shipments model for each freezer product class. Instead, DOE used various data and assumptions to disaggregate total shipments into product classes.

9.3.2.1 Historical Shipments

DOE used data on historical shipments (i.e., domestic shipments and imports) from *Appliance* magazine's Statistical Review,[10] AHAM Factbook,[5] and an AHAM data submittal[7] to populate and calibrate its shipments model. DOE built up a total stock of freezers by integrating historical shipments. Over time, some of the units are retired and removed from the stock, triggering the shipment of new units to replace them. Because of the relationship between retirements and total stock, there is a strong correlation between past and future shipments, independent of conservation standards. Table 9.3.6 summarizes the historical shipments data for standard-size freezers.

Table 9.3.6 Standard-size Freezers: Historical Shipments

Year	Shipments *millions*	Year	Shipments *millions*
1983	1.320	1996	1.548
1984	1.261	1997	1.490
1985	1.222	1998	1.628
1986	1.209	1999	1.988
1987	1.242	2000	1.963
1988	1.316	2001	2.215
1989	1.172	2002	2.535
1990	1.241	2003	2.523
1991	1.324	2004	2.516
1992	1.525	2005	2.214
1993	1.438	2006	2.148
1994	1.546	2007	1.992
1995	1.558		

Sources: 2005–2007: AHAM Data Submittal, 2009; 1997–2004: AHAM *Fact Book* 2005; 1983–1996: Appliance Magazine, "Statistical Review," various issues

9.3.2.2 Markets and Model Calibration

The shipments market for standard-size freezers is primarily comprised of units for new construction and replacement units for products that have been retired. DOE's shipments model also assumes that some existing households that do not currently own the appliance (i.e. *EHA*) will enter the market as new owners. Total shipments are represented by the following equation:

$$Ship_{SF}(j) = Rpl_{SF}(j) + NH_{SF}(j) + EHA_{SF}(j)$$

Where:

$Ship_{SF}(j)$ = total shipments of standard-size freezers in year j,
$Rpl_{SF}(j)$ = replacement shipments in year j,
$NH_{SF}(j)$ = shipments to new households in year j, and
$EHA_{SF}(j)$= shipments to existing households without the appliance in year j.

The following sections discuss all three of these markets in further detail.

New Construction. To forecast the shipments of standard-size freezers for new construction for any given year, DOE multiplied the forecasted housing starts by the forecasted saturation of standard-size freezers for new housing. DOE used saturation in new housing from the 1993, 1997, 2001, and 2005 RECS surveys.[8] DOE determined the saturations in new homes by using a sample of RECS household records whose home is less than 5 years old, with freezers of age less than 5 years. DOE froze the saturation at the estimated level corresponding to year 2007 (0.119 per new home). Table 9.3.7 presents the freezer saturation data in new housing units.

Table 9.3.7 Saturation of Freezers in New Housing

Year	**New Housing Units that Contain New Freezers %**
1993	7.78
1994	
1995	
1996	
1997	11.31
1998	
1999	
2000	
2001	11.22
2002	
2003	
2004	
2005	11.67

Source: Source: EIA, Residential Energy Consumption Survey, for the years listed.

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. DOE estimated the stock of standard-size freezers by vintage by integrating historical shipments. Over time, some units are retired and removed from the stock, triggering the shipment of a replacement unit. A certain percentage (depending on the age) of units will fail each year and need to be replaced. To determine when a unit fails, DOE used a survival function based on a product lifetime distribution that had an average value of 22.7 years. Chapter 8 presents a more thorough discussion of the lifetimes of standard-size freezers. Figure 9.3.5 shows the survival and retirement functions that DOE used to estimate shipments of replacement freezers.

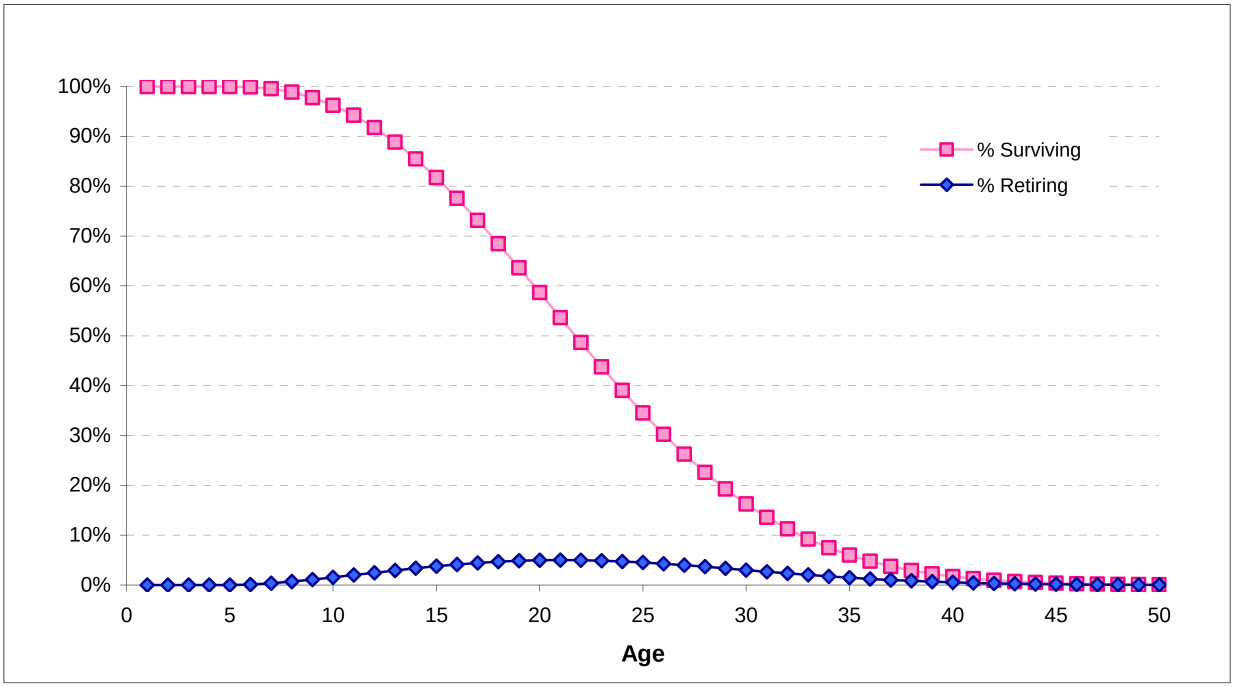

Figure 9.3.5 Standard-size Freezers: Survival and Retirement Functions

Model Calibration—New Owners. To calibrate estimated shipments with the historical data, DOE introduced a market segment that consists of households that currently do not own a freezer. DOE estimated shipments to this market segment as residual historical shipments after shipments for new housing and replacements were subtracted from total shipments. DOE then used a 3-year moving average to estimate the percent of households who enter the market as new owners for 2008-2043. The following equation illustrates the calculations.

$$EHA_{SF}(j) = (1 - StockSat_j) \times HStock_j \times EHAfrac_j$$

Where:

$EHA_{SF}(j)$ = number of freezers shipped to existing households without the appliance in year j,
$StockSat_j$ = stock saturation of freezers in year j,
$HStock_j$ = housing stock in year j, and
$EHAfrac_j$ = fraction of housing units without the appliance and obtain a freezer in year j.

9.3.2.3 Disaggregation into Separate Freezer Product Classes

To disaggregate the total shipments of standard-size freezers into shipments to each of the freezer product classes, DOE used the market share information submitted by AHAM.[7] The data submitted by AHAM provided an aggregated market share of 50.6 percent for product classes 8 and 10. DOE then used the shipments data from the 2005 AHAM Fact Book[5] and *Appliance* magazine[2] to disaggregate market shares for product classes 8 and 10. The AHAM Fact Book indicates a 59.5 percent market share for the combination of product classes 10 and 10A. Since the market share for 10A is near zero, DOE attributed the combined market share of product classes 8 and 10 from the AHAM data submittal (50.6 percent) entirely to product class 10 in order to be as close as possible to the AHAM Fact Book data. Table 9.3.8 presents the market share forecast used for disaggregating modeled shipments. DOE used these estimated market shares throughout the forecast period.

Table 9.3.8 Product Class Market Share of Standard-size Freezers

Year	PC8	PC9	PC10	PC10A
2008	0.0%	49.4%	50.6%	0.0%

9.3.2.4 Base Case Shipments

Figure 9.3.6 shows the forecasted shipments of standard-size freezer in the base case (without new energy conservation standards) and the historical shipments DOE used to calibrate the forecast. The figure also presents forecasted shipments disaggregated into its modeled market segments. Figure 9.3.7 presents shipment forecasts of standard-size freezers in the base case, disaggregated into product class groups.[a]

[a] DOE grouped product classes 10 and 10A into one group.

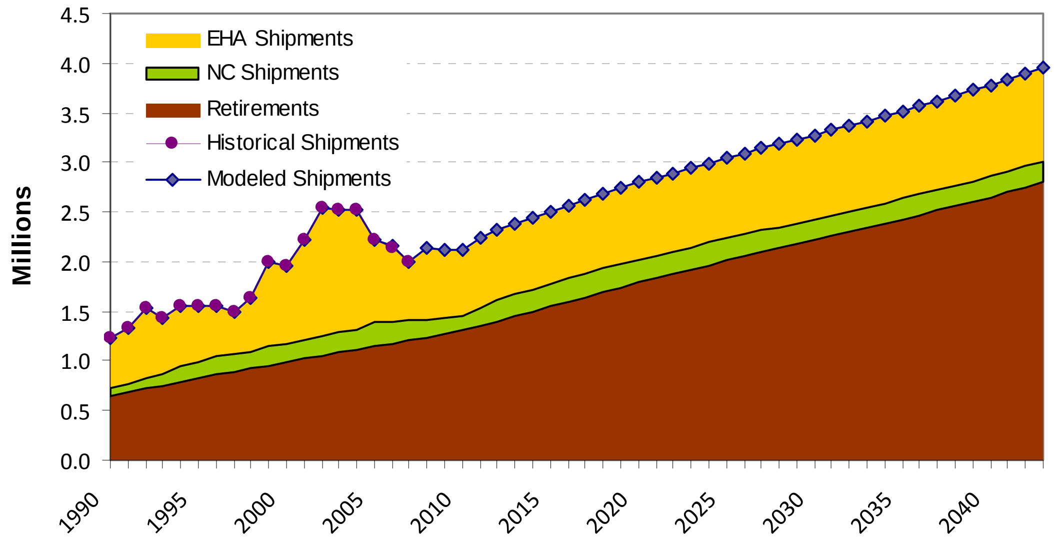

Figure 9.3.6 Standard-size Freezers: Historical and Base Case Shipments Forecast by Market Segment

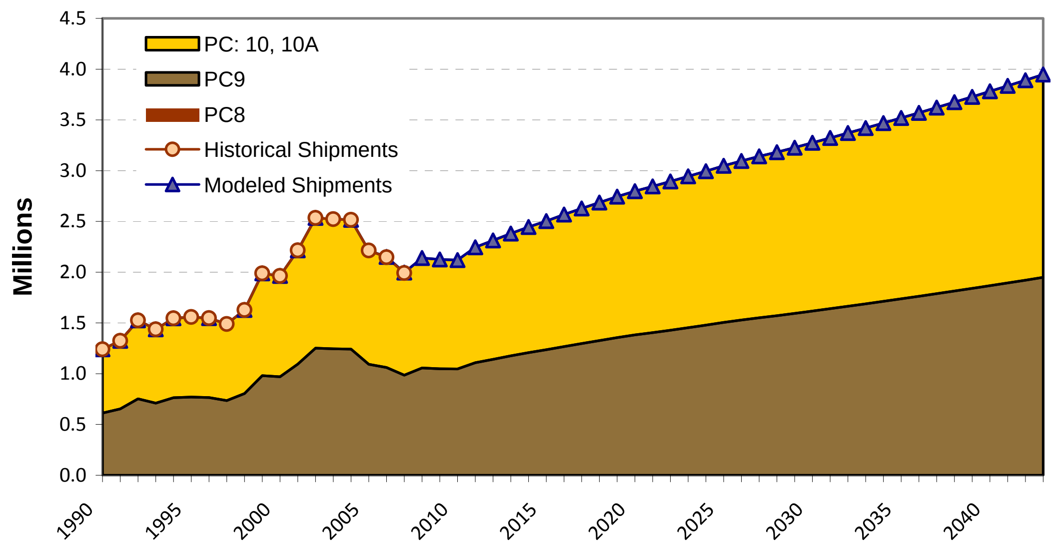

Figure 9.3.7 Standard-size Freezers: Base Case Shipments Forecast by Product Class

9.3.3 Compact Refrigerators and Refrigerator-Freezers

DOE analyzed five product classes of compact refrigerators for this rulemaking. DOE's shipments model for these products utilizes aggregate shipments for all five product classes as the basis for its forecasts. In other words, DOE did not develop a separate shipments model for each product class. Instead, DOE used various data and assumptions to disaggregate total shipments into product classes.

9.3.3.1 Historical Shipments

DOE used data on historical shipments (domestic shipments and imports) to calibrate its shipments model. It developed historical shipments data based on data submitted by AHAM[7] and various issues of *Appliance* magazine.[2,9] DOE built up a total stock of compact refrigerators by integrating historical shipments. Over time, some units are retired and removed from the stock, triggering the shipment of new units to replace them. Because of the relationship between retirements and total stock, there is a strong correlation between past and future shipments. Table 9.3.9 summarizes the historical shipments data for compact refrigerators.

Table 9.3.9 Compact Refrigerators: Historical Shipments

Year	Shipments (millions)	Year	Shipments (millions)
1983	0.568	1996	1.070
1984	0.602	1997	1.110
1985	0.783	1998	1.186
1986	0.810	1999	1.498
1987	0.830	2000	1.530
1988	1.000	2001	1.355
1989	0.925	2002	2.038
1990	0.933	2003	2.844
1991	0.925	2004	2.567
1992	0.950	2005	2.792
1993	1.030	2006	1.641
1994	0.950	2007	2.194
1995	1.032		

Sources: 2005–2007: estimates based on AHAM Data Submittal, 2009;and 1983–2004: Appliance Magazine, "Statistical Review," various issues.

9.3.3.2 Markets and Model Calibration

The market for compact refrigerators is primarily comprised of units that replace products that have been retired from service, and units installed in new housing, new lodging in the commercial sector (such as hotel rooms and dormitories), and in other new construction in the commercial sector. Total compact refrigerator shipments are represented by the following equation:

$$Ship_{CRRF}(j) = Rpl_{CRRF}(j) + NH_{CRRF}(j) + NLodg_{CRRF}(j) + NOthComm_{CRRF}(j)$$

Where:

$Ship_{CRRF}(j) =$	total shipments of compact refrigerators in year j,
$Rpl_{CRRF}(j) =$	replacement shipments in year j,
$NH_{CRRF}(j) =$	shipments to new households in year j,
$NLodg_{CRRF}(j) =$	shipments to new lodging units in year j, and
$NOthComm_{CRRF}(j) =$	shipments to other new commercial establishments in year j.

The following sections discuss these markets.

New Housing. To estimate shipments to new housing in each year, DOE multiplied forecasted housing starts by the estimated saturation of compact refrigerators in new housing units. DOE forecasted market saturation for this segment using the saturation of compact refrigerators in newly built homes in RECS 2001 and 2005 (2.7 percent and 3.2 percent, respectively). For years beyond 2005, DOE maintained the growth in new housing saturation measured between 2001 and 2005.

New Lodging and Other Commercial New Construction. To estimate shipments to new commercial establishments, DOE used forecasts of new construction in lodging and other commercial establishments coupled with market saturation data (in units per building). DOE obtained the saturation data from the American Lodging Association (ALA)[11] and the EIA's Commercial Building Energy Consumption Survey (CBECS).[12] For lodging, DOE used saturations from ALA for the years 1998, 2003, and 2008. For future years, DOE maintained the growth in saturation rates seen between 2003 and 2008. For other commercial applications, DOE used saturations from CBECS for the years 1999 and 2003. DOE maintained the growth in saturation rates seen between 1999 and 2003 for subsequent years.

Figure 9.3.8 presents the forecast for saturation of compact refrigerators for the three market segments for new construction.

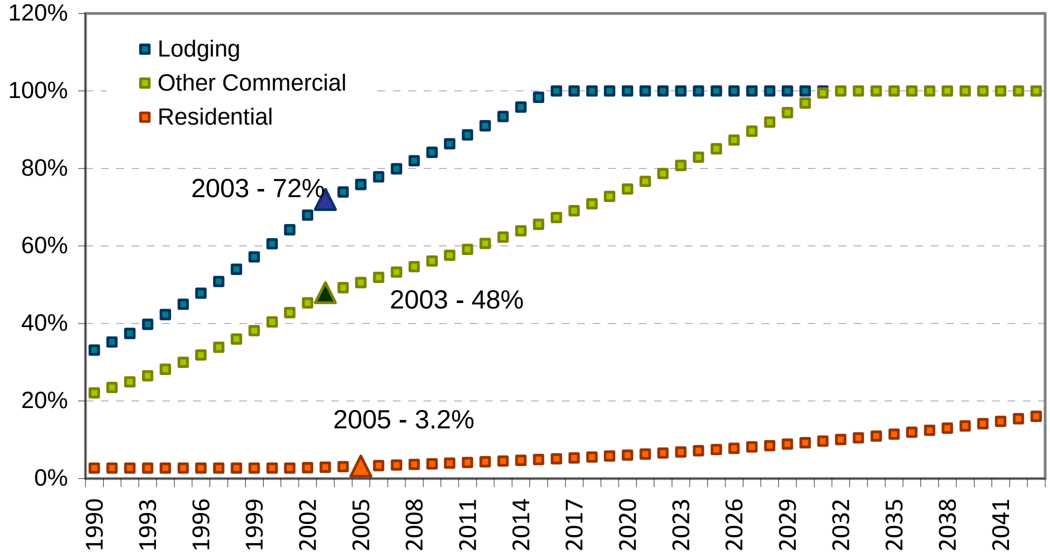

Figure 9.3.8 Forecast of Saturation of Compact Refrigerators in New Construction Market Segments

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. DOE integrated historical shipments to estimate each year's stock of compact refrigerators by vintage. Over time, some of the units are retired and removed from the stock, triggering the shipment of a new unit. Because of the relationship between retirements and total stock, there is a strong correlation between past and future shipments, independent of conservation standards.

A certain percentage (depending on the age) of units will fail each year and need to be replaced. To determine when a compact refrigerator fails, DOE used a product survival function based on a lifetime distribution with an average value of 5.6 years. Chapter 8 presents a more thorough discussion of product lifetimes for compact refrigerators. Figure 9.3.9 shows the survival and retirement functions that DOE used to estimate replacement shipments.

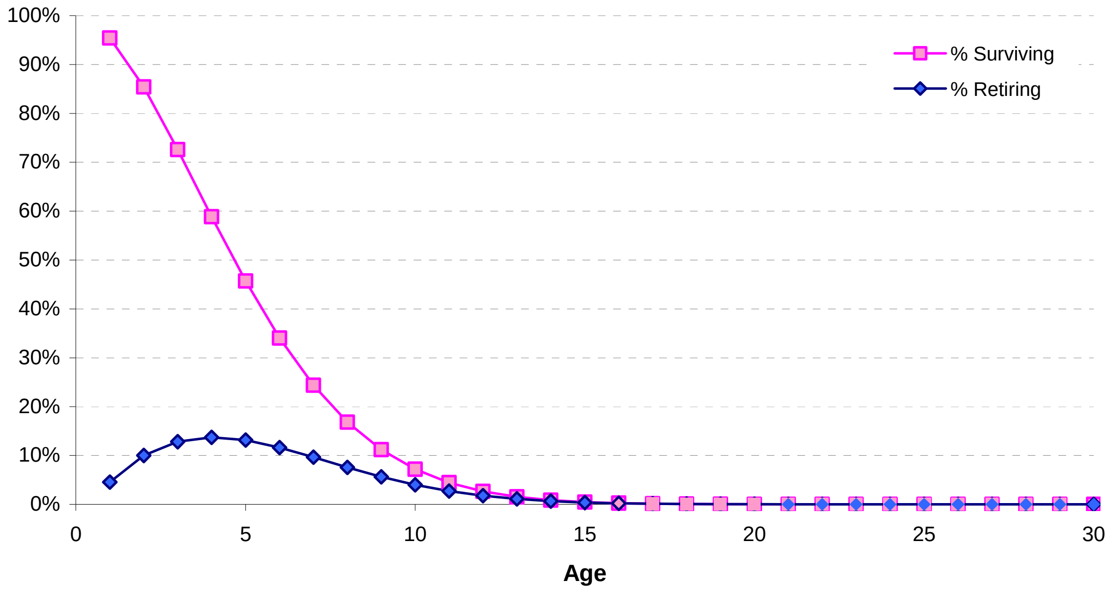

Figure 9.3.9 Compact Refrigerators: Survival and Retirement Functions

Model Calibration. To calibrate estimated shipments with the historical data, DOE utilized compact refrigerator stock data for 2003. DOE obtained commercial stock data from CBECS 2003 and estimated the 2003 residential stock from various years of RECS. Based on these sources, DOE estimated that in 2003 the stock was split 30 percent, 18 percent, and 52 percent between residential, lodging, and other commercial sectors, respectively**.**

9.3.3.3 Disaggregation into Separate Compact Refrigerator Product Classes

DOE based its product class market shares for compact refrigerators on data submitted by AHAM[7] and CEC data[13] on available compact refrigerator models. Table 9.3.10 presents the market share forecast used for disaggregating total modeled shipments. DOE used these estimated market shares throughout the forecast period.

Table 9.3.10 Product Class Market Shares of Compact Refrigerators

Year	PC11	PC12	PC13	PC14	PC15
2008	84.40%	5.92%	9.03%	0.32%	0.32%

9.3.3.4 Base Case Shipments

Figures 9.3.10 shows the forecasted shipments of compact refrigerators in the base case (without new energy conservation standards) along with the historical shipments DOE used to calibrate the forecast. The figure also presents forecasted shipments disaggregated into modeled market segments. Figure 9.3.11 presents the base case shipments forecast for compact refrigerators disaggregated by product class. (Product classes 14 and 15 are not visible in the figure because they account for a very small share of shipments.)

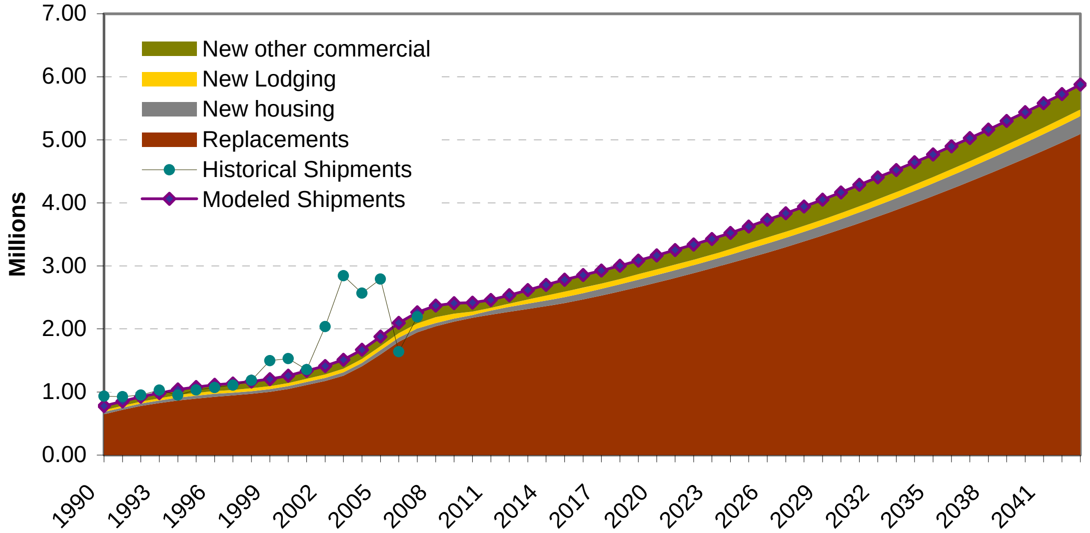

Figure 9.3.10 Compact Refrigerators: Base Case Shipments Forecast by Market Segment

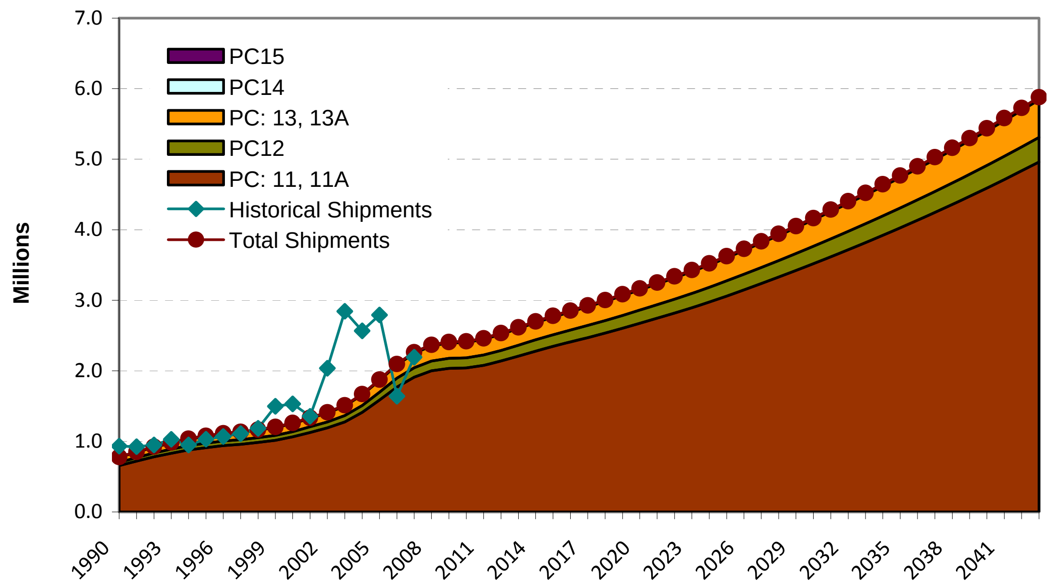

Figure 9.3.11 Compact Refrigerators: Base Case Shipments Forecast by Product Class

9.3.4 Compact Freezers

DOE considered three product classes of compact freezers for this analysis. DOE based its forecast shipments compact freezers on aggregate shipments, that is, shipments for all three product classes. In other words, DOE did not develop a separate shipments model for each product class. Instead, DOE used various data and assumptions to disaggregate total estimated shipments into product classes.

9.3.4.1 Historical Shipments

DOE used data on historical shipments (domestic shipments and imports) to populate and calibrate its shipments model for compact freezers. It obtained historical shipments data from data submitted by AHAM[7] and various issues of *Appliance* magazine[2,9] (Table 9.3.11). DOE built up a total stock of compact freezers by integrating historical shipments. Over time, some units are retired and removed from the stock, triggering the shipment of new units to replace them. Because of the relationship between retirements and total stock, there is a strong correlation between past and future shipments.

Table 9.3.11 Compact Freezers: Historical Shipments

Year	Shipments (millions)	Year	Shipments (millions)
1983	0.237	1996	0.335
1984	0.242	1997	0.378
1985	0.234	1998	0.393
1986	0.247	1999	0.434
1987	0.255	2000	0.474
1988	0.287	2001	0.490
1989	0.325	2002	0.520
1990	0.337	2003	0.512
1991	0.333	2004	0.696
1992	0.319	2005	0.591
1993	0.326	2006	0.524
1994	0.304	2007	0.500
1995	0.324		

Sources: 2005–2007: estimates based on AHAM Data Submittal, 2009; and 1983–2004: Appliance Magazine, "Statistical Review," various issues.

9.3.4.2 Markets and Model Calibration

The market for compact freezers is primarily comprised of replacement units for products that have been retired from service and units purchased by new owners (not new construction) in both residential and commercial sectors. Total compact freezer shipments are represented by the following equation:

$$Ship_{CF}(j) = Rpl_{CF}(j) + NR_{CF}(j) + NC_{CF}(j)$$

Where:

$Ship_{CF}(j)$ =	total shipments of compact freezers in year *j*,
$Rpl_{CF}(j)$ =	replacement shipments in year *j*,
$NR_{CF}(j)$ =	shipments to new residential owners in year *j*, and
$NC_{CF}(j)$=	shipments to new commercial owners in year *j*.

The following sections discuss these markets in further detail.

Replacements. DOE determined shipments to the replacement market using an accounting method that tracks the total stock of units by vintage. DOE integrated historical shipments to estimate each year's stock of compact freezers by vintage. Over time, some units are retired and removed from the stock, triggering the shipment of a replacement unit. A certain percentage (depending on the age) of units will fail each year and need to be replaced. To determine when a compact freezer fails, DOE used a product survival function based on a lifetime distribution with an average value of 7.46 years. Chapter 8 provides a more thorough discussion of product lifetimes for compact freezers. Figure 9.3.12 shows the survival and retirement functions that DOE used to estimate shipments of replacement units.

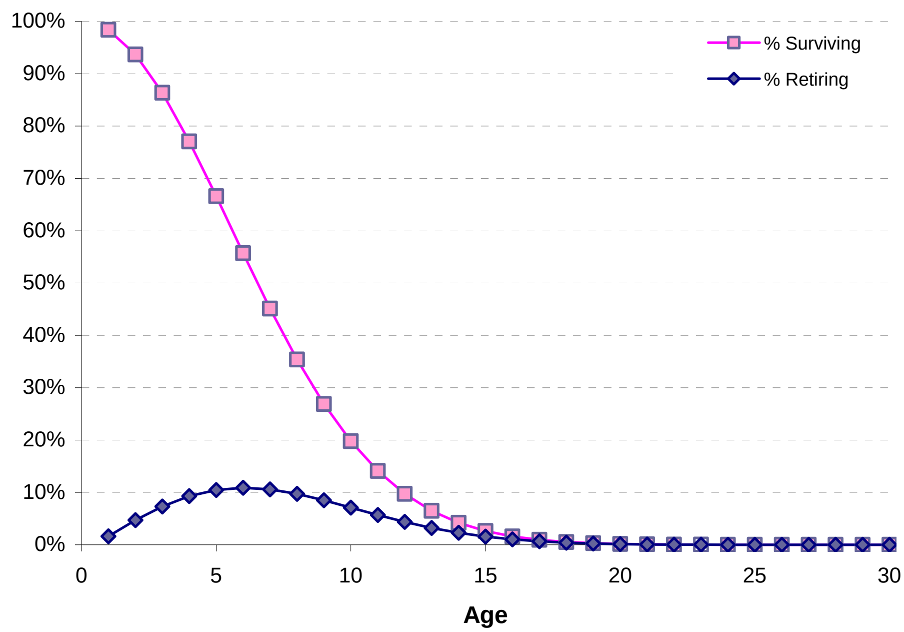

Figure 9.3.12 Compact Freezers: Survival and Retirement Functions

New Owner. In the absence of data on saturation of compact freezers in homes or commercial applications, DOE estimated historical shipments to new owners based on the difference between total shipments of compact freezers and estimated replacement shipments. DOE forecast new owner shipments using a 3-year moving average method. DOE assumed an even split between residential and commercial new owners for this segment.

9.3.4.3 Disaggregation into Separate Compact Freezer Product Classes

DOE used California Energy Commission (CEC) data on available freezer models to estimate market shares of product classes 16, 17, and 18.[14] Table 9.3.11 presents the market share forecast used in this analysis for disaggregating total modeled shipments. DOE used the 2008 market share estimates throughout the forecast period.

Table 9.3.12 Product Class Market Shares of Compact Freezers

Year	PC16	PC17	PC18
2008	50.0%	30.0%	20.0%

9.3.4.4 Base Case Shipments

Figure 9.3.13 shows the forecasted compact freezer shipments in the base case (without new energy efficiency standards), along with the historical shipments DOE used to calibrate the forecast. The figure presents compact freezer shipments disaggregated into the modeled market segments. Figure 9.3.14 presents forecasted base case compact freezer shipments disaggregated into the product classes.

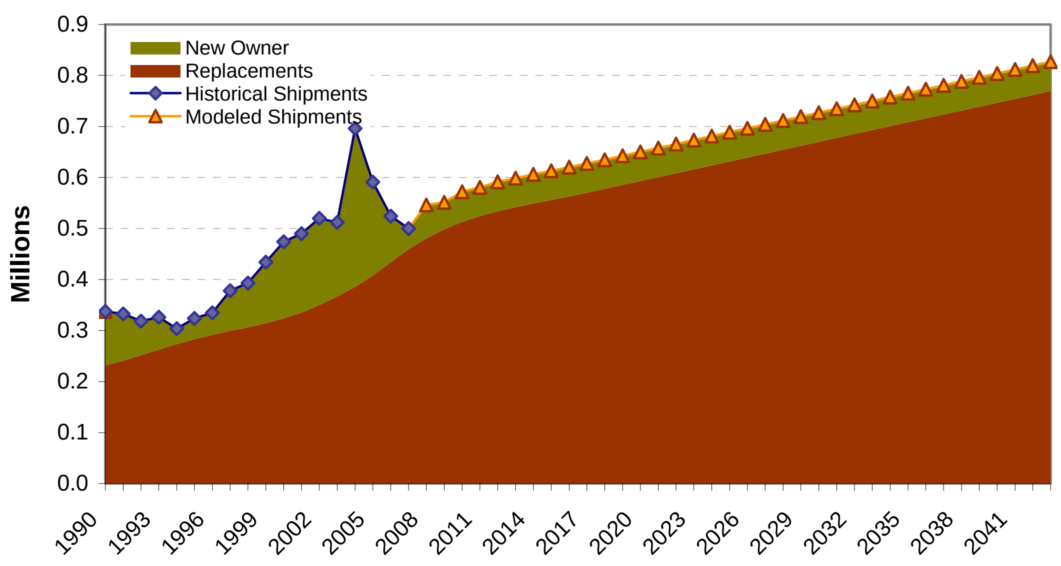

Figure 9.3.13 Compact Freezers: Historical and Base Case Shipments Forecast by Market Segment

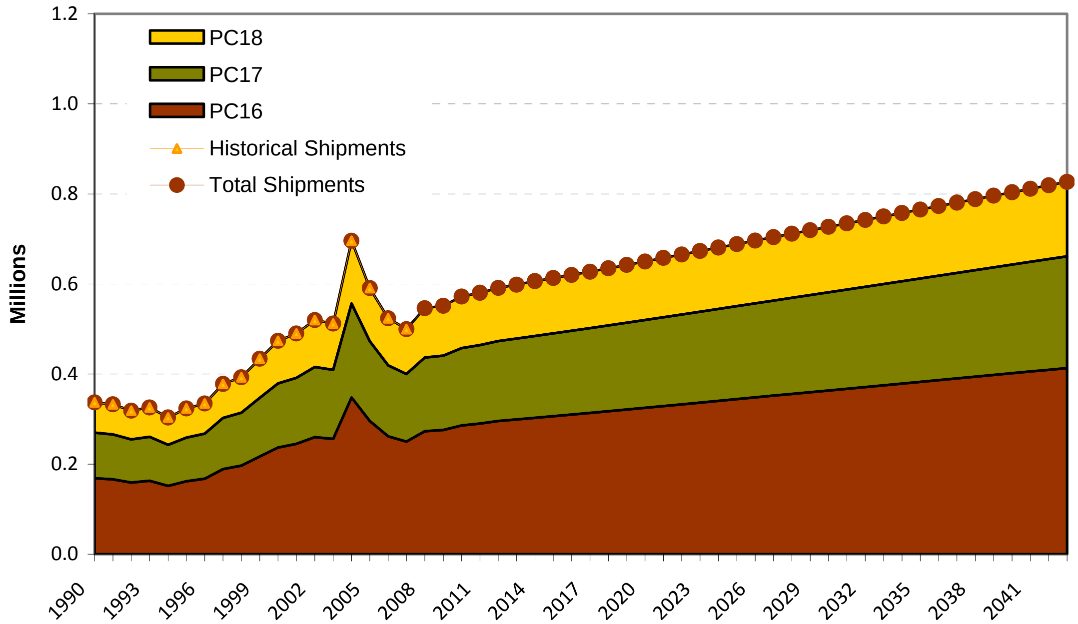

Figure 9.3.14 Compact Freezers: Base Case Shipments Forecast Disaggregated by Product Class

9.4 PURCHASE PRICE, OPERATING COST, AND HOUSEHOLD INCOME IMPACTS

DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the combined effects on product shipments from increases in product purchase price, decreases in product operating costs, and changes to household income. Appendix 9-A provides a detailed explanation of the methodology DOE used to quantify the impacts from these variables.

In the literature, DOE found only a few studies of appliance markets that are relevant to this rulemaking analysis. DOE identified no studies that use time-series data of product price and shipments data after 1980. The information that can be summarized from the literature suggests that the demand for appliances is price-inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that consumers use relatively high implicit discount rates[b] when comparing appliance prices and appliance operating costs.

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[b] A high implicit discount rate with regard to operating costs means that consumers do not put much economic value on the operating cost savings realized from more-efficient appliances. In other words, consumers are much more concerned with higher purchase prices.

DOE found insufficient data on product purchase price and operating cost to perform a thorough analysis of dynamic changes in the appliance market. Rather, it used purchase price and efficiency data specific to residential refrigerators, clothes washers, and dishwashers over the period 1980–2002 to evaluate broad market trends and conduct simple regression analyses. These data indicate that there has been a rise in appliance shipments and a decline in appliance purchase price and operating costs over the time period. Household income has also risen during this time. To simplify the analysis, DOE combined the available economic information into one variable, termed the *relative price*, and used this variable in an analysis of market trends, as well as to conduct a regression analysis. The *relative price* is defined with the following expression:

$$\boldsymbol{RP} = \frac{\boldsymbol{TP}}{\boldsymbol{Income}} = \frac{\boldsymbol{PP} + \boldsymbol{PVOC}}{\boldsymbol{Income}}$$

Where:

RP =	relative price,
TP =	total price,
Income =	household income,
PP =	appliance purchase price, and
PVOC =	present value of operating cost.

In this equation, DOE used an implicit discount rate of 37 percent to determine the present value of operating costs.

DOE's analysis of market trends suggests that the *relative price* elasticity of demand for the three appliances is relatively inelastic (i.e., under 1.0). DOE's regression analysis suggests that the *relative price* elasticity of demand, averaged over the three appliances, is -0.34. For example, a *relative price* increase of 10 percent results in a 3.4 percent decrease in shipments. Note that, because the *relative price* elasticity incorporates the impacts from three effects (i.e., purchase price, operating cost, and household income), the impact from any single effect is mitigated by changes from the other two effects. The *relative price* elasticity of -0.34 is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using simple statistical analysis. More importantly, the measure is based on an assumption that economic variables, including purchase price, operating costs, and household income, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but DOE did not account for them in this analysis. Despite these uncertainties, DOE believes that its estimate of the relative price elasticity of demand provides a reasonable assessment of the impact that purchase price, operating cost, and household income have on product shipments.

Because DOE's forecasts of shipments and national impacts due to standards is over a 30-year time period, it needed to consider how the *relative price* elasticity is affected once a new standard takes effect. DOE considered the *relative price* elasticity provided by the preceeding analysis to be a short-run value. It was unable to identify sources specific to household durable goods, such as appliances, to indicate how short-run and long-run price elasticities differ. Therefore, to estimate how the *relative price* elasticity changes over time, DOE relied on a study pertaining to automobiles.[15] This study shows that the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the purchase price change, the price elasticity becomes smaller (more inelastic) until it reaches a terminal value around the tenth year after the price change. Table 9.4.1 shows the relative change in the price elasticity of demand for automobiles over time. DOE developed a time series of *relative price* elasticities for home appliances based on the relative change in the automobile price elasticity of demand. For years not shown in Table 9.4.1, DOE performed a linear interpolation to obtain the *relative price* elasticity.

Table 9.4.1 Change in Relative Price Elasticity following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

Based on the following equation, DOE estimated standards case shipments by incorporating the impact of the *relative price* into the base case shipments forecast. Note that in this equation, the *relative price* and the *relative price* elasticity are functions of the year because both change with time.

$$\boldsymbol{Ship_{STD\_p}(j) = \left(Rpl_{BASE\_p}(j) + NI_{BASE\_p}(j) + M_{BASE\_p}(j)\right) \times \left(1 - e_{RP}(j) \times \Delta RP(j)\right)}$$

Where:

$Ship_{STD\_p}(j)$ = total shipments under the standards case of product p in year j,
$Rpl_{BASE\_p}(j)$ = units of product p under the base case retired and replaced in year j,
$NI_{BASE\_p}(j)$ = number of new construction installations under the base case of product p in year j,
$M_{BASE\_p}(j)$ = units installed in market M under the base case of product p in year j (M represents purchases for existing homes for standard-size freezers, and purchase of an additional refrigerator for standard-size refrigerators),
$e_{RP}(j)$= *relative price* elasticity in year j (equals -0.34 for year 1), and
$\Delta RP(j)$= change in *relative price* due to a standard level in year j.

9.5 AFFECTED STOCK

In addition to the forecast of product shipments under both the base case and the standards case, the affected stock is a key output of DOE's shipments models. The affected stock

(stock that is affected by a standards level) consists of those in-service units that are purchased in or after the year the standard has taken effect, as described by the following equation:

$$Aff\ Stock_p(j) = Ship_p(j) + \sum_{age=1}^{j-Std\_yr} Stock_p(age)$$

Where:

$Aff\ Stock_p(j)$ = affected stock of units of product p of all vintages that are in service in year j,
$Ship_p(j)$ = shipments of product p in year j,
$Stock_p(j)$ = stock of units of product p of all vintages that are in service in year j,
age = age of the units (years), and
Std_yr = effective date of the standard.

For the NES and NPV results presented in Chapter 10, DOE assumed that new energy efficiency standards will become effective in the year 2014. Thus, all appliances purchased starting on the first day of the year 2014 are affected by the standard level.

9.6 RESULTS

This section presents the shipments forecasts for the various standard levels that DOE considered for each of the four refrigeration product types.

Figure 9.6.1 shows the standard-size refrigerator-freezer shipment forecasts for the base case and for two standard levels for which an impact is evident. The differences between the base case and standard level shipments forecasts represent the annual shipments reductions attributable to the standard levels.

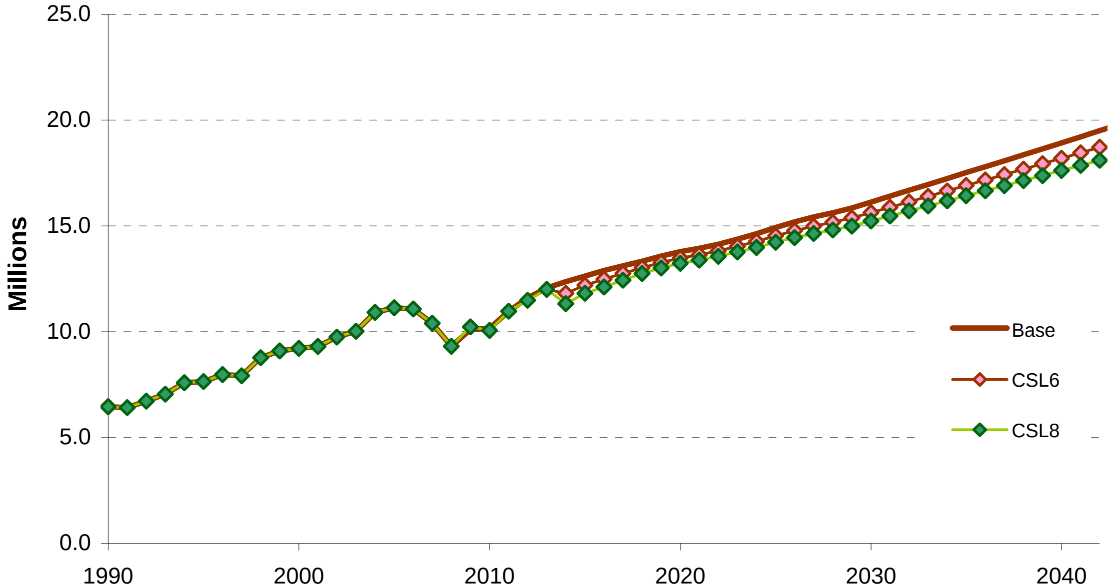

Figure 9.6.1 Standard-Size Refrigerator-Freezers: Base Case and Standards Case Shipments Forecasts

Figure 9.6.2 shows the standard-size freezer shipment forecasts for the base case and for several standard levels for which an impact is evident. The differences between the base case and standard level shipments forecasts represent the annual shipments reductions attributable to the standard levels.

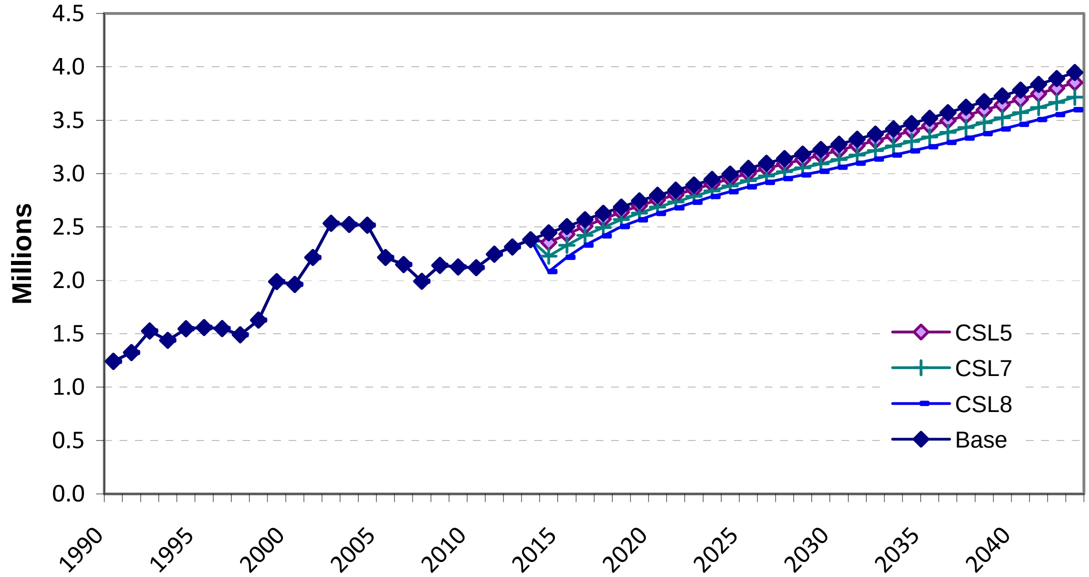

Figure 9.6.2 Standard-size Freezers: Base Case and Standards Case Shipments Forecasts

Figure 9.6.3 shows the compact refrigerator shipment forecasts for the base case and for those standard levels for which an impact is evident. The differences between the base case and standard level shipments forecasts represent the annual shipments reductions attributable to the standard levels.

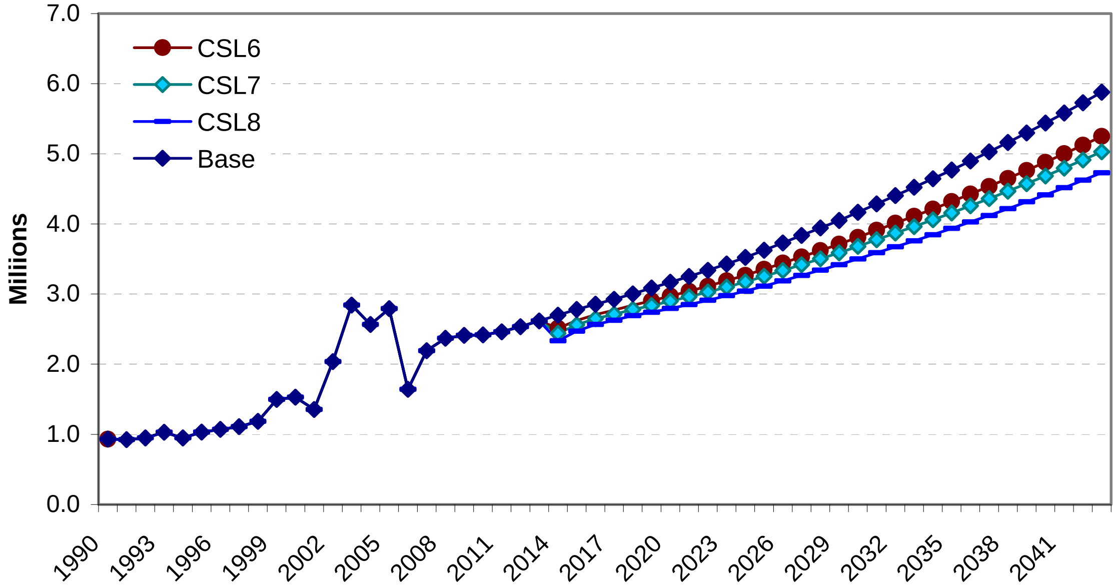

Figure 9.6.3 Compact Refrigerators: Base Case and Standards Case Shipments Forecasts

Figure 9.6.4 shows the compact freezer shipment forecasts for the base case and for selected standard levels for which an impact is evident. The differences between the base case and standard level shipments forecasts represent the annual shipments reductions attributable to the standard levels.

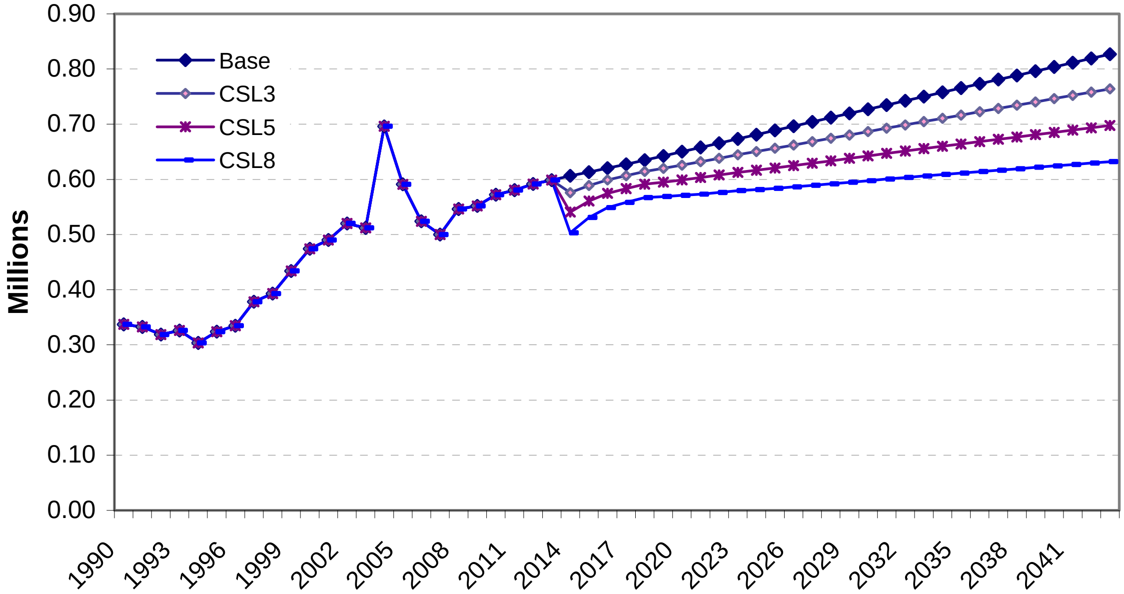

Figure 9.6.4 Compact Freezers: Base Case and Standards Case Shipments Forecasts

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[2] Statistical Review. *Appliance Magazine*, April, 1993.

[3] Statistical Review. *Appliance Magazine*, April, 1990.

[4] Statistical Review. *Appliance Magazine*, April, 1982.

[5] Association of Home Appliance Manufacturers. *AHAM 2005 Fact Book*, 2005. Washington, DC.

[6] Association of Home Appliance Manufacturers. *AHAM 2003 Fact Book*, 2003. Washington, DC.

[7] Association of Home Appliance Manufacturers. *Aggregated Refrigerator - Freezer Shipments and Efficiency Data for DOE Refrigerator - Freezer Energy Efficiency Standards Rulemaking*, January 16, 2009**.** Memo to Detlef Westphalen, Navigant Consulting, Inc.

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APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

9-A.1 INTRODUCTION

This appendix summarizes DOE's study of the price elasticity of demand for home appliances, including refrigerators, clothes washers and dishwashers. DOE chose this particular set of appliances because of the availability of data to determine a price elasticity. This appendix begins with a review of the existing economics literature describing the impact of economic variables on the sale of durable goods in section 9A.2. In section 9A.3, the market for home appliances and changes in it over the past 20 years is described. In section 9A.4, DOE summarizes the results of its regression analysis and presents estimates of the price elasticity of demand for the three appliances. In section 9A.5, DOE presents development of an 'effective' purchase price elasticity. DOE's interpretation of its results is presented in section 9A.6. Finally, section 9A.7 describes the data used in DOE's analysis.

9-A.2 LITERATURE REVIEW

There are relatively few studies measuring the impact of price, income and efficiency on the sale of household appliances. In this section DOE provides a short review of this literature which suggests the likely importance of these variables.

9-A.2.1 Price

The goal of many of the studies covered in this review is to measure the impact of price on sales in a dynamic market. One study of the automobile market prior to 1970 finds the price elasticity of demand to decline over time. The author explains this as the result of buyers delaying purchases after a price increase but eventually making the purchase (Table 9A.2.1).[1] A contrasting study of household white goods also prior to 1970, finds the elasticity of demand to increase over time as more price-conscious buyers enter the market.[2] A recent analysis of refrigerator market survey data finds that consumer purchase probability decreases with survey asking price.[3] Estimates of the price elasticity of demand for different brands of the same product tend to vary. A review of 41 studies of the impact of price on market share found the average price elasticity to be -1.75.[4] The average estimate of price elasticity of demand reported in these studies is -0.33 in the appliance market and -0.47 in the combined automobile and appliance markets.

9-A.2.2 Income

Higher income households are more likely to own household appliances.[5] The impact of income on appliance shipments is explored in two econometric studies of the automobile and appliance markets. [1,2] The average income elasticity of demand is 0.50 in the appliance study cited in the literature review, much larger in the automobile study (Table 9.A.2.1).

9-A.2.3 Appliance Efficiency and Discount Rates

Many studies estimate the impact of appliance efficiency on consumer appliance choice. Typically, this impact is summarized by the implicit discount rate, i.e., the rate consumers use to compare future appliance operating cost savings against an appliance purchase price premium. One early and much cited study concludes that consumers use a 20 percent implicit discount rate when purchasing room air conditioners (Table 9A.2.1).[6] A survey of several studies of different appliances suggests that the consumer implicit discount rate has a broad range and averages about 37 percent.[7]

Table 9-A.2.1 Estimates of the Impact of Price, Income and Efficiency on Automobile and Appliance Sales

Durable Good	Price Elasticity	Income Elasticity	Brand Price Elasticity	Implicit Discount Rate	Model	Data Years	Time Period
Automobiles[1]	-1.07	3.08	-	-	Linear Regression, stock adjustment	-	Short run
Automobiles[1]	-0.36	1.02	-	-	Linear Regression, stock adjustment	-	Long run
Clothes Dryers[2]	-0.14	0.26	-	-	Cobb-Douglas, diffusion	1947-1961	Mixed
Room Air Conditioners[2]	-0.37[8]	0.45	-	-	Cobb-Douglas, diffusion	1946-1962	Mixed
Dishwashers[2]	-0.42	0.79	-	-	Cobb-Douglas, diffusion	1947-1968	Mixed
Refrigerators[3]	-0.37	-	-	39%	Logit probability, survey data	1997	Short run
Various[4]	-	-	-1.76[9]	-	Multiplicative regression	-	Mixed
Room Air Conditioners[5]	-	-	-1.72	-	Non-linear diffusion	1949-1961	Short run
Clothes Dryers[5]	-	-	-1.32	-	Non-linear diffusion	1963-1970	Short run
Room Air Conditioners[6]	-	-	-	20%	Qualitative choice, survey data	-	-
Household Appliances[7]	-	-	-	37%[10]	Assorted	-	-

Sources: [1] S. Hymens. 1971; [2] P. Golder and G. Tellis, 1998; [3] D. Revelt and K. Train, 1997; [4] G. Tellis, 1988; [5] D. Jain and R. Rao; [6] J. Hausman; [7] K. Train, 1985.

Notes: [8] Logit probability results are not directly comparable to other elasticity estimates in this table.
[9] Average brand price elasticity across 41 studies.
[10] Averaged across several household appliance studies referenced in this work.

9-A.3 VARIABLES DESCRIBING THE MARKET FOR REFRIGERATORS, CLOTHES WASHERS, AND DISHWASHERS

In this section DOE evaluates variables that appear to account for refrigerator, clothes washer and dishwasher shipments, including physical household/appliance variables, and economic variables.

9-A.3.4 Physical Household/Appliance Variables

Several variables influence the sale of refrigerators, clothes washers and dishwashers. The most important for explaining appliance sales trends are the annual number of new households formed (housing starts) and the number of appliances reaching the end of their operating life (replacements). Housing starts influence sales because new homes are often provided with, or soon receive, new appliances, including dishwashers and refrigerators. Replacements are correlated with sales because new appliances are typically purchased when old ones wear out. In principle, if households maintain a fixed number of appliances, shipments should equal housing starts plus appliance replacements.

9-A.3.5 Economic variables

Appliance price, appliance operating cost and household income are important economic variables affecting shipments. Low prices and costs encourage household appliance purchases and a rise in income increases householder ability to purchase appliances. In principle, changes in economic variables should explain changes in the number of appliances per household.

During the 1980–2002 study period, annual shipments grew 69 percent for clothes washers, 81 percent for refrigerators and 105 percent for dishwashers (Table 9A.3.1). This rising shipments trend is explained in part by housing starts, which increased 6 percent and by appliance replacements, which rose between 49 percent and 90 percent, depending on the appliance, over the period (Table 9A.3.1).[a] For mature markets such as these, replacements exceed appliance sales associated with new housing construction.

Table 9-A.3.1 Physical Household/Appliance Variables

	Shipments[1] (millions)			Housing Starts[2] (millions)			Replacements[3] (millions)		
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**
Refrigerators	5.124	9.264	81%	1.723	1.822	6%	3.93	5.84	49%
Clothes Washers	4.426	7.492	69%	1.723	1.822	6%	3.66	5.50	50%
Dishwashers	2.738	5.605	105%	1.723	1.822	6%	1.99	3.79	90%

[1]Shipments: Number of units sold. **Sources:** AHAM Fact Book and Appliance Magazine.
[2]Housing Starts: Annual number of new homes constructed. **Source:** U.S. Census.
[3]Replacements: Average of annual lagged shipments, with lag equal to expected appliance operating life, ± 5 years.

Nevertheless, it is apparent that appliance shipments increased somewhat more rapidly than housing starts and replacements. This is shown by comparing the beginning and end points of lines representing "starts plus replacements" (uppermost solid line in Figure 9A.3.1) and "shipments" (diamond linked line in Figure 9A.3.1). In 1980 the "shipment" line begins below the "starts plus replacements" line. In 2002, the "shipments" line ends above the "starts plus replacements" line. This more rapid increase in shipments, compared to housing starts plus replacements, suggests that the appliance per household ratio increased over the study period.

[a] Appliance replacements are determined from the expected operating life of refrigerators (19 years), clothes washers (14 years), and dishwashers (12 years) and from past shipments. Replacements are further discussed in section 9A.3.

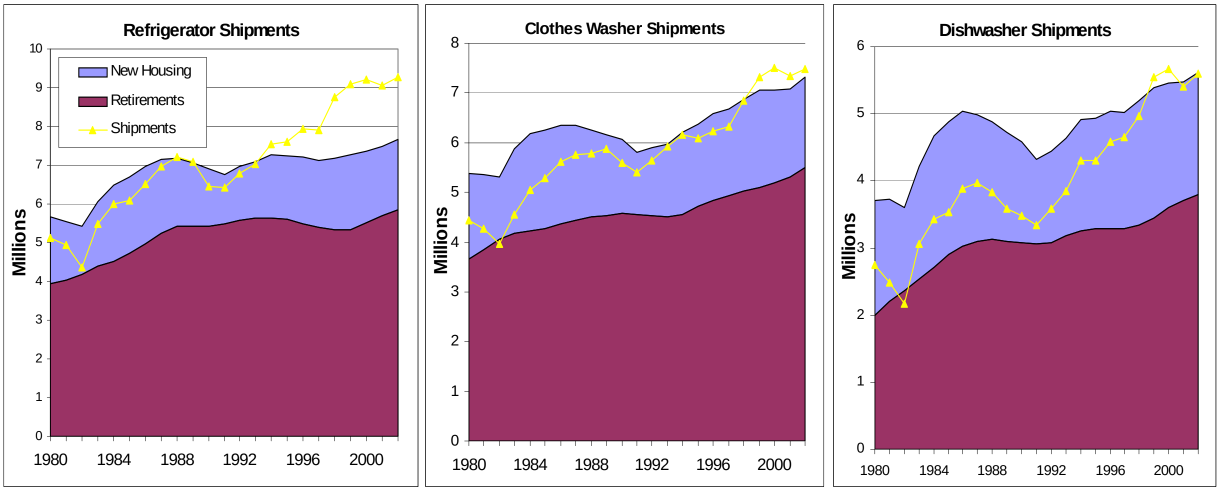

Figure 9-A.3.1 Trends in Appliance Shipment, Housing Starts and Replacements

Economic variables, including price, cost and income, may explain this increase in appliances per household. Over the period, appliance prices decreased 40 percent to 50 percent, operating costs fell between 33 percent and 72 percent, and median household income rose 16 percent (Table 9A.3.2).

Table 9-A.3.2 Economic Variables

	Price[1] (1999$)			Operating Cost[2] (1999$)			Household Income[3] (1999$)		
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**
Refrigerators	1208	726	-40%	333	94	-72%	37,447	43,381	16%
Clothes Washers	779	392	-50%	262	175	-33%	37,447	43,381	16%
Dishwashers	713	369	-48%	183	95	-48%	37,447	43,381	16%

[1]Price: Shipment weighted retail sales price. **Sources:** AHAM Fact Book and Appliance Magazine.
[2]Operating Cost: Annual electricity price times electricity consumption. **Source:** AHAM Fact Book.
[3]Income: Mean Household income. **Source:** U.S. Census.

9-A.4 REGRESSION ANALYSIS OF VARIABLES AFFECTING APPLIANCE SHIPMENTS

Little data is available for estimating the impact of economic variables on the demand for appliances. Industry operating cost data is incomplete—appliance energy use data is available for only 12 years of the 1980-2002 study period. Industry price data is also incomplete—available for only 8 years of the study period for each of the appliances.

The lack of data suggests that regression analysis can at best evaluate broad data trends, utilizing relatively few explanatory variables. This section begins by describing broad trends apparent in the economic and physical household data sets and then specifies a simple regression model to measure these trends, making assumptions to minimize the number of explanatory variables. Finally, results are presented of the regression analysis and the estimate of the price elasticity of demand for appliances. In this section (specifically section 9A.4.5), DOE also presents the results of regression analysis performed with more complex models, and used to test assumptions made to specify the simple model. These results support the simple model specification, and estimates of the price elasticity of appliance demand measured with that model.

9-A.4.1 Broad Trends

In this section DOE reviews trends in the physical household and economic data sets and posit a simple approach for estimating the price elasticity of appliance demand. As noted above, the physical household variables (starts and appliance replacements), explain most of the variability in appliance shipments over the period.[b] DOE assumes the rest of the variability in shipments (referred to as "residual shipments") is explained by economic variables, and present a tabular method for measuring price elasticities described below.

To illustrate this tabular approach, DOE defines two new variables—residual shipments and total price. Residual shipments are defined as the difference between shipments and physical household demand (starts plus replacements). Total price, represented by the following equation, is defined as appliance price plus the present value of lifetime appliance operating cost:[c]

$$\boldsymbol{TP = PP + PVOC}$$

where:

TP =	Total price,
PP =	Appliance purchase price, and
PVOC =	Present value of operating cost.

Over the study period, residual shipments increase 30 percent for refrigerators, 19 percent for clothes washers, and 23 percent for dishwashers in proportion to total shipments. At the same time, total prices decline 47 percent, 45 percent and 48 percent for refrigerators, clothes washers, and dishwashers, respectively. Assuming that total price explains the entire change in per household appliance usage, a rough estimate is calculated of the total price elasticity of demand equal to -0.48 for refrigerators, -0.32 for clothes washers and -0.37 for dishwashers (Table 9A.4.1).

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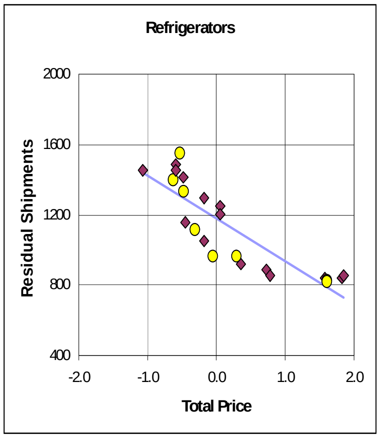
[b] A log regression of the form: Shipments = a + b • Housing Starts + c • Retirements, indicates that these two variables explain 89 percent of the variation in refrigerator shipments, 97 percent of the variation in clothes washer shipments, and 97 percent of the variation in dishwasher shipments.

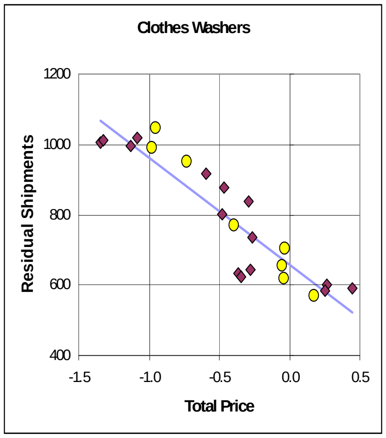
[c] Present value operating cost is calculated assuming a 19 year operating life for refrigerators, 14 year operating life for clothes washers, and a 12 year operating life for dishwashers. A 37 percent discount rate is used to sum annual operating costs into a present value operating cost.

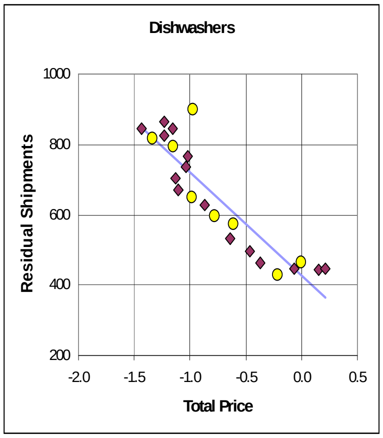
Table 9-A.4.1 Simple Estimate of Total Price Elasticity of Demand

	Residual Shipments (millions)				Total Price (199$)			
Appliance	**1980**	**2002**	**Difference**	**Change**	**1980**	**2002**	**Change**	**Elasticity**
Refrigerators	-0.5	1.6	2.1	30%	1541	820	-61%	-0.48
Clothes Washers	-1.0	0.2	1.1	19%	1042	567	-59%	-0.32
Dishwashers	-1.0	-0.01	1.0	23%	896	464	-64%	-0.37

The negative correlation between total price and residual shipments suggested by these negative price elasticities is illustrated in a graph of residual shipments on the y-axis and total price on the x-axis (Figure 9A.4.1).







Yellow points are observed price data; red points are interpolated price data.

Figure 9-A.4.1 Residual Shipments and Appliance Price

Household income rose during the study period, making it easier for households to purchase appliances. Assuming that a rise in income has a similar impact on shipments as a decline in price, the impact of income is incorporated by defining a third variable, termed *relative* price, calculated as total price divided by household income and represented by the following equation:[d]

$$RP = \frac{TP}{Income}$$

where:

RP = Relative price,
TP = Total price, and
Income = Household income.

[d] Recall that the income elasticity of demand cited in the literature review is 0.50 and the price elasticity of demand cited in the review averages -0.35. This suggests that combining the effects of income and price will yield an elasticity less negative than price elasticity alone.

The percent decline in *relative* price for the three appliances divided by the percent decline in residual shipments suggests a rough estimate of *relative* price elasticity equal to -0.40 for refrigerators, -0.26 for clothes washers and -0.30 for dishwashers (Table 9A.4.2).

Table 9-A.4.2 Tabular Estimate of Relative Price Elasticity of Appliance Demand

	Residual Shipments (millions)			Relative Price (1999$)			
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**Elasticity**
Refrigerators	-0.532	1.597	30%	0.041	0.019	-74%	-0.40
Clothes Washers	-0.953	0.174	19%	0.028	0.013	-72%	-0.26
Dishwashers	-0.974	-0.005	23%	0.024	0.011	-76%	-0.30

9-A.4.2 Model Specification

The limited price data suggests using a simple regression model to estimate the impact of economic variables on shipments, using few explanatory variables. The following equation chosen for this analysis includes one physical household variable (starts plus replacements) and one *relative* price variable (the sum of purchase price plus operating cost, divided by income).

$$\boldsymbol{Ship} = \boldsymbol{a} + \boldsymbol{b} \times \boldsymbol{RP} + \boldsymbol{c} \times \lfloor \boldsymbol{Starts} + \boldsymbol{Rplc} \rfloor \qquad \textbf{Eq. 9A.1}$$

where:

Ship = Quantity of appliance sold,
RP = Relative price,
Starts = Number of new homes, and
Rplc = Number of appliances at the end of their operating life.

The natural logs are taken of all variables so that the estimated coefficients for each variable in the model may be interpreted as the percent change in shipments associated with the percent change in the variable. Thus, the coefficient b in this model is interpreted as the *relative* price elasticity of demand for the three appliances.

The following combined regression equation is used to estimate an average price elasticity of demand across the three appliances, using pooled data in a single regression. A combined regression specification is justified, given limited data availability and similarity in price and shipment behavior across appliances (see Figure 9A.4.1). Thus, the model represented by the combined regression equation is considered the basic model in DOE's analysis of appliance shipments.

$$\boldsymbol{Ship} = \boldsymbol{a} + \boldsymbol{b} \times \boldsymbol{RP} + \boldsymbol{c} \times \lfloor \boldsymbol{Starts} + \boldsymbol{Rplc} \rfloor + \boldsymbol{d} \times \boldsymbol{CW} + \boldsymbol{e} \times \boldsymbol{DW} \qquad \textbf{Eq. 9A.2}$$

where:

CW = Quantity of clothes washers sold, and
DW = Quantify of dishwashers sold.

9-A.4.3 Model Discussion

The most important assumption used to specify this model is that changes in economic variables over the study period—income, price, and operating cost—are responsible for all observed growth in residual appliance shipments. In other words, DOE assumes other possible explanations, such as changing consumer preferences and increases in the quality of appliances—had no impact. This assumption seems unlikely but without additional data, the impact of this assumption on the price elasticity of demand cannot be measured. DOE effectively assumes that changes in consumer preferences and appliance characteristics, while affecting which specific models are purchased, have relatively little impact on the total number of appliances purchased in a year.

Three additional assumptions used to specify this model deserve comment. The *relative* price variable is specified in the model, assuming that (1) the correct implicit discount rate is used to combine appliance price and operating cost and that (2) rising income has the same impact on shipments as falling total price. The “starts + replacements” variable is specified, assuming (3) that starts and replacements have similar impacts on shipments.

To investigate the first assumption about discount rates, DOE calculated “present value operating cost” using a 20 percent implicit discount rate and performed a second regression analysis based on the models described in equations. 9A.1 and 9A.2. The results of this analysis, presented in section 9A.4.5, indicate that the elasticity of *relative* price is relatively insensitive to changes in the discount rate.

To investigate the second and third assumptions, DOE specified a regression model separating income from total price and replacements from starts, thus adding two additional explanatory variables to the basic model as shown in the following equation:

$$\boldsymbol{Ship} = \boldsymbol{a} + \boldsymbol{b} \times \boldsymbol{TP} + \boldsymbol{c} \times \boldsymbol{Incone} + \boldsymbol{d} \times \boldsymbol{Start} + \boldsymbol{e} \times \boldsymbol{Rplc} + \boldsymbol{f} \times \boldsymbol{CW} + \boldsymbol{g} \times \boldsymbol{DW} \qquad \textbf{Eq. 9A.3}$$

The results of the regression analysis of this model are also presented in section 9A.4.5. These results suggest that the elasticity of total price (coefficient b) is relatively insensitive to changes in the treatment of income and “starts + replacements” in the model.

9-A.4.4 Analysis Results

9A.4.4.1 Individual Appliance Model

The individual appliance regression equations are specified as followed (as shown earlier as Eq. 9A.1):

$$\boldsymbol{Ship} = \boldsymbol{a} + \boldsymbol{b} \times \boldsymbol{RP} + \boldsymbol{c} \times \lfloor \boldsymbol{Starts} + \boldsymbol{Rplc} \rfloor$$

In regression analysis of this model, the elasticity of *relative* price (b) is estimated to be

-0.40 for refrigerators, -0.31 for clothes washers and -0.32 for dishwashers (Table 9A.4.3), averaging -0.35. These elasticities are similar to those reported in the literature survey for appliances (Table 9A.2.1). They are remarkably similar to the price elasticity calculated using a tabular approach presented above (Table 9A.4.2).

The estimated coefficient associated with the "starts + replacements" variable is close to one. A coefficient equal to one for this variable would imply that shipments increase in direct proportion to an increase in "starts + replacements", holding economic variables constant. The high R squared values (above 95) and t statistics (above 5) in the results provide a measure of confidence in this analysis, despite the very small data set.

Table 9-A.4.3 Individual Appliance Model Results

	Refrigerator		Clothes Washer		Dishwasher	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Intercept	-1.51	-7.26	-1.47	-8.23	-2.08	-16.78
Relative Price	-0.40	-6.60	-0.31	-5.69	-0.32	-7.03
Starts + Replacements	1.05	5.90	1.08	6.41	1.35	11.46
R^2	0.954		0.954		0.975	
Observations	23		23		23	

9A.4.4.2 Combined Appliance Model

The combined appliance regression equation is specified as follows (as shown earlier as Eq. 9A.2):

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor + d \times CW + e \times DW}$$

This regression analysis indicates that the model fits the existing shipments data well (high R squared) and that the variables included in the model are statistically significant (Table 9A.4.4). The elasticity of *relative* price estimated with this model is -0.34, close to the average value estimated in the individual appliance models (-0.35). It is also similar to elasticity estimates reported in the literature survey and calculated using the tabular approach above.

Table 9-A.4.4 Combined Appliance Model Result

Variable	**Coefficient**	**t-stat**
Intercept	-1.60	-15.54
Relative Price	-0.34	-10.74
Starts + Replacements	1.21	13.95
CW	-0.20	-9.04
DW	-0.32	-6.58
R^2	0.983	
Observations	69	

9-A.4.5 Additional Regression Specifications and Results

As described above in section 9A.4.3, DOE used three assumptions to specify its appliance models. The first is that the implicit price variable in the basic regression model is specified using a 37 percent implicit discount rate, to aggregate appliance price and operating cost. The second states that the implicit price variable is defined assuming that rising income has the same impact on shipments as falling total price. The third states that the "starts + replacements" variable is defined assuming that housing starts have a similar impact on shipments as appliance replacements.

9A.4.5.1 Lower Consumer Discount Rate

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20 percent implicit discount rate and performed a second regression analysis based on the models described in equations 9A.1 and 9A.2. The estimated coefficient associated with the *relative* price variable in these regressions is almost identical to the coefficients estimated for same variable reported above using a 37 percent implicit discount rate. The elasticity of *relative* price calculated using a 20 percent discount rate is -0.33 in the combined regression and averages -0.35 for the three appliances (Table 9A.4.5). The elasticity of price calculated using a 37 percent discount rate is -0.34 in the combined regression and averages -0.35 for the three appliances. DOE concludes from this analysis that the elasticity of *relative* price is relatively insensitive to changes in the discount rate.

Table 9-A.4.5 Combined and Individual Results, 20 percent discount rate

Three Appliances Variable	Coefficient	t-Stat
Intercept	-1.53	-14.61
Total Price / Income	-0.33	-10.69
Starts + Retirements	1.20	13.65
CW	-0.18	-8.69
DW	-0.32	-6.57
R^2	0.982	
Observations	69	

Variable	Refrigerator Coefficient	t-Stat	Clothes Washers Coefficient	t-Stat	Dishwasher Coefficient	t-Stat
Intercept	-1.36	-6.26	-1.41	-7.49	-2.04	-17.23
Total Price / Income	-0.38	-6.50	-0.32	-5.29	-0.33	-7.30
Starts + Retirements	1.04	5.73	1.06	5.83	1.34	11.64
R^2		0.953		0.950		0.977
Observations		23		23		23

9A.4.5.2 Disaggregated Variables

To investigate the second and third assumptions, DOE constructed a regression model separating income from total price and replacements from starts, thus adding two additional explanatory variables to the basic model (as shown earlier as Eq. 9A.3).

$$Ship = a + b \times TP + c \times Incone + d \times Start + e \times Rplc + f \times CW + g \times DW$$

The estimated coefficient associated with the total price variable in these regressions is almost identical to the coefficients estimated for the *relative* price variable reported above. The elasticity of total price in the above equation is -0.36 in the combined appliance regression and averages -0.35 for the three appliances (Table 9A.4.6). The elasticity of *relative* price based on the model described in equation 9A.2 is -0.34 in the combined regression (Table 9A.4.4) and averages -0.35 across the individual appliances (Table 9A.4.3). DOE concludes that the price elasticity calculated in this analysis is relatively insensitive to the specification of household income and "starts + replacements" variables in the model.

Table 9-A.4.6 Disaggregated Regression Results, 37 percent discount rate

Three Appliances		
Variable	**Coefficient**	**t-Stat**
Intercept	-2.92	-1.26
Income	0.58	2.92
Total Price	-0.36	-7.06
Housing Starts	0.44	10.02
Retirements	0.62	8.12
CW	-0.24	-9.25
DW	-0.46	-7.68
R^2		0.985
Observations		69

	Refrigerator		**Clothes Washers**		**Dishwasher**	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Intercept	-6.19	-2.24	-6.64	-1.63	1.00	0.23
Income	0.89	3.80	0.87	2.31	0.20	0.52
Total Price	-0.35	-5.48	-0.27	-2.51	-0.43	-5.18
Housing Starts	0.41	7.38	0.25	3.29	0.62	8.24
Retirements	0.56	6.06	0.56	2.09	0.65	5.86
R^2		0.984		0.958		0.979
Observations		23		23		23

9-A.5 LONG RUN IMPACTS

As noted above in Table 9A.2.1 in section 9A.2, the literature review provides price elasticities over short and long time periods, also referred to as short run and long run price elasticities. As noted in the first two rows of Table 9A.2.1, one source (i.e., Hymans) shows that the price elasticity of demand is significantly different over the short run and long run for automobiles.[1] Because DOE's forecasts of shipments and national impacts due to standards is over a 30-year time period, consideration must be given as to how the *relative* price elasticity is affected once a new standard takes effect.

DOE considers the *relative* price elasticities determined above in section 9A.4 to be short run elastcities. DOE was unable to identify sources specific to household durable goods, such as appliances, to indicate how short run and long run price elasticities differ. Therefore, to estimate how the *relative* price elasticity changes over time, DOE relied on the Hymans study pertaining to automobiles. Based on the Hymans study, Table 9A.5.1 shows how the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the price change, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change.

Table 9-A.5.1 Change in Price Elasticity of Demand for Automobiles following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Price Elasticity of Demand	-1.20	-0.93	-0.75	-0.55	-0.42	-0.40
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33

Source: Hymans, 1971.

Based on the relative change in the automobile price elasticity of demand shown in Table 9A.5.1, DOE developed a time series of *relative* price elasticities for home appliances. Table 9A.5.2 presents the time series.

Table 9-A.5.2 Change in *Relative* Price Elasticity for Home Appliances following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

9-A.6 SUMMARY

This appendix describes the results of a literature search, tabular analysis and regression analysis of the impact of price and other variables on appliance shipments. In the literature, DOE finds only a few studies of appliance markets that are relevant to this analysis, and no studies using time series price and shipments data after 1980. The information that can be summarized from the literature, suggests that the demand for appliances is price inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that consumers use relatively high implicit discount rates, when comparing appliance prices and appliance operating costs.

There is not enough price and operating cost data available to perform complex analysis of dynamic changes in the appliance market. In this analysis, DOE uses data available for refrigerators, clothes washers and dishwashers to evaluate broad market trends and to perform simple regression analysis.

These data indicate that there has been a rise in appliance shipments and a decline in appliance price and operating cost over the period. Household income has also risen during this time. To simplify the analysis, DOE combined the available economic information into one variable, termed *relative* price, and used this variable in a tabular analysis of market trends, and a regression analysis.

DOE's tabular analysis of trends in the number of appliances per household suggests that the price elasticity of demand for the three appliances is inelastic. Our regression analysis of these same variables suggests that the *relative* price elasticity of demand is -0.34. The price elasticity is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using very simple statistical analysis. More important, the measure is based on an assumption that economic variables, including price, income and operating costs, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but they are not accounted for in this analysis.

9-A.7 DATA USED IN THE ANALYSIS

- **Appliance Shipments:** Shipments are defined as the annual number of units shipped in millions. These data were collected from the Association of Home Appliance Manufacturers (AHAM)[8] and Appliance Magazine[9] as annual values for each year, 1980–2002. AHAM was used for the period 1989–2002 while Appliance Magazine was used for the period 1980–1988.

- **Appliance Price:** Price is defined as the shipments weighted retail sales price of the unit in 1999 dollars. Price values for 1980, 1985, 1986, 1991, 1993, 1994, 1998, and 2002 were collected from AHAM Fact Books.[10] Price values for other years were interpolated from these eight years of data.

- **Housing Starts:** Housing starts data were collected from U.S. Census construction statistics (C25 reports) as annual values for each year, 1980–2002.[11]

- **Replacements:** Retirement-driven replacements are estimated with the assumption that some fraction of sales arise from consumers replacing equipment at the end of its useful life. Since each appliance has a different expected lifespan (19 years for refrigerators[12], 14 years for clothes washers[13], 12 years for dishwashers[14]), replacements are calculated differently for each appliance type. Replacements are estimated as the average of shipments 14–24 years previous for refrigerators, 9–19 years previous for clothes washers, and 7–17 years previous for dishwashers. Historical shipments data were collected from AHAM and Appliance Magazine.

- **Annual Electricity Consumption:** Electricity Use (UEC) is defined as the energy consumption of the unit in kilowatt-hours. Electricity consumption is dependent on appliance capacity and efficiency. These data were provided by AHAM for 1980, 1990–1997 and 1999–2002.[15] Data were interpolated in the years for which data were not available.

- **Operating Cost:** Operating Cost is the present value of the electricity consumption of an appliance over its expected lifespan. The lifespans of refrigerators, clothes washers and dishwashers are assumed to be 19, 14, and 12 years respectively. Discount rates of 20 percent[6] and 37 percent[16] were used, producing similar estimates of price elasticity. A study by Hausman recommended a discount rate of "about 20 percent" in its introduction, and presented results ranging from 24.1 percent to 29 percent based on his calculations for room air conditioners. A study by Train suggests a range of implicit discount rates averaging 35 percent for appliances.

- **Income:** Median annual household income in 2003 dollars. This data was collected for each year, 1980–2002, from Table H-6 of the U.S. Census.[17]

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CHAPTER 10: NATIONAL IMPACT ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 10. NATIONAL IMPACT ANALYSIS

10.1 INTRODUCTION

This chapter describes the method the U.S. Department of Energy (DOE) used to estimate the national impacts of candidate standard levels for residential refrigeration products. DOE evaluated the following impacts: (1) national energy savings (NES) attributable to each possible standard, (2) monetary value of those energy savings to consumers of the considered products, (3) increased total installed cost of the products because of standards, and (4) net present value (NPV) of energy savings (the difference between the value of energy savings and increased total installed cost).

DOE determined both the NES and NPV for all the efficiency levels considered for new standards for residential refrigeration products. DOE performed all calculations for each considered product using a Microsoft Excel spreadsheet model, which is accessible on the Internet. <www.eere.energy.gov/buildings/appliance_standards/> The spreadsheets, which implement the National Impact Analysis (NIA) model, combine the calculations for determining the NES and NPV for each considered product with input from the appropriate shipments model. Details and instructions for using the NIA model are provided in appendix 10-A.

Chapter 9 provides a detailed description of the shipments models that DOE used to forecast future purchases of the considered products. Chapter 9 includes detailed descriptions of consumers' sensitivities to total installed cost, operating cost, and income, and how DOE captured those sensitivities within the model.

Throughout its analysis, DOE studied seven product classes in detail. For the National Impact Analysis, each of these classes represents a product category which also contains other product classes. DOE assigned each of the twenty product classes to one of these seven product categories. The following list indicates which product classes are associated with each product category:

- Top-mount refrigerator-freezers: product classes 1, 1A, 2, 3, 3A, and 6; represented by product class 3.
- Bottom-mount refrigerator-freezers: product classes 5 and 5A; represented by product class 5.
- Side-by-side refrigerator-freezers: product classes 4 and 7; represented by product class 7.
- Upright freezers: product class 9 only.
- Chest freezers: product classes 8[a], 10, and 10A; represented by product class 10.

[a] Product class 8, "upright freezers with manual defrost" is analyzed as part of the "chest freezer" category because products in this class are much more technologically similar to chest freezers.

- Compact refrigerators: product classes 11, 11A, 12, 13, 13A, 14, and 15; represented by product class 11.
- Compact freezers: product classes 16, 17, and 18; represented by product class 18.

To estimate the national impacts of new standards for all the product classes considered in this rulemaking, DOE allocated the product cost and annual energy consumption of each representative product class to all product classes within its category.

10.2 FORECASTED EFFICIENCIES FOR BASE AND STANDARDS CASES

This section describes the method DOE used to forecast the energy efficiencies of considered products under the base case and each of the potential standards cases. It provides efficiency distributions for all product classes of standard-size refrigerator-freezers, standard-size freezers, and compact refrigerators and freezers.

10.2.1 Method and Assumptions

A key factor in estimating NES and NPV is the trend in energy efficiency forecasted for the base case (without new standards) and each of the standards cases. In calculating the NES, per-unit annual energy consumption is a direct function of product efficiency. For the NPV, two inputs, the per-unit total installed cost and the per-unit annual operating cost, depend on efficiency. The first input, the per-unit total installed cost, is a direct function of efficiency. The per-unit annual operating cost, because it is a function of the per-unit annual consumption, is indirectly dependent on product efficiency.

For each product class considered for new standards, DOE determined the distribution of product efficiencies in the marketplace in 2007 based on data submitted by the Association of Home Appliance Manufacturers (AHAM).[1] Using the 2007 efficiency distribution as a starting point, DOE developed a base-case efficiency distribution based on certain assumptions regarding future trends. DOE assumed that increases in efficiency are driven largely by the ENERGY STAR program and the consumer incentives available for ENERGY STAR appliances. DOE evaluated the historical trends in energy use by refrigeration products, as reported in the AHAM *Fact Book* 2005[2] (as well as data provided by AHAM for 2006 and 2007[1]). Based on the AHAM information, DOE concluded that the roughly constant energy use per appliance observed between 2001 and 2007 reflected the growing market share for larger appliances and product classes that use more energy, such as side-mount refrigerator-freezers, balanced by an increasing market share for ENERGY STAR appliances.

The requirements for meeting ENERGY STAR qualification were changed on April 1, 2008, for standard-size refrigerator-freezers, but remained the same for standard-size freezers and compact products.[3] DOE assumed that the market for standard-size refrigerators will shift toward greater efficiency between 2007 and 2014 (the assumed effective date of a new standard) in response to the change in ENERGY STAR requirements. In particular, DOE assumed (for all product classes) that the percentage of shipments that meet the new ENERGY STAR criteria will be the same in 2014 as it was in 2007. For standard-size freezers and all compact products, DOE assumed no change in the distribution of efficiencies before 2014. For standard-size refrigerator-freezers, DOE assumed that the market share of products that qualified for the ENERGY STAR label in 2007 but could not meet the 2008 criteria, gradually will shift to meet the new criteria, resulting in the same market share for ENERGY STAR refrigeration products in 2014 as in 2007. For product class 3, for example, the ENERGY STAR market share in 2007 was 13.4 percent. The assumed market share in 2014 (under the new criteria) also is 13.4 percent (see Table 10.2.1).

Base case. For the base-case scenario, DOE assumed that the ENERGY STAR requirements for all product classes will become more stringent in 2014 than in 2008, if there were no revised standards. This assumption reflects the view that, in the absence of DOE standards, the ENERGY STAR program (and or other federal or State programs) would feel compelled to increase promotion of higher-efficiency refrigeration products. DOE assumed that energy use by ENERGY STAR products would be required to be 25 percent, rather than 20 percent, lower than the standard for standard-size refrigerator-freezers and compact products, and 15 percent, rather than 10 percent lower for standard-size freezers. DOE then assumed that the ENERGY STAR market shares in 2021, under the new qualification criteria, would equal the ENERGY STAR market shares in 2007. Finally, DOE assumed that the efficiency distributions would be fixed from 2021 until the end of the forecast period (30 years after the assumed effective date of 2014).

Table 10.2.1 shows the market shares of product efficiencies that DOE projected for standard-size refrigerator-freezers in 2007, 2014, and 2021. The table also lists the shipment-weighted energy use factor (SWEUF) for each product class for those years. The distributions for product classes of freezers and compact models are not projected to change between 2007 and 2014, but are projected to change between 2014 and 2021 in response to assumed ENERGY STAR requirements (Tables 10.2.2 and 10.2.3).

Table 10.2.1 Standard-Size Refrigerator-Freezers: Base-Case Efficiency Distributions

Energy Use Factor	Top-Mount Refrigerator-Freezers *(market share in %)*			Bottom-Mount Refrigerator-Freezers *(market share in %)*			Side-by-Side Refrigerator-Freezers *(market share in %)*		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**	**2007**	**2014**	**2021**
1.0	80.7	80.7	80.7	11.8	11.8	11.8	25.0	25.0	25.0
0.90	5.9	5.9	5.9	0.1	0.1	0.1	43.0	43.0	43.0
0.85	13.2	0.0	0.0	69.8	0.0	0.0	30.3	0.0	0.0
0.80*	0.2	13.4	0.0	18.3	88.1	0.0	1.7	32.0	0.0
0.75	0.0	0.0	13.4	0.0	0.0	88.1	0.0	0.0	32.0
0.70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.55	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-
SWEUF	0.974	0.967	0.961	0.859	0.824	0.780	0.908	0.893	0.877

* Meets 2008 ENERGY STAR criteria.

Table 10.2.2 Standard-Size Freezers: Base-Case Efficiency Distributions

Energy Use Factor	Upright Freezers *(market share in %)*			Chest Freezers *(market share in %)*		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**
1.0	81.5	81.5	81.5	84.7	84.7	84.7
0.90*	17.0	17.0	0.0	14.3	14.3	0.0
0.85	1.0	1.0	18.0	0.8	0.8	15.1
0.80	0.1	0.1	0.1	0.0	0.0	0.0
0.75	0.2	0.2	0.2	0.0	0.0	0.0
0.70	0.2	0.2	0.2	0.2	0.2	0.2
0.65	0.0	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.0	0.0
0.55	0.0	0.0	0.0	0.0	0.0	0.0
SWEUF	0.980	0.980	0.972	0.984	0.984	0.977

* Meets 2008 ENERGY STAR criteria.

Table 10.2.3 Compact Refrigerators and Freezers: Base-Case Efficiency Distributions

Energy Use Factor	Compact Refrigerators *(market share in %)*			Compact Freezers *(market share in %)*		
	2007	**2014**	**2021**	**2007**	**2014**	**2021**
1.0	97.1	97.1	97.1	95.4	95.4	95.4
0.90	0.3	0.3	0.3	4.6	4.6	4.6
0.85	0.0	0.0	0.0	0.0	0.0	0.0
0.80*	0.9	0.9	0.0	0.0	0.0	0.0
0.75	1.7	1.7	2.6	0.0	0.0	0.0
0.70	0.0	0.0	0.0	0.0	0.0	0.0
0.65	0.0	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.0	0.0
0.55	0.0	0.0	0.0	0.0	0.0	0.0
SWEUF	0.994	0.994	0.993	0.995	0.995	0.995

* Meets 2008 ENERGY STAR criteria.

Standards cases. To determine efficiency distributions for cases in which a candidate standard applies, DOE used a "roll-up + market shift" scenario for 2014, the year that revised standards are assumed to become effective, and subsequent years. DOE assumed that product efficiencies in the base case that did not meet the standard under consideration would roll up to meet the new standard in 2014.

DOE further assumed that revised standards would result in a market shift such that market shares of products with efficiency better than the standard would gradually increase. In keeping with the perspective of the base case scenario that energy efficiency will be a policy priority, DOE assumed that the ENERGY STAR program will continue to promote efficient appliances after revised standards are introduced in 2014. For a standard that calls for an energy use factor of 0.9 (a 10-percent reduction in energy use from the current standard) for standard-size refrigerator-freezers, DOE assumed that the ENERGY STAR requirement would remain 20 percent better than the standard. For all other standard levels for standard-size refrigerator-freezers other than the maximum-efficiency level, DOE assumed that the ENERGY STAR program would use a threshold of 15 percent better than the standard, because it might be difficult to achieve 20 percent better than the standard at the new, higher efficiency levels. For all standard levels other than the maximum-efficiency level, DOE assumed that the ENERGY STAR program would use a threshold of 10 percent better than the standard for standard-size freezers, and 20 percent better than the standard for compact refrigeration products. Those levels correspond to the current ENERGY STAR requirements (relative to the standard).

Using the above criteria, DOE assumed that from 2014 to 2021 the market share of ENERGY STAR appliances for each product category would grow linearly until it reached the level obtained in 2007. DOE assumed that after 2021 the percentage of shipments at each efficiency level would remain fixed at the 2021 values.

Figure 10.2.1 is a graphical representation of DOE's approach. The figure shows a plot of the shipment-weighted energy use factor for product class 7 (representative of all side-by-side refrigerator-freezers) for the base case and each candidate standard level. Some units in each year exceed the standard level in all cases except candidate standard level 7, which represents the maximum-efficiency case. Similar figures could be created for every product class.

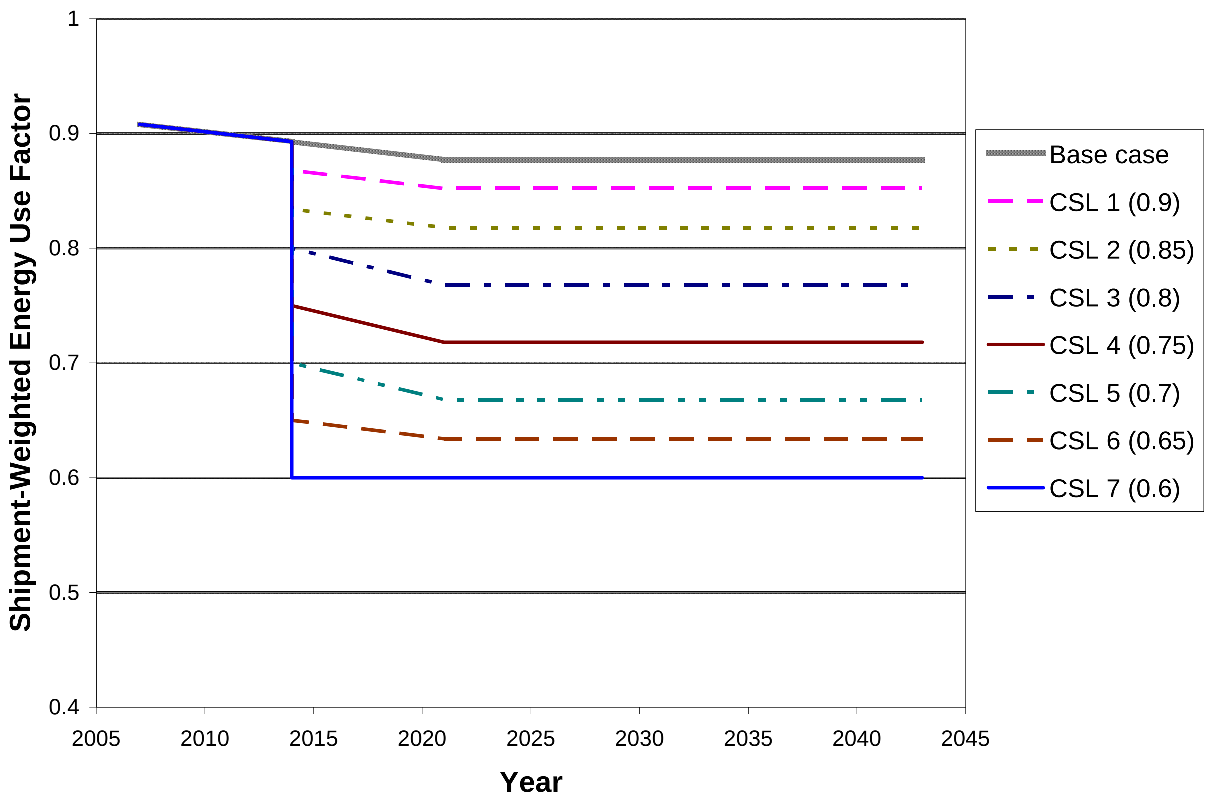

Figure 10.2.1 Projected Shipment-Weighted Energy Use Factors as a Function of Standard Level for Product Class 7

10.2.2 Standard-Size Refrigerator-Freezers

Tables 10.2.4 through 10.2.9 show the efficiency distributions for 2014 and 2021 that DOE used for the considered refrigerator-freezer product classes under the base case and each potential standards case. Efficiency distributions for the base and standards cases transition linearly from 2014 to 2021, after which they remain fixed. The tables include the shipment-weighted energy use factor (SWEUF) associated with each case.

Table 10.2.4 Top-Mount Refrigerator-Freezers: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	80.7	-	-	-	-	-	-	-	-
1 (10)	0.90	5.9	86.6	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	86.6	-	-	-	-	-	-
3 (20)	0.80	13.4	13.4	13.4	100.0	-	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.967	0.887	0.843	0.800	0.750	0.700	0.650	0.600	0.550

Table 10.2.5 Top-Mount Refrigerator-Freezers: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	80.7	-	-	-	-	-	-	-	-
1 (10)	0.90	5.9	86.6	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	86.6	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	86.6	-	-	-	-	-
4 (25)	0.75	13.4	13.4	13.4	0.0	86.6	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	13.4	0.0	86.6	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	13.4	0.0	86.6	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	13.4	13.4	86.6	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	100.0
	SWEUF	0.961	0.880	0.837	0.787	0.737	0.687	0.643	0.593	0.550

Table 10.2.6 Bottom-Mount Refrigerator-Freezers: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	11.8	-	-	-	-	-	-	-	-
1 (10)	0.90	0.1	11.9	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	11.9	-	-	-	-	-	-
3 (20)	0.80	88.1	88.1	88.1	100.0	-	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.824	0.812	0.806	0.800	0.750	0.700	0.650	0.600	0.550

Table 10.2.7 Bottom-Mount Refrigerator-Freezers: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	11.8	-	-	-	-	-	-	-	-
1 (10)	0.90	0.1	11.9	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	11.9	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	11.9	-	-	-	-	-
4 (25)	0.75	88.1	88.1	88.1	0.0	11.9	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	88.1	0.0	11.9	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	88.1	0.00	11.9	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	88.1	88.1	11.9	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.00	0.00	88.1	100.0
	SWEUF	0.780	0.768	0.762	0.712	0.662	0.622	0.606	0.556	0.550

Table 10.2.8 Side-by-Side Refrigerator-Freezers: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %							
		Base Case	Standards Case						
			1	2	3	4	5	6	7
Baseline	1.0	25.0	-	-	-	-	-	-	-
1 (10)	0.90	43.0	68.0	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	68.0	-	-	-	-	-
3 (20)	0.80	32.0	32.0	32.0	100.0	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.893	0.868	0.834	0.800	0.750	0.700	0.650	0.600

Table 10.2.9 Side-by-Side Refrigerator-Freezers: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %							
		Base Case	Standards Case						
			1	2	3	4	5	6	7
Baseline	1.0	25.0	-	-	-	-	-	-	-
1 (10)	0.90	43.0	68.0	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	68.0	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	68.0	-	-	-	-
4 (25)	0.75	32.0	32.0	32.0	0.0	68.0	-	-	-
5 (30)	0.70	0.0	0.0	0.0	32.0	0.0	68.0	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	32.0	0.0	68.0	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	32.0	32.0	100.0
	SWEUF	0.877	0.852	0.818	0.768	0.718	0.668	0.634	0.600

10.2.3 Standard-Size Freezers

Tables 10.2.10 through 10.2.13 give the efficiency distributions in 2014 and 2021 that DOE used for the base case and each standards case for the standard-sized freezer product classes. The efficiency distributions for the base and all standards cases transition linearly from 2014 to 2021, after which they remain fixed. The tables include the SWEUF associated with each case.

Table 10.2.10 Upright Freezers: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	81.5	-	-	-	-	-	-	-	-
1 (10)	0.90	17.0	98.5	-	-	-	-	-	-	-
2 (15)	0.85	1.0	1.0	99.5	-	-	-	-	-	-
3 (20)	0.80	0.1	0.1	0.1	99.6	-	-	-	-	-
4 (25)	0.75	0.2	0.2	0.2	0.2	99.8	-	-	-	-
5 (30)	0.70	0.2	0.2	0.2	0.2	0.2	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.980	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.550

Table 10.2.11 Upright Freezers: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	81.5	-	-	-	-	-	-	-	-
1 (10)	0.90	0.0	81.5	-	-	-	-	-	-	-
2 (15)	0.85	18.0	18.0	81.5	-	-	-	-	-	-
3 (20)	0.80	0.1	0.1	18.1	81.5	-	-	-	-	-
4 (25)	0.75	0.2	0.2	0.2	18.3	81.5	-	-	-	-
5 (30)	0.70	0.2	0.2	0.2	0.2	18.5	81.5	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	18.5	81.5	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	18.5	81.5	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.5	100.0
	SWEUF	0.972	0.890	0.840	0.791	0.741	0.691	0.641	0.591	0.550

Table 10.2.12 Chest Freezers: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
			Standards Case							
		Base Case	1	2	3	4	5	6	7	8
Baseline	1.0	84.7	-	-	-	-	-	-	-	-
1 (10)	0.90	14.3	99.0	-	-	-	-	-	-	-
2 (15)	0.85	0.8	0.8	99.8	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	99.8	-	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	99.8	-	-	-	-
5 (30)	0.70	0.2	0.2	0.2	0.2	0.2	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.984	0.900	0.850	0.800	0.750	0.700	0.650	0.600	0.550

Table 10.2.13 Chest Freezers: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
			Standards Case							
		Base Case	1	2	3	4	5	6	7	8
Baseline	1.0	84.7	-	-	-	-	-	-	-	-
1 (10)	0.90	0.0	84.7	-	-	-	-	-	-	-
2 (15)	0.85	15.1	15.1	84.7	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	15.1	84.7	-	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	15.1	84.7	-	-	-	-
5 (30)	0.70	0.2	0.2	0.2	0.2	15.3	84.7	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	15.3	84.7	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	15.3	84.7	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	100.0
	SWEUF	0.977	0.892	0.842	0.792	0.742	0.692	0.642	0.592	0.550

10.2.4 Compact Refrigerators and Freezers

Tables 10.2.14 through 10.2.17 show the efficiency distributions in 2014 and 2021 that DOE used for the base case and all potential standards cases for compact refrigeration product classes. The efficiency distributions for the base and standards cases transition linearly from 2014 to 2021, after which they remain fixed. The tables include the SWEUF associated with each case.

Table 10.2.14 Compact Refrigerators: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
			Standards Case							
		Base Case	1	2	3	4	5	6	7	8
Baseline	1.0	97.1	-	-	-	-	-	-	-	-
1 (10)	0.90	0.3	97.4	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	97.4	-	-	-	-	-	-
3 (20)	0.80	0.9	0.9	0.9	98.3	-	-	-	-	-
4 (25)	0.75	1.7	1.7	1.7	1.7	100.0	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.993	0.897	0.848	0.799	0.750	0.700	0.650	0.600	0.550

Table 10.2.15 Compact Refrigerators: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
			Standards Case							
		Base Case	1	2	3	4	5	6	7	8
Baseline	1.0	97.1	-	-	-	-	-	-	-	-
1 (10)	0.90	0.3	97.4	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	97.4	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	97.4	-	-	-	-	-
4 (25)	0.75	2.6	2.6	0.0	0.0	97.4	-	-	-	-
5 (30)	0.70	0.0	0.0	2.6	0.0	0.0	97.4	-	-	-
6 (35)	0.65	0.0	0.0	0.0	2.6	0.0	0.0	97.4	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	2.6	2.6	0.0	97.4	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.6	100.0
	SWEUF	0.993	0.896	0.846	0.796	0.746	0.697	0.647	0.599	0.550

Table 10.2.16 Compact Freezers: Efficiency Distributions in 2014 for Base and Standards Cases

Efficiency Level (%less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	95.4	-	-	-	-	-	-	-	-
1 (10)	0.9	4.6	100.0	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	100.0	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	100.0	-	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.600	0.550

Table 10.2.17 Compact Freezers: Efficiency Distributions in and After 2021 for Base and Standards Cases

Efficiency Level (% less than baseline energy use)	Energy Use Factor	Market Share %								
		Base Case	Standards Case							
			1	2	3	4	5	6	7	8
Baseline	1.0	95.4	-	-	-	-	-	-	-	-
1 (10)	0.90	4.6	100.0	-	-	-	-	-	-	-
2 (15)	0.85	0.0	0.0	100.0	-	-	-	-	-	-
3 (20)	0.80	0.0	0.0	0.0	100.0	-	-	-	-	-
4 (25)	0.75	0.0	0.0	0.0	0.0	100.0	-	-	-	-
5 (30)	0.70	0.0	0.0	0.0	0.0	0.0	100.0	-	-	-
6 (35)	0.65	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-	-
7 (40)	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	-
8 (45)	0.55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.600	0.550

10.3 NATIONAL ENERGY SAVINGS

DOE calculated the national energy savings associated with the difference between the base case and the case associated with each potential standard for the refrigeration products considered herein. DOE calculated cumulative energy savings throughout the forecast period, which extends from 2014 to 2044.

10.3.1 Definition

The following equation shows that DOE calculated annual national energy savings (NES) as the difference between two projections: a base case (without new standards) and a standards case. Positive values of NES represent energy savings (that is, national annual energy consumption (AEC) under a standard is less than in the base case).

$$\boldsymbol{NES_y = AEC_{BASE} - AEC_{STD}}$$

Cumulative energy savings are the sum of annual national energy savings throughout the forecast period, which extends from the assumed effective date of new standards (2014) to 30 years after that date (2044). The calculation is represented by the following equation.

$$\boldsymbol{NES_{cum} = \sum NES_y}$$

DOE calculated the national annual energy consumption by multiplying the number or stock of each product class (by vintage) by its unit energy consumption (UEC; also by vintage). The calculation of national annual energy consumption is represented by the following equation.

$$AEC_y = \sum STOCK_V \times UEC_V$$

DOE defined the quantities for the above expressions as follows.

AEC =	national annual energy consumption each year in quadrillion British thermal units (quads), summed over vintages of the product stock, $STOCK_V$;
NES =	annual national energy savings (quads);
$STOCK_V$ =	stock of product (millions of units) of vintage V that survive in the year for which DOE calculated annual energy consumption;
UEC_V =	annual energy consumption per product in kilowatt hours (kWh) [electricity consumption is converted from site energy to source energy (quads) by applying a time-dependent conversion factor];
V =	year in which the product was purchased as a new unit; and
y =	year in the forecast.

The stock of a product depends on annual shipments and the lifetime of the product. As described in chapter 9, DOE projected product shipments under the base case and standards cases. DOE projected that shipments under the standards cases would be slightly lower than under the base case, because of the higher purchase cost of more efficient products. In other words, DOE believes that the higher purchase cost would cause some consumers to forego purchasing new products.

To avoid including savings attributable to shipments displaced because of standards, DOE used the projected standards-case shipments and, in turn, the standards-case stock, to calculate the annual energy consumption for the base case.

10.3.2 Inputs

The inputs to the calculation of national energy savings (NES) are:

- Shipments;
- product stock ($STOCK_V$);
- annual energy consumption per unit (*UE*C);
- national annual energy consumption (*AEC*); and
- site-to-source conversion factor (*src_conv*).

10.3.2.1 Shipments

DOE forecasted shipments of each considered product class under the base case and all standards cases. Several factors affect forecasted shipments, including purchase cost, operating cost, and household income. As noted earlier, the increased cost of more efficient products causes some consumers to forego buying the products. Consequently, shipments forecasted under the standards cases are lower than under the base case. The method DOE used to calculate and generate the shipments forecasts for each considered product class is described in detail in Chapter 9, Shipments Analysis.

10.3.2.2 Equipment Stock

The equipment stock in a given year is the number of products shipped from earlier years that survive in that year. The NIA model tracks the number of the number of units shipped each year. DOE assumes that products have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is the survival function. Chapter 9 provides additional details on the survival functions that DOE used for each product.

10.3.2.3 Annual Energy Consumption per Unit

DOE used the shipment-weighted energy use factors (SWEUFs) presented in section 10.2 for the base case and standards cases, along with the data on annual energy consumption presented in chapters 7 and 8, to estimate the shipment-weighted average annual per-unit energy consumption under the base and standards cases. The average annual per-unit energy consumption projected for 2014 for each product category is shown in Tables 10.3.1 through 10.3.3.

Table 10.3.1 Standard-Size Refrigerator-Freezers: Shipment-Weighted Average Annual Energy Consumption in 2014

	Base Case	Standards Case							
		1	2	3	4	5	6	7	8
Top-Mount									
SWEUF	0.967	0.887	0.843	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Energy Use (kWh)	636	582	554	526	493	460	427	394	361
Bottom-Mount									
SWEUF	0.824	0.812	0.806	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Energy Use (kWh)	575	567	563	559	524	489	454	419	384
Side-by-Side									
SWEUF	0.893	0.868	0.834	0.800	0.750	0.700	0.650	0.600	-
Avg. Energy Use (kWh)	971	944	907	870	815	761	707	652	-

Table 10.3.2 Standard-Size Freezers: Shipment-Weighted Average Annual Energy Consumption in 2014

	Base Case	Standards Case							
		1	2	3	4	5	6	7	8
Upright									
SWEUF	0.980	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Energy Use (kWh)	960	881	832	784	735	686	637	588	539
Chest									
SWEUF	0.984	0.899	0.850	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Energy Use (kWh)	613	560	529	498	467	436	405	374	343

Table 10.3.3 Compact Refrigerators and Freezers: Shipment-Weighted Average Annual Energy Consumption in 2014

	Base Case	Standards Case							
		1	2	3	4	5	6	7	8
Refrigerator									
SWEUF	0.994	0.897	0.848	0.799	0.750	0.700	0.650	0.600	0.550
Avg. Energy Use (kWh)	323	291	275	260	244	227	211	195	179
Freezer									
SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Energy Use (kWh)	311	281	266	250	235	219	203	188	172

10.3.2.4 National Annual Energy Consumption

The national annual energy consumption (AEC) is the product of the annual energy consumption per unit and the number of units of each vintage. This method of calculation accounts for differences in unit energy consumption from year to year. The equation for determining the annual energy consumption, which was presented in section 10.3.1, is repeated here.

$$AEC = \sum STOCK_V \times UEC_V$$

In determining national annual energy consumption, DOE first calculated annual energy consumption at the site, then applied a conversion factor, described below, to calculate primary energy consumption.

10.3.2.5 Site-to-Source Conversion Factors

In determining national annual energy consumption, DOE initially calculated the annual energy consumption at the site (for electricity, the energy in kWh consumed at the household or establishment). It then used site energy consumption to calculate primary (source) energy consumption by applying a conversion factor to account for losses associated with the generation, transmission, and distribution of electricity. The site-to-source conversion factor is a multiplicative factor used to convert site energy consumption into primary or source energy consumption, expressed in quads (quadrillion Btus). DOE used annual site-to-source conversion factors based on the version of the National Energy Modeling System (NEMS)[b] that corresponds to EIA's *Annual Energy Outlook 2008* (AEO 2008).[4] The factors are marginal values, which represent the response of the system to an incremental decrease in consumption. For electricity, the conversion factors change over time in response to projected changes in generation sources (*i.e.*, the types of power plants projected to provide electricity to the Nation). Figure 10.3.1 shows the site-to-source conversion factors from 2005 to the end of the forecast period. DOE assumed that conversion factors remain at 2030 values throughout the rest of the forecast.

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[b] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000), March 2000. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed). NEMS-BT was previously called NEMS-BRS.

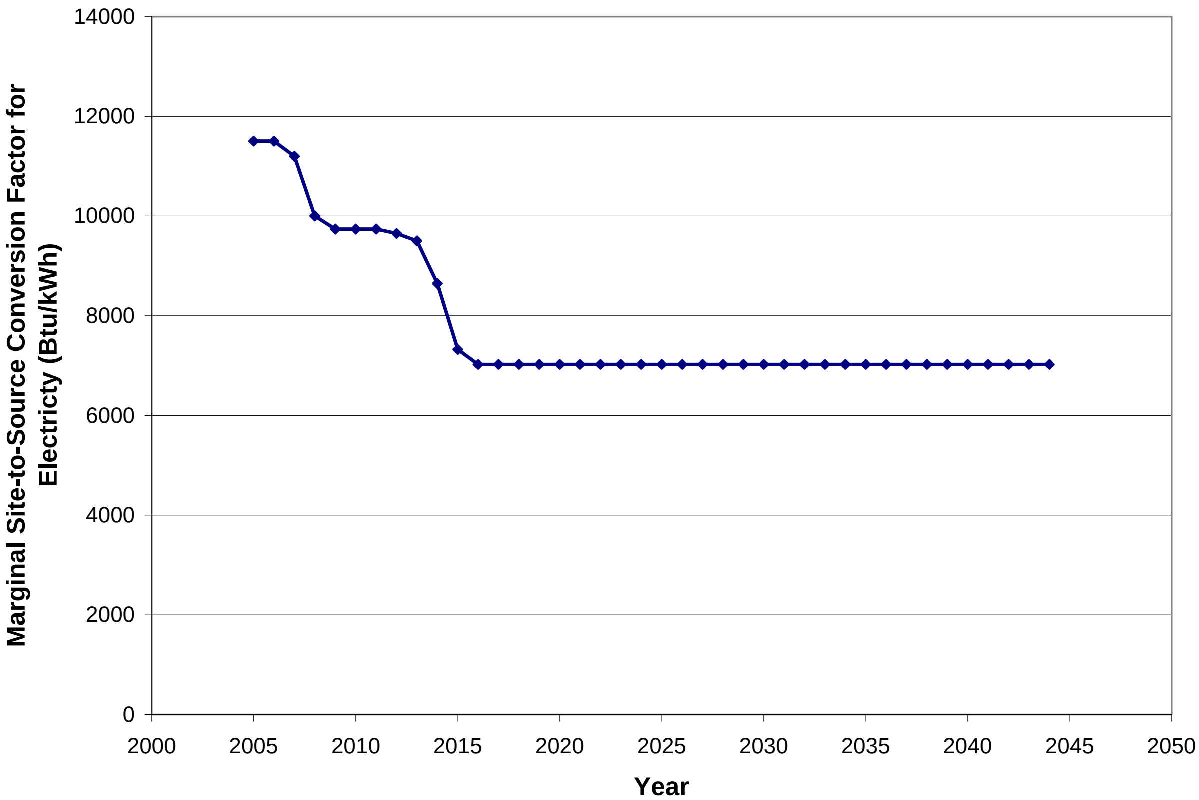

Figure 10.3.1 Marginal Site-to-Source Conversion Factors for Electricity

10.4 NET PRESENT VALUE

DOE calculated the net present value (NPV) of the increased product cost and reduced operating cost associated with the difference between the base case and each potential standards case for the considered refrigeration products.

10.4.1 Definition

The NPV is the value in the present of a time-series of costs and savings. The NPV is described by the equation:

$$\boldsymbol{NPV = PVS - PVC}$$

Where:

PVS = present value of savings in operating cost, and
PVC = present value of increased total product cost to consumers.

DOE determined the *PVS* and *PVC* according to the following expressions.

$$\boldsymbol{PVS = \sum OCS_y \times DF_y}$$

$$\boldsymbol{PVC = \sum TIC_y \times DF_y}$$

Where:

OCS =	total annual savings in operating cost each year summed over vintages of the product stock, $STOCK_V$;
TIC =	total annual increases in product cost each year summed over years of the product shipments, $SHIP_y$;
DF =	discount factor in each year; and
y =	year in the forecast.

DOE calculated the total annual consumer savings in operating cost by multiplying the number or stock of a given product class (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increases in consumer product cost by multiplying the number or shipments of the given product class (by vintage) by its per-unit increase in consumer product cost (also by vintage). The calculation of total annual operating cost savings and total annual product cost increases is represented by the following equations.

$$\boldsymbol{OCS_y = \sum STOCK_V \times UOCS_V}$$

$$TIC_y = \sum SHIP_y \times UTIC_y$$

Where:

$STOCK_V$ =	stock of products of vintage *V* that survive in the year for which DOE calculated annual energy consumption,
$UOCS_V$ =	annual per-unit savings in operating cost,
V =	year in which the product was purchased as a new unit,
$SHIP_y$ =	shipments of products in year *y*, and
$UTIC_y$ =	annual per-unit increase in installed product cost in year *y*.

DOE determined the total increased product cost for each year from the effective date of a potential standard to 2044. It determined the present value of operating cost savings for each year from the effective date of the standard to the year when all units purchased by 2044 have been retired. DOE calculated costs and savings as the difference between a standards case and a base case without new standards.

DOE developed a discount factor from the national discount rate and the number of years between the present (*i.e.*, year to which the sum is being discounted) and the year in which the costs and savings occur. The NPV is the sum over time of the discounted net savings.

10.4.2 Inputs

The inputs to calculation of the net present value (NPV) are:

- Average annual product cost;
- average annual savings in operating cost,;
- total annual increases in product cost;
- total annual savings in operating cost;
- discount factor;
- present value of costs; and
- present value of savings.

The increase in total annual product cost is equal to the annual change in the average annual product cost (difference between base case and standards case) multiplied by the shipments forecasted in the standards case. As with the calculation of the NES, DOE did not calculate total annual product costs using base-case shipments. To avoid including savings due to displaced shipments (by consumers deciding not to buy higher-cost products), DOE used the standards-case projection of shipments and, in turn, the standards-case stock, to calculate product costs.

The total annual savings in operating cost are equal to the change in annual operating cost (difference between base case and standards case) per unit multiplied by the shipments forecasted in the standards case.

10.4.2.1 Average Annual Product Cost

The average annual product cost is directly dependent on efficiency. DOE therefore used the SWEUFs presented in section 10.2 for the base case and each standards case, along with the product costs at various efficiency levels (presented in chapter 8), to estimate the shipment-weighted average annual product cost under the base and standards cases. Tables 10.4.1 through 10.4.3 show the shipment-weighted average consumer product cost based on the SWEUFs that correspond to the base case and each standards case in 2014.

Table 10.4.1 Standard-Size Refrigerator-Freezers: Shipment-Weighted Average Product Cost in 2014 for Base and Standards Cases

	Base Case	Standards Case							
		1	2	3	4	5	6	7	8
Top-Mount									
SWEUF	0.967	0.887	0.843	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Product Cost *2008$*	1,081	1,086	1,090	1,099	1,121	1,155	1,206	1,271	1,335
Bottom-Mount									
SWEUF	0.824	0.812	0.806	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Product Cost *2008$*	1,447	1,449	1,449	1,451	1,470	1,525	1,614	1,696	1,790
Side-by-Side									
SWEUF	0.893	0.868	0.834	0.800	0.750	0.700	0.650	0.600	-
Avg. Product Cost *2008$*	1,456	1,460	1,466	1,496	1,559	1,634	1,710	1,817	-

Table 10.4.2 Standard-Size Freezers: Shipment-Weighted Average Product Cost in 2014 for Base and Standards Cases

	Base Case	Standards Case							
		1	2	3	4	5	6	7	8
Upright									
SWEUF	0.980	0.899	0.849	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Product Cost *2008$*	501	507	514	517	533	563	597	657	758
Chest									
SWEUF	0.984	0.899	0.850	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Product Cost *2008$*	514	519	524	545	564	568	581	621	707

Table 10.4.3 Compact Refrigerators and Freezers: Shipment-Weighted Average Product Cost in 2014 for Base and Standards Cases

	Base Case	Standards Case							
		1	2	3	4	5	6	7	8
Refrigerator									
SWEUF	0.994	0.897	0.848	0.799	0.750	0.700	0.650	0.600	0.550
Avg. Product Cost *2008$*	159	164	167	171	186	187	192	205	224
Freezer									
SWEUF	0.995	0.900	0.850	0.800	0.750	0.700	0.650	0.600	0.550
Avg. Product Cost *2008$*	207	214	219	238	258	273	300	302	311

10.4.2.2 Annual Operating Cost Savings per Unit

The average annual operating cost includes the costs for energy, repair, and maintenance. As described in chapter 8, for all the considered products DOE assumed that potential standards would produce no increase in maintenance or repair costs. For all the considered products, therefore, DOE determined the per-unit annual savings in operating cost based only on the savings in energy costs attributable to a standard. DOE determined the per-unit annual savings in operating cost by multiplying the per-unit annual savings in energy consumption developed for each product class by the appropriate energy price. As described in chapter 8, DOE forecasted energy prices based on EIA's AEO 2009.[5]

10.4.2.3 Total Annual Increases in Product Cost

The total annual increase in product cost for any given standards case is the product of the average cost increase per unit due to the standard and the number of units of each vintage shipped. This method accounts for differences in product cost from year to year. The equation for determining the total annual increase in product cost for a given standards case, which was shown in section 10.4.1, is repeated here.

$$TIC_y = \sum SHIP_y \times UTIC_y$$

10.4.2.4 Total Annual Savings in Operating Cost

The total annual savings in operating cost for any given standards case is the product of the annual savings in operating cost per unit attributable to the standard and the number of units of each vintage. This method accounts for differences in annual savings in operating cost from year to year. The equation for determining the total annual savings in operating cost for a given standards case, which was presented in section 10.4.1, is repeated here.

$$\boldsymbol{OCS} = \sum \boldsymbol{STOCK_V} \times \boldsymbol{UOCS_V}$$

10.4.2.5 Discount Factor

DOE multiplied monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by the equation:

$$\boldsymbol{DF} = \frac{1}{\boldsymbol{(}1+\boldsymbol{r}\boldsymbol{)}^{\boldsymbol{(y-yp)}}}$$

Where:

r = discount rate,
y = year in which the monetary value exists, and
y_P = year in which the present value is being determined.

Although DOE used consumer discount rates to determine the life-cycle cost of refrigeration products (chapter 8), it used national discount rates to calculate national NPV. DOE estimated NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the

Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: *Identifying and Measuring Benefits and Costs*.[6] DOE defined the present year as 2009.

10.4.2.6 Present Value of Costs

The present value of increased product costs is the annual total cost increase in each year (the difference between a standards case and the base case), discounted to the present and summed throughout the period in which DOE is considering the installation of products (that is, from the effective date of standards, 2014, to 2044). DOE calculated annual increases in installed cost as the difference in total product cost for new appliances purchased each year, multiplied by the shipments in the standards case.

10.4.2.7 Present Value of Savings

The present value of savings in operating cost is the annual savings on operating cost (the difference between the base case and a standards case), discounted to the present and summed from the effective date to the time when the last unit installed by 2044 is retired from service. Savings are decreases in operating cost associated with the higher energy efficiency of products purchased in the standards case compared to the base case. Total annual savings in operating cost are the savings per unit multiplied by the number of units of each vintage that survive in a particular year.

10.5 RESULTS OF NES AND NPV CALCULATIONS

The National Impact Analysis (NIA) model produces estimates of the NES and NPV attributable to a given candidate standard level. The inputs to the NIA model were discussed in sections 10.3.2 (inputs to NES) and 10.4.2 (inputs to NPV). DOE generated the NES and NPV results using a Microsoft Excel spreadsheet, which is accessible on the Internet <www.eere.energy.gov/buildings/appliance_standards/> Details regarding and instructions for using the spreadsheet are provided in appendix 10-A.

10.5.1 Summary of Inputs

Table 10.5.1 summarizes the inputs to the NIA model. A brief description of the data is provided for each input.

Table 10.5.1 Inputs to Calculation of National Energy Savings and Net Present Value

Input	Description
Shipments	Annual shipments from shipments model. (See chapter 9.)
Effective date of standard	2014.
Base-case forecasted efficiencies	See section 10.2.
Standards-case efficiencies	See section 10.2.
Annual energy consumption per unit	Annual weighted-average values are a function of SWEUF. (See section 10.3.2.1.)
Total installed cost per unit	Annual weighted-average values are a function of the efficiency distribution. (See section 10.4.2.1.)
Energy cost per unit	Annual weighted-average values are a function of annual energy consumption per unit and energy prices. (See chapter 8 for energy prices.)
Repair and maintenance costs per unit	No changes in repair and maintenance cost assumed at higher-than-baseline efficiency levels.
Forecast of energy prices	Energy prices: EIA *AEO2009*[5] forecasts (to 2030) and extrapolation thereafter. (See chapter 8.)
Marginal energy site-to-source conversion factor	A time-series conversion factor that includes electric generation, transmission, and distribution losses. Conversion, which changes yearly, is generated by DOE-EIA's NEMS* program.
Discount rates	3% and 7% real.
Present year	Future expenses are discounted to 2009.

* Chapter 13, Utility Impact Analysis, provides more detail on the National Energy Modeling System (NEMS).

10.5.2 Results of National Energy Savings Calculations

The following sections provide results of calculating NES for the efficiency levels analyzed for the considered products. NES results, which are cumulative from 2014 to 2044, are primary energy savings. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values as in the life-cycle cost and payback period analyses. The results in Tables 10.5.2 through 10.5.7 represent all the product classes that DOE included in each of the seven representative product categories, not only the primary product class that accounts for the bulk of shipments in each category.

10.5.2.1 Standard-Size Refrigerator-Freezers

Table 10.5.2 shows the NES results for the efficiency levels analyzed for standard-size refrigerator-freezers. Table 10.5.3 shows the magnitude of the NES if the savings are discounted at rates of 3 percent and 7 percent.

Table 10.5.2 Standard-Size Refrigerator-Freezers: Cumulative National Energy Savings, *quads*

Efficiency Level (% less than baseline energy use)	Top-Mount Refrigerator-Freezer*	Bottom-Mount Refrigerator-Freezer**	Side-by-Side Refrigerator-Freezer***
1 (10)	1.10	0.04	0.31
2 (15)	1.69	0.06	0.73
3 (20)	2.35	0.20	1.31
4 (25)	3.01	0.37	1.91
5 (30)	3.65	0.53	2.50
6 (35)	4.20	0.57	2.93
7 (40)	4.78	0.73	3.35
8 (45)	5.28	0.77	-

* Includes product classes 1, 1A, 2, 3A, and 6 as well as product class 3.
** Includes product class 5A as well as product class 5.
*** Includes product class 4 as well as product class 7.

Table 10.5.3 Standard-Size Refrigerator-Freezers: Discounted Cumulative National Energy Savings, *quads*

Efficiency Level (% less than baseline energy use)	Top-Mount Refrigerator-Freezer*		Bottom-Mount Refrigerator-Freezer**		Side-by-Side Refrigerator-Freezer***	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
1 (10)	0.57	0.26	0.02	0.01	0.16	0.07
2 (15)	0.87	0.40	0.03	0.01	0.37	0.17
3 (20)	1.21	0.56	0.10	0.04	0.67	0.30
4 (25)	1.55	0.72	0.18	0.08	0.98	0.44
5 (30)	1.88	0.87	0.27	0.12	1.28	0.58
6 (35)	2.17	1.00	0.29	0.13	1.50	0.68
7 (40)	2.47	1.13	0.37	0.17	1.72	0.78
8 (45)	2.72	1.25	0.40	0.18	-	-

* Includes product classes 1, 1A, 2, 3A, and 6 as well as product class 3.
** Includes product class 5A as well as product class 5.
*** Includes product class 4 as well as product class 7.

10.5.2.2 Standard-Size Freezers

Table 10.5.4 shows the NES results for the efficiency levels analyzed for standard-size freezers. Table 10.5.5 shows the magnitude of the NES if the savings are discounted at rates of 3 percent and 7 percent.

Table 10.5.4 Standard-Size Freezers: Cumulative National Energy Savings, *quads*

Efficiency Level (% less than baseline energy use)	Upright Freezers*	Chest Freezers**
1 (10)	0.34	0.23
2 (15)	0.55	0.37
3 (20)	0.75	0.50
4 (25)	0.96	0.63
5 (30)	1.15	0.76
6 (35)	1.34	0.87
7 (40)	1.51	1.00
8 (45)	1.63	1.07

* Includes product class 9 only.
** Includes product classes 8 and 10A as well as product class 10.

Table 10.5.5 Standard-Size Freezers: Discounted Cumulative National Energy Savings, *quads*

Efficiency Level (% less than baseline energy use)	Upright Freezers*		Chest Freezers**	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
1 (10)	0.17	0.08	0.12	0.05
2 (15)	0.28	0.12	0.19	0.08
3 (20)	0.38	0.17	0.25	0.11
4 (25)	0.48	0.22	0.32	0.14
5 (30)	0.58	0.26	0.38	0.17
6 (35)	0.68	0.30	0.44	0.20
7 (40)	0.76	0.34	0.50	0.22
8 (45)	0.83	0.37	0.54	0.24

* Includes product class 9 only.
** Includes product classes 8 and 10A as well as product class 10.

10.5.2.3 Compact Refrigerators and Freezers

Table 10.5.6 shows the NES results for the efficiency levels analyzed for compact refrigerators and freezers. Table 10.5.7 shows the magnitude of the NES if the savings are discounted at rates of 3 percent and 7 percent.

Table 10.5.6 Compact Refrigerators and Freezers: Cumulative National Energy Savings, *quads*

Efficiency Level (% less than baseline energy use)	Compact Refrigerators*	Compact Freezers**
1 (10)	0.13	0.03
2 (15)	0.20	0.04
3 (20)	0.27	0.06
4 (25)	0.32	0.07
5 (30)	0.38	0.08
6 (35)	0.44	0.09
7 (40)	0.48	0.10
8 (45)	0.52	0.11

* Includes product classes 11A, 12, 13, 13A, 14, and 15 as well as product class 11
** Includes product classes 16 and 17 as well as product class 18

Table 10.5.7 Compact Refrigerators and Freezers: Discounted Cumulative National Energy Savings, *quads*

Efficiency Level (% less than baseline energy use)	Compact Refrigerators*		Compact Freezers**	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
1 (10)	0.07	0.03	0.02	0.01
2 (15)	0.11	0.05	0.02	0.01
3 (20)	0.14	0.07	0.03	0.02
4 (25)	0.17	0.08	0.04	0.02
5 (30)	0.21	0.10	0.04	0.02
6 (35)	0.24	0.12	0.05	0.03
7 (40)	0.26	0.13	0.06	0.03
8 (45)	0.28	0.14	0.06	0.03

* Includes product classes 11A, 12, 13, 13A, 14, and 15 as well as product class 11
** Includes product classes 16 and 17 as well as product class 18

10.5.3 Annual Costs and Savings

Figure 10.5.1 illustrates the basic inputs to the calculation of net present value (NPV) by showing the non-discounted annual increases in product cost and annual savings in operating cost at the national level for efficiency level 3 for product class 3 (refrigerator-freezers–automatic defrost with top-mounted freezer and without through-the-door ice service). The figure also shows the net savings, which is the difference between the savings and costs for each year. The annual increase in product cost is the total cost for products purchased each year in the forecast period. The annual savings in operating cost applies to products operating in each year. The NPV is the difference between the cumulative annual discounted savings and cumulative annual discounted costs. DOE could create figures like Figure 10.5.1 for each of the considered efficiency levels for each product class.

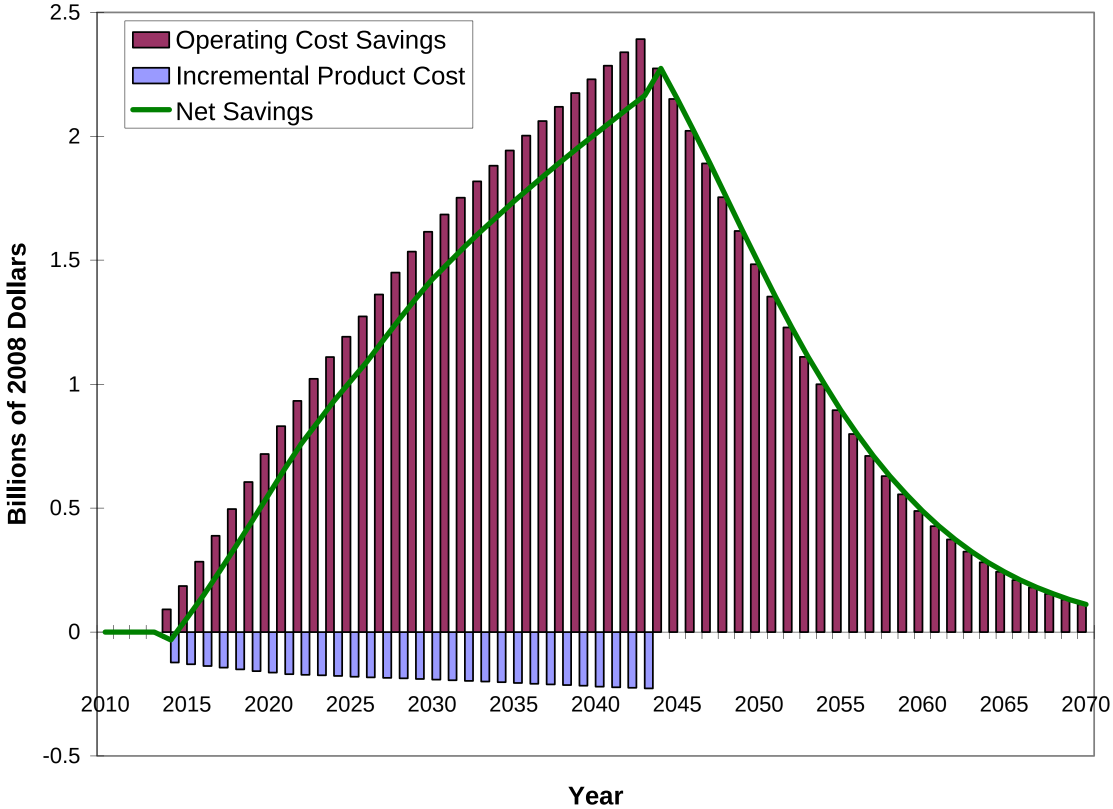

Figure 10.5.1 Non-Discounted Annual Increases in Installed Cost and Savings in Operating Cost for Product Class 3 at Standard Level 3

10.5.4 Results of Net Present Value Calculations

This section provides results of calculating net present value (NPV) for the potential efficiency standards for the considered refrigeration product classes. Results, which are cumulative, are shown as the discounted value of the savings in dollar terms. Results are provided for each potential efficiency standard. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values as in the life-cycle cost and payback period analysis.

The present value of increased total installed cost is the total annual increase in installed cost (the difference between the standards case and base case), discounted to the present and summed throughout the period for which DOE evaluated the impact of standards.

Savings are decreases in operating cost associated with the higher energy efficiency of products purchased in the standards case compared to the base case. Total savings in operating cost are the savings per unit multiplied by the number of units of each vintage (*i.e.*, year of manufacture) that survive in a particular year. For units purchased by 2044, the operating cost includes energy consumed until the last unit is retired from service.

Tables 10.5.8 though 10.5.10 show the NPV associated with the potential standards for the considered refrigeration products. Detailed results showing the breakdown of the NPV into national installed product cost and operating cost savings are provided in appendix 10-B. As was the case with NES results, the results for NPV refer to all the product classes that DOE included in each of the seven representative product class categories, not simply to the primary product class that accounts for the bulk of shipments in each case.

Table 10.5.8 Standard-Size Refrigerator-Freezers: Discounted Cumulative Net Present Values

Efficiency Level (% less than baseline energy use)	Top-Mount Refrigerator-Freezer*		Bottom-Mount Refrigerator-Freezer**		Side-by-Side Refrigerator-Freezer***	
	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*
1 (10)	13.39	5.08	0.50	0.19	3.68	1.35
2 (15)	20.16	7.60	0.73	0.27	8.52	3.11
3 (20)	26.57	9.79	2.13	0.70	11.89	3.82
4 (25)	31.08	11.01	1.98	0.40	14.15	3.94
5 (30)	33.86	11.35	1.61	0.01	15.12	3.42
6 (35)	34.26	10.57	1.43	-0.19	16.17	3.20
7 (40)	32.78	8.75	0.60	-0.91	15.73	2.22
8 (45)	31.53	7.18	0.40	-1.12	-	-

* Includes product classes 1, 1A, 2, 3A, and 6 as well as product class 3.
** Includes product class 5A as well as product class 5.
*** Includes product class 4 as well as product class 7.

Table 10.5.9 Standard-Size Freezers: Discounted Cumulative Net Present Values

Efficiency Level (% less than baseline energy use)	Upright Freezers*		Chest Freezers**	
	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*
1 (10)	4.52	1.59	3.11	1.10
2 (15)	7.21	2.53	4.78	1.68
3 (20)	9.92	3.48	6.04	2.03
4 (25)	12.23	4.23	7.68	2.60
5 (30)	14.28	4.86	9.14	3.07
6 (35)	15.82	5.25	9.61	3.06
7 (40)	16.62	5.29	11.01	3.52
8 (45)	16.54	4.98	10.51	3.09

* Includes product class 9 only.
** Includes product classes 8 and 10A as well as product class 10.

Table 10.5.10 Compact Refrigerators and Freezers: Discounted Cumulative Net Present Values

Efficiency Level (% less than baseline energy use)	Compact Refrigerators*		Compact Freezers**	
	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*	3% Discount Rate *billion 2008$*	7% Discount Rate *billion 2008$*
1 (10)	1.00	0.43	0.20	0.08
2 (15)	1.39	0.59	0.30	0.12
3 (20)	1.81	0.76	0.08	0.00
4 (25)	1.45	0.55	0.10	0.00
5 (30)	1.97	0.78	0.00	-0.06
6 (35)	2.12	0.83	0.09	-0.02
7 (40)	1.72	0.59	0.06	-0.05
8 (45)	0.92	0.17	0.01	-0.08

* Includes product classes 11A, 12, 13, 13A, 14, and 15 as well as product class 11.
** Includes product classes 16 and 17 as well as product class 18.

10.5.5 Summary of NIA Results

This section provides NES (undiscounted) and NPV results together for each efficiency level considered for the refrigeration product classes. Tables 10.5.11 though 10.5.13 allow the reader to see which efficiency levels have the highest energy savings while also having a positive NPV.

Table 10.5.11 Standard-Size Refrigerator-Freezers: NES and NPV Results

Efficiency Level (percent less than baseline energy use)	Top-Mount Refrigerator-Freezer*			Bottom-Mount Refrigerator-Freezer**			Side-by-Side Refrigerator-Freezer***		
	NES (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*	**NES** (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*	**NES** (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*
1 (10%)	1.10	13.39	5.08	0.04	0.50	0.19	0.31	3.68	1.35
2 (15%)	1.69	20.16	7.60	0.06	0.73	0.27	0.73	8.52	3.11
3 (20%)	2.35	26.57	9.79	0.20	2.13	0.70	1.31	11.89	3.82
4 (25%)	3.01	31.08	11.01	0.37	1.98	0.40	1.91	14.15	3.94
5 (30%)	3.65	33.86	11.35	0.53	1.61	0.01	2.50	15.12	3.42
6 (35%)	4.20	34.26	10.57	0.57	1.43	-0.19	2.93	16.17	3.20
7 (40%)	4.78	32.78	8.75	0.73	0.60	-0.91	3.35	15.73	2.22
8 (45%)	5.28	31.53	7.18	0.77	0.40	-1.12	-	-	-

* Includes product classes 1, 1A, 2, 3A, and 6 as well as product class 3.
** Includes product class 5A as well as product class 5.
*** Includes product class 4 as well as product class 7.

Table 10.5.12 Standard-Size Freezers: NES and NPV Results

Efficiency Level (percent less than baseline energy use)	Upright Freezers*			Chest Freezers**		
	NES (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*	**NES** (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*
1 (10%)	0.34	4.52	1.59	0.23	3.11	1.10
2 (15%)	0.55	7.21	2.53	0.37	4.78	1.68
3 (20%)	0.75	9.92	3.48	0.50	6.04	2.03
4 (25%)	0.96	12.23	4.23	0.63	7.68	2.60
5 (30%)	1.15	14.28	4.86	0.76	9.14	3.07
6 (35%)	1.34	15.82	5.25	0.87	9.61	3.06
7 (40%)	1.51	16.62	5.29	1.00	11.01	3.52
8 (45%)	1.63	16.54	4.98	1.07	10.51	3.09

* Includes product class 9 only.
** Includes product classes 8 and 10A as well as product class 10.

Table 10.5.13 Compact Refrigerators and Freezers: NES and NPV Results

Efficiency Level (percent less than baseline energy use)	Compact Refrigerators*			Compact Freezers**		
	NES (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*	**NES** (quads)	**NPV @ 3% Discount Rate** *(billion 2008$)*	**NPV@ 7% Discount Rate** *(billion 2008$)*
1 (10%)	0.13	1.00	0.43	0.03	0.20	0.08
2 (15%)	0.20	1.39	0.59	0.04	0.30	0.12
3 (20%)	0.27	1.81	0.76	0.06	0.08	0.00
4 (25%)	0.32	1.45	0.55	0.07	0.10	0.00
5 (30%)	0.38	1.97	0.78	0.08	0.00	-0.06
6 (35%)	0.44	2.12	0.83	0.09	0.09	-0.02
7 (40%)	0.48	1.72	0.59	0.10	0.06	-0.05
8 (45%)	0.52	0.92	0.17	0.11	0.01	-0.08

* Includes product classes 11A, 12, 13, 13A, 14, and 15 as well as product class 11.
** Includes product classes 16 and 17 as well as product class 18.

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APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NIA SPREADSHEETS

TABLE OF CONTENTS

APPENDIX 10-A. USER INSTRUCTIONS FOR SHIPMENTS AND NIA SPREADSHEETS

10-A.1 INTRODUCTION

The results obtained for the shipments analysis and the national impact analysis (NIA) can be examined and reproduced using the Microsoft Excel spreadsheet available on the U.S. Department of Energy Building Technologies website at: http://www.eere.energy.gov/buildings/appliance_standards/.

There are a total of four NIA spreadsheets, one each for the following product types: standard-size refrigerator-freezers, standard-size freezers, compact refrigerators, and commercial compact freezers. The four spreadsheets posted on the DOE website represent the latest versions and have been tested with Microsoft Excel 2003.

To execute the spreadsheet requires Microsoft Excel 2003 or a later version. The NIA spreadsheet performs calculations to forecast the change in national energy use and net present value due to an energy conservation standard. The energy use and associated costs for a given standard are determined first by calculating the shipments and then calculating the energy use and costs for all equipment shipped under that standard. The differences between the standards and base cases can then be compared and the overall energy savings and present values determined.

10-A.1.1 Standard-Size Refrigerator-Freezers

The standard-size refrigerator-freezer NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary	Contains user input selections under “User Inputs” and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for standard-size refrigerator-freezers and the associated incremental prices. This sheet also contains base and standards case efficiency trends for standard-size refrigerator-freezers, and efficiency weighted average energy use and equipment price for the base and standards cases.
Historical Shipment & Market Share	Contains data for historical sales of standard-size refrigerator-freezers by product class. The forecast market share between top-mount and side/bottom-mount refrigerator-freezers is provided.
Base Case	Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival

function to calculate the surviving stock. It then performs calculations of replacements, and shipments going into new housing. The sheet calculates replacement units, shipments going into new units, and early replacement shipments, and aggregates them into total shipments.

Base Energy Calc Contains additional stock accounting calculations to properly allocate shipments, energy use, and costs to top-mount and side/bottom-mount refrigerator-freezers for the base case.

Standards Case Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.

Standards Energy Calc Contains additional stock accounting calculations to properly allocate shipments, energy use, and costs to top-mount and side/bottom-mount refrigerator-freezers for the standards case.

Housing Projections Contains the projected new housing construction starts and total housing stock for the three economic scenarios (Reference, Low Growth, and High Growth). Also provides the early replacement rate.

Fuel Prices Contains projected average energy prices for the three economic scenarios.

Heat Rates Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.

Lifetime Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.1.2 Standard-Size Freezers

The standard-size freezer NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary Contains user input selections under “User Inputs” and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for standard-size freezers and the associated incremental prices. This sheet also contains base

	and standards case efficiency trends for standard-size freezers, and efficiency weighted average energy use and equipment price for the base and standards cases.
Historical Shipment	Contains data for historical sales of standard-size freezers by product class.
Base Case	Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going into new housing. The sheet calculates replacement units, shipments going into new units, and shipments going to first time owners (existing households that do not already own the product), and aggregates them into total shipments.
Standards Case	Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.
Housing Projections	Contains the projected new housing construction starts and total housing stock for the three economic scenarios (Reference, Low Growth, and High Growth). Also provides the early replacement rate.
Fuel Prices	Contains projected average energy prices for the three economic scenarios.
Heat Rates	Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.
Lifetime	Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.1.3 Compact Refrigerators

The compact refrigerator NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary	Contains user input selections under “User Inputs” and a summary table, Cumulative Energy Savings and NPV for the selected

	standard level efficiency distribution. The sheet contains the efficiency levels being considered for compact refrigerators and the associated incremental prices. This sheet also contains base and standards case efficiency trends for compact refrigerators, and efficiency weighted average energy use and equipment price for the base and standards cases.
Historical Shipment	Contains data for historical sales of compact refrigerators by product class. Also provides historical saturations of compact refrigerators in lodging, residential, and commercial buildings.
Base Case	Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going into new housing, new lodging, and new commercial buildings, and aggregates them into total shipments.
Standards Case	Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.
Housing & Comm Flrspc Project	Contains the projected new housing construction starts, total housing stock, projected new commercial floorspace projections, and total lodging and commercial floorspace stock for the three economic scenarios (Reference, Low Growth, and High Growth).
Fuel Prices	Contains projected average energy prices for the three economic scenarios.
Heat Rates	Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.
Lifetime	Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.1.4 Compact Freezers

The compact freezer NIA spreadsheet or workbook consists of the following worksheets:

Input and Summary	Contains user input selections under "User Inputs" and a summary table, Cumulative Energy Savings and NPV for the selected standard level efficiency distribution. The sheet contains the efficiency levels being considered for compact freezers and the associated incremental prices. This sheet also contains base and standards case efficiency trends for compact freezers, and efficiency weighted average energy use and equipment price for the base and standards cases.
Historical Shipment	Contains data for historical sales of compact freezers by product class.
Base Case	Contains the calculations for determining the shipments, energy consumption, and operating costs for the base case. The sheet starts with the stock accounting of the equipment and uses the survival function to calculate the surviving stock. It then performs calculations of replacements, and shipments going to first time owners (existing households that do not already own the product), and aggregates them into total shipments.
Standards Case	Contains stock accounting of the equipment that calculates annual shipments estimates, energy savings, and operating cost savings for the standards case. The energy and cost savings in a single year are the difference between the base case energy use and costs and the standard case energy use and costs for that year.
Housing Projections	Contains the projected new housing construction starts and total housing stock for the three economic scenarios (Reference, Low Growth, and High Growth). Housing data used solely to determine a compact freezer saturation in new housing.
Fuel Prices	Contains projected average energy prices for the three economic scenarios.
Heat Rates	Contains the marginal site to source conversion factors that are used in the source energy savings calculations, for both electricity and gas.
Lifetime	Contains the probability of survival of a standard-size refrigerator-freezer at a given age and the average lifetime of a unit.

10-A.2 BASIC INSTRUCTIONS

Basic instructions for operating the NIA spreadsheets are as follows:

1. Once the NIA spreadsheets have been downloaded from the Web, open the file using Excel. At the bottom, click on the tab for the worksheet 'Input and Summary'.

2. Use Excel's View/Zoom commands at the top menu bar to change the size of the display to make it fit your monitor.

3. The user can change the model parameters listed in the grey box labelled "User Inputs". The parameters are:
    a. Lifetime: To change value, type in the desired value that lies within the maximum lifetime indicated.
    b. Discounting future values: To change the value used for discounting NPV and national energy savings, and the year in which to discount to.
    c. Relative Price Elasticity: To change value, use the drop-down arrow and select the desired impact (this parameter is not considered in the cooking products analysis).
    d. Economic Growth: To the change value, use the drop-down arrow and select the desired Growth level (Reference, Low, or High).

4. Once the parameters have been set, there are two options;
    a. Click the "Select CSL' button to choose which candidate standard level to analyze. The associated efficiency distributions and growth trends are fixed as specified in Chapter 10 of this preliminary technical support document. Once the CSL has been selected, click the "OK" button to make your selected CSL effective. (This option is not available for compact freezers.)
    b. Click the "Set base case/Standards Case" button and define the efficiency distribution of the market, and the efficiency growth rate for both the base case and the standards case. Once the distribution and the growth rate have been set, click the "update" button to make your defined distribution effective.

5. The results are automatically updated and are reported in the summary table for each product class to the right of the "User Inputs" box.

APPENDIX 10-B. NATIONAL EQUIPMENT AND OPERATING COSTS

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 10-B. NATIONAL EQUIPMENT AND OPERATING COSTS

10-B.1 INTRODUCTION

In this appendix, the Department presents the components of the net present value (NPV), namely, the present value of the equipment (or total installed costs) and the present value of the operating costs for each of the four residential refrigerator-freezer product types. The present value of equipment costs is also termed the cumulative national equipment costs while the present value of operating costs is also termed the cumulative national operating costs.

As presented in Chapter 10, National Impact Analysis, the NPV is described by the equation:

$$NPV = PVS - PVC$$

where:

PVS = Present value of operating cost savings (including energy, water, repair, and maintenance costs) and
PVC = Present value of increased total installed costs (including equipment and installation).

The *PVS* and *PVC* are determined according to the following expressions:

$$PVS = \sum OCS_y \times DF_y$$

$$PVC = \sum TIC_y \times DF_y$$

where:

OCS = Total annual operating cost savings each year summed over vintages of the product stock,
TIC = Total annual installed cost increases each year summed over vintages of the product stock,
DF = Discount factor in each year, and
y = Year in the forecast (i.e., 2012 to 2042).

PVS and *PVC* are determined for each year from the effective date of the standard to the year when units purchased in 2042 retire.

The present value of operating costs and the present value of equipment costs (or total installed costs) are the components comprising the *PVS* and *PVC*, respectively. The *PVS* is determined by taking the difference between the present value of operating costs for the base case and the present value of operating costs for the standards case. The *PVC* is determined by taking the difference between the present value of equipment costs for the base case and the present value of equipment costs for the standards case.

10-B.2 RESULTS

For following sections provide tables showing the present value of operating costs (also known as the cumulative national operating costs) and the present value of equipment costs (also known as the cumulative national equipment costs) each of the four appliance products. For each product, two sets of results are presented; one based on a seven-percent and another based on a three-percent discount rate.

In the tables provided in the following sections, the national operating and equipment costs are presented for the base case (i.e., without standards) and each standard level analyzed. Differences between the base case and standards cases are also presented. The difference in the national equipment costs represents the *PVC* or present value of equipment cost increases while the difference in the national operating costs represents the *PVS* or present value of operating cost savings. The difference between the base case and standards case total national equipment and operating costs represents the *NPV*.

10-B.2.1 Standard-Size Refrigerator-Freezers

Tables 10B.2.1–10B.2.6 present the national equipment and operating costs, *PVC*, *PVS*, and *NPV* for standard-size refrigerator-freezers at real discount rates of seven- and three-percent, respectively.

All base case values were determined with shipments projections established under the standards case. As detailed in Chapter 9, shipments projections under the standards cases were determined to be lower than those in the base case projection due to the higher installed cost of the more efficient equipment. As a result, DOE used the standards case shipments projection and, in turn, the standards case equipment stock, to determine the *NPV* to avoid the inclusion of savings due to displaced shipments. Thus, the base case values shown in Tables 10B.2.1–10B.2.6 vary with the standards case.

DOE studied seven three product classes in detail for standard-size refrigerator-freezers. For the National Impact Analysis, each of these classes represents a product category which also contains other product classes. For standard-size refrigerator-freezers, the following list indicates which product classes are associated with each product category:

- Top-mount refrigerator-freezers: product classes 1, 1A, 2, 3, 3A, and 6; represented by product class 3.
- Bottom-mount refrigerator-freezers: product classes 5 and 5A; represented by product class 5.

- Side-by-side refrigerator-freezers: product classes 4 and 7; represented by product class 7.

Table 10-B.2.1 Standard-Size Refrigerator-Freezers, Top-Mount Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	46.62	101.53	148.15
Standard Level 1	46.89	96.18	143.07
Difference*	-0.27	5.36	***5.08***
Base Case	46.56	101.46	148.03
Standard Level 2	47.19	93.24	140.43
Difference*	-0.62	8.22	***7.60***
Base Case	46.42	101.26	147.68
Standard Level 3	48.03	89.86	137.89
Difference*	-1.61	11.40	***9.79***
Base Case	46.11	100.85	146.96
Standard Level 4	49.72	86.24	135.95
Difference*	-3.60	14.61	***11.01***
Base Case	45.68	100.26	145.93
Standard Level 5	52.06	82.53	134.59
Difference*	-6.38	17.73	***11.35***
Base Case	45.10	99.49	144.59
Standard Level 6	54.92	79.10	134.02
Difference*	-9.82	20.39	***10.57***
Base Case	44.32	98.43	142.75
Standard Level 7	58.77	75.23	134.00
Difference*	-14.45	23.20	***8.75***
Base Case	43.61	97.47	141.08
Standard Level 8	62.04	71.86	133.89
Difference*	-18.43	25.61	***7.18***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.2 Standard-Size Refrigerator-Freezers, Top-Mount Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	88.80	223.02	311.83
Standard Level 1	89.32	209.12	298.44
Difference*	-0.52	13.91	***13.39***
Base Case	88.71	222.85	311.57
Standard Level 2	89.90	201.51	291.40
Difference*	-1.18	21.35	***20.16***
Base Case	88.45	222.37	310.81
Standard Level 3	91.57	192.68	284.24
Difference*	-3.12	29.69	***26.57***
Base Case	87.91	221.37	309.27
Standard Level 4	94.86	183.33	278.19
Difference*	-6.96	38.04	***31.08***
Base Case	87.14	219.95	307.08
Standard Level 5	99.45	173.78	273.22
Difference*	-12.31	46.17	***33.86***
Base Case	86.15	218.14	304.29
Standard Level 6	104.96	165.07	270.03
Difference*	-18.80	53.06	***34.26***
Base Case	84.79	215.63	300.42
Standard Level 7	112.48	155.16	267.64
Difference*	-27.69	60.47	***32.78***
Base Case	83.57	213.38	296.95
Standard Level 8	118.84	146.58	265.42
Difference*	-35.27	66.80	***31.53***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.3 Standard-Size Refrigerator-Freezers, Bottom-Mount Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	31.06	17.30	48.36
Standard Level 1	31.06	17.11	48.17
Difference*	0.00	0.19	***0.19***
Base Case	31.06	17.30	48.36
Standard Level 2	31.07	17.01	48.08
Difference*	-0.02	0.29	***0.27***
Base Case	31.03	17.29	48.31
Standard Level 3	31.27	16.34	47.61
Difference*	-0.24	0.95	***0.70***
Base Case	30.88	17.22	48.10
Standard Level 4	32.22	15.48	47.70
Difference*	-1.34	1.75	***0.40***
Base Case	30.72	17.16	47.88
Standard Level 5	33.25	14.62	47.87
Difference*	-2.53	2.54	***0.01***
Base Case	30.63	17.12	47.74
Standard Level 6	33.59	14.35	47.94
Difference*	-2.97	2.77	***-0.19***
Base Case	30.39	17.02	47.41
Standard Level 7	34.84	13.48	48.32
Difference*	-4.45	3.54	***-0.91***
Base Case	30.29	16.98	47.27
Standard Level 8	35.18	13.21	48.40
Difference*	-4.89	3.77	***-1.12***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.4 Standard-Size Refrigerator-Freezers, Bottom-Mount Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	60.30	40.68	100.98
Standard Level 1	60.31	40.17	100.48
Difference*	-0.01	0.51	***0.50***
Base Case	60.30	40.68	100.97
Standard Level 2	60.33	39.92	100.24
Difference*	-0.03	0.76	***0.73***
Base Case	60.24	40.64	100.88
Standard Level 3	60.75	38.01	98.75
Difference*	-0.51	2.64	***2.13***
Base Case	59.95	40.48	100.43
Standard Level 4	62.72	35.73	98.45
Difference*	-2.77	4.75	***1.98***
Base Case	59.63	40.30	99.93
Standard Level 5	64.86	33.46	98.32
Difference*	-5.23	6.84	***1.61***
Base Case	59.50	40.23	99.73
Standard Level 6	65.41	32.89	98.30
Difference*	-5.91	7.34	***1.43***
Base Case	59.08	40.00	99.08
Standard Level 7	67.86	30.61	98.47
Difference*	-8.78	9.38	***0.60***
Base Case	58.94	39.92	98.86
Standard Level 8	68.41	30.06	98.47
Difference*	-9.47	9.86	***0.40***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.5 Standard-Size Refrigerator-Freezers, Side-Mount Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	63.01	81.15	144.17
Standard Level 1	63.16	79.65	142.81
Difference*	-0.15	1.50	***1.35***
Base Case	62.97	81.12	144.09
Standard Level 2	63.40	77.58	140.98
Difference*	-0.43	3.53	***3.11***
Base Case	62.68	80.87	143.55
Standard Level 3	65.16	74.57	139.73
Difference*	-2.48	6.30	***3.82***
Base Case	62.25	80.52	142.77
Standard Level 4	67.53	71.30	138.83
Difference*	-5.28	9.22	***3.94***
Base Case	61.72	80.08	141.81
Standard Level 5	70.39	68.00	138.39
Difference*	-8.67	12.08	***3.42***
Base Case	61.33	79.76	141.09
Standard Level 6	72.31	65.58	137.89
Difference*	-10.98	14.18	***3.20***
Base Case	60.81	79.33	140.15
Standard Level 7	74.82	63.11	137.93
Difference*	-14.00	16.22	***2.22***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.6 Standard-Size Refrigerator-Freezers, Side-Mount Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	122.36	182.70	305.06
Standard Level 1	122.64	178.74	301.38
Difference*	-0.29	3.96	***3.68***
Base Case	122.28	182.62	304.90
Standard Level 2	123.11	173.27	296.38
Difference*	-0.83	9.35	***8.52***
Base Case	121.74	182.00	303.73
Standard Level 3	126.69	165.15	291.84
Difference*	-4.96	16.84	***11.89***
Base Case	120.97	181.13	302.09
Standard Level 4	131.39	156.55	287.94
Difference*	-10.43	24.58	***14.15***
Base Case	120.02	180.06	300.09
Standard Level 5	137.07	147.90	284.97
Difference*	-17.05	32.17	***15.12***
Base Case	119.36	179.31	298.67
Standard Level 6	140.78	141.72	282.50
Difference*	-21.42	37.59	***16.17***
Base Case	118.47	178.32	296.79
Standard Level 7	145.61	135.45	281.06
Difference*	-27.14	42.87	***15.73***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

10-B.2.2 Standard-Size Freezers

Tables 10B.2.7–10B.2.10 present the national equipment and operating costs, *PVC*, *PVS*, and *NPV* for standard-size freezers at real discount rates of seven- and three-percent, respectively.

All base case values were determined with shipments projections established under the standards case. As detailed in Chapter 9, shipments projections under the standards cases were determined to be lower than those in the base case projection due to the higher installed cost of the more efficient equipment. As a result, DOE used the standards case shipments projection and, in turn, the standards case equipment stock, to determine the *NPV* to avoid the inclusion of savings due to displaced shipments. Thus, the base case values shown in Tables 10B.2.7–10B.2.10 vary with the standards case.

Throughout its analysis, DOE studied two product classes in detail for standard-size freezers. For the National Impact Analysis, each of these classes represents a product category which also contains other product classes. For standard-size freezers, the following list indicates which product classes are associated with each product category:

- Upright freezers: product class 9 only.
- Chest freezers: product classes 8[a], 10, and 10A; represented by product class 10.

Table 10-B.2.7 Standard-Size Freezers, Upright Product Class: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	7.01	34.32	41.33
Standard Level 1	7.09	32.65	39.74
Difference*	-0.09	1.68	***1.59***
Base Case	6.99	34.29	41.28
Standard Level 2	7.16	31.59	38.75
Difference*	-0.17	2.70	***2.53***
Base Case	6.98	34.26	41.24
Standard Level 3	7.21	30.54	37.76
Difference*	-0.23	3.71	***3.48***
Base Case	6.94	34.13	41.07
Standard Level 4	7.42	29.43	36.84
Difference*	-0.48	4.71	***4.23***
Base Case	6.88	33.96	40.84
Standard Level 5	7.70	28.28	35.98
Difference*	-0.82	5.68	***4.86***
Base Case	6.78	33.69	40.47
Standard Level 6	8.13	27.09	35.22
Difference*	-1.34	6.60	***5.25***
Base Case	6.63	33.26	39.90
Standard Level 7	8.77	25.83	34.61
Difference*	-2.14	7.43	***5.29***
Base Case	6.44	32.72	39.17
Standard Level 8	9.49	24.70	34.19
Difference*	-3.05	8.03	***4.98***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

[a] Product class 8, "upright freezers with manual defrost" is analyzed as part of the "chest freezer" category because products in this class are much more technologically similar to chest freezers.

Table 10-B.2.8 Standard-Size Freezers, Upright Product Class: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	13.45	78.49	91.94
Standard Level 1	13.62	73.80	87.42
Difference*	-0.17	4.69	***4.52***
Base Case	13.43	78.38	91.81
Standard Level 2	13.74	70.86	84.60
Difference*	-0.32	7.53	***7.21***
Base Case	13.41	78.30	91.71
Standard Level 3	13.85	67.93	81.78
Difference*	-0.45	10.37	***9.92***
Base Case	13.32	77.96	91.29
Standard Level 4	14.24	64.81	79.06
Difference*	-0.92	13.15	***12.23***
Base Case	13.21	77.49	90.69
Standard Level 5	14.79	61.63	76.42
Difference*	-1.58	15.86	***14.28***
Base Case	13.03	76.73	89.76
Standard Level 6	15.63	58.31	73.93
Difference*	-2.60	18.42	***15.82***
Base Case	12.75	75.56	88.30
Standard Level 7	16.88	54.81	71.69
Difference*	-4.13	20.75	***16.62***
Base Case	12.39	74.10	86.49
Standard Level 8	18.26	51.69	69.95
Difference*	-5.86	22.41	***16.54***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.9 Standard-Size Freezers, Chest Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	4.65	22.50	27.15
Standard Level 1	4.69	21.36	26.05
Difference*	-0.03	1.14	***1.10***
Base Case	4.64	22.46	27.09
Standard Level 2	4.77	20.65	25.42
Difference*	-0.13	1.80	***1.68***
Base Case	4.59	22.31	26.90
Standard Level 3	5.00	19.87	24.86
Difference*	-0.41	2.44	***2.03***
Base Case	4.57	22.27	26.84
Standard Level 4	5.07	19.17	24.24
Difference*	-0.50	3.10	***2.60***
Base Case	4.54	22.19	26.74
Standard Level 5	5.20	18.46	23.66
Difference*	-0.66	3.73	***3.07***
Base Case	4.43	21.88	26.32
Standard Level 6	5.66	17.60	23.26
Difference*	-1.23	4.29	***3.06***
Base Case	4.41	21.81	26.22
Standard Level 7	5.79	16.91	22.71
Difference*	-1.38	4.90	***3.52***
Base Case	4.25	21.35	25.60
Standard Level 8	6.41	16.10	22.51
Difference*	-2.17	5.26	***3.09***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.10 Standard-Size Freezers, Chest Product Classes: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	8.93	51.47	60.40
Standard Level 1	9.00	48.29	57.29
Difference*	-0.07	3.18	***3.11***
Base Case	8.90	51.34	60.25
Standard Level 2	9.16	46.31	55.47
Difference*	-0.25	5.03	***4.78***
Base Case	8.81	50.95	59.76
Standard Level 3	9.60	44.12	53.72
Difference*	-0.79	6.83	***6.04***
Base Case	8.78	50.83	59.61
Standard Level 4	9.74	42.19	51.92
Difference*	-0.96	8.64	***7.68***
Base Case	8.73	50.61	59.34
Standard Level 5	10.01	40.19	50.19
Difference*	-1.28	10.42	***9.14***
Base Case	8.52	49.77	58.30
Standard Level 6	10.88	37.80	48.69
Difference*	-2.36	11.97	***9.61***
Base Case	8.47	49.57	58.04
Standard Level 7	11.14	35.89	47.03
Difference*	-2.67	13.68	***11.01***
Base Case	8.17	48.32	56.49
Standard Level 8	12.34	33.64	45.98
Difference*	-4.17	14.68	***10.51***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

10-B.2.3 Compact Refrigerators

Tables 10B.2.11 and 10B.2.12 present the national equipment and operating costs, *PVC*, *PVS*, and *NPV* for compact refrigerators at real discount rates of seven- and three-percent, respectively.

All base case values were determined with shipments projections established under the standards case. As detailed in Chapter 9, shipments projections under the standards cases were determined to be lower than those in the base case projection due to the higher installed cost of the more efficient equipment. As a result, DOE used the standards case shipments projection and, in turn, the standards case equipment stock, to determine the *NPV* to avoid the inclusion of savings due to displaced shipments. Thus, the base case values shown in Tables 10B.2.11 and 10B.2.12 vary with the standards case.

Throughout its analysis, DOE studied one product class in detail for compact refrigerators. For the National Impact Analysis, this class represents a product category which also contains other product classes. For compact refrigerators, the following indicates which product classes are associated with the product category:

- Compact refrigerators: product classes 11, 11A, 12, 13, 13A, 14, and 15; represented by product class 11.

Table 10-B.2.11 Compact Refrigerators: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	**Equipment**	**Operating**	**Total**
Base Case	5.54	6.65	12.19
Standard Level 1	5.68	6.09	11.76
Difference*	-0.14	0.56	***0.43***
Base Case	5.50	6.60	12.10
Standard Level 2	5.75	5.76	11.51
Difference*	-0.25	0.84	***0.59***
Base Case	5.46	6.56	12.02
Standard Level 3	5.82	5.44	11.25
Difference*	-0.36	1.12	***0.76***
Base Case	5.28	6.37	11.65
Standard Level 4	6.09	5.01	11.10
Difference*	-0.81	1.36	***0.55***
Base Case	5.27	6.36	11.62
Standard Level 5	6.11	4.73	10.85
Difference*	-0.85	1.62	***0.78***
Base Case	5.19	6.27	11.46
Standard Level 6	6.23	4.40	10.64
Difference*	-1.04	1.87	***0.83***
Base Case	5.01	6.09	11.09
Standard Level 7	6.47	4.03	10.50
Difference*	-1.47	2.06	***0.59***
Base Case	4.75	5.82	10.58
Standard Level 8	6.78	3.62	10.41
Difference*	-2.03	2.20	***0.17***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.12 Compact Refrigerators: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	10.95	14.10	25.05
Standard Level 1	11.22	12.83	24.06
Difference*	-0.27	1.26	***1.00***
Base Case	10.86	13.98	24.84
Standard Level 2	11.36	12.09	23.45
Difference*	-0.50	1.89	***1.39***
Base Case	10.78	13.88	24.66
Standard Level 3	11.48	11.37	22.85
Difference*	-0.71	2.52	***1.81***
Base Case	10.40	13.44	23.84
Standard Level 4	12.00	10.39	22.39
Difference*	-1.59	3.04	***1.45***
Base Case	10.37	13.40	23.77
Standard Level 5	12.04	9.76	21.80
Difference*	-1.67	3.64	***1.97***
Base Case	10.20	13.20	23.40
Standard Level 6	12.26	9.01	21.28
Difference*	-2.06	4.18	***2.12***
Base Case	9.83	12.75	22.58
Standard Level 7	12.71	8.15	20.86
Difference*	-2.88	4.60	***1.72***
Base Case	9.30	12.12	21.42
Standard Level 8	13.27	7.24	20.51
Difference*	-3.97	4.89	***0.92***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

10-B.2.4 Compact Freezers

Tables 10B.2.13 and 10B.2.14 present the national equipment and operating costs, *PVC*, *PVS*, and *NPV* for compact freezers at real discount rates of seven- and three-percent, respectively.

All base case values were determined with shipments projections established under the standards case. As detailed in Chapter 9, shipments projections under the standards cases were determined to be lower than those in the base case projection due to the higher installed cost of the more efficient equipment. As a result, DOE used the standards case shipments projection and, in turn, the standards case equipment stock, to determine the *NPV* to avoid the inclusion of savings due to displaced shipments. Thus, the base case values shown in Tables 10B.2.13 and 10B.2.14 vary with the standards case.

Throughout its analysis, DOE studied one product class in detail for compact freezers. For the National Impact Analysis, this class represents a product category which also contains other product classes. For compact freezers, the following indicates which product classes are associated with the product category:

- Compact freezers: product classes 16, 17, and 18; represented by product class 18.

Table 10-B.2.13 Compact Freezers: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Seven-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	1.31	1.70	3.01
Standard Level 1	1.36	1.57	2.93
Difference*	-0.05	0.13	***0.08***
Base Case	1.30	1.69	2.99
Standard Level 2	1.37	1.49	2.87
Difference*	-0.07	0.20	***0.12***
Base Case	1.24	1.63	2.87
Standard Level 3	1.49	1.38	2.87
Difference*	-0.25	0.25	***0.00***
Base Case	1.22	1.60	2.82
Standard Level 4	1.53	1.29	2.82
Difference*	-0.31	0.31	***0.00***
Base Case	1.18	1.56	2.74
Standard Level 5	1.60	1.20	2.80
Difference*	-0.42	0.36	***-0.06***
Base Case	1.17	1.55	2.72
Standard Level 6	1.61	1.14	2.75
Difference*	-0.44	0.42	***-0.02***
Base Case	1.14	1.52	2.67
Standard Level 7	1.65	1.06	2.71
Difference*	-0.51	0.47	***-0.05***
Base Case	1.11	1.49	2.60
Standard Level 8	1.70	0.98	2.68
Difference*	-0.59	0.51	***-0.08***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

Table 10-B.2.14 Compact Freezers: Cumulative National Equipment and Operating Costs with NPV from 2014–2044, Three-Percent Discount Rate (billion 2008$)

Standard Level	Equipment	Operating	Total
Base Case	2.48	3.46	5.94
Standard Level 1	2.56	3.17	5.74
Difference*	-0.09	0.29	***0.20***
Base Case	2.46	3.44	5.90
Standard Level 2	2.60	3.00	5.60
Difference*	-0.14	0.43	***0.30***
Base Case	2.34	3.28	5.62
Standard Level 3	2.81	2.73	5.54
Difference*	-0.47	0.55	***0.08***
Base Case	2.29	3.23	5.53
Standard Level 4	2.87	2.55	5.42
Difference*	-0.58	0.68	***0.10***
Base Case	2.21	3.13	5.34
Standard Level 5	3.00	2.34	5.34
Difference*	-0.79	0.79	***0.00***
Base Case	2.20	3.11	5.31
Standard Level 6	3.02	2.19	5.21
Difference*	-0.82	0.92	***0.09***
Base Case	2.14	3.04	5.18
Standard Level 7	3.09	2.02	5.11
Difference*	-0.96	1.02	***0.06***
Base Case	2.07	2.96	5.03
Standard Level 8	3.18	1.85	5.02
Difference*	-1.11	1.11	***0.01***

* Equipment Cost Difference represents the *PVC*; Operating Cost Difference represents the *PVC*; *NPV* is represented by the bold and italicized values.

CHAPTER 11. LIFE-CYCLE COST SUBGROUP ANALYSIS

TABLE OF CONTENTS

CHAPTER 11. LIFE-CYCLE COST SUBGROUP ANALYSIS

11.1 INTRODUCTION

The life-cycle cost (LCC) subgroup analysis evaluates impacts on any identifiable groups or customers who may be disproportionately affected by any national energy efficiency standard level. The Department of Energy (DOE) will conduct this analysis as one of the analyses for the notice of proposed rulemaking (NOPR). DOE will accomplish this, in part, by analyzing the LCC and payback periods (PBPs) for those customers that fall into any identifiable groups. DOE plans to evaluate variations in regional energy prices and variations in energy use that might affect the net present value of a standard to customer subpopulations. To the extent possible, DOE will obtain estimates of each input parameter's variability and will consider this variability in its calculation of customer impacts. DOE plans to perform sensitivity analyses to consider how differences in energy use will affect subgroups of customers.

DOE will determine the impact on customer subgroups using the LCC Spreadsheet Model, which allows for different data inputs. The standard LCC analysis (described in Chapter 8) focuses on the households and establishments that use refrigerators, refrigerator-freezers, and freezers. For standard-size refrigerator-freezers and freezers, DOE can use the LCC Spreadsheet Models to analyze the LCC for any subgroup by sampling only that subgroup. (Chapter 8 explains in detail the inputs to the model used in determining LCC and PBPs.)

In the case of households that use refrigerator-freezers and freezers, some possible subgroups DOE may choose to consider are: (1) low-income households, and (2) senior citizens. In the case of commercial establishments that use compact refrigerators and freezers, small businesses are a subgroup that DOE may choose to consider. If it analyzes small businesses, DOE will likely focus on small business subgroups such as lodging establishments.

11.2 PURCHASE PRICE IMPACTS

DOE will be especially sensitive to increases in the purchase price of the equipment due to new standards, to avoid negative impacts on identifiable population groups that may not be able to afford significant increases in equipment price. For such customers that are sensitive to price increases, increases in first costs of a product can preclude the purchase of a new model of that product. As a result, some customers may retain products past their useful life. These older products are generally less efficient to begin with, and their efficiency may deteriorate further if they are retained beyond their useful life. Increases in first cost also can preclude the purchase and use of a product altogether, resulting in a potentially large loss of utility to the customer.

CHAPTER 12. PRELIMINARY MANUFACTURER IMPACT ANLAYSIS

TABLE OF CONTENTS

CHAPTER 12. PRELIMINARY MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

The purpose of the manufacturer impact analysis (MIA) is to identify the likely impacts of amended energy conservation standards on manufacturers. The U.S. Department of Energy (DOE) will conduct this analysis with input from manufacturers and other interested parties and will apply this methodology to its evaluation of amended energy conservation standards for residential refrigerators, refrigerator-freezers, and freezers. DOE will also consider financial impacts and a wide range of quantitative and qualitative industry impacts that might occur following the amendment of an energy conservation standard. For example, a particular energy conservation standard level, if adopted by DOE, could require changes to residential refrigeration products manufacturing practices. DOE will identify and come to understand these impacts through interviews with manufacturers and other interested parties during the Notice of Proposed Rulemaking (NOPR) stage of its analysis.

Recently, DOE announced changes to the MIA format through a report issued to Congress on January 31, 2006 (as required by section 141 of the Energy Policy Act of 2005 (EPACT 2005)), entitled “Energy Conservation Standards Activities.”[a] Previously, DOE did not report any MIA results until the Notice of Proposed Rulemaking (NOPR) phase; however, under this new format, DOE has collected, evaluated, and reported preliminary information and data during the preliminary phase (the phase preceding the NOPR) of this rulemaking. Such preliminary information includes the anticipated conversion capital expenditures by efficiency level and the corresponding anticipated impacts on jobs. DOE solicited this information during the engineering analysis manufacturer interviews and reported the results below.

12.2 METHODOLOGY

DOE conducts the MIA in three phases and further tailors the analytical framework based on comments from interested parties. In Phase 1, DOE creates an industry profile to characterize the industry and conducts a preliminary MIA to identify important issues that require consideration. The preliminary technical support document (preliminary TSD) presents the results of the Phase 1 analysis. In Phase 2, DOE prepares an industry cash-flow model and an interview questionnaire to guide subsequent discussions. In Phase 3, DOE interviews manufacturers, and assesses the impacts of amended energy conservation standards both quantitatively and qualitatively. Using the government regulatory impact model (GRIM), DOE assesses industry and sub-group

[a] This report is available on the DOE website at www.eere.energy.gov/buildings/appliance_standards/2006_schedule_setting.html.

cash flow and NPV. Then, DOE assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions. The NOPR TSD presents results of the Phase 2 and 3 analyses.

12.2.1 Phase 1: Industry Profile

In Phase 1 of the manufacturer impact analysis, DOE collects pertinent qualitative and quantitative financial and market information. This includes residential refrigerator, refrigerator-freezer, and freezer manufacturer market share, corporate operating ratios, wages, employment, and production cost ratios. Sources of information may include reports published by industry groups, trade journals, the U.S. Census Bureau, copies of Securities Exchange Commission (SEC) 10-K filings, and interviews with manufacturers. DOE also relies on information from its market and technology assessment, engineering analysis, life-cycle cost analysis, markup analysis, and analysis of capital expenditure requirements and other data submitted by AHAM to determine the product prices to characterize the residential refrigeration product industry.

12.2.2 Phase 2: Industry Cash-Flow Analysis and Interview Guide

In Phase 2, DOE will perform a preliminary industry cash-flow analysis and prepare written guidelines for interviewing manufacturers.

12.2.2.1 Industry Cash-Flow Analysis

DOE uses the GRIM to analyze the financial impacts of amended energy conservation standards on the residential refrigeration products industries. Standards will likely require additional investment, raise production costs, and affect revenue through higher prices and, possibly, lower sales. The GRIM uses several factors to determine a series of annual cash flows for the year standards become effective and for several years after implementation. These factors include annual expected revenues, costs of sales, selling and general administration costs, taxes, and capital expenditures related to depreciation, new standards, and maintenance. Inputs to the GRIM include manufacturing costs, shipments forecasts, and price forecasts developed in other analyses. Another input, financial information, will be developed based on publicly available data and confidentially submitted manufacturer information. DOE compares the results of the GRIM against baseline projections where no standards are in place. The financial impact of amended energy conservation standards is the difference between the two sets of discounted annual cash flows.

12.2.2.2 Interview Guide

DOE will conduct interviews with manufacturers to gather information on the effects of standards on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE will distribute an interview guide that will provide a starting point to identify relevant issues and help identify the impacts of standards on individual manufacturers or sub-groups of manufacturers. DOE anticipates that the interview guide will cover current organizational characteristics, industry infrastructure, manufacturer cash-flow analysis, a competitive impacts assessment, an employment impacts assessment, and a manufacturing capacity impacts assessment.

12.2.3 Phase 3: Sub-Group Analysis

Phase 3 activities will take place after the publication of the NOPR documents and will include manufacturer interviews, revision of the industry cash-flow analysis, manufacturer sub-group cash-flow analysis, competitive impact assessment, manufacturing capacity impact, employment impact, and cumulative regulatory burden.

12.2.3.1 Manufacturer Interviews

The information gathered in Phase 1 and the cash-flow analysis performed in Phase 2 will be supplemented with information gathered during interviews with manufacturers during Phase 3. The interview process has a key role in the manufacturer impact analyses, since it provides an opportunity for interested parties to express their views privately on important issues, allowing confidential or sensitive information to be considered in the rulemaking decision.

DOE will conduct detailed interviews with as many manufacturers as necessary to gain insight into the range of potential impacts of standards. During the interviews, DOE will solicit information on the possible impacts of standards on sales, direct employment, capital assets, and industry competitiveness. Both qualitative and quantitative information are valuable. Interviews will be scheduled well in advance in order to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire will be acceptable, DOE prefers an interactive interview process because it helps clarify responses and provides the opportunity to identify additional issues.

All information transmitted will be considered, as appropriate, in DOE's decision-making process. Interview participants will be asked to identify all confidential information provided in writing or orally; no confidential information will be made available in the public record. Participants will also be asked to identify all information they wish included in the public record but do not want to have associated with their interview. This information will be incorporated into the public record but reported without attribution.

12.2.3.2 Revised Industry Cash-Flow Analysis

In Phase 2 of the MIA, DOE will provide manufacturers with a preliminary GRIM for review and evaluation. During the interviews, DOE will seek comment and suggestions regarding the values selected for the parameters. Upon completion of the interviews, DOE will revise its industry cash-flow model based on manufacturer feedback.

12.2.3.3 Manufacturer Sub-Group Analysis

Using average cost assumptions to develop an industry cash-flow estimate is not adequate for assessing differential impacts among sub-groups of manufacturers. Smaller manufacturers, niche players, or manufacturers exhibiting a cost structure that differs largely from the industry average could be more negatively affected. Ideally, DOE would consider the impact on every firm individually; however, it typically uses the results of the industry characterization to group manufacturers exhibiting similar characteristics. During the interview process, DOE will discuss the potential sub-groups and sub-group members that have been identified for the analysis. DOE will look to the manufacturers and other stakeholders to suggest what sub-groups or characteristics are most appropriate for the analysis.

12.2.3.4 Competitive Impact Assessment

Section 342 (6)(B)(i)(V) of the Energy Policy Act of 1992 (EPCA) directs DOE to consider any lessening of competition likely to result from imposition of standards. It further directs the U.S. Attorney General to determine the impacts, if any, of any decrease in competition. DOE will make a determined effort to gather and report firm-specific financial information and impacts. The competitive analysis will focus on assessing the impacts on smaller, yet significant, manufacturers. The assessment will be based on manufacturing cost data and information collected from interviews with manufacturers. The manufacturer interviews will focus on gathering information that would help in assessing asymmetrical cost increases to some manufacturers, the potential increase in business risks from an increased proportion of fixed costs, and potential barriers to market entry (*e.g.,* proprietary technologies).

12.2.3.5 Manufacturing Capacity Impact

One of the significant outcomes of standards could be the obsolescence of existing manufacturing assets, including tooling and investment. The manufacturer interview guide will have a series of questions to help identify impacts on manufacturing capacity, specifically capacity utilization and plant location decisions in North America with and without a standard; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of stranded assets, if any; and estimates for any one-time restructuring and other charges, where applicable.

12.2.3.6 Employment Impact

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic employment patterns might be affected, the interview will explore current employment trends in the refrigeration products industry. The interview will also solicit manufacturer views on changes in employment patterns that may result from increased standard levels. The employment impacts section of the interview guide will focus on current employment levels associated with manufacturers at each of their production facilities, expected future employment levels with and without a standard, and differences in workforce skills and issues related to the retraining of employees.

12.2.3.7 Cumulative Regulatory Burden

DOE recognizes and seeks to mitigate the overlapping effects on manufacturers of amended energy conservation standards and other regulatory actions affecting the same products. DOE will analyze and consider the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified several regulations and proposed regulations relevant to refrigerator, refrigerator-freezer, and freezer manufacturers, including existing or new standards, potential limits on greenhouse gas (GHG) emissions, including hydrofluorocarbon (HFC) refrigerants and foam-blowing agents, standards for other products made by refrigerator, refrigerator-freezer, and freezer manufacturers, State energy conservation standards, and International energy conservation standards. DOE will study the potential impacts of these cumulative burdens in greater detail during the MIA conducted during the NOPR phase.

12.3 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

During the preliminary rulemaking phase, DOE conducted a preliminary evaluation of the impact of potential amended energy conservation standards on manufacturer financial performance, manufacturing capacity and employment levels, and product utility and innovation. A primary focus was to identify the cumulative burden that industries face from the overlapping effect of new or recent DOE energy conservation standards and/or other regulatory action affecting the same products or industries.

The primary sources of information for this analysis were on-site or telephone interviews with manufacturers of residential refrigeration products conducted during the fall and winter of 2008. To maintain confidentiality, DOE did not identify the individual manufacturers that disclosed information. The evaluation only reports aggregated information and does not disclose sensitive or company-specific information.

For the preliminary MIA, DOE conducted interviews with manufacturers primarily to identify key issues and gain insights into the qualitative impacts of amended energy conservation standards. For each product, DOE used an interview guide to gather responses from multiple manufacturers on many issues. All of the interview guides covered the same general topic areas, but each interview guide was adapted to the needs of each product category. Appendix 12-A contains a copy of the interview guides for residential refrigerators, refrigerator-freezers, and freezers.

12.3.1 General Interview Structure

The manufacturer interviews included questions relating to the following topics. DOE received responses to most, if not all, of these topics from various manufacturers.

12.3.1.1 Key Issues

Perhaps the most important aspect of the preliminary MIA is the opportunity to identify key manufacturer issues early in the development of amended energy conservation standards. During the interviews, DOE engages manufacturers in a discussion about what they perceive to be the key issues in the rulemaking. Key issues, once identified, are added to the list of topics explored during the interviews. For example, key issues in previous rulemakings have included concerns over patent protections that might prevent some companies from implementing higher efficiency designs.

12.3.1.2 Shipment Projections

Shipment projections can be a significant factor in determining the impacts of amended energy conservation standards. The interviews provide an opportunity for manufacturers to share information that can help DOE quantify the magnitude of any changes in shipments resulting from amended energy conservation standards. DOE is interested in information relating to the current number of product shipments, broken down by product class, capacity rating, and efficiency level. DOE also seeks input on the forecast of future shipments absent amended energy conservation standards. Manufacturers are asked how they would expect shipments to change for the industry as a whole as a function of standard levels and why they expect these changes might occur. More specific questions aim to derive a price elasticity estimate for use in the national impact analysis (NIA) spreadsheet.

Another aspect of the shipments discussion is to understand the impacts of a reduction in shipments on individual refrigeration products companies.

12.3.1.3 Profitability

DOE requests manufacturers' views on what they perceive to be the possible impact of potential amended energy conservation standards on their future profitability. Amended energy conservation standards could affect financial performance in several different ways. Several of these impacts are captured in previous sections. For instance, the capital and product conversion outlays needed to upgrade or redesign products and product platforms before they have reached the end of their useful life can engender significant conversion costs that otherwise would not be expended, resulting in reduced cash flow and stranded investments. Higher energy efficiency standards also can result in higher per-unit costs that may deter some consumers from purchasing the products, or cause some consumers to choose less efficient products, thereby reducing shipments.

12.3.1.4 Product Mix

DOE is interested in understanding if amended energy conservation standards might change a manufacturer's product mix and if this change affects profits. For example, higher energy efficiency standards might limit a manufacturer's ability to differentiate products and market premium products that command higher profit margins.

The interview guide also investigates how amended energy conservation standards might affect a manufacturer's consumer mix and its distribution channels, and how in turn this might change profitability.

12.3.1.5 Conversion Costs, Manufacturing Capacity, and Employment Levels

During the interviews, DOE asks manufacturers to quantify and explain both the capital and product conversion costs necessary to raise the energy efficiency of their product lines to the proposed standard levels. In some instances, manufacturers may be able to meet proposed standard levels by modifying existing products. In other cases, the necessary changes may entail a complete product-line redesign. In these situations, an increase in efficiency standards will cause manufacturers to incur one-time conversion capital expenditures and product-conversion expenses. Conversion capital expenditures are one-time investments in property, plant, and equipment. Product-conversion expenses include one-time investments in research, product development, testing, and marketing.

One of the significant outcomes of amended energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and other capital investment. The interview guide includes questions to identify impacts on manufacturing capacity. DOE developed these questions to understand the impact of potential amended standards on:

- North American manufacturing capacity;
- capacity utilization and plant location decisions in North America both with and without standards;
- the ability of manufacturers to upgrade or remodel existing facilities to accommodate a new product mix; and
- the nature and value of stranded assets, if any.

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. DOE uses the interviews to explore current trends in production employment and solicit manufacturer views on changes in employment patterns resulting from amended energy conservation standards. Questions regarding employment impacts help to understand

- current employment levels associated with manufacturing the subject products at each production facility;
- expected future employment levels both with and without amended standards; and
- differences in workforce skills and issues related to retraining employees.

12.3.1.6 Market Shares and Industry Consolidation

Amended energy conservation standards can alter the competitive dynamics of the marketplace. This can include prompting companies to enter the market, exit the market, or merge with other companies. The preliminary MIA interview questions ask manufacturers to share their perspectives on industry consolidation both in the absence of amended standards and assuming amended standards at various efficiency levels. The interview questions focus on gathering information that helps in assessing

- disproportionate cost increases to some manufacturers;
- increased proportion of fixed costs potentially increasing business risks; and
- potential barriers to market entry (*e.g.*, proprietary technologies).

DOE conducts an assessment of anti-competitive effects of proposed standards in order to protect the interests of the consumer. During the interviews, DOE solicits information to understand if amended standards could result in disproportionate economic or performance penalties for particular consumer/user sub-groups.

DOE also asks manufacturers if amended energy conservation standards could result in products that will be more or less desirable to consumers due to changes in product functionality, utility, or other features.

12.3.1.7 Product Utility and Innovation

Amended energy conservation standards can force manufacturers to compromise product utility to consumers by eliminating energy-consuming features. During the interviews, DOE requests information on the effects of proposed standards on product utility.

Amended energy conservation standards may require investment in conversion costs, including research and development (R&D). This required spending may force a manufacturer to reduce funding usually allocated to product innovation. Amended energy conservation standards may also force manufacturers to eliminate innovative energy-consuming features from their products. During the interviews, DOE requests information on the effect of proposed standards on innovation.

12.3.1.8 Impact on Small Manufacturers

DOE will consider the possibility of small businesses being affected by the promulgation of amended energy conservation standards for residential refrigerators, refrigerator-freezers, and freezers. Should any small business manufacturers be identified, DOE will study the potential impacts on these small businesses in greater detail during the MIA.

12.3.1.9 Cumulative Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or entire industries. Assessing the impact of a single regulation may overlook this cumulative regulatory burden.

Expenditures associated with meeting other regulations are an important aspect of DOE's consideration of the "cumulative regulatory burden" the industry faces. The interviews help DOE identify the level and timing of investments manufacturers are expecting to incur as a result of these regulations. Manufacturers are also asked under what circumstances they might be able to coordinate any expenditures related to these regulations and efficiency standards.

In addition to the amended energy conservation for residential refrigeration products, several other Federal regulations and pending regulations apply to other products these manufacturers make. DOE will investigate these cumulative regulatory burdens in greater detail during the NOPR phase of the rulemaking.

12.3.1.10 State Energy Conservation Standards

DOE identified and described regulatory programs at the state level in the market and technology assessment (chapter 3 of the preliminary TSD) for the products covered in this rulemaking. Multiple States have requirements for products covered under this rulemaking. Accommodating multiple State standards in addition to National standards raises costs for manufacturers.

12.3.1.11 International Energy Conservation Standards

DOE discussed regulatory programs from certain other countries, such as Canada and Mexico, in the market and technology assessment, (chapter 3 of the preliminary TSD). A few manufacturers sell a small portion of their total production to countries outside the United States. In these cases, the products must meet the standards for each country. Companies may design some units to meet more stringent standards than those imposed by the United States in order to minimize the number of product variations.

12.4 RESIDENTIAL REFRIGERATION PRODUCT PRELIMINARY MIA RESULTS

During the preliminary MIA interview, manufacturers identified key issues surrounding DOE's rulemaking for refrigeration products and provided feedback regarding the potential impact of amended energy conservation standards. DOE summarized the feedback below.

12.4.1 Key Issues

One of the main questions in each of the preliminary interview guide asks: "What are the key issues for your company regarding the refrigeration products energy conservation standard rulemaking?" This open question initiated dialogue with the manufacturers, enabling them to identify key points that DOE would explore and discuss during the interview. This section describes the key issues manufacturers felt were of the highest importance in relation to the residential refrigeration products energy conservation standards rulemaking and that would have the most significant impact on the industry. Manufacturers indicated that, for the most part, the risks associated with these issues increase with more stringent energy conservation standards. The issues are overall concerns that many manufacturers expressed and in some cases, are dependent upon the product class.

Refrigerator, refrigerator-freezer, and freezer manufacturers cited concerns regarding a number of issues that are covered in greater detail elsewhere in this chapter. These issues were conversion costs, the impact to U.S. production and jobs, cumulative regulatory burden, and the impact on product utility. Detailed descriptions of these manufacturer concerns are provided in the appropriate sections that follow; only brief descriptions are provided here.

- *Increased Conversion Costs* – A number of manufacturers indicated that conversion costs will be much greater if the adopted standards require significant changes to efficiency rather than moderate changes to efficiency. This is due to the need for wall thickness increases rather than just component swaps in the case of significantly more stringent energy standards.

- *Impact to U.S. Production and Jobs* – Manufacturers generally agreed that increased standards requiring investment in new plants would most likely have the effect of lowering U.S. production and jobs because plants would be built overseas for the benefit of lower labor costs.

- *Cumulative Regulatory Burden* – Many manufacturers indicated that refrigeration products face a number of pieces of new legislation that would exacerbate the burden created from more stringent energy standards. These include a potential Greenhouse Gas (GHG) bill in the U.S. and changing energy standards in Canada and abroad.

- *Impact to Product Utility* – Several manufacturers expressed concern about the possibility of lower product utility resulting from stricter energy standards. If thicker walls are required to meet new standards, internal volumes would be reduced while still using the same amount of floor space. Other features that can increase energy usage, such as glass doors and multiple temperature zones in drawer compartments, may have to be removed if standards are significantly stricter.

The other issues of key importance to manufacturers are the current poor economic conditions, the circumvention of new standards and need for enforcement, and the timing and technical difficulty of achieving new standards.

- *Current Economic Conditions* – A number of manufacturers indicated that the current status of the U.S. economy has put strains on the financial conditions of their companies. This strain diminishes their ability to support the investments required to meet new energy standards and causes a competition for capital between these required investments and other opportunities such as research and new product development. Any impact from new standards on conversion costs, U.S. production, and jobs would be greater because of the difficult economic environment.

- *Circumvention and Enforcement* – Several manufacturers expressed concern that some manufacturers have not followed the intent of the current test procedure or have actively circumvented the test procedure via sensors that detect test conditions. These sensors direct a controller to disable certain energy-using functions during the test in order to achieve lower energy consumption for the Energy Guide labeling. These actions have hurt domestic manufacturers competitively. Other companies expressed concern that there is not enough enforcement of energy standards to ensure that products meet the ratings on their labels. Some import brands have submitted incorrect or incomplete data to DOE for labeling, particularly for compact product classes. Since some importers source from multiple manufacturers, and label submissions are associated with the import brand rather than the manufacturing company, it is difficult to track labeling issues to the original manufacturer.

- *Technical Difficulty to Achieve New Standards* – Many manufacturers expressed concerns about the technical difficulty in achieving new standards that are significantly more stringent than current levels. They pointed out that there are fewer additional low-cost technology improvements available now than there were during past rulemakings. Specifically, compact freezers were cited as a product class in which it will be especially difficult to make significant improvements. The standards for compact freezers are already more stringent relative to capacity than are standards for compact refrigerators. Compact units, in general, pose a challenge because there are very few low-capacity compressors with sufficiently high efficiencies. Several manufacturers indicated that improvements could be made, but highlighted the importance of staying informed by DOE of the proposed new standard levels throughout the rulemaking process. They also emphasized having adequate time between the final rule and the effective date of the new standards to ensure adequate time is available to redesign products and to make the appropriate investments in manufacturing lines.

12.4.2 Profitability, Product Mix, and Shipments

DOE asked manufacturers during the preliminary manufacturer interviews how amended energy conservation standards would affect their profitability, product mix, and overall shipments. Nearly all manufacturers stated that amended energy conservation standards could lower profits depending upon the efficiency level under consideration by DOE. In particular, manufacturers indicate that new standards requiring cost increases of 15-20 percent or more would have significant impacts through lowered industry shipments and a shift in product mix.

Manufacturers of all types of refrigeration products state that cost increases at these levels would drive consumers toward lower-cost products. Nearly all manufacturers have certain product lines that would have difficulty meeting new standards that are significantly stricter. They say that they would most likely drop some of these products because of technical difficulties in achieving new standards.

Several manufacturers of refrigerators and refrigerator-freezers stated that they would shift their product mix to compete in lower cost products or would no longer be able to compete as heavily in ENERGY STAR products. This would lower profitability because lower cost and baseline products typically cannot command as much of a margin as do premium and Energy Star products. Contrarily, some manufacturers expect to move more strongly towards higher-end products because of the higher profit margins available. They contend that the cost-competitive nature of low-end refrigeration products makes it very difficult to pass on increased costs to the consumer. For this reason, they indicate that they would modify their product mix to be weighted more heavily toward higher-margin products. One manufacturer even noted that it would exit certain low-margin product classes completely if the investment costs required to meet the amended energy standards were too high. Still, other manufacturers did not expect to change their product mix much at all, either because their product platforms are far from the end of their efficiency capability or because their market strategy calls for maintaining a fixed portion of ENERGY STAR products.

All manufacturers agree that amended energy standards would decrease profit margins for refrigeration products in general. Manufacturers stated that the extent to which margins diminish will depend on how much cost their competitors are able to pass through to the customer. Manufacturers of higher-end products have higher margins, and thus greater capacity to absorb cost increases, whereas entry level products have very thin margins and minimal capacity to absorb cost increases. Manufacturers stated that customers of lower-end products are very price-sensitive and the ability of a manufacturer to pass cost increases through without affecting demand for low-end products is extremely limited. In general, most manufacturers agree that significantly stricter amended energy standards would increase retail prices and lower demand for refrigeration products across the board. Specifically, many indicated that increased costs will price some consumers out of the market completely and bring would-be purchasers of higher-end units down to entry-level products, thereby reducing both overall demand and demand for higher-margin refrigeration products.

12.4.3 Conversion Costs, Manufacturing Capacity, and Employment Levels

DOE estimated that a typical high-volume domestic refrigerator, refrigerator-freezer, or freezer production line would have a life cycle of approximately ten years in the absence of amended energy conservation standards. During that period, manufacturers would not make major equipment changes that alter the underlying platforms. Thus, an amended energy conservation standard that took effect and resulted in a major platform redesign before the end of the platform's life would strand a portion of the earlier capital investments.

DOE asked manufacturers what level of conversion costs they anticipate if amended energy conservation standards were to take effect. Manufacturers said that conversion costs would be significant if amended standards require new product platforms, as opposed to component swaps only. The primary changes that would dictate new product platforms are significant alterations to wall thicknesses or the use of vacuum insulated panels (VIP). The cost of such changes varies by manufacturer, depending on the volume of production and whether capital, tooling, and engineering investments are required. Lower-volume manufacturers have indicated that conversion costs in this scenario could range from a few million dollars to tens of millions. Higher volume manufacturers have indicated potential costs in the range of hundreds of millions of dollars.

Additionally, manufacturers have identified the cost of plant closings as an important component of conversion costs. Several manufacturers indicated that significant energy efficiency increases would drive them to construct new plants in lower-cost labor markets. Mexico, specifically, was offered as a potential location. Some existing U.S. plants would either be closed or downsized, reducing domestic employment levels and leaving some stranded assets. Contrarily, a few domestic manufacturers indicated that they would have few stranded assets or that they would not move production outside the U.S.

12.4.3.1 Impact on U.S. Production and Jobs

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. As indicated in section 12.3.2.3 above, significant increases to the energy efficiency standards for refrigeration products would cause some manufacturers to close domestic production facilities and to construct new plants outside of the U.S. Manufacturers with existing facilities abroad indicated that they may expand or modify those facilities rather than build entirely new plants.

12.4.3.2 Foreign Labor

Manufacturers indicated that there has been a shift in production out of the United States, in particular to Mexico. For compact products, the trend has been towards production even further from the U.S., particularly China. Manufacturers said that amended energy conservation standards could exacerbate these trends. Some manufacturers are very committed to keeping production in the U.S., but in general these do not include the highest-volume manufacturers. Consideration of production outside the U.S. is primarily driven by concerns about profitability and the opportunity for lower labor costs.

12.4.4 Industry Consolidation

Three companies now account for the majority of U.S. sales of residential refrigeration products. The relative market share among these companies and between these companies and other manufacturers varies depending on product class. In certain product classes, other manufacturers dominate the market. A trend of consolidation has occurred within the industry in recent years. Most manufacturers anticipate further consolidation in the future, even in the absence of amended energy conservation standards. Manufacturers also indicated that new standards could impact future consolidation by making certain manufacturers less competitive.

12.4.5 Impact on Product Utility and Innovation

Amended energy conservation standards can affect purchasers of residential refrigeration products by increasing or decreasing the utility of such products. Manufacturers generally agree that stringent energy efficiency standards would decrease innovations and reduce product utility. They believe that product utility would be impacted in several ways. First, significantly stricter standards would increase the costs of refrigeration products across the board. Most manufacturers believe that the price increases would force lower income customers out of the market for refrigeration products altogether. Second, meeting new standards will likely require manufacturers to increase product wall thicknesses. Most residential kitchens have limited refrigerator space, so the wall thicknesses of refrigeration products would be forced to grow inward. This leaves less internal volume available for use by the customer. This is an issue of great concern for virtually all manufacturers. Finally, several manufacturers indicated that other product features currently available today may have to be removed in order to meet new standard levels and maintain acceptable product costs. Examples of these features include ice and water dispensers, glass doors, soda can dispensers, crisper compartments, antisweat features, and food preservation capabilities.

Manufacturers also believe that product innovation would be affected by amended energy conservation standards. Specifically, they say that innovation will increase in the area of energy efficiency, but it will decrease or disappear in the development of other features. New efficiency standards would cause manufacturers to divert money from the development of new, brand-differentiating features to the development of features that decrease energy usage.

12.4.6 Cumulative Burdens

Based on its own research and discussions with manufacturers, DOE identified several regulations relevant to residential refrigeration products, including:

- regulations from the Consumer Products Safety Commission (CPSC);

- potential climate change and greenhouse gas (GHG) regulation;
- new DOE test procedures for residential refrigeration products;
- standards for other products made by residential refrigeration product manufacturers;
- other State energy conservation standards; and
- international energy conservation standards.

Complying with such regulations requires corporations to invest both human and capital resources. The following subsections discuss in greater detail regulations affecting the residential refrigeration products industry.

12.4.6.1 Pending Regulations from the CPSC

Several manufacturers stated that the CPSC was considering regulations regarding the labeling and materials identification for residential refrigeration products. They indicated that the regulations would essentially duplicate existing Underwriters Laboratories (UL) certification requirements for safety. At the time that the manufacturer impact analysis interviews were conducted, the new CPSC regulations were still pending. The rulemaking was passed in December 2008, however, and is published in 16 CFR 1101.

12.4.6.2 Potential Climate Change and Greenhouse Gas Legislation

Many manufacturers expressed concern about potential climate change legislation. This is an area of great importance within the industry. Manufacturers expect a climate change bill that regulates the use and emissions of GHG's to be passed by Congress in the near future. As a result, use of hydrofluorocarbons (HFC's), the most commonly used refrigerants and foam-blowing agents, would become restricted. These substances would eventually be phased out, or their use capped at a restricted level. This presents a problem for manufacturers because the key alternative insulation foam blowing agent is cyclopentane. Insulation made with this blowing agent has higher conductivity than current state-of-the art foam insulation, and conversion to cyclopentane presents factory issues due to its flammability..Conversion of the currently-used refrigerant, HFC-134a, to the most likely alternative, R-600a or isobutane, would require product redesign, and causes issues associated with safety certification compliance under UL regulations. Proposed legislation presents uncertainty for manufacturers as to how hydrocarbon refrigerants and foam-blowing agents would be regulated for safety within the U.S. Manufacturers indicate that the costs of making changes associated with conversion to new refrigerants and blowing agents would be in the millions of dollars.

12.4.6.3 Standards for Other Products Made by Residential Refrigeration Products Manufacturers

In addition to the efficiency regulations for residential refrigeration products, several other Federal regulations and pending regulations apply to other products manufactured by the companies that manufacture refrigeration products. Many of these companies manufacture multiple lines of residential appliances, including clothes washers, clothes dryers, dishwashers, and cooking products, all of which are also subject to Federal efficiency regulations. Some of these products are currently undergoing rulemakings amending the test procedures to incorporate standby and off mode energy consumption as well. Additionally, manufacturers pointed out that changes are being made to the refrigeration products test procedures concurrent with the refrigeration products energy conservation standard rulemaking.

12.4.6.4 State and International Standards

Manufacturers stated that there are a number of state and international standards that they must adhere to in addition to those currently under consideration in this rulemaking. European standards such as the Restriction on the use of Hazardous Substances (RoHS), Waste Electrical and Electronic Equipment (WEEE), and the Registration, Evaluation, Authorization, and restriction of Chemicals (REACH) create additional compliance costs for manufacturers that compete in Europe. Manufacturers indicated that California has programs similar to these that are either already in place or are currently in development. Additionally, different efficiency standards in foreign countries add to the range of regulations that manufacturers must meet. DOE will investigate these cumulative regulatory burdens in greater detail during the MIA analysis.

12.4.7 Impact on Small Manufacturers

The Small Business Administration (SBA) defines small business manufacturing enterprises for North American Industry Classification System (NAICS) code 335222, *Household Refrigerator and Home Freezer Manufacturing*, as companies with 1000 or less employees. SBA lists small business size standards that are matched to industries as they are described in the NAICS. The size standard defines the maximum allowable size of a for-profit small business for Federal Government programs. Size standards are generally based on the average annual receipts or the average number of employees at a firm.

The manufacturer interviews indicated that smaller refrigeration product manufacturers typically have smaller corporate research and development and engineering staff than larger manufacturers. Smaller manufacturers often produce niche or specialty products and focus on providing products that other larger manufacturers do not produce. Although small manufacturers often have a more limited product range than larger manufacturers, the effort to address some aspects of regulations are relatively fixed and do not scale directly with the number of products or product platforms produced. Consequently, the cumulative burden of regulations will tend to place more of a burden on smaller manufacturers because of their more limited resources.

DOE will study the potential impacts to these small businesses in greater detail during the MIA.

APPENDIX 12-A. PRELIMINARY MANUFACTURER IMPACT ANALYSIS QUESTIONNAIRE

TABLE OF CONTENTS

APPENDIX 12-A. PRELIMINARY MANUFACTURER IMPACT ANALYSIS QUESTIONNAIRE

12-A.1 INTRODUCTION

DOE used the questionnaire below to interview a number of refrigerator and freezer manufacturers during the pre-NOPR phase of the rulemaking to analyze the impact of energy conservation standards on manufacturers. Individual manufacturer responses are kept confidential. Aggregated results are summarized in chapter 12.

12-A.2 QUESTIONNAIRE

1 Issues

1.1 What are the key issues for your company regarding a possible future product rulemaking?

2 Shipment Projections

2.1 What is your company's approximate market share in each of the product classes?
2.2 Would you expect your market share to change once standards become effective? Does your outlook change with higher efficiency levels?
2.3 How would you expect shipments to change for the industry as a whole as a function of standards and why?
2.4 Looking at price/cost effects only, how would you expect shipments to change for a 25 percent, 50 percent, 100 percent, or 200 percent manufacturer price/cost increase?

3 Conversion Costs

3.1 What level of capital expenditure and product conversion costs would you anticipate to make at higher standard levels? Please describe what they are and provide your best estimate of their respective magnitudes.
3.2 How would the imposition of new energy conservation standards affect capacity utilization and manufacturing assets at your domestic production facilities? Would a new standard result in stranded capital assets? Would any facilities be closed or downsized? Added or upgraded?
3.3 How might a new standard impact product innovation?

4 Product Mix and Profitability

4.1 How would your company's product mix and marketing strategy change with changes in the efficiency standard?
4.2 Would the current percentage of shipments at the Energy Star level be the same under a new standard?
4.3 What distribution channels are used from the manufacturer to the retail outlet? What is the share of product going through each distribution channel?
4.4 Generally, how would new product standards affect your customer mix, distribution channels, and corresponding profit margins?
4.5 How might a new standard affect the Energy Star program, and consequently your firm?

5 Market Shares and Industry Consolidation

5.1 In the absence of new standards, do you expect any industry consolidation?
5.2 How would new standards affect your ability to compete?
5.3 Could new standards disproportionately advance or harm the competitive positions of some firms?
5.4 Are there concerns over intellectual property?
5.5 Could new standards result in disproportionate economic or performance penalties for particular consumer/user subgroups?
5.6 Beyond price and energy efficiency, could new standards result in products that will be more or less desirable to consumers due to changes in product functionality, utility, or other features?

6 Cumulative Regulatory Burden

6.1 Are there recent or impending regulations on your specific product or other products that impose a cumulative burden on the industry?
6.2 If so, what is the total expected impact of those other regulations?

CHAPTER 13. UTILITY IMPACT ANALYSIS

TABLE OF CONTENTS

CHAPTER 13. UTILITY IMPACT ANALYSIS

13.1 INTRODUCTION

The Department of Energy (DOE) will analyze specific effects of its proposed standard levels on the electric utility industry as part of the notice of proposed rulemaking analyses, using a variant of the U.S. DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS). The NEMS is a large, multi-sectoral, partial equilibrium model of the U.S. energy sector. EIA uses NEMS to produce the *Annual Energy Outlook (AEO)*.[1] NEMS produces a widely recognized baseline energy forecast for the United States, and this energy forecast is available in the public domain. DOE will use a variant known as NEMS-BT to provide key inputs to the analysis.[a]

The utility impact analysis will consist of a comparison between model results for the base case and for policy cases in which proposed standards are in place. The use of NEMS-BT for the utility analysis offers several advantages. As the official DOE energy forecasting model, NEMS relies on a set of assumptions that are transparent and have received wide exposure and commentary. NEMS-BT allows an estimate of the interactions between the various energy supply and demand sectors and the economy as a whole. The utility impact analysis will report the changes in installed capacity and generation, by fuel type, that result for each trial standard level, as well as changes in electricity and natural gas sales to the residential and commercial sectors.

DOE plans to conduct the utility impact analysis as a policy deviation from the 2009 version of the *AEO* that reflect provisions of the American Recovery and Reinvestment Act (ARRA) and recent changes in the economic outlook (*AEO2009*),[1] applying the same basic set of assumptions. For example, the operating characteristics (e.g., energy conversion efficiency, emissions rates) of future electricity generating plants are as specified in the *AEO2009* reference case. DOE also will explore deviations from some of the reference case assumptions, to represent alternative futures. Two alternative scenarios use the high and low economic growth cases. (The reference case corresponds to medium growth.) The high economic growth case assumes higher projected growth rates for population, labor force, and labor productivity, resulting in lower predicted inflation and interest rates relative to the reference case and higher overall aggregate economic growth. The opposite is true for the low growth case. Because EIA does not plan to produce high and low economic growth cases corresponding to the *AEO2009* that

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[a] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000), March 2000. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed). NEMS-BT was previously called NEMS-BRS.

includes the ARRA, DOE plans to estimate these cases based on the March 2009 release of the *AEO2009* that excludes the ARRA.[2]

13.2 METHODOLOGY

The electric utility impact analysis will consist of NEMS-BT forecasts for generation, installed capacity, sales, and prices. NEMS provides reference case load shapes for several end uses. The model uses predicted growth in demand for each end use to build up a projection of the total electric system load growth for each region, which it uses in turn to predict the necessary additions to capacity. NEMS-BT accounts for the implementation of efficiency standards by decrementing the appropriate reference case load shape. DOE will determine the size of the decrement using data for the per-unit energy savings developed in the life-cycle cost and payback period analysis (Chapter 8) and the forecast of shipments developed for the national impact analysis (Chapter 9).

The predicted reduction in capacity additions is sensitive to the peak load impacts of the standard. DOE will investigate the need to adjust the hourly load profiles that include this end use in NEMS-BT.

Since the *AEO2009* version of NEMS forecasts only to the year 2030, DOE must extrapolate results to 2044. DOE conducts an extrapolation to 2044 to be consistent with the analysis period being used by DOE in the national impact analysis (NIA). It will not be feasible to extend the forecast period of NEMS-BT for the purposes of this analysis, nor does EIA have an approved method for extrapolation of many outputs beyond 2030. While it might seem reasonable in general to make simple linear extrapolations of results, in practice this is not advisable because outputs could be contradictory. For example, changes in the fuel mix implied by extrapolations of those outputs could be inconsistent with the extrapolation of marginal emissions factors. An analysis of various trends sufficiently detailed to guarantee consistency is beyond the scope of this work and, in any case, would involve a great deal of uncertainty. Therefore, for all extrapolations beyond 2030, DOE intends to use simple replications of year 2030 results; in this way results are guaranteed to be consistent. As with the *AEO* reference case in general, the implicit assumption is that the regulatory environment does not deviate from the current known situation during the extrapolation period. Only changes that have been announced with date-certain introduction are included in NEMS-BT.

For petroleum products, EIA uses the average growth rate for the world oil price over the years 2010 to 2025, in combination with the refinery and distribution markups from the year 2025, to determine the regional price forecasts. Similarly, EIA derives natural gas prices from an average growth rate figure in combination with regional price margins from the year 2025.

13.3 RESULTS

Results of the analysis will include changes in residential and commercial electricity sales, installed capacity and generation by fuel type for each trial standard level, in five-year increments extrapolated to the year 2044.

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CHAPTER 14. EMPLOYMENT IMPACT ANALYSIS

TABLE OF CONTENTS

CHAPTER 14. EMPLOYMENT IMPACT ANALYSIS

14.1 INTRODUCTION

The Department of Energy (DOE) intends the employment impact analysis to estimate national job creation or job elimination resulting from possible new standards, due to reallocation of the associated expenditures for purchasing and operating equipment. DOE will conduct this analysis as one of the analyses for the notice of proposed rulemaking (NOPR). DOE will estimate national impacts on major sectors of the U.S. economy, using publicly available data and incorporating different energy price scenarios that it will carry out as part of the analysis for the NOPR. DOE will make all methods and documentation available for review.

The imposition of standards can impact employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered equipment, along with the affiliated distribution and service companies, resulting from the imposition of standards. DOE will evaluate direct employment impacts in its manufacturer impact analysis, as described in Chapter 12. Indirect employment impacts may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to the imposition of standards.

DOE expects new equipment standards to decrease energy consumption, and therefore to reduce expenditures for energy. The savings in energy expenditures may be spent on new investment and other items. The standards may increase the purchase price of equipment, including the retail price plus sales tax, and increase installation costs.

Using an input-output model of the U.S. economy, this analysis seeks to estimate the year-to-year effect of these expenditure impacts on net economic output and employment. A simple model might involve reduced expenditures for energy and reallocation of that money toward other sectors in the economy. DOE intends the employment impact analysis to quantify the indirect employment impacts of these expenditure changes. It will evaluate direct employment impacts in the manufacturer impact analysis step of the process.

14.2 METHODOLOGY

To investigate the combined direct and indirect employment impacts, DOE will use the Pacific Northwest National Laboratory (PNNL)'s 'Impact of Sector Energy Technologies' (ImSET) model.[1] PNNL developed ImSET, a spreadsheet model of the U.S. economy that focuses on 188 sectors most relevant to industrial, commercial, and residential building energy use, for DOE's Office of Energy Efficiency and Renewable Energy. ImSET is a special-purpose version of the U.S. Benchmark National Input-Output (I-O) model, which has been designed to estimate the national employment and income effects of energy saving technologies that are deployed by DOE's Office of Energy Efficiency and Renewable Energy. In comparison with the previous versions of the model used in earlier rulemakings, this version allows for more complete and automated analysis of the essential features of energy efficiency investments in buildings, industry, transportation, and the electric power sectors.

The ImSET software includes a computer-based I-O model with structural coefficients to characterize economic flows among the 188 sectors. ImSET's national economic I-O structure is based on the 1997 Benchmark U.S. table, specially aggregated to 188 sectors.[2]

DOE intends to use the ImSet model to estimate changes in employment, industry output, and wage income in the overall U.S. economy resulting from changes in expenditures in the various sectors of the economy. For example, commercial clothes washer standards may reduce energy expenditures and increase equipment prices in the commercial sector. These expenditure changes are likely to reduce commercial and energy sector employment. At the same time, these equipment standards may increase commercial sector investment, and increase employment in other sectors of the economy. DOE designed the employment impact analysis to estimate the year-to-year net national employment effect of these different expenditure flows.

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ENVIRONMENTAL ASSESSMENT FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR RESIDENTIAL REFRIGERATAORS, REFRIGERATOR-FREEZERS, AND FREEZERS

TABLE OF CONTENTS

LIST OF TABLES

ENVIRONMENTAL ASSESSMENT FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR RESIDENTIAL REFRIGERATAORS, REFRIGERATOR-FREEZERS, AND FREEZERS

1.0 INTRODUCTION

The Department of Energy (DOE) will conduct an environmental assessment as part of the notice of proposed rulemaking. DOE will assess the impacts of proposed energy conservation standards for residential refrigerators, refrigerator-freezers, and freezers on certain environmental indicators using a variant of the U.S. DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] EIA uses NEMS to produce the *Annual Energy Outlook (AEO).*[1] DOE will use a variant known as NEMS-BT to provide key inputs to the analysis, based on the 2009 version of the *AEO* (*AEO2009*). Results of the environmental assessment will be similar to those provided in *AEO2009*.

DOE intends the environmental assessment to provide emissions results to policymakers and other stakeholders, and to fulfill requirements that the environmental effects of all new Federal rules be properly quantified and considered. The environmental assessment considers three pollutants— sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury (Hg)—as well as carbon emissions. The only form of carbon emissions tracked by NEMS-BT is carbon dioxide (CO_2), so the carbon discussed in this report is only in the form of CO_2. For each of the trial standard levels, DOE will calculate total emissions using NEMS-BT, using additional, external analysis as needed.

Although DOE plans to consider only SO_2, NO_x, mercury, and CO_2 in its environmental assessment, there are other air pollutants which are of concern. Specifically, the Clean Air Act requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards for the following six common air pollutants, also know as "criteria pollutants": (1) ozone, (2) particulate matter (PM), (3) carbon monoxide (CO), (4) nitrogen dioxide, (5) SO_2, and (6) lead.[2] EPA recently added to this list mercury. But none of the "criteria pollutants" not already considered (i.e., ozone, PM, CO, and lead) are driven significantly by electric utility power plants. Therefore, DOE does not intend on addressing them in the environmental assessment. In the case of ozone and particulate matter, other pollutants are precursors to their formation and atmospheric conditions are the driver behind their formation. Also, SO_2 and NO_x are the primary precursors to ozone and PM, respectively, and will already be addressed by the environmental assessment. In the case of CO, electric utilities are not significant sources. For electric power plants, almost all carbon emissions come out in the form of CO_2 as the combustion process is lean enough not to yield CO in significant amounts. Finally, with regard to lead, the ban on the use of leaded gasoline has resulted in a dramatic decrease in lead emissions since the mid 1970s. Now industrial processes (not electric utilities), particularly

[a] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000), March 2000. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model as NEMS-BT (BT is DOE's Building Technologies Program). NEMS-BT was previously called NEMS-BRS.

primary and secondary lead smelters and battery manufacturers, are responsible for most of lead emissions and all violations of the lead air quality standards.

2.0 METHODOLOGY

DOE plans to conduct the utility impact analysis as a policy deviation from the 2009 version of the *AEO* that reflect provisions of the American Recovery and Reinvestment Act (ARRA) and recent changes in the economic outlook (*AEO2009*),[1] applying the same basic set of assumptions. For example, the emissions characteristics of an electricity generating plant will be exactly those used in *AEO2009*. The NEMS reference case and alternative growth scenarios are as described in the utility impact analysis (see Chapter 13 of the preliminary technical support document). Below are descriptions of the air emissions that DOE will analyze in the environmental assessment.

2.1 Air Emissions

Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) is not a regulated or criteria pollutant, but it is of interest because of its classification as a greenhouse gas (GHG). GHGs trap the sun's radiation inside the Earth's atmosphere and either occur naturally in the atmosphere or result from human activities. Naturally occurring GHGs include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Human activities, however, add to the levels of most of these naturally occurring gases. For example, CO_2 is emitted to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), wood, and wood products are burned. During the past 20 years, about three-quarters of anthropogenic (i.e., human-made) CO_2 emissions resulted from burning fossil fuels.

Concentrations of CO_2 in the atmosphere are naturally regulated by numerous processes, collectively known as the "carbon cycle." The movement of carbon between the atmosphere and the land and oceans is dominated by natural processes, such as plant photosynthesis. While these natural processes can absorb some of the anthropogenic CO_2 emissions produced each year, billions of metric tons are added to the atmosphere annually. In the U. S., CO_2 emissions from both energy generation and industrial processes account for 84.6 percent of total U.S. GHG emissions.

NEMS-BT tracks carbon emissions using a detailed carbon module; this approach provides good results because of its broad coverage of all sectors and inclusion of interactive effects. Past experience with carbon results from NEMS suggests that the NEMS-generated emissions estimates are somewhat lower than estimates based on simple average factors. One of the reasons for this divergence is that NEMS tends to predict that conservation displaces renewable generating capacity in the later years of its forecast. On the whole, NEMS-BT provides carbon emissions results of reasonable accuracy, at a level consistent with other published Federal results.

Sulfur Dioxide (SO_2)

The NEMS-BT model reports the two airborne pollutant emissions that DOE has reported in past analyses, SO_2 and NO_x. The Clean Air Act Amendments of 1990 set an SO_2 emissions cap on all power generation.[3] The attainment of this target, however, is flexible among generators through the use of emissions allowances and tradable permits. The NEMS-BT model includes a module for SO_2 allowance trading and delivers a forecast of SO_2 allowance prices. Accurate simulation of SO_2 trading tends to imply that physical emissions effects will be zero, as long as emissions are at the ceiling. But to the extent reduced power generation demand decreases the demand for and price of emissions allowance permits, there is an environmentally related economic benefit from the proposed energy conservation standards reducing SO_2 emissions allowance demand. Furthermore, over time, if emissions decline, there is greater flexibility in reducing the ceiling amount. However, since DOE does not anticipate a change in SO_2 emissions, DOE does not plant to report SO_2 emission impacts. There is an SO_2 benefit from conservation in the form of a lower allowance price but, since the impact of any one standard on the allowance price is likely small and highly uncertain, DOE does not plan to monetize the SO_2 benefit.

Nitrogen Oxides (NOx)

Nitrogen oxides**,** or NOx, are the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts. Many of the nitrogen oxides are colorless and odorless. However, one common pollutant, nitrogen dioxide (NO_2), along with particles in the air can often be seen as a reddish-brown layer over many urban areas. NO_2 is the specific form of NOx reported in this document. NOx is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems. It can contribute to the formation of acid rain, and can impair visibility in areas such as national parks. NO_x also contributes to the formation of fine particles that can impair human health.

Nitrogen oxides form when fossil fuel is burned at high temperatures, as in a combustion process. The primary manmade sources of NO_x are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fossil fuels. NO_x can also be formed naturally. Electric utilities account for about 22 percent of NO_x emissions in the United States.

NEMS-BT also has an algorithm for estimating NOx emissions from power generation. The impact of these emissions, however, will be affected by the Clean Air Interstate Rule (CAIR), which the U.S. Environmental Protection Agency (EPA) issued under sections 110 and 111 of the Clean Air Act (40 CFR Parts 51, 96, and 97) on May 12, 2005.[4] CAIR will permanently cap emissions of SO_2 and NOx in eastern states of the United States. CAIR achieves large reductions of SO_2 and/or NOx emissions across 28 eastern states and the District of Columbia (DC). States must achieve the required emission reductions using one of two compliance options: 1) meet an emission budget for each regulated state by requiring power plants to participate in an EPA-administered interstate cap-and-trade system that caps emissions in two stages, or 2) meet an individual state emissions budget through measures of the state's choosing. Phase 1 caps for NO_x are to be in place in 2009. Phase 1 caps for SO_2 are to be in place in 2010. The Phase 2 caps for both pollutants are due in 2015.

On July 11, 2008, the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) issued its decision in North Carolina v. Environmental Protection Agency, which vacated the CAIR issued by the U.S. Environmental Protection Agency on March 10, 2005.[5] But on December 23, 2008, the D.C. Circuit decided to allow CAIR to remain in effect until it is replaced by a rule consistent with the court's earlier opinion. North Carolina v. Environmental Protection Agency, 550 F.3d 1176 (D.C. Cir. 2008) (remand of vacatur).

The NEMS-BT version to be used by DOE to estimate NOx emission impacts includes the cap on NOx emissions as specified by CAIR. As with SO_2 emissions, a cap on NOx emissions means that equipment efficiency standards may have no physical effect on these emissions in the 28 eastern states and DC. When NOx emissions are subject to emissions caps, DOE's emissions reduction estimate corresponds to incremental changes in the prices of emissions allowances in cap-and-trade emissions markets rather than physical emissions reductions. Therefore, while the emissions cap may mean that physical emissions reductions will not result from standards in those states covered by CAIR, standards could produce an environmental-related economic benefit in the form of lower prices for emissions allowance credits. However, as with SO_2 allowance prices, DOE does not plan to monetize this benefit because the impact on the NO_x allowance price from any single energy conservation standard is likely small and highly uncertain. For those states not covered by CAIR, DOE intends to estimate the impact on NOx emissions using NEMS-BT.

Mercury (Hg)

Coal-fired power plants emit Hg found in coal during the burning process. While coal-fired power plants are the largest remaining source of human-generated Hg emissions in the United States, they contribute very little to the global Hg pool or to contamination of U.S. waters. U.S. coal-fired power plants emit Hg in three different forms: oxidized Hg (likely to deposit within the United States); elemental Hg, which can travel thousands of miles before depositing to land and water; and Hg that is in particulate form. Atmospheric Hg is then deposited on land, lakes, rivers, and estuaries through rain, snow, and dry deposition. Once there, it can transform into methylmercury and accumulate in fish tissue through bioaccumulation.

Americans are exposed to methylmercury primarily by eating contaminated fish. Because the developing fetus is the most sensitive to the toxic effects of methylmercury, women of childbearing age are regarded as the population of greatest concern. Children exposed to methylmercury before birth may be at increased risk of poor performance on neurobehavioral tasks, such as those measuring attention, fine motor function, language skills, visual-spatial abilities, and verbal memory.

NEMS-BT has an algorithm for estimating these emissions from power generation. EPA issued on May 18, 2005 the final rule entitled "Standards of Performance for New and Existing Stationary Sources: Electric Steam Generating Units," under sections 110 and 111 of the Clean Air Act (40 CFR Parts 60, 63, 72, and 75).[6] This rule, also called the Clean Air Mercury Rule (CAMR), was closely related to the CAIR and established standards of performance for Hg emissions from new and existing coal-fired electric utility steam generating units. The CAMR regulated Hg emissions from coal-fired power plants. But on February 8, 2008, the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) issued its decision in State of New Jersey, *et al.* v. Environmental Protection Agency,[7] in which the Court, among other actions, vacated the CAMR referenced above. EPA has recently decided to develop emissions standards for power plants under the Clean Air Act (Section 112), consistent with the D.C. Circuit's opinion on the CAMR. Accordingly, on February 6, 2009, the Department of Justice, on behalf of EPA, asked the Supreme Court to dismiss EPA's request (petition for certiorari) that the Court review the D.C. Circuit Court's vacatur of the Clean Air Mercury Rule (CAMR). On February 23, 2009, the Court also denied the Utility Air Regulatory Group's request to review the U.S. Circuit Court of Appeals decision.

The NEMS-BT version to be used by DOE to estimate Hg emission impacts does not cap Hg emissions and will not do so until the EPA issues a rule regarding Hg that is consistent with the Court's decision.

2.2 Economic Value of Emission Reductions

In examining the impact of potential standards, DOE plans to assess potential monetary benefits from reduced emissions of CO_2, NOx, Hg, and SO_2 associated with this rulemaking.

Carbon Dioxide (CO_2)

DOE plans on relying on a set of values developed by an interagency process that conducted a thorough review of existing estimates of the social cost of carbon (SCC). The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damages from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

For at least three reasons, any single estimate of the SCC will be contestable. First, scientific and economic knowledge about the impacts of climate change continues to grow. With new and better information about relevant questions, including the cost, burdens, and possibility of adaptation, current estimates will inevitably change over time. Second, some of the likely and potential damages from climate change—for example, the value society places on adverse impacts on endangered species—are not included in all of the existing economic analyses. These omissions may mean that the best current estimates are too low. Third, controversial ethical judgments, including those involving the treatment of future generations, play a role in judgments about the SCC (see in particular the discussion of the discount rate, below).

To date, regulations have used a range of values for the SCC. For example, a regulation proposed by the U.S. Department of Transportation (DOT) in 2008 assumed a value of $7 per ton CO_2 (2006$) for 2011 emission reductions (with a range of $0–14 for sensitivity analysis). Regulation finalized by DOE used a range of $0–$20 (2007$). Both of these ranges were designed to reflect the value of damages to the United States resulting from carbon emissions, or the "domestic" SCC. In the final Model Year 2011 Corporate Average Fuel Economy rule, DOT used both a domestic SCC value of \$2/t CO_2 and a global SCC value of \$33/t CO_2 (with sensitivity analysis at \$80/tCO_2), increasing at 2.4 percent per year thereafter.

In recent months, a variety of agencies have worked to develop an objective methodology for selecting a range of interim SCC estimates to use in regulatory analyses until improved SCC estimates are developed. The following summary reflects the initial results of these efforts and proposes ranges and values for interim social costs of carbon used in this rule. It should be emphasized that the analysis described below is preliminary. These complex issues are of course undergoing a process of continuing review. Relevant agencies will be evaluating and seeking comment on all of the scientific, economic, and ethical issues before establishing final estimates for use in future rulemakings.

The interim judgments resulting from the recent interagency review process can be summarized as follows: (a) DOE and other Federal agencies should consider the global benefits associated with the reductions of CO_2 emissions resulting from efficiency standards and other similar rulemakings, rather continuing the previous focus on domestic benefits; (b) these global benefits should be based on SCC estimates (in 2007\$) of \$55, \$33, \$19, \$10, and \$5 per ton of CO_2 equivalent emitted (or avoided) in 2007; (c) the SCC value of emissions that occur (or are avoided) in future years should be escalated using an annual growth rate of 3 percent from the current values); and (d) domestic benefits are estimated to be approximately 6 percent of the global values. These interim judgments are based on the following considerations.

1. <u>Global and domestic estimates of SCC</u>. Because of the distinctive nature of the climate change problem, estimates of both global and domestic SCC values should be considered, but the global measure should be "primary." This approach represents a departure from past practices, which relied, for the most part, on measures of only domestic impacts. As a matter of law, both global and domestic values are permissible; the relevant statutory provisions are ambiguous and allow the agency to choose either measure. (It is true that Federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to Federal law and hence does not intrude on such interests.)

   It is true that under OMB guidance, analysis from the domestic perspective is required, while analysis from the international perspective is optional. The domestic decisions of one nation are not typically based on a judgment about the effects of those decisions on other nations. But the climate change problem is highly unusual in the sense that it involves (a) a global public good in which (b) the emissions of one nation may inflict significant damages on other nations and (c) the United States is actively engaged in promoting an international agreement to reduce worldwide emissions.

   In these circumstances, the global measure is preferred. Use of a global measure reflects the reality of the problem and is expected to contribute to the continuing efforts of the United States to ensure that emission reductions occur in many nations.

Domestic SCC values are also presented. The development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential estimate comes from the DICE (Dynamic Integrated Climate Economy, William Nordhaus) model. In an unpublished paper, Nordhaus (2007) produced disaggregated SCC estimates using a regional version of the DICE model. He reported a U.S. estimate of \$1/tCO_2 (2007 value, 2007\$), which is roughly 11 percent of the global value.

An alternative source of estimates comes from a recent EPA modeling effort using the FUND (Climate Framework for Uncertainty, Negotiation and Distribution, Center for Integrated Study of the Human Dimensions of Global Change) model. The resulting estimates suggest that the ratio of domestic to global benefits varies with key parameter assumptions. With a 3-percent discount rate, for example, the U.S. benefit is about 6 percent of the global benefit for the "central" (mean) FUND results, while, for the corresponding "high" estimates associated with a higher climate sensitivity and lower global economic growth, the U.S. benefit is less than 4 percent of the global benefit. With a 2-percent discount rate, the U.S. share is about 2 to5 percent of the global estimate.

Based on this available evidence, a domestic SCC value equal to 6 percent of the global damages is used in this rulemaking. This figure is in the middle of the range of available estimates from the literature. It is recognized that the 6 percent figure is approximate and highly speculative and alternative approaches will be explored before establishing final values for future rulemakings.

2. Filtering existing analyses. There are numerous SCC estimates in the existing literature, and it is legitimate to make use of those estimates to produce a figure for current use. A reasonable starting point is provided by the meta-analysis in Richard Tol, "The Social Cost of Carbon: Trends, Outliers, and Catastrophes, Economics: The Open-Access, Open-Assessment E-Journal," Vol. 2, 2008-25. http://www.economics-ejournal.org/economics/journalarticles/2008-25 (2008). With that starting point, it is proposed to "filter" existing SCC estimates by using those that (1) are derived from peer-reviewed studies; (2) do not weight the monetized damages to one country more than those in other countries; (3) use a "business as usual" climate scenario; and (4) are based on the most recent published version of each of the three major integrated assessment models (IAMs): FUND, DICE and PAGE (Policy Analysis of the Greenhouse Effect).

   Proposal (1) is based on the view that those studies that have been subject to peer review are more likely to be reliable than those that have not been. Proposal (2) is based on a principle of neutrality and simplicity; it does not treat the citizens of one nation differently on the basis of speculative or controversial considerations. Proposal (3) stems from the judgment that as a general rule, the proper way to assess a policy decision is by comparing the implementation of the policy against a counterfactual state where the policy is not implemented. A departure from this approach would be to consider a more dynamic setting in which other countries might implement policies to reduce GHG emissions at an unknown future date, and the United States could choose to implement such a policy now or in the future.

Proposal (4) is based on three complementary judgments. First, the FUND, PAGE, and DICE models now stand as the most comprehensive and reliable efforts to measure the damages from climate change. Second, the latest versions of the three IAMs are likely to reflect the most recent evidence and learning, and hence they are presumed to be superior to those that preceded them. It is acknowledged that earlier versions may contain information that is missing from the latest versions. Third, any effort to choose among them, or to reject one in favor of the others, would be difficult to defend at this time. In the absence of a clear reason to choose among them, it is reasonable to base the SCC on all of them.

The agency is keenly aware that the current IAMs fail to include all relevant information about the likely impacts from greenhouse gas emissions. For example, ecosystem impacts, including species loss, do not appear to be included in at least two of the models. Some human health impacts, including increases in food-borne illnesses and in the quantity and toxicity of airborne allergens, also appear to be excluded. In addition, there has been considerable recent discussion of the risk of catastrophe and of how best to account for worst-case scenarios. It is not clear whether the three IAMs take adequate account of these potential effects.

3. <u>Use a model-weighted average of the estimates at each discount rate</u>. At this time, there appears to be no scientifically valid reason to prefer any of the three major IAMs (FUND, PAGE, and DICE). Consequently, the estimates are based on an equal weighting of estimates from each of the models. Among estimates that remain after applying the filter, the average of all estimates within a model is derived. The estimated SCC is then calculated as the average of the three model-specific averages. This approach ensures that the interim estimate is not biased towards specific models or more prolific authors.

4. <u>Apply a 3-percent annual growth rate to the chosen SCC values</u>. SCC is assumed to increase over time, because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed as the magnitude of climate change increases. Indeed, an implied growth rate in the SCC is produced by most studies that estimate economic damages caused by increased GHG emissions in future years. But neither the rate itself nor the information necessary to derive its implied value is commonly reported. In light of the limited amount of debate thus far about the appropriate growth rate of the SCC, applying a rate of 3 percent per year seems appropriate at this stage. This value is consistent with the range recommended by IPCC (2007) and close to the latest published estimate (Hope, 2008).

For climate change, one of the most complex issues involves the appropriate discount rate. OMB's current guidance offers a detailed discussion of the relevant issues and calls for discount rates of 3 percent and 7 percent. It also permits a sensitivity analysis with low rates for intergenerational problems. ("If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.") The SCC is being developed within the general context of the current guidance.

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. See, e.g., William Nordhaus, "The Challenge of Global Warming (2008); Nicholas Stern, The Economics of Climate Change" (2007); "Discounting and Intergenerational Equity" (Paul Portney and John Weyant, eds., 1999). Under imaginable assumptions, decisions based on cost-benefit analysis with high discount rates might harm future generations—at least if investments are not made for the benefit of those generations. (See Robert Lind, "Analysis for Intergenerational Discounting," id. at 173, 176–177.) At the same time, use of low discount rates for particular projects might itself harm future generations, by ensuring that resources are not used in a way that would greatly benefit them. In the context of climate change, questions of intergenerational equity are especially important.

Reasonable arguments support the use of a 3-percent discount rate. First, that rate is among the two figures suggested by OMB guidance, and hence it fits with existing National policy. Second, it is standard to base the discount rate on the compensation that people receive for delaying consumption, and the 3-percent rate is close to the risk-free rate of return, proxied by the return on long term inflation-adjusted U.S. Treasury Bonds. (In the context of climate change, it is possible to object to this standard method for deriving the discount rate.) Although these rates are currently closer to 2.5 percent, the use of 3 percent provides an adjustment for the liquidity premium that is reflected in these bonds' returns.

At the same time, other arguments support use of a 5-percent discount rate. First, that rate can also be justified by reference to the level of compensation for delaying consumption, because it fits with market behavior with respect to individuals' willingness to trade off consumption across periods as measured by the estimated post-tax average real returns to private investment (e.g., the S&P 500). In the climate setting, the 5-percent discount rate may be preferable to the riskless rate because it is based on risky investments and the return to projects to mitigate climate change is also risky. In contrast, the 3-percent riskless rate may be a more appropriate discount rate for projects where the return is known with a high degree of confidence (e.g., highway guardrails).

Second, 5 percent, and not 3 percent, is roughly consistent with estimates implied by reasonable inputs to the theoretically derived Ramsey equation, which specifies the optimal time path for consumption. That equation specifies the optimal discount rate as the sum of two components. The first reflects the fact that consumption in the future is likely to be higher than consumption today (even accounting for climate impacts), so diminishing marginal utility implies that the same monetary damage will cause a smaller reduction of utility in the future. Standard estimates of this term from the economics literature are in the range of 3 to 5 percent. The second component reflects the possibility that a lower weight should be placed on utility in the future, to account for social impatience or extinction risk, which is specified by a pure rate of time preference (PRTP). A conventional estimate of the PRTP is 2 percent. (Some observers believe that a principle of intergenerational equity suggests that the PRTP should be close to zero.) It follows that discount rate of 5 percent is within the range of values which are able to be derived from the Ramsey equation, albeit at the low end of the range of estimates usually associated with Ramsey discounting.

It is recognized that the arguments above—for use of market behavior and the Ramsey equation—face objections in the context of climate change, and of course there are alternative approaches. In light of climate change, it is possible that consumption in the future will not be higher than consumption today, and if so, the Ramsey equation will suggest a lower figure. Some people have suggested that a very low discount rate, below 3 percent, is justified in light of the ethical considerations calling for a principle of intergenerational neutrality. See Nicholas Stern, "The Economics of Climate Change" (2007); for contrary views, see William Nordhaus, The A Question of Balance (2008); Martin Weitzman, "Review of the Stern Review on the Economics of Climate Change." Journal of Economic Literature, 45(3): 703–724 (2007). Additionally, some analyses attempt to deal with uncertainty with respect to interest rates over time; a possible approach enabling the consideration of such uncertainties is discussed below. Richard Newell and William Pizer, "Discounting the Distant Future: How Much do Uncertain Rates Increase Valuations?" J. Environ. Econ. Manage. 46 (2003) 52-71.

The application of the methodology outlined above yields estimates of the SCC that are reported in Table EA.1. These estimates are reported separately using 3-percent and 5-percent discount rates. The cells are empty in rows 10 and 11 because these studies did not report estimates of the SCC at a 3-percent discount rate. The model-weighted means are reported in the final or summary row; they are $33 per t CO_2 at a 3-percent discount rate and $5 per t CO_2 with a 5-percent discount rate.

Table EA.1 Global Social Cost of Carbon (SCC) Estimates ($/t CO_2 in 2007 (2006$)), Based on 3% and 5% Discount Rates*

	Model	Study	Climate Scenario	3%	5%
1	FUND	Anthoff et al. 2009	FUND default	6	-1
2	FUND	Anthoff et al. 2009	SRES A1b	1	-1
3	FUND	Anthoff et al. 2009	SRES A2	9	-1
4	FUND	Link and Tol 2004	No THC	12	3
5	FUND	Link and Tol 2004	THC continues	12	2
6	FUND	Guo et al. 2006	Constant PRTP	5	-1
7	FUND	Guo et al. 2006	Gollier discount 1	14	0
8	FUND	Guo et al. 2006	Gollier discount 2	7	-1
			FUND Mean	**8.25**	**0**
9	PAGE	Wahba & Hope 2006	A2-scen	57	7
10	PAGE	Hope 2006			7
11	DICE	Nordhaus 2008			8
Summary			**Model-weighted Mean**	**33**	**5**

*The sample includes all peer reviewed, non-equity-weighted estimates included in Tol (2008), Nordhaus (2008), Hope (2008), and Anthoff et al. (2009), that are based on the most recent published version of FUND, PAGE, or DICE and use business-as-usual climate scenarios. All values are based on the best available information from the underlying studies about the base year and year dollars, rather than the Tol (2008) assumption that all estimates included in his review are 1995 values in 1995$. All values were updated to 2007 using a 3-percent annual growth rate in the SCC, and adjusted for inflation using GDP deflator.

DOE has conducted analyses at $33 and $5 per ton as these represent the estimates associated with the 3 percent and 5 percent discount rates, respectively. The 3 percent and 5 percent estimates have independent appeal and at this time a clear preference for one over the other is not warranted. Thus, DOE has also included—and centered its current attention on—the average of the estimates associated with these discount rates, which is $19. (Based on the $19 global value, the domestic value would be $1.14 per ton of CO_2 equivalent.)

It is true that there is uncertainty about interest rates over long time horizons. Recognizing that point, Newell and Pizer have made a careful effort to adjust for that uncertainty. See Newell and Pizer, supra. This is a relatively recent contribution to the literature.

There are several concerns with using this approach in this context. First, it would be a departure from current OMB guidance. Second, an approach that would average what emerges from discount rates of 3 percent and 5 percent reflects uncertainty about the discount rate, but based on a different model of uncertainty. The Newell-Pizer approach models discount rate uncertainty as something that evolves over time; in contrast, one alternative approach would assume that there is a single discount rate with equal probability of 3 percent and 5 percent.

Table EA.2 reports on the application of the Newell-Pizer adjustments. The precise numbers depend on the assumptions about the data generating process that governs interest rates. Columns (1a) and (1b) assume that “random walk” model best describes the data and uses 3-percent and 5-percent discount rates, respectively. Columns (2a) and (2b) repeat this, except that it assumes a “mean-reverting” process. As Newell and Pizer report, there is stronger empirical support for the random walk model.

Table EA.2 Global Social Cost of Carbon Estimates ($/t CO2 in 2007 in 2006$),* Using Newell & Pizer Adjustment for Future Discount Rate Uncertainty**

	Model	**Study**	**Climate Scenario**	Random- walk model		Mean-reverting model	
				3%	5%	3%	5%
				(1a)	(1b)	(2a)	(2b)
1	FUND	Anthoff et al. 2009	FUND default	10	0	7	-1
2	FUND	Anthoff et al. 2009	SRES A1b	2	0	1	-1
3	FUND	Anthoff et al. 2009	SRES A2	15	0	10	-1
4	FUND	Link and Tol 2004	No THC	20	6	13	4
5	FUND	Link and Tol 2004	THC continues	20	4	13	2
6	FUND	Guo et al. 2006	Constant PRTP	9	0	6	-1
7	FUND	Guo et al. 2006	Gollier discount 1	14	0	14	0
8	FUND	Guo et al. 2006	Gollier discount 2	7	-1	7	-1
			FUND Mean	**12**	**1**	**9**	**0**
9	PAGE	Wahba & Hope 2006	A2-scen	97	13	63	8
10	PAGE	Hope 2006			13		8
11	DICE	Nordhaus 2008			15		9
Summary			**Model-weighted Mean**	**55**	**10**	**36**	**6**

*The sample includes all peer reviewed, non-equity-weighted estimates included in Tol (2008), Nordhaus (2008), Hope (2008), and Anthoff et al. (2009), that are based on the most recent published version of FUND, PAGE, or DICE and use business-as-usual climate scenarios. All values are based on the best available information from the underlying studies about the base year and year dollars, rather than the Tol (2008) assumption that all estimates included in his review are 1995 values in 1995$. All values were updated to 2007 using a 3-percent annual growth rate in the SCC, and adjusted for inflation using GDP deflator.
**Assumes a starting discount rate of 3 percent. Newell and Pizer (2003) based adjustment factors are not applied to estimates from Guo et al. (2006) that use a different approach to account for discount rate uncertainty (rows 7-8).

The resulting estimates of the social cost of carbon are necessarily greater. When the adjustments from the random walk model are applied, the estimates of the social cost of carbon are $10 and $55, with the 3 percent and 5 percent discount rates, respectively. The application of the mean-reverting adjustment yields estimates of $6 and $36. Since the random walk model has greater support from the data, DOE also conducted analyses with the value of the SCC set at $10 and $55.

In summary, DOE will consider in its decision process for the notice of proposed rulemaking the potential global benefits resulting from reduced CO_2 emissions valued at $5, $10, $19, $30 and $55 per metric ton, and has also presented the domestic benefits derived using a value of $1.14 per metric ton.

DOE is well aware that scientific and economic knowledge about the contribution of CO_2 and other GHG emissions to changes in the future global climate and the potential resulting damages to the world economy continues to evolve rapidly. Thus, any value placed in this rulemaking on reducing CO_2 emissions is subject to likely change.

DOE, together with other Federal agencies, is reviewing various methodologies for estimating the monetary value of reductions in CO_2 and other GHG emissions. This review will consider the comments on this subject that are part of the public record for this and other rulemakings, as well as other methodological assumptions and issues, such as whether the appropriate values should represent domestic U.S. benefits, as well as global benefits (and costs). Given the complexity of the many issues involved, this review is ongoing.

Nitrogen Oxides (NOx)

As discussed earlier, with respect to NOx the CAIR rule has been reinstated by the courts. Therefore, NOx emissions in those states covered by CAIR will be subject to a cap with corresponding annual allowances openly traded. DOE's approach to NOx allowance price impacts are discussed below.

For those states not covered by CAIR, DOE plans on estimating the monetized benefits of NOx emissions reductions in these states based on environmental damage estimates from the literature. Available estimates suggest a very wide range of monetary values for NOx emissions, ranging from $370 per ton to $3,800 per ton of NOx from stationary sources, measured in 2001$ or a range of $432 per ton to $4,441 per ton in 2007$.[8]

Mercury (Hg)

DOE plans on estimating the monetized benefits of Hg emissions reductions based on environmental damage estimates from the literature. DOE has determined that the basic science linking mercury emissions from power plants to impacts on humans is considered highly uncertain. However, DOE identified two estimates of the environmental damages of mercury based on two estimates of the adverse impact of childhood exposure to methyl mercury on IQ for American children, and subsequent loss of lifetime economic productivity resulting from these IQ losses. The high-end estimate is based on an estimate of the current aggregate cost of the loss of IQ in American children that results from exposure to mercury of U.S. power plant origin ($1.3 billion per year in 2000$), which translates to $32.6 million per ton emitted per year (2007$).[9] The low-end estimate was $664,000 per ton emitted in 2004$ or $729,000 per ton in 2007$, which DOE derived from a published evaluation of mercury control using different methods and assumptions from the first study, but also based on the present value of the lifetime earnings of children exposed.[10] [b]

Sulfur Dioxide (SO_2) and Nitrogen Oxides (NOx) Allowance Prices

With regard to SO_2 emissions, unlike the other pollutants to be considered in this analysis, these emissions have for some time been subject to a national cap with corresponding annual allowances openly traded; therefore, considerable market experience with these instruments has already been accumulated. It has been argued that imposition of any standard that lowers U.S. national electricity consumption creates beneficial downward pressure on the prices of these allowances, and this cost reduction benefit should be considered in any analysis of a proposed standard. While this assertion is fundamentally sound (i.e., reduced electricity demand should *ceteris paribus* bring about lower SO_2 and NOx allowance prices) there are a myriad of complications impeding any meaningful quantification of any associated benefit.

[b] The estimate was derived by back-calculating the annual benefits per ton from the net present value of benefits reported in the study.

While complexity of analysis alone clearly cannot justify disregarding a potential consequence of a standard, DOE additionally believes these benefits to be both volatile and *de minimis* when compared to the direct effects of a standard as estimated in this analysis.

Some of the problems to be confronted in an allowance price effect forecast are:

- Only any net lowering of the total allowance bill to generators free of transfers is the potential source of a benefit. Any such compliance cost saving would need to be accurately estimated, and this effect is no different from the benefit derived from a cost reduction for other inputs, such as fuel. When the SO_2 allowance market that was created in 1995 under the Clean Air Act Amendments began, initial allowance allocations were directly granted to large *affected units* based on their historic (1985-87) use of fuel. For 30 years, allowances for the following year are issued every spring at a declining rate to these entitled parties, and thereafter can be freely used, traded, or banked. Some additional allowances are allocated in diverse ways (e.g. as rewards to generators installing control equipment). In other words, the entitled generators holding emission rights are losers when the value of allowances declines, while the buyers of allowances are gainers. Before they are used, allowances may be traded many times at prices reflecting the marginal not average cost of compliance.

- The trading system allows for allowance banking. Consequently, any observed change in a forecast year could represent the manifestation of market fundamentals but could similarly just indicate deposit or withdrawal of allowances. In general, used allowances have fallen short of the cap so emissions may exceed the specified cap for future years.

- Control efforts could further reduce the SO_2 cap for some jurisdictions, creating regulatory uncertainty that perturbs the allowance market. The issuance of the proposed and final CAIR rules were likely contributing factors to allowance price increases leading to a dramatic 2005 allowance price spike. While prices had already fallen far below their historic highs by the time CAIR was vacated in the summer of 2008, spot allowance prices nonetheless made a further precipitous drop following the D.C. Circuit Court ruling.

- Because allowances can be traded freely by generators, brokers, and investors, they can serve as financial instruments, and, especially since 2003, allowance prices have been volatile. Between 2000, when a tightened Clean Air Amendment cap came into force, and 2007, allowances traded between a low of about $120/short ton in 2002 and a high of about $1600/short ton, with the 2005 spike being particularly dramatic.[11] [12] Since there is no reason to believe that these conditions will alter over the life of a proposed standard, the challenge of forecasting prices is much more complex than a simple supply-demand balance might suggest. Also, note that any quantification of the benefit likely depends on the level of prices as well as their net change. To believe that a simple delta in the prices could be used to estimate the benefit is to believe that the same numerical reduction in price would result from the standard whether the prevailing trading price were $100 or $1000 per short ton.

With regard to NOx emissions, CAIR has only recently been reinstated by the courts, therefore market instruments with regard to NOx are not known. But DOE is left to presume that the same problems that confront an SO_2 allowance price effect forecast would also apply to a NOx allowance price effect forecast.

As noted earlier, the forecasting tool to be used for this analysis is the *AEO2009* version of NEMS-BT, which generates forecasts of both SO_2 and NOx emissions and allowance prices. DOE intends to review the allowance price forecasts and the effect that refrigerator standards have on them. If this review suggests that the SO_2 and NOx allowance price effects are both significant and estimable using NEMS-BT, it may be included in the environmental assessment for the notice of proposed rulemaking.

3.0 RESULTS

The results for the environmental assesssment are similar to a complete NEMS run, as published in the *AEO2009*. These include emissions for SO_2, NO_x, mercury, and CO_2 in five-year forecasted increments, extrapolated to the year 2043. DOE will report the outcome of the analysis for each trial standard level as a deviation from the *AEO2009* reference case results.

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REGULATORY IMPACT ANALYSIS FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR RESIDENTIAL REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

TABLE OF CONTENTS

LIST OF TABLES

REGULATORY IMPACT ANALYSIS FOR PROPOSED ENERGY CONSERVATION STANDARDS FOR RESIDENTIAL REFRIGERATORS, REFRIGERATOR-FREEZERS, AND FREEZERS

1.0 INTRODUCTION

Under the Process Rule (*Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products*, 61 FR 36974 (July 15, 1996)), the Department of Energy (DOE) is committed to continually explore non-regulatory alternatives to standards. DOE will prepare a draft regulatory impact analysis pursuant to E.O. 12866, "Regulatory Planning and Review," which will be subject to review under the Executive Order by the Office of Management and Budget's Office of Information and Regulatory Affairs. 58 FR 51735. DOE has identified six major alternatives to standards as representing feasible policy options to achieve customer product energy efficiency. It will evaluate each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and will compare the effectiveness of each one to the effectiveness of the proposed standards rule.

The non-regulatory means of achieving energy savings that DOE proposes to analyze are listed in Table RA.1. The technical support document (TSD) in support of DOE's notice of proposed rulemaking will include a complete quantitative analysis of each alternative, the methodology for which is discussed briefly below.

Table RA.1 Non-Regulatory Alternatives to Standards

No new regulatory action
Consumer tax credits
Manufacturer tax credits
Performance Standards
Rebates
Voluntary energy efficiency targets
Early replacement
Bulk government purchases

2.0 METHODOLOGY

DOE will use the National Impact Analysis (NIA) Spreadsheet Models for each of the four appliance products to calculate the national energy savings and the net present value (NPV) corresponding to each alternative to the proposed standards. The NIA Spreadsheet Models for residential refrigerators, refrigerator-freezers, and freezers are discussed in Chapter 10 of the preliminary TSD. To compare each alternative quantitatively to the proposed conservation standards, DOE will need to quantify the effect of each alternative on the purchase and use of energy efficient residential dishwashers, dehumidifiers, and cooking products, and commercial clothes washers. Once it has quantified each alternative, DOE will make the appropriate revisions to the inputs in the NIA Spreadsheet Models. Key inputs that DOE may revise in these models are:

- Energy prices and escalation factors;
- Implicit market discount rates for trading off purchase price against operating expense when choosing equipment efficiency;
- Consumer purchase price, operating cost, and income elasticities;
- Consumer price-versus-efficiency relationships; and
- Equipment stock data (purchase of new equipment or turnover rates for inventories).

The key measures of the impact of each alternative will be:

- energy use (in exajoules, or 10^{18} joules): Cumulative energy use of the equipment from the effective date of the new standard to the year 2042. DOE will report electricity consumption as primary energy.
- National energy savings: Cumulative national energy use from the base case projection minus the alternative policy case projection.
- Net present value: The value of future operating cost savings from equipment bought in the period from the effective date of the new standard (2012) to the year 2042. DOE will calculate the NPV as the difference between the present value of equipment and operating expenditures (including energy) in the base case, and the present value of expenditures in each alternative policy case. DOE will discount future operating and equipment expenditures to 2009 using a seven-percent and three-percent real discount rate. It will calculate operating expenses (including energy costs) for the life of the equipment.