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 commercial refrigeration equipment (CRE) covered in this rulemaking. This equipment includes commercial ice-cream freezers; self-contained commercial refrigerators, commercial freezers, and commercial refrigerator-freezers without doors; and remote condensing commercial refrigerators, commercial freezers, and commercial refrigerator-freezers. The "cost-efficiency" relationship serves as the basis for cost-benefit calculations in terms of individual customers, manufacturers, and the Nation. In determining this relationship, the U.S. Department of Energy (DOE) estimates the increase in manufacturer production cost (MPC) associated with technological changes that reduce the energy consumption of the baseline models.

The primary inputs to the engineering analysis are baseline information and data for each equipment class addressed in the market and technology assessment (Chapter 3) and technology options from the screening analysis (Chapter 4). Additional inputs include cost and energy consumption data that DOE estimated using a cost model and an energy-consumption model, respectively. The primary output of the engineering analysis is a set of cost-efficiency curves (both analytically derived and industry-supplied curves), and a manufacturer markup used to convert MPC to manufacturer selling price (MSP). In the subsequent markups analysis (Chapter 6), DOE determines customer prices by applying distribution markups, sales tax, and contractor markups. After applying these markups, the data serve as inputs to the building energy-use and end-use load characterization (Chapter 7) and the life-cycle cost and payback period analyses (Chapter 8).

This chapter discusses the equipment classes DOE analyzed, representative baseline units, sensitivity to material prices, and use of alternative refrigerants. The chapter also covers the methodology DOE used to develop MPC, estimate energy consumption and cost-efficiency curves, and extend the analysis to low-shipment volume equipment classes.

5.2 EQUIPMENT CLASSES ANALYZED

In the advance notice of proposed rulemaking (ANOPR) engineering analysis, DOE did not directly analyze all covered equipment classes. This methodology has been maintained in the notice of proposed rulemaking (NOPR) and the final rule engineering analysis. DOE used the shipment data presented in the market and technology assessment (recreated in Table 5.2.1) to prioritize the analysis by eliminating equipment classes with fewer than 100 annual shipments. DOE analyzed the 14 remaining high-shipment volume equipment classes. One additional equipment class, the VOP.RC.L equipment class, was added after discussions with manufacturers.[a]

According to Air-Conditioning and Refrigeration Institute (ARI) equipment shipments data, these 15 equipment classes represent 98 percent of the shipments of covered commercial refrigeration equipment. Table 5.2.2 shows the 15 equipment classes (out of 38 total) DOE analyzed in the engineering analysis, organized by equipment family, condensing unit type, and rating temperature.

---

[a] Product class designations consist of a combination (in sequential order separated by periods) of product family code (VOP=vertical open, SVO=semivertical open, HZO=horizontal open, VCT=vertical transparent doors, VCS=vertical solid doors, HCT=horizontal transparent doors, HCS=horizontal solid doors, or SOC=service over counter), operating mode code (RC=remote condensing or SC=self-contained), and rating temperature code (M=medium temperature (38°F), L=low temperature (0°F), or I=ice-cream temperature (-15°F)). For example, "VOP.RC.M" refers to the "vertical open, remote condensing, medium temperature" product class. See Chapter 3, market and technology assessment, for a more detailed explanation of the product class terminology.

Table 5.2.1 Shipment Data and Equipment Classes Analyzed

Equipment Family Designation	Condensing Unit Type Designation	Rating Temperature Designation	Equipment Class Designation*	ARI Shipments**
VOP	RC	M (38°F)	**VOP.RC.M**	38,743
		L (0°F)	**VOP.RC.L†**	0†
		I (-15°F)	VOP.RC.I	0
	SC	M (38°F)	**VOP.SC.M**	6,512
		L (0°F)	VOP.SC.L	0
		I (-15°F)	VOP.SC.I	0
SVO	RC	M (38°F)	**SVO.RC.M**	29,552
		L (0°F)	SVO.RC.L	0
		I (-15°F)	SVO.RC.I	0
	SC	M (38°F)	**SVO.SC.M**	9,750
		L (0°F)	SVO.SC.L	0
		I (-15°F)	SVO.SC.I	0
HZO	RC	M (38°F)	**HZO.RC.M**	4,541
		L (0°F)	**HZO.RC.L**	14,278
		I (-15°F)	HZO.RC.I	0
	SC	M (38°F)	**HZO.SC.M**	838
		L (0°F)	**HZO.SC.L**	1,738
		I (-15°F)	HZO.SC.I	0
VCT	RC	M (38°F)	**VCT.RC.M**	2,767
		L (0°F)	**VCT.RC.L**	38,483
		I (-15°F)	VCT.RC.I	0
	SC	M (38°F)	VCT.SC.M‡	43,374‡
		L (0°F)	VCT.SC.L‡	2,472‡
		I (-15°F)	**VCT.SC.I**	1,898
VCS	RC	M (38°F)	VCS.RC.M	49
		L (0°F)	VCS.RC.L	2
		I (-15°F)	VCS.RC.I	43
	SC	M (38°F)	VCS.SC.M‡	4‡
		L (0°F)	VCS.SC.L‡	4,202‡
		I (-15°F)	**VCS.SC.I**	470
HCT	RC	M (38°F)	HCT.RC.M	0
		L (0°F)	HCT.RC.L	15
		I (-15°F)	HCT.RC.I	0
	SC	M (38°F)	HCT.SC.M‡	724‡
		L (0°F)	HCT.SC.L‡	0‡
		I (-15°F)	**HCT.SC.I**	9,056
HCS	RC	M (38°F)	HCS.RC.M	37
		L (0°F)	HCS.RC.L	0
		I (-15°F)	HCS.RC.I	0
	SC	M (38°F)	HCS.SC.M‡	39,761‡
		L (0°F)	HCS.SC.L‡	4,109‡
		I (-15°F)	HCS.SC.I	0
SOC	RC	M (38°F)	**SOC.RC.M**	9,312
		L (0°F)	SOC.RC.L	9
		I (-15°F)	SOC.RC.I	0
	SC	M (38°F)	SOC.SC.M‡	1,108‡
		L (0°F)	SOC.SC.L‡	0‡
		I (-15°F)	SOC.SC.I	0

* Equipment classes that DOE directly analyzed are shown in **bold** font.

**Source: ARI, No. 7 Exhibit B at p. 1.

† Based on discussions with manufacturers, the VOP.RC.L equipment class was added to the analysis.

‡ These equipment classes have standards established by Energy Policy Act of 2005 (EPACT 2005) and are therefore not covered under this rulemaking.

Table 5.2.2 Equipment Classes Analyzed in the Engineering Analysis

Equipment Family		Remote Condensing			Self-Contained		
		Medium	Low	Ice Cream	Medium	Low	Ice Cream
Without Doors	VOP	✓	✓		✓		
	SVO	✓			✓		
	HZO	✓	✓		✓	✓	
With Doors	VCT	✓	✓		*		✓
	VCS						✓
	HCT						✓
	HCS						
	SOC	✓					

✓ Full analysis conducted.
* Shaded boxes indicate that these equipment classes have standards established by EPACT 2005 and are therefore not considered in this rulemaking.

The engineering analysis considered refrigerators (medium temperature), freezers (low temperature), and ice-cream freezers (ice-cream temperature) individually, but did not consider refrigerator-freezers directly (combinations of compartments at different temperatures). Although DOE did not explicitly analyze refrigerator-freezers in the engineering analysis, it did develop a method to combine the standards for refrigerators, freezers, and ice-cream freezers to create standards for refrigerator-freezers. Because of the similarities in construction, components, and features, DOE believes refrigerator-freezers have a cost-efficiency relationship comparable to refrigerators and freezers. Thus DOE assumed that standards developed separately for refrigerators and freezers can be applied to refrigerator-freezers. The final rule *Federal Register* notice describes in detail the methodology used to combine standards for refrigerators and freezers into standards for refrigerator-freezers.

5.3 METHODOLOGY OVERVIEW

This section describes the analytical methodology DOE used in the engineering analysis. In this rulemaking, DOE is adopting a design-option approach. For all 15 equipment classes directly analyzed, DOE used the analytically derived curves developed using a design-option approach in the downstream analyses. ARI provided four industry-supplied curves for the four highest shipment volume equipment classes (VCT.RC.L, VOP.RC.M, SVO.RC.M, and HZO.RC.L). These curves were used as a check against the four corresponding curves DOE developed to allow DOE and stakeholders to verify the validity of the engineering model.

Figure 5.3.1 shows a flow diagram of that methodology and the corresponding sections in this chapter, starting with models and sub-analyses on the left, and ending with results on the right. DOE developed the cost and energy-consumption models in the engineering analysis. The sub-analyses are the markups analysis and the matched pair analysis. The results of the engineering analysis are 15 analytically derived cost-efficiency curves (four of which have been validated by industry-supplied curves), and two sensitivity analyses.

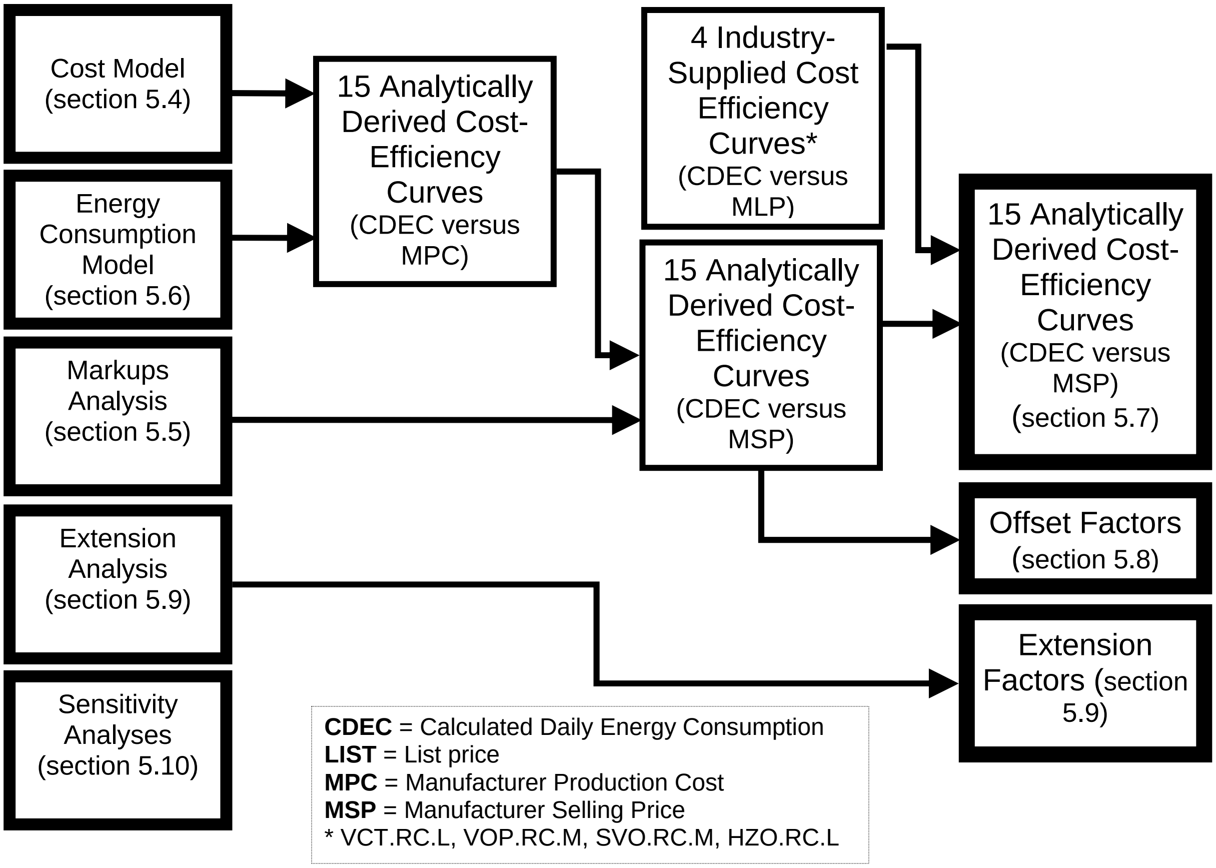

Figure 5.3.1 Flow Diagram of Engineering Methodology

The foundation of the engineering analysis is the 15 curves DOE developed. These analytically derived curves were developed using a design option analysis on the selected 15 equipment classes. In the markups analysis, DOE developed a markup between manufacturer production cost MPC and MSP. DOE used this markup to convert the MPC (developed in the cost model) to MSP for comparison to the industry-supplied curves.

DOE used the data submitted by ARI to check its engineering analysis. ARI submitted four cost-efficiency curves developed using an efficiency-level approach in the form of calculated daily energy consumption (CDEC) versus manufacturer list price (MLP). These industry-supplied curves were for the VCT.RC.L, VOP.RC.M, SVO.RC.M, and HZO.RC.L equipment classes. As part of the markups analysis, DOE estimated the average industry discount from MLP to MSP (the list price discount). DOE used this discount to convert the industry-supplied curves into CDEC versus MSP.

As explained in section 5.2, some equipment classes have very low or no shipments and were not included in the direct analysis. To develop standards for these equipment classes, DOE developed extension factors for 23 low shipment volume classes using analytical correlations. Section 5.8 explains this methodology.

DOE developed offset factors for the engineering analysis as a way to correct standards for smaller-sized equipment. Because cost-efficiency curves were typically developed for large equipment sizes (*e.g.*, a 12-foot VOP.RC.M case or a 5-door VCT.RC.L case), the resulting standard equations could be unfair to smaller-sized cases. In general, the loads a particular case is subject to do not go to zero as the size of the case is decreased. Certain components of the refrigeration load (such as the conduction end effects) remain constant. These constant loads affect smaller cases disproportionately. Offset factors are intended to approximate these constant loads and provide a second end point for the line that will become the standard equation (the first end point being one of the values of energy consumption determined in the engineering analysis). Section 5.8 describes the methodology DOE used to develop offset factors.

The primary results of the engineering analysis are a set of cost-efficiency curves, in the form of MSP versus CDEC, for 15 equipment classes. For four of these equipment classes, the DOE cost-efficiency curves are validated by the industry-supplied curves. The secondary results of the engineering analysis are two sensitivity analyses, a set of offset factors, and a set of extension factors. One sensitivity analysis deals with commodity prices performed on the VOP.RC.M cost-efficiency curve. The other is a sensitivity analysis of alternative refrigerants. The offset factors will be used in formulating standards equations, while the extension factors will be used to extend standards developed for the 15 primary equipment classes to the remaining 23 equipment classes.

5.4 COST MODEL

DOE used a cost model to estimate the MPC of commercial refrigeration equipment. This approach involved disassembling a unit from the VCT.SC.M equipment class, analyzing the materials and manufacturing processes, and developing a parametric spreadsheet model flexible enough to cover all equipment classes. The manufacturing cost model estimated MPC and reported it in aggregated form to maintain confidentiality of sensitive cost data. DOE obtained input from stakeholders on the MPC estimates and assumptions to confirm accuracy. The cost model was applied directly to 7 of the 15 covered equipment classes, and the results were extended to 6 of the remaining equipment classes. The cost of remaining two equipment classes was estimated using available MLP information discounted to MPC.

5.4.1 Manufacturer Production Cost Estimates and Assumptions

Manufacturer production cost is the sum of direct labor, direct material, and overhead (including investment depreciation). Other non-production cost elements include selling, general and administrative, research and development, and interest. Together, these costs make up the MPC, shown in Figure 5.4.1.

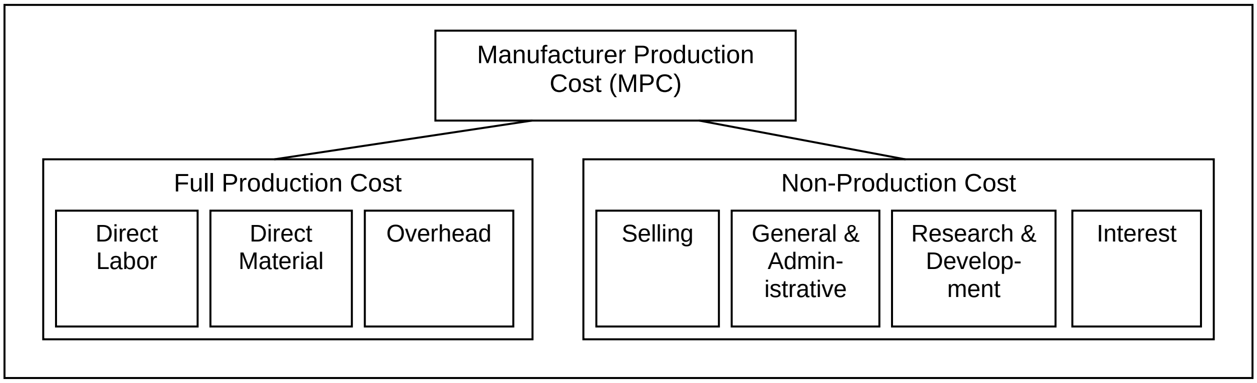

Figure 5.4.1 Components of Manufacturer Production Cost

The cost of specific models—or costs to individual manufacturers—will vary, depending on the equipment's precise characteristics, the actual manufacturing processes, the equipment mix in the factory, and other elements. There are also considerable differences in the levels of vertical integration (companies with a large market share and/or revenue base tend to be more vertically integrated than their smaller competitors) that affect cost structure and thus the cost of equipment. Yet, potentially all manufacturers buy at least some of their parts and/or subsystems from outside vendors.

The CRE market includes producers that span the range from mass-customized equipment to tailored, one-off fabricators. Most equipment listed in catalogs uses platforms that are then customized to meet the particular needs of customers. Depending on the manufacturer and the degree of customization, engineering costs can thus represent a significant portion of the MPC.

DOE made a number of simplifying assumptions to reflect common industry practice. For example, DOE assumed that the cabinets for the VCT equipment family are made in-house, but the entire door system (frames, doors, frame heaters, lights, ballasts, etc.) is purchased as an assembled sub-system from a door manufacturer. Further, DOE assumed that completed heat exchanger assemblies, fan motors and blades, or compressor sleds for self-contained units are also purchased as completed sub-systems that need to be integrated into the finished case.

Since there was only one equipment teardown from which to draw data regarding manufacturing practices, DOE built a parametric model that allowed the scaling of most input factors. The assumptions behind the model are based on published data by manufacturers, general industry practice (based on site visits), manufacturer interviews, and previously published DOE reports. DOE compared the model results to published unit data, list prices, and stakeholders comments. For example, DOE compared listed shipping weights with the calculated weights for cabinets and doors.

The lack of detailed teardowns for every equipment class and the varying degrees of vertical integration in the industry make calculating representative investment requirements difficult. Not only does the market share vary for each manufacturer across every equipment class, the scale of operations also varies greatly. It is also quite likely that high-volume manufacturers derive a cost advantage based on their purchasing volume for common raw materials and purchased parts alike. Lacking detailed data, DOE did not try to account for low- versus high-volume purchasing power.

DOE updated the cost model in engineering analysis to reflect improved understanding of the various cost components that make up the full manufacturing production cost. This included changes to the calculation of factory overhead, depreciation, and indirect labor.

5.4.2 Structure of the Cost Model Spreadsheet

DOE used a detailed, component-focused manufacturing cost assessment methodology to estimate the MPC of each equipment class analyzed in the cost model, taking into account, for example, direct materials, direct labor, and factory overhead costs. Figure 5.4.2 shows the three major steps in generating the MPC.

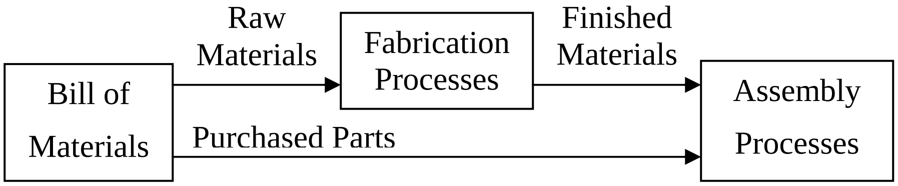

Figure 5.4.2 Manufacturer Production Cost Assessment Stages

The first step in the MPC assessment was creating a complete and structured bill of materials (BOM) from the disassembly of a commercial refrigerator with transparent doors (VCT.SC.M). DOE dismantled the commercial refrigerator and characterized each part according to weight, manufacturing processes, dimensions, material, and quantity. The BOM includes the costs for materials, components, and fasteners, and provides estimates for the cost of raw materials and purchased parts. DOE based assumptions about the sourcing of parts and in-house fabrication on industry experience, information in trade publications, and discussions with manufacturers. DOE conducted interviews and plant visits with manufacturers to ensure accuracy in methodology and pricing.

Following the development of a detailed BOM, DOE identified the major manufacturing processes and developed the spreadsheet model. Table 5.4.1 lists these processes. DOE estimated fabrication process cycle times and entered them into the BOM. For this analysis, DOE used $24 per hour as the average fully burdened labor rate based on the typical annual wages and benefits of industry employees. In the final step of the cost assessment, DOE estimated assembly times and associated direct labor costs. Once the cost estimate for each unit was finalized, DOE prepared a detailed summary of relevant components, subassemblies, and processes.

Table 5.4.1 Major Manufacturing Processes

Fabrication	Finishing	Assembly/Joining
Fixturing	Washing	Adhesive Bonding
Stamping/Pressing	Powder Coating	Spot Welding
Brake Forming	De-burring	Seam Welding
Cut and Shearing	Polishing	Inspecting & Testing
Insulating		

5.4.3 Material Prices

DOE determined the cost of raw materials by using prices for copper, steel, and aluminum from the American Metals Market.[1] DOE obtained prices for rifled and unrifled copper tubing directly from a tubing manufacturer. There have been drastic fluctuations in metal prices over the last few years. To account for these large fluctuations, DOE used prices of metals that reflect a 5-year average of the Bureau of Labor Statistics Producer Price Indices (PPIs) spanning 2002 to 2006 with an adjustment to 2007$.[2] DOE used the PPIs for steel mill products and for copper rolling, drawing, and extruding, and then adjusted to 2007$ using the gross domestic product implicit price deflator.[3]

Between 2003 and 2006, the price of steel rose over 60 percent and the price of copper rose over 140 percent. Because DOE used a 5-year average in material prices from 2002 to2006, these drastic increases are normalized to some extent to better represent long-term material price averages. Because it is not clear if these material price trends will continue, DOE conducted a sensitivity analysis to illustrate the effect of raw material price increases on the cost of commercial refrigeration equipment (section 5.10.1).

5.4.4 Results

DOE reported the cost model results as a core case cost for seven analyzed equipment classes: VCT.RC.L, VOP.RC.M, SVO.RC.M, HZO.RC.L, HCT.SC.I, HZO.SC.M, and VCT.SC.I. The core case cost is the cost of the structure and other features, but excludes all components that relate to design options (such as fans, doors, and evaporator coils) and special exterior materials (such as signage and other customer-specified options). Figure 5.4.3 through Figure 5.4.5 show the part count, weight, and cost, respectively, for the seven equipment classes directly analyzed in the cost model.

Figure 5.4.3 details the part count by equipment class, cabinet size, and sub-system. The large number of cabinet parts is driven primarily by fasteners holding all the sheet metal parts together. The distinction between inner, outer, and other cabinet parts represents DOE’s best effort to disaggregate the various cabinet categories. “Other” can include some fascia and structural elements that help keep the inner and outer skins in alignment. The condenser and evaporator descriptors attempt to capture all components outside the heat exchangers that are related to condensers and evaporator circuits. The electrical section mainly captures the cost of wiring for the ballasts.

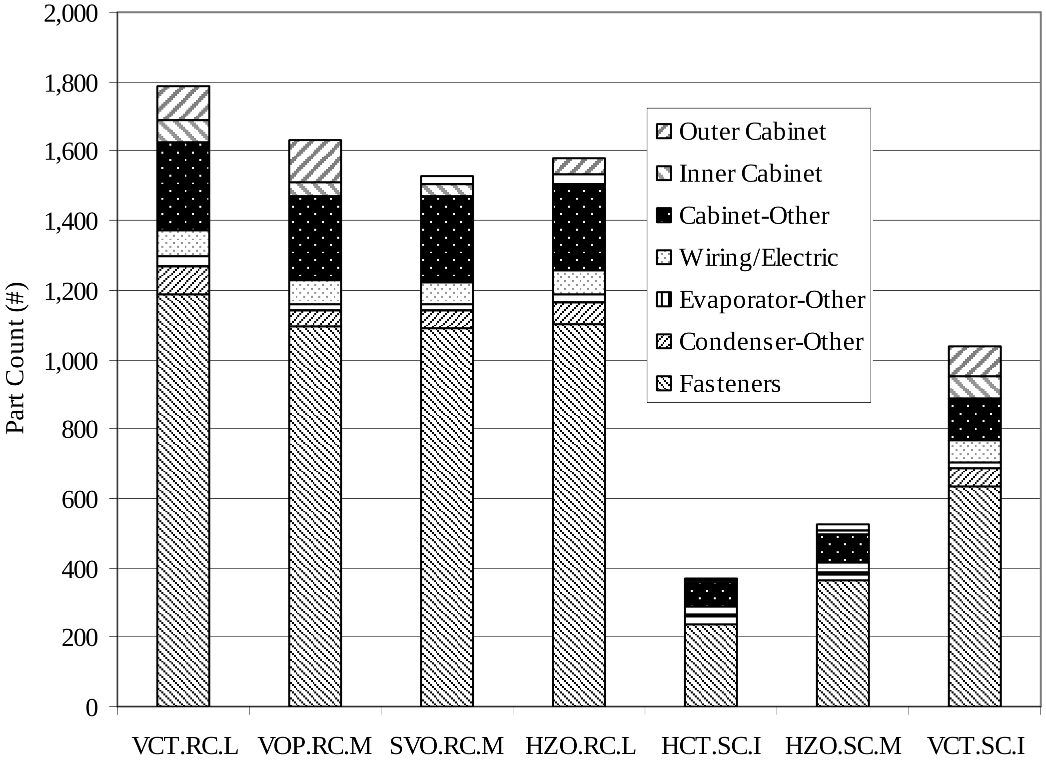

Figure 5.4.3 Part Count by Equipment Class and Subsystem

Figure 5.4.4 summarizes the weight that each subsystem contributes to the overall weight of baseline CRE units of different lengths. These calculated weights are for the basic case only and do not incorporate the weight of doors or frames (in the VCT or VCS equipment families), compressor sleds (for SC units), heat exchangers, or other design options. Thus, depending on the equipment class, the weight reported in this figure is lighter compared to manufacturer-reported shipping weights for completed units.

The weight of commercial refrigeration equipment is heavily influenced by the weight of the inner, outer, and cabinet base assemblies. This equipment is built to withstand years of use, and the shipping weights of the cabinets reflect this necessity. The degree to which a design option adds weight and expense is largely driven by the subsystem. For example, the design options include doors with two to three panes of glass. While adding coatings to the glass may reduce the energy consumption without a weight impact, a design option calling for additional panes will require stronger door hinges and frames.

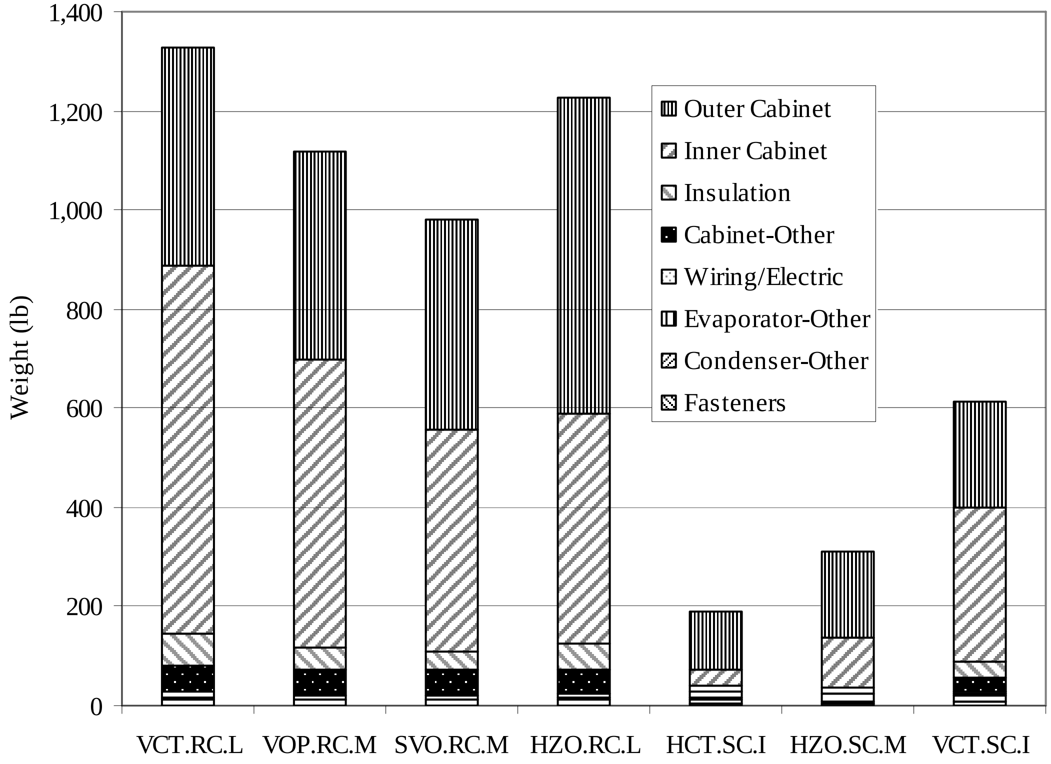

Figure 5.4.4 Weight by Equipment Class and Subsystem

The actual MPC of this equipment is driven by the processes used to make them, the cost of the underlying raw and purchased materials, and the labor required to assemble them into a working commercial refrigerator. Figure 5.4.5 shows the MPC for the basic cases discussed in this section.

When the costs are considered by percentage, the inner cavity assembly dominates the overall cost due largely to the higher raw material costs; the manufacturing steps required to form, shape, and paint these parts; and the time and effort required to assemble and seal them.

Exterior parts that are not visible to the supermarket consumer tend to be made of uncoated galvanized cold rolled steel, remain unpainted, and usually do not require nearly as much work to be prepared for assembly. As expected, freestanding units like those in the HZO.SC.M equipment class tend to have higher relative costs for their exterior cabinet assemblies, which have ten highly visible surfaces, compared to units in the VCT.RC.L equipment class, which have six surfaces.

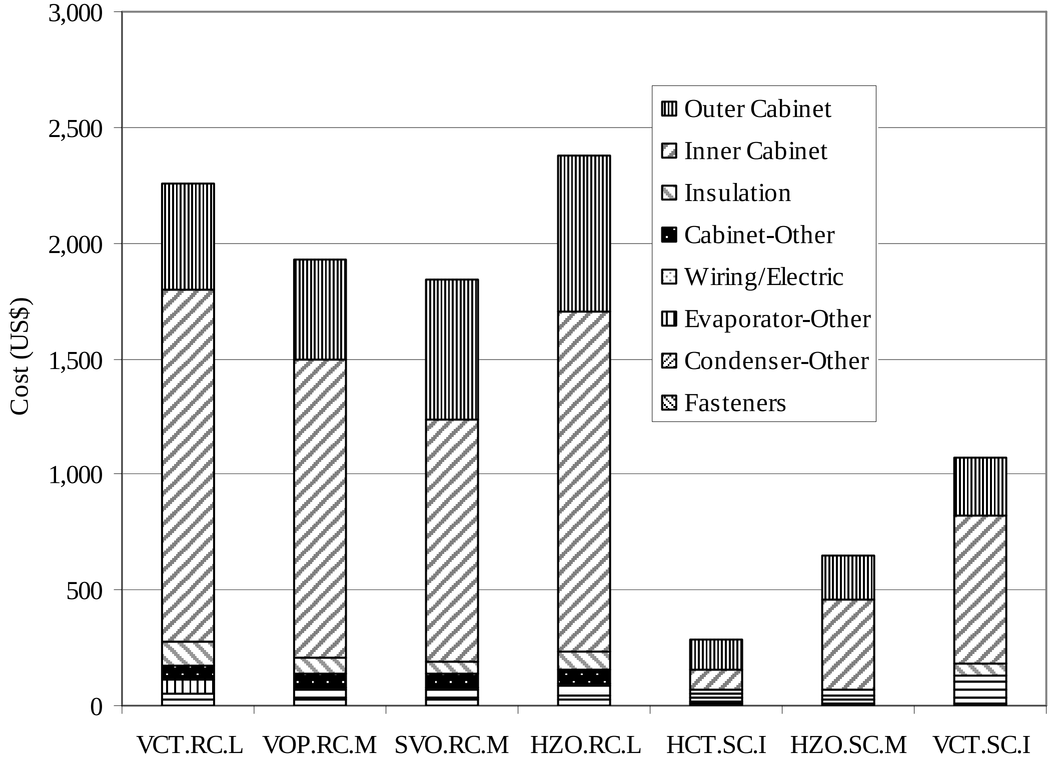

Figure 5.4.5 Manufacturer Production Cost by Equipment Class and Subsystem

DOE developed basic case costs (as MPC) for the seven equipment classes. As Table 5.4.2 illustrates, these results were extended to six of the remaining equipment classes directly analyzed in the engineering analysis. Because of the complexity of construction, the cost of the remaining two equipment classes (SOC.RC.M and VOP.RC.L) was estimated using MLP information from several manufacturers. DOE discounted the MLP values to MPC, and subtracted the estimated costs of known components (fan motors, lighting, etc.) to arrive at a basic case cost. These basic case costs (in the form of MPC) were incorporated into an engineering spreadsheet, where the costs for various design options were added and markups were applied.

Table 5.4.2 Extension of Cost Model Estimates to Other Equipment Classes

Developed in Cost Model	Extended to
VCT.RC.L	VCT.RC.M
VOP.RC.M	VOP.SC.M
SVO.RC.M	SVO.SC.M
HZO.RC.L	HZO.RC.M
HCT.SC.I	-
HZO.SC.M	HZO.SC.L
VCT.SC.I	VCS.SC.I

5.5 MANUFACTURER MARKUP AND LIST PRICE MARKUP

At each stage of the distribution chain, manufacturers, wholesalers, and contractors apply a markup to cover their operating costs and profit margins. In the engineering analysis, DOE determined a manufacturer markup, and applied it to the MPC to arrive at the MSP. Wholesaler, contractor, and other markups are determined in the markups analysis, Chapter 6 of the TSD.

The manufacturer markup was calculated as the market share weighted average value for the industry. For the ANOPR, DOE developed this manufacturer markup by examining several major CRE manufacturers' gross margin information from annual reports and Securities and Exchange Commission (SEC) 10-K reports. The manufacturers DOE analyzed account for approximately 80 percent of the CRE market. Each company is a subsidiary of a more diversified parent company that manufactures equipment other than commercial refrigeration equipment. Because the 10-K reports do not provide gross margin information at the subsidiary level, the estimated markups represent the average markups that the parent company applies over its entire range of equipment offerings and does not necessarily represent the manufacturer markup of the subsidiary. The result of the ANOPR analysis shows that the average manufacturer markup is 1.39. However, following discussions with manufacturers during the manufacturer impact analysis (MIA) interviews (Chapter 13), DOE adjusted the markups to be more representative of the industry. An aggregation of the MIA interview responses gives a market share weighted average manufacturer markup value of 1.32. DOE used this updated manufacturer markup with the MPC values from the engineering analysis to arrive at the MSP values used in the GRIM.

DOE also estimated an industry list price markup, which is a markup on the MSP that gives the MLP. DOE understands that manufacturers typically offer a discount off the MLP, which depends on various factors such as the relationship with the customer, and the volume and type of equipment being purchased. For this estimate, DOE relied on information gathered on self-contained commercial refrigeration equipment, since list price information is readily available and typically published by manufacturers. A review of the data for self-contained equipment shows that the list price markup is typically 2.0. During manufacturer interviews, some CRE manufacturers agreed with the 2.0 markup estimate, while others stated the estimate was somewhat high. DOE further verified the estimate by obtaining list price quotes from several remote condensing equipment manufacturers. Because list price markup is highly uncertain and depends on many factors, DOE applied the same estimated list price markup across each equipment class to simplify the analysis. DOE compared the analytically derived cost-efficiency curves to the industry-supplied cost-efficiency curves using the list price markup estimate. (See section 5.7 for these comparisons.)

5.6 ENERGY CONSUMPTION MODEL

The energy consumption model is the second of two key analytical models used in constructing cost-efficiency curves. This model estimates the CDEC of commercial refrigeration equipment in kilowatt hours (kWh) at various performance levels using a design-options approach. The model is specific to the types of equipment covered under this rulemaking (described in Chapter 3 of this TSD), but is sufficiently generalized to model the energy consumption of all covered equipment classes. DOE developed the energy consumption model as a Microsoft Excel spreadsheet, which is available to the public on DOE's website (http://www.eere.energy.gov/buildings/appliance_standards/ commercial_products.html). Appendix A provides instructions for using the spreadsheet.

For a given equipment class, the model estimates the daily energy consumption for the baseline and the energy consumption of several levels of performance above the baseline. The model calculates each performance level separately. For the baseline level, a corresponding cost is calculated using the cost model (section 5.4). For each level above the baseline, the cost increases of the various design options are used to recalculate the cost.

These are substantive changes that have been made to improve the accuracy of the engineering spreadsheet, and affect the numerical output of the model. Other formatting, layout, and editorial changes have been made to the spreadsheet, but are not detailed here. Changes to specific model components are detailed in their respective sections. Major revisions include changes to infiltration load calculation (section 5.6.7.6), radiation load calculation (section 5.6.7.4), LED lighting energy use (section 5.6.3.1), and the self-contained compressor model (section 5.6.7.2).

5.6.1 Screened-In Technologies

DOE analyzed the following 15 technology options:

- higher efficiency lighting
- higher efficiency lighting ballasts
- remote lighting ballast location
- higher efficiency evaporator fan motors
- evaporator fan motor controllers
- higher efficiency evaporator fan blades
- increased evaporator surface area
- low pressure differential evaporators
- insulation increases or improvements
- defrost mechanism
- defrost cycle control
- higher efficiency compressors (self-contained equipment only)

- increased condenser surface area (self-contained equipment only)
- higher efficiency condenser fan motors (self-contained equipment only)
- higher efficiency condenser fan blades (self-contained equipment only)

5.6.2 Screened-In Technologies Not Considered in the Engineering Analysis

In the market and technology assessment (Chapter 3), DOE defined an initial list of technologies that can reduce the energy consumption of commercial refrigeration equipment. In the screening analysis, DOE first narrowed this list by eliminating from consideration those technologies that can reduce annual energy consumption of commercial refrigeration equipment but do not reduce CDEC. DOE screened out the remaining technologies that were not technologically feasible, were not practical to manufacture, reduced equipment utility, or were considered unsafe.

The remaining list of screened-in technologies became one of the inputs to the engineering analysis. However, for reasons noted below, DOE did not incorporate all of these technologies in the energy consumption model. These include location of remote lighting ballasts, evaporator fan motor controllers, higher efficiency evaporator and condenser fan blades, insulation increases or improvements, low-pressure differential evaporators, defrost cycle controls, and defrost mechanisms.

5.6.2.1 Remote Lighting Ballast Location

Relocation of fluorescent lamp ballasts outside the refrigerated space can reduce energy consumption by lessening the refrigeration load on the compressor. However, for the majority of commercial refrigeration equipment currently manufactured, ballasts are already located in electrical trays outside the refrigerated space, in either the base or top of the equipment. The notable exceptions are the equipment classes in the VCT equipment family, where ballasts are most often located on the interior of each door mullion.

Most CRE manufacturers purchase doors for VCT units that are preassembled with the entire lighting system in place rather than configured for separate ballasts. DOE believes that most CRE manufacturers choose these kinds of doors because it would be labor intensive and time consuming to relocate these ballasts at the factory and wire separate ballasts. Also, the potential energy savings are small, since modern electronic ballasts are very efficient and typically contribute only a few watts each to the refrigeration load. Therefore, DOE did not consider remote relocation of ballasts as a design option.

5.6.2.2 Evaporator Fan Motor Controllers

Evaporator fan motor controllers allow fan motors to run at variable speed to match changing conditions in the case. For evaporator fan motor controllers, there is some opportunity for energy savings since frost buildup and removal creates differing pressure drops across the evaporator coil. Theoretically, less fan power is required when the coil is free of frost. The coil also would operate at a more stable temperature during frost build-up. However, the effectiveness of the air curtain in equipment without doors is very sensitive to changes in airflow, and fan motor controllers could disrupt the air curtain. The potential of disturbance to the air curtain, which could lead to higher infiltration loads, does not warrant the use of evaporator fan motor controllers in equipment without doors, even if there were some reduction in fan energy use. In addition, savings from evaporator fan motor controllers in all equipment types would be small. Therefore, DOE did not consider evaporator fan motor controllers as a design option.

5.6.2.3 Higher Efficiency Evaporator and Condenser Fan Blades

Higher efficiency evaporator and condenser fan blades reduce motor shaft power requirements by moving air more efficiently. Current technology used in commercial refrigeration equipment is stamped sheet metal or plastic axial fan blades. These fan blades are lightweight and inexpensive. DOE was not able to identify any axial fan blade technology that is significantly more efficient than what is currently used, but did identify one alternative fan blade technology that might improve efficiency: tangential fan blades. They can produce a wide, even airflow, and have the potential to allow for increased saturated evaporator temperature (SET) through improved air distribution across the evaporator coil, which would reduce compressor power. However, tangential fan blades in small sizes are themselves less efficient at moving air, and thus require greater motor shaft power. Because of these competing effects, DOE did not consider tangential fan blades as a design option.

5.6.2.4 Improved Insulation

Improvements to insulation material include better polyurethane foams and vacuum panels. In consultation with insulation material manufacturers, DOE determined that there are no significant differences in “grades” of insulation material, so most equipment manufacturers are already using the best commercially available foam materials in their equipment. Vacuum panels are an alternative form of insulation, but they may degrade in performance in time as small leaks develop. In addition, vacuum panels cannot be penetrated by fasteners, and do not provide the rigidity of “foamed-in-place” panels that polyurethane insulation creates. Therefore, DOE did not consider insulation thickness increases or improvements as a design option.

DOE also did not include insulation thickness increases as a design option in the ANOPR because thicker insulation must either borrow volume from the refrigerated space or increase the overall size of the equipment cabinet. Because the outer dimensions of commercial refrigeration equipment are limited (*e.g.,* by interior dimensions of shipping containers), it is often not practical to increase the overall size of the cabinet. In addition, reducing the volume of the refrigerated space to accommodate thicker insulation would reduce the utility of the equipment.

DOE understands that in equipment classes where conduction makes up a significant portion of the total refrigeration load, an insulation thickness increase can lead to small, but significant energy savings. DOE decided to add insulation thickness increase as a design option in the NOPR, and maintained this in the final rule, because it is cost-effective in several equipment types, most notably self-contained ice-cream freezers with doors. DOE also considered improvements to the efficiency (*e.g.,* thermal conductance) of doors in the design options analysis. Higher efficiency doors reduce the overall heat gain to the case by using better frame materials, more panes of glass, and better (or more) insulation in the doorframe.

5.6.2.5 Low-Pressure Differential Evaporators

Low-pressure differential evaporators reduce energy consumption by reducing the power of evaporator fan motors. However, in space-constrained equipment such as commercial refrigeration equipment, this reduction usually comes from a decrease in evaporator coil surface area, which generally requires a lower SET to achieve the same discharge air temperature and cooling potential. This, in turn, results in a reduction in compressor efficiency. Because of these competing effects, DOE did not consider low-pressure differential evaporators as a design option.

5.6.2.6 Defrost Cycle Control

Defrost cycle control can reduce energy consumption by reducing the frequency and duration of defrost periods. The majority of equipment currently manufactured already uses partial defrost cycle control in the form of cycle termination control. However, defrost cycle initiation is still scheduled at regular intervals. Full defrost cycle control would involve a method of detecting frost buildup and initiating defrost. As described in the market and technology assessment (Chapter 3), this could be accomplished through an optical sensor or sensing the temperature differential across the evaporator coil. However, both of these methods are unreliable due to fouling of the coil with dust and other surface contaminants. This becomes more of an issue as the display case ages. Because of these issues, DOE did not consider defrost cycle control as a design option.

5.6.2.7 Defrost Mechanisms

Defrosting for medium-temperature equipment is typically accomplished with off-cycle defrost. Because off-cycle defrost uses no energy (and decreases compressor on-time), there is no defrost design option capable of reducing defrost energy in cases that use off-cycle defrost. Some medium temperature cases and all low temperature and ice-cream temperature cases use supplemental heat for defrost. Electric resistance heating (electric defrost) is commonly used in these cases. An alternative to electric defrost in those cases that require supplemental defrost heat is hot-gas defrost. This is most often seen in remote condensing equipment and involves using the hot compressor discharge gas to warm the evaporator from the refrigerant side. The test procedure for commercial refrigeration equipment is not capable of quantifying the energy expenditure of the compressor during a hot-gas defrost cycle. Therefore, DOE did not consider it as a design option.

5.6.3 Design Options

After conducting the screening analysis and removing from consideration those technologies described above, DOE implemented the remaining technologies as design options in the energy consumption model:

- higher efficiency lighting and ballasts for VOP, SVO, HZO, and SOC equipment families (horizontal fixtures);
- higher efficiency lighting and ballasts for VCT equipment family (vertical fixtures);

- higher efficiency evaporator fan motors;
- increased evaporator surface area;
- increased insulation thickness;
- improved doors for VCT equipment family, low temperature (hinged, 30 x 67 inches);
- improved doors for VCT equipment family, medium temperature (hinged, 30 x 67 inches);
- improved doors for HCT equipment family, ice-cream temperature (sliding, 18 x 20.5 inches);
- improved doors for SOC equipment family, medium temperature (sliding, 20 x 24 inches);
- higher efficiency condenser fan motors (for self-contained equipment only);
- increased condenser surface area (for self-contained equipment only); and
- higher efficiency compressors (for self-contained equipment only).

Each design option has two to three technology levels, ranging from the minimum (worst performing) to the maximum (best performing) technology. The design options and the technology levels for each design option are described below.

5.6.3.1 Higher Efficiency Lighting and Ballasts

Lighting is an important characteristic of commercial refrigeration equipment because it makes the product visible to the consumer. Lighting systems operate continuously and provide an opportunity for significant energy savings. As lighting system efficiency increases, reductions in total case energy consumption can be achieved through a direct reduction in electricity consumption by the lighting system, and a reduction of heat inside the case, thereby reducing compressor work.

It is important that product illumination not degrade with higher design option levels, which would decrease the utility of the equipment. DOE made every effort to maintain constant system illumination among design options. This approach meant that DOE had to consider lighting as a system, rather than distinguishing lamps and ballasts as separate design options. This approach becomes more important when considering light emitting diode (LED) lighting systems, which do not use ballasts, as fluorescent lighting systems do.

Although LED systems generally have lower efficacy than the fluorescent systems they replace, the fixtures are more efficient at directing light onto the product. Although the total lumen output of LED systems is lower than comparable fluorescent systems, the amount of light incident on the product (illuminance) is roughly equivalent. Consultation with CRE manufacturers, lighting manufacturers, and other technical experts indicate that current LED technology provides product lighting that is adequate, and in most cases comparable to fluorescent lighting.

To account for the variation in design between equipment families, DOE used two lighting design options in the energy-consumption model. DOE used the “higher efficiency lighting and ballasts for VOP, SVO, HZO, and SOC equipment families” design option for lighting in a horizontal configuration, and the "higher efficiency lighting and ballasts for VCT equipment family" design option for the lighting in a vertical configuration. The VCS and HCS equipment families do not require lighting because they are not designed to display food, while the HCT equipment family typically does not have lighting because it relies on store ambient lighting. Therefore, DOE did not consider lighting design options for these three equipment families.

Because of the horizontal configuration of shelving and the linear nature of display-case lineups in the VOP, SVO, HZO, and SOC equipment families, fluorescent lighting is typically installed with the bulb in a horizontal plane. Details for the "higher efficiency lighting and ballasts for VOP, SVO, HZO, and SOC equipment families" design option are shown in Table 5.6.1. Remote condensing versions of these display cases are most often sold in 8-foot and 12-foot sections, using multiples of 4-foot fluorescent lamps to continuously light the entire width of the case. Self-contained versions are commonly sold in 4-foot lengths, so that a single 4-foot fluorescent lamp will light the full width of the case. Therefore, 4-foot lamps were specified for all lighting systems in the horizontal configuration. These lamps also were required to have a color temperature of 3,500 Kelvin (K), which is typical for this type of equipment. Fluorescent T12 magnetic and electronic systems were not considered for the horizontal lighting because a survey of existing equipment and discussions with manufacturers indicate that this technology is no longer used in these equipment classes.

In the NOPR engineering analysis, DOE revised its cost assumptions for LED lighting used in the VOP, SVO, HZO, and SOC equipment families (horizontal 4-foot fixtures) and in the VCT equipment family (vertical 5-foot fixtures). DOE originally based LED lighting costs on an LED retrofit case study for the ANOPR, but revised some of its assumptions based on conversations with manufacturers for the NOPR. Specifically, DOE revised the assumption regarding the relative cost of one-row and two-row LED fixtures, giving more weight to the labor involved in manufacturing the fixtures. DOE assumed labor accounts for approximately half of the fixture cost, and that LED chips account for the majority of the material costs. Thus, removing half of the LED chips would reduce the cost by approximately 25 percent. DOE therefore assumed a one-row fixture costs 75 percent of a two-row fixture. DOE also assumed that a 4-foot fixture costs approximately 90 percent of a 5-foot fixture. These two changes cause the original equipment manufacturer (OEM) cost of LED fixtures to increase for the equipment families for which they are an option: VOP, SVO, HZO, and SOC families (horizontal fixtures) and VCT (vertical fixtures).

Also, for the NOPR, DOE could only identify LED luminaires on the market specifically for use in vertical refrigerated cases with transparent doors (i.e., the VCT equipment family). Since DOE could not identify LED luminaires specifically for use in open refrigerated cases (i.e., the VOP equipment family), DOE used the LED luminaires specifically for use in vertical refrigerated cases with transparent doors as the basis for the LED lighting for open refrigerated cases.

In the final rule engineering analysis, DOE updated its assumptions for all LED lighting to reflect the current state of the technology. DOE was able to identify more efficacious LED luminaires on the market specifically for use in both open and closed refrigeration cases than was used in the NOPR. DOE updated the LED lighting prices and efficacies for open refrigerated cases using these newly identified LED luminaires. DOE also updated the lighting configurations specific to each equipment class for the final rule. For more detail on the updates to the LED lighting assumptions used in the engineering analysis, see Appendix B.

Table 5.6.1 Details for Lighting for VOP, SVO, HZO, and SOC Equipment Families Design Option

Level	Description	Lamp Type	Lamp Rated Power *(W)*	Lamp Rated Light Output *(Lumens)*	System Efficacy *(Lumens/W)*	System Light Output *(Lumens)*
T8	4 ft, T8 Elec.	F32T8	32.0	2,850	85.0	2,679
T8S	4 ft, Super T8 Elec.	F32T8/HL	32.0	3,100	91.4	2,697
LED	4 ft, LED	LED 4 ft	15.0	888	59.2	888

Because of the vertical configuration of the doors in the VCT equipment family, fluorescent lamps are typically installed vertically behind the mullions between doors. Such lighting systems typically consist of a single 5-foot or 6-foot lamp and a single ballast per mullion and are installed at each end of the case. All lighting systems in the vertical configuration were specified to have 5-foot lamps and a color temperature of 4,100 K, which is typical for this equipment family.

As stated earlier, for the final rule, DOE updated the LED lighting efficacy for the VCT equipment family based on newly identified LED luminaires that is currently available. In addition, DOE also modified the assumption of the LED lighting configuration for the final rule. Table 5.6.2 shows details for the "lighting for VCT equipment family" design option. For more detail on the LED lighting assumptions used in the engineering analysis, see Appendix B.

Table 5.6.2 Details for Lighting for VCT Equipment Family Design Option

Level	Description	Lamp Type	Lamp Rated Power *(W)*	Lamp Rated Light Output *(Lumens)*	System Efficacy *(Lumens/W)*	System Light Output *(Lumens)*
T8	5 ft, T8 Elec.	F58T8/835	58.0	5,400	93.1	5,400
LED	5 ft, LED	-	29.0	1,564	53.9	1,564

5.6.3.2 Higher Efficiency Evaporator Fan Motors

In conjunction with fan blades, fan motors are necessary for transferring heat from the display case to the refrigerant and, in the case of self-contained equipment, rejecting heat from the refrigerant into the ambient air. Fan motors are also responsible for maintaining product temperatures and air curtains on open cases. They must operate virtually continuously, and therefore use a significant amount of energy. As motor efficiency increases, reductions in total case energy consumption are achieved through a direct reduction both in electricity consumption and waste heat inside the case, reducing compressor work.

Table 5.6.3 shows details for the evaporator fan motor design option. DOE considers shaded-pole motors (SPM) as the minimum technology, permanent split capacitor (PSC) motors as the mid-level technology, and brushless direct current (DC) or electronically commutated motors (ECMs) as the maximum technology level. DOE took the motor efficiency levels listed in Table 5.6.3 taken from American National Standards Institute (ANSI)/ARI Standard 1200-2006 (ARI 1200), Performance Rating of Commercial Refrigerated Display Merchandisers and Storage Cabinets.

Table 5.6.3 Details for Evaporator Fan Motor Design Option

Rated Power *(W)*	Shaded-Pole Motor (SPM)		Permanent Split Capacitor (PSC) Motor		Brushless DC Motor (ECM)	
	Actual Power *(W)*	Efficiency *(%)*	Actual Power *(W)*	Efficiency *(%)*	Actual Power *(W)*	Efficiency *(%)*
15.0	75.0	20	51.7	29	22.7	66
9.0	45.0	20	31.0	29	13.6	66
6.0	30.0	20	20.7	29	9.1	66

5.6.3.3 Increased Evaporator Surface Area

Evaporator coils are another component necessary for transferring heat from the display case to the refrigerant. Table 5.6.4 shows details for the evaporator coil design option. In view of available information, DOE considered a minimum and a maximum technology level for this design option. For each level, DOE specified an overall UA-value[b] and a coil cost. The UA-value is normalized to the standard coil, and the coil cost is normalized to the heat removal capacity of the coil. This allowed DOE to apply these details of coil design across all equipment classes. In consultation with outside experts, DOE determined that applying the same coil improvements to different sized coils would result in similar performance improvements.

Table 5.6.4 Details for Evaporator Coil Design Option

Level	Description	Normalized UA (-)	Normalized Coil Cost *($/Btu/hr)*
EVAP1	Standard Coil	1	$0.0358
EVAP2	High-Performance Coil	1.667	$0.0500

DOE based the details of coil construction (Table 5.6.5) on a baseline and prototype high-performance coil evaluated in a study by Oak Ridge National Laboratory.[4] The high-performance coil uses a combination of enhancements to the heat transfer surfaces that increased its overall UA-value. These enhancements include higher fin pitch, rifled tubing, and different tube spacing. In sum, these improvements allow the prototype coil to run at a SET that is 6° warmer than the baseline coil and maintain the same discharge air temperature (30°F) and heat removal capacity (12,990 British thermal units per hour (Btu/hr)).

---

[b] The overall UA-value is the product of the overall heat transfer coefficient (Btu/h-ft^2-°F) and the total surface area (ft^2) of the coil. This value can be derived from the total heat transfer rate of the coil (Btu/h) divided by the average temperature difference between the discharge air and the saturated evaporator temperature (ΔT).

Table 5.6.5 Properties of Standard and Enhanced Evaporator Coil

Property	Standard Coil	High-Performance Coil
Overall Width (in)	81	81
Overall Height (in)	7 5/8	7 1/2
Overall Depth (in)	12	13 9/16
Tube Rows per Circuit	12	12
Number of Parallel Circuits	4	6
Tubing Material	Copper	Copper
Tubing Outer Diameter (in)	1/2	3/8
Tubing Wall Thickness (in)	0.012	0.012
Tubing Inner Surface	Smooth	Rifled
Fin Material	Aluminum	Aluminum
Fin Surface	Flat	Flat
Fin Dimensions (in)	8.66 x 7.5 (all rows)	5.415 x 7.5 (5 front rows)
		7.581 x7.5 (7 rear rows)
Fin Pitch (fins per inch)	2 (all rows)	3 (5 front rows)
		4 (7 rear rows)

Because compressor performance is directly related to SET, reductions in total case energy consumption are realized through an improved energy efficiency ratio (EER) at the condensing unit. In consultation with outside experts, DOE determined that applying the same coil improvements to different sized coils and at different temperatures would result in similar SET improvements.

5.6.3.4 Increased Insulation Thickness

DOE included increased foam insulation thickness as a design option in the NOPR and final rule engineering analysis because it is cost-effective in several equipment types, most notably self-contained ice-cream freezers with doors. A half-inch increase in insulation thickness was modeled for all equipment classes. DOE added this increase in thickness to the baseline value of insulation thickness and recalculated the conduction load (section 5.6.7.5). The cost of increasing the insulation thickness is based on a sunk cost per unit, considering foam fixture engineering and tooling costs, production line lifetime, and number of fixtures and units produced. Table 5.6.6 provides details of the assumptions used to calculate the additional cost of insulation thickness increases. DOE assumed that the cost increase due to additional foam material is insignificant compared to the cost of upgrading foam fixtures.

Table 5.6.6 Insulation Thickness Increase Assumptions

Item	Value	Notes
Cost to Upgrade Single Insulation Fixture	$100,000	
Number of Fixtures	25	Based on a survey of the number of products offered by each manufacturer
Engineering Costs	$5,000,000	Assumes $100,000 per year salary and one month to complete redesign per machine plus one month for testing
Interest Rate	7.0%	
Product Line Lifetime *(years)*	7.0	
Units per Year	35,000	
Sunk Cost Per Machine	$39.76	Assumes changes in material costs are negligible compared to fixture and engineering costs

5.6.3.5 Improved Doors

Transparent doors allow refrigerated products to be displayed to consumers while keeping cold air inside of the display case. On freezers and some refrigerators, glass doors must be heated to prevent frost from forming and rubber seals from freezing. These “anti-sweat” heaters often run continuously and consume significant amounts of energy. Transparent doors also allow heat to radiate into the display case and have a lower insulation value than solid walls. Reductions in total case energy consumption can be achieved both by improving the overall insulation value (U-factor) of the door and by reducing the required anti-sweat heater power.

A wide variety of door types are used on the equipment covered in this rulemaking. Door construction and performance can vary by equipment family as well as operating temperature of the case. To account for this variation, DOE developed four separate design options for the different door types represented in the 15 equipment classes that DOE analyzed. For all door design options, DOE estimated the thermal performance of the door (expressed as an overall U-factor) using information about door construction from manufacturers and WINDOW 5 software available from Lawrence Berkley National Laboratory.[5]

Doors for the VCT equipment family operating at low temperature are hinged and are 30 inches wide and 67 inches tall with three panes of glass. Table 5.6.7 shows details of thermal performance and anti-sweat heater requirements for this door type.

DOE considered two technology levels for this design option: the high-performance door that uses a combination of low-emissivity coating, frame material, and inert fill-gas to reduce the overall U-factor; and a standard door. DOE updated the design option for glass doors for vertical equipment with glass doors (VCT equipment family) in the NOPR and final rule engineering analysis. Based on discussions with manufacturers and data from manufacturer specification sheets, the anti-sweat heater power for both the baseline and high-efficiency doors increased from 160 to 200 for baseline doors and from 60 to 110 for high-efficiency doors. DOE did not update the cost data because more accurate data was unavailable.

Table 5.6.7 Details for Doors for VCT Equipment Family, Low Temperature Design Option

Level	Description	Overall U-Factor *(Btu/hr-ft-°F)*	Anti-Sweat Heater Power *(W/door)*
DOOR1	Standard Door	0.547	200
DOOR2	High-Performance Door	0.276	110

Doors for the VCT equipment family operating at medium temperature are hinged and 30 inches wide and 67 inches tall with two panes of glass. Table 5.6.8 shows details of thermal performance and anti-sweat heater requirements for this door type.

DOE considered two technology levels for this design option. The high-performance door uses a combination of low-emissivity coating, frame material, and inert fill-gas to reduce the overall U-factor compared to the standard door and eliminate anti-sweat heater power. DOE updated the design option for glass doors for medium temperature VCT equipment in the NOPR engineering analysis, and maintained this in the final rule. Based on discussions with manufacturers and data from manufacturer specification sheets, the anti-sweat heater power for both the baseline and high-efficiency doors increased from 60 to 100 for baseline doors and from 0 to 50 for high-efficiency doors. DOE did not update the cost data because more accurate data was unavailable.

Table 5.6.8 Details for Doors for VCT Equipment Family, Medium Temperature Design Option

Level	Description	Overall U-Factor *(Btu/hr-ft-°F)*	Anti-Sweat Heater Power *(W/door)*
DOOR1	Standard Door	0.560	100
DOOR2	High-Performance Door	0.478	50

Doors for the HCT equipment family operating at ice-cream temperature (HCT.SC.I and HCT.RC.I equipment class) are sliding and18 inches wide and 20.5 inches tall with one pane of glass. Table 5.6.9 shows details of thermal performance and anti-sweat heater requirements for this door type.

DOE considered two technology levels for this design option: a high-performance door that uses a combination of low-emissivity coating, frame material, and an extra pane with inert fill-gas to reduce the overall U-factor; and a standard door. Typically, a high-performance door does not require anti-sweat heater power.

Table 5.6.9 Details for “Doors for HCT Equipment Family, Ice-Cream Temperature” Design Option

Level	Description	Overall U-Factor (Btu/hr-ft-°F)	Anti-Sweat Heater Power (W/door)
DOOR1	Standard Door	1.046	0
DOOR2	High-Performance Door	0.377	0

Doors for the SOC equipment family operating at medium temperature are of the sliding type and are 24 inches wide and 20 inches tall with two panes of glass. Table 5.6.10 shows details of door thermal performance and anti-sweat heater requirements for this door type. DOE considered two technology levels for this design option: a high-performance door that uses a combination of low-emissivity coating, frame material, and inert fill-gas to achieve a reduced overall U-factor; and a standard door. Typically, a high-performance door does not require anti-sweat heater power.

Table 5.6.10 Details for Doors for SOC Equipment Family, Medium Temperature Design Option

Level	Description	Overall U-Factor (Btu/hr-ft-°F)	Anti-Sweat Heater Power (W/door)
DOOR1	Standard Door	0.672	0
DOOR2	High-Performance Door	0.320	0

5.6.3.6 Higher Efficiency Condenser Fan Motors

The condenser fan motor design option applies only to those equipment classes that are self-contained. Details for the condenser fan motor design option are identical to those shown in Table 5.6.3. As with evaporator fan motors, the SPM is the minimum technology, the PSC motor is the mid-technology, and the DC motor or ECM is the maximum technology level. Because condenser fan motors are outside the refrigerated space, efficiency improvements only affect the direct electrical consumption of the motors and not the total case heat load.

5.6.3.7 Increased Condenser Surface Area

Table 5.6.11 shows details for this design option, which only applies to self-contained equipment classes. Details of coil construction are based on data from tear-downs by Southern California Edison’s Refrigeration and Thermal Test Center (RTTC).[6] Based on this information, DOE considered both minimum and maximum technology levels for this design option. For each level, DOE specified an overall UA-value and a coil cost. The UA-value is normalized to the standard coil, and the coil cost is normalized to the heat removal capacity of the coil. This approach allowed DOE to apply the details of coil design across all self-contained equipment classes. In consultation with outside experts, DOE determined that applying the same coil improvements to different sized coils would result in similar performance improvements.

Table 5.6.11 Details for "Increased Condenser Surface Area" Design Option

Level	Description	Normalized UA (-)	Normalized Coil Cost ($/Btu/h)
COND1	Standard Coil	1.00	$0.0146
COND2	High-Performance Coil	2.56	$0.0439

Table 5.6.12 shows details of coil construction. The high-performance coil uses a combination of enhancements to the heat transfer surfaces that increased its overall UA-value. These enhancements include higher fin pitch, rifled tubing and different tube spacing. These improvements allow the prototype coil to run at a saturated condenser temperature (SCT) that is 14°F cooler than the baseline coil while maintaining the same heat rejection rate (1,600 Btu/hr). Because compressor performance is directly related to SCT, reductions in total case energy consumption are achieved through an improved EER at the condensing unit.

Table 5.6.12 Properties of Standard and Enhanced Condenser Coil

Property	Standard Coil	High-Performance Coil
Overall Width (in)	12.5	24
Overall Height (in)	10	10
Overall Depth (in)	2.25	3
Tube Rows per Circuit	28	16
Number of Parallel Circuits	3	2
Tubing Material	Copper	Copper
Tubing Outer Diameter (in)	3/8	3/8
Tubing Wall Thickness (in)	0.012 in	0.012 in
Tubing Inner Surface	Smooth	Rifled
Fin Material	Aluminum	Aluminum
Fin Surface	Flat	Flat
Fin Pitch (fins per inch)	6	7

5.6.3.8 Higher Efficiency Compressors

The compressor design option applies only to self-contained equipment classes. In consultation with compressor manufacturers and external technical experts, DOE determined that two levels of technology were applicable for the compressor design option. The minimum technology level is a standard single-speed hermetic compressor, and the maximum technology level is a high-efficiency single-speed hermetic compressor. (See section 5.6.5 for a discussion of why DOE did not consider variable-speed compressors.) Reductions in total case energy consumption are achieved through a reduction in compressor power consumption.

Several manufacturers provided DOE performance data for standard single-speed hermetic compressors a range of capacities applicable to the covered equipment (1,500 - 20,000 Btu/h). DOE used this data to find appropriately sized compressors when developing each design-option curve. (See section 5.6.7.2 for information on the calculation of compressor energy consumption.) Although several compressor manufacturers produce high-efficiency compressors, little data are currently available on their performance. Therefore, DOE approximated a set of high-efficiency compressors by adjusting the power consumption of the standard compressors using a constant multiplier. DOE developed this multiplier through its own research and consultation with outside experts. (See section 5.6.5 for details on this multiplier.)

In the NOPR, DOE updated the assumptions used to estimate the changes in cost and efficiency for high-efficiency single-speed compressors. Based on discussions with manufacturers and other experts, DOE concluded that the assumptions used in the ANOPR (a 10-percent increase in cost results in a 20-percent reduction in energy use) overstated the actual efficiency gains that are possible in today's compressors. Therefore, DOE revised its assumptions for the NOPR and final rule (a 5-percent increase in cost results in a 10-percent reduction in compressor energy use). Per dollar, efficiency gains are equivalent with these new assumptions, but the overall magnitude of power reduction is lower, as well as the cost premium. This change affects only the self-contained equipment classes analyzed in the engineering analysis.

5.6.4 Baseline Specifications

DOE defined baseline specifications (or case design specifications) for each equipment class. These specifications include dimensions, numbers of components, temperatures, nominal power ratings, and other case features that are necessary to calculate energy consumption. In conjunction with the lowest technological level of each design option (section 5.6.3), the baseline specifications define the energy consumption and cost of the typical minimum technology equipment on the market. Table 5.6.13 shows the specifications and units that DOE defined for each equipment class.

Table 5.6.13 Baseline Specifications

Specification	**Units**
Case Length	ft
Case Gross Refrigerated Volume	ft^3
Case Total Display Area	ft^2
Number of Lamps in Conditioned Space	#
Number of Lamps Not in Conditioned Space	#
Number of Ballasts in Conditioned Space	#
Number of Ballasts Not in Conditioned Space	#
Evaporator Fan Nominal Rated Wattage	W
Number of Evaporator Fans per Case	#
Condenser Fan Nominal Rated Wattage	W
Number of Condenser Fans per Case	#
Defrost Mechanism Type (Off-Cycle, Electric, Manual)	n/a
Defrost Time per Day	hr
Defrost and Drain Heater Power	W
Anti-Sweat Power Other Than Doors	W
Condensate Pan Heater Power	W
Average Case Temperature	°F
Saturated Evaporator Temperature (SET) Nominal	°F
Saturated Condenser Temperature (SCT) Nominal	°F
Compressor Oversize Factor (>1)	n/a
Nominal Insulation Thickness	in
Wall Area	ft^2
Number of Doors	#
Single Door Area	ft^2
Non-Door Glass Area	ft^2
Case Interior Surface Area	ft^2
Air-Curtain Height	ft
Air-Curtain Angle from Vertical	°
Infiltrated Air Mass	lb/hr

DOE established baseline specifications for each equipment class modeled in the engineering analysis by reviewing available manufacturer data, selecting several representative units from that data, and then aggregating the physical characteristics of the selected units. This process created a representative unit for each equipment class with average characteristics for physical parameters (*e.g.*, volume, total display area), and minimum performance of energy-consuming components (*e.g.*, fans, lighting). Appendix B provides these numerical specifications for each equipment class, as well as changes to baseline design specifications.

5.6.5 Non-Numerical Assumptions

In developing the energy consumption model, DOE made certain general non-numerical assumptions about the analysis, as well as specific assumptions about load components and design options.

DOE assumed that all conditions are based on new equipment tested in a controlled-environment chamber subjected to ARI 1200, which references the ANSI/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 72-2005 (ASHRAE 72), Method of Testing Commercial Refrigerators and Freezers. Manufacturers that certify their equipment to comply with Federal standards will be required to test new units to this test method, which specifies ambient temperature, humidity, light level, and other requirements.

DOE assumed that there is no pull-down load associated with re-shelving products since the test procedure does not address product re-shelving. Product re-shelving is the act of loading new products into refrigerated display cases as existing products are sold. Typically, commercial refrigeration equipment is not designed to pull down the temperature of warm products, but only to display products that were already chilled or frozen in a refrigerated storage unit.

DOE also assumed that there are no pull-down loads associated with post-defrost periods. During defrost periods, the compressor (or the flow of refrigerant for remote condensing cases) stops and the coil warms to a temperature above freezing (aided by electric resistance heating in the case of electric defrosts). After the evaporator coil has been cleared of frost, the merchandise in the case will typically have warmed several degrees. The merchandise must be returned to normal operating temperature when the refrigeration cycle resumes, adding an additional load to the condensing unit. Between equipment families and even within equipment classes there is a large variation in defrost mechanism, defrost cycle time, temperature recovery time, and product mass. Because of the uncertainty of these factors, DOE was unable to accurately calculate the defrost pull-down load and did not include it in the model. Sample calculations show that this load may only account for two to four percent of the total refrigeration load for a VOP.RC.M case, or roughly one to two percent of the total daily energy consumption.

DOE did not consider hot-gas defrost as a design option for defrost mechanisms in remote condensing cases (Chapter 4 of this TSD). During hot-gas defrost, hot refrigerant from the compressor rack bypasses the condenser and expansion device and is piped directly to the evaporator coil, melting the frost on the coil. The ASHRAE 72 test procedure provides a method for measuring the total refrigeration load during steady-state conditions, and does not capture the energy added to a display case during a hot-gas defrost cycle. Therefore, DOE did not consider this technique.

DOE did not consider liquid suction heat exchangers (LSHX) as a design option (Chapter 4 of this TSD). As with hot-gas defrost, the effects of LSHX cannot be measured with the ASHRAE 72 test procedure.

DOE did not consider variable-speed compressors as a compressor design option. Variable-speed compressors reduce energy consumption under real-world conditions by matching their capacity to the refrigeration load, which can change due to variation in ambient conditions and product loading. This eliminates the inefficiencies that occur due to mismatched capacity and load in a single-speed compressor during part-load operation. The ASHRAE 72 test procedure prescribes steady-state conditions. Thus, a variable-speed compressor would be limited to single-speed operation, the EER would be no better than a properly sized single-speed compressor, and no appreciable energy savings would result. Similarly, under ASHRAE 72, the performance of a high-efficiency variable-speed compressor would be comparable to a high-efficiency single-speed compressor.

5.6.6 Numerical Constants and Assumptions

In developing the energy consumption model, DOE identified constants and made assumptions concerning numerical values used in the analysis. These include ambient conditions, financial assumptions, and parameters necessary to calculate the component and non-electric loads. Table 5.6.14 shows details of these assumptions.

Table 5.6.14 Energy Consumption Model Numerical Constants and Assumptions

Numerical Constants and Assumptions	Number	Source
Test Chamber Temperature *(°F)*	75	ASHRAE 72[7]
Test Chamber Relative Humidity *(%)*	55	ASHRAE 72[7]
Test Chamber Pressure *(pounds per square in (psi), absolute)*	14.7	Assumed
Manufacturer Markup *($/$)*	1.32	Publicly available corporate financial data
List Price Markup *($/$)*	2.00	DOE estimate based on discussion with manufacturers
Fraction of Anti-Sweat Heater Power into Case *(W/W)*	0.7	DOE estimate based on discussions with manufacturers
Fraction of Lighting Power into Case for Lamps Outside of Air Curtain *(W/W)*	0.5	Electric Power Research Institute (EPRI), Supermarket Simulation Tool (SST) v3.0[8]
Lighting Operating Time per Day *(hr)*	24	Assumed
Thermal Conductivity of Foam Insulation *(Btu-in/hr-ft^2-F)*	0.125	Discussions with foam manufacturers; Manufacturer data sheets
Convective Film Coefficient Inside Case Walls *(Btu/hr-ft^2-F)*	4.00	Communication with Southern California Edison, RTTC
Convective Film Coefficient Outside Case Walls *(Btu/hr-ft^2-F)*	1.46	Communication with RTTC
Overall U-Value of Single-Pane Glass *(Btu/hr-ft^2-F)*	1.059	Lawrence Berkeley National Laboratory WINDOW 5 Software[5]
Emissivity of Test Chamber Walls *(-)*	0.9	Communication with RTTC
Emissivity of Case Inner Walls *(-)*	0.9	Communication with RTTC
Area of Test Chamber Walls *(ft^2)*	1000	Communication with RTTC
Case Interior Relative Humidity *(%)*	65	R. Faramarzi, *Efficient Display Case Refrigeration,* ASHRAE Journal, November 1999[9]
Evaporator Coil Overall Bypass Factor *(%)*	17	DOE estimate
High-Efficiency Compressor Cost Premium	5%	Communication with manufacturers
High-Efficiency Compressor Power Reduction	10%	Communication with manufacturers

5.6.7 Model Components

Figure 5.6.1 presents a schematic showing the components in the energy consumption model. The model calculates energy consumption in two major subsections (expressed as kWh/day): compressor energy consumption and component energy consumption. Component energy consumption is the sum of electrical energy directly consumed by each fan motor, lamp, defrost and drain heater, anti-sweat heater, and pan heater.

Compressor energy consumption is calculated from the total heat load (expressed as Btu/h) and one of two compressor models: one version for remote condensing equipment, and one for self-contained equipment. The total heat load is a sum of the component load and the non-electric load. The component load is a sum of the heat emitted by evaporator fan motors, lighting, defrost heaters, drain heaters, and anti-sweat heaters inside and adjacent to the refrigerated space (condenser fan motors and pan heaters are outside the refrigerated space and do not contribute to the component heat load). The non-electric load is the sum of the heat contributed by radiation through glass and openings, heat conducted through walls and doors, and warm air infiltration through openings.

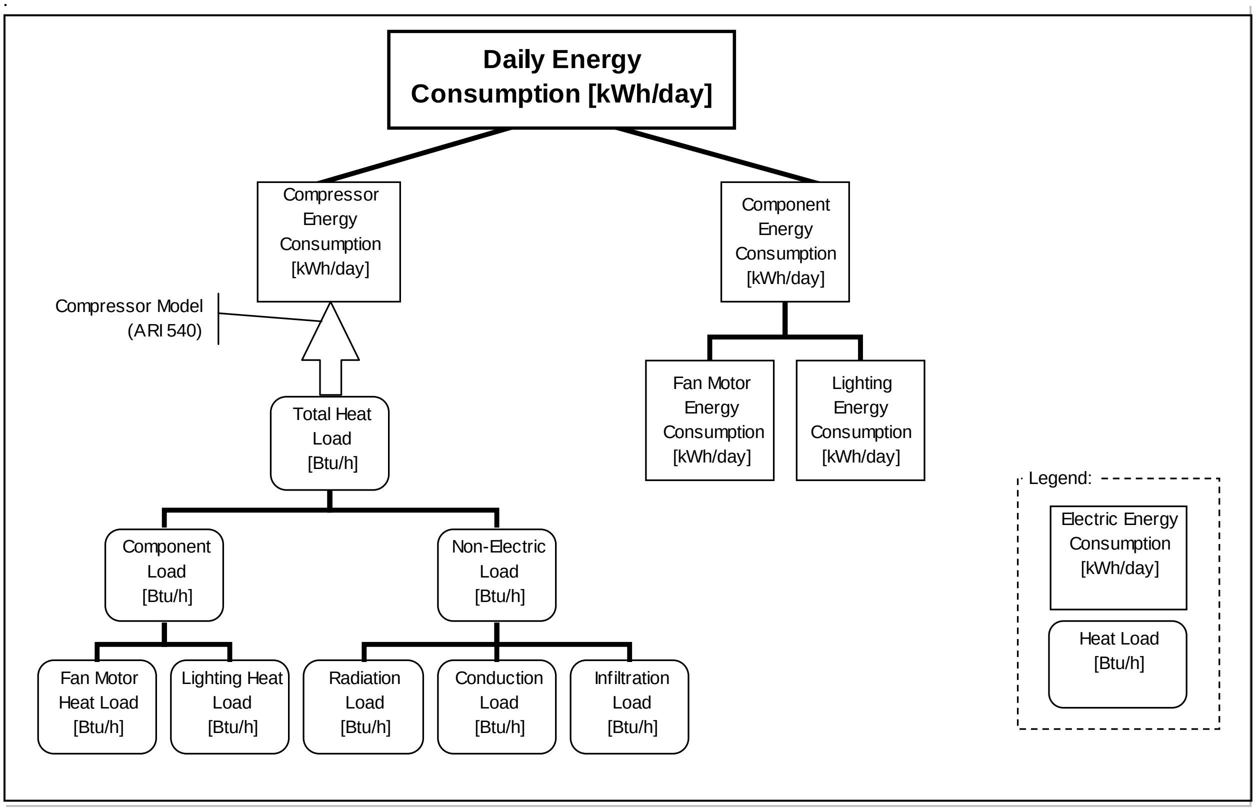

Figure 5.6.1 Components of the Energy Consumption Model

5.6.7.1 Component Energy Consumption

Fan motor energy consumption is calculated by summing the power draw of each evaporator and condenser fan motor, and multiplying the total motor power by the total running time over a 24-hour period. (This calculation assumes that evaporator and condenser fans run continuously when off-cycle defrost is used, and are turned off during defrost when electric defrost is used).

Lighting energy consumption is calculated by summing the power draw of each lamp and ballast, and multiplying the total by the total operating time of the lighting system over a 24-hour period. (This calculation assumes that lighting operates continuously.) In the ANOPR, the calculation of LED energy use assumed that the LED lighting fixtures at the ends of VCT cases were identical to those between doors. With fluorescent fixtures, manufacturers install the same lamp whether the lamp is at the end of the case (an end mullion) or between doors (an interior mullion). This causes excess of light at the ends of the case, since the light output of a single lamp between two doors goes in both directions. Lamps at the ends direct light only on the contents behind the end door.

LED fixtures are inherently scalable, so manufacturers can install an LED fixture in the end mullion that uses half the energy (and produces half the light) of fixtures in interior mullions. The calculation in the NOPR analysis assumes single-row LED fixtures are used in the end mullions. Single-row fixtures are assumed to use half the energy of double-row fixtures in interior mullions.

Defrost and drain heater energy consumption is calculated by summing the power draw of each defrost heater and drain heater, and multiplying by the total time the case is in defrost operation over a 24-hour period.

Anti-sweat energy consumption is calculated by summing the power draw of each anti-sweat heater, and multiplying by the total operating time of the heaters over a 24-hour period. (This calculation assumes that anti-sweat heaters run continuously.)

Pan heater energy consumption is calculated by multiplying the power draw of each pan heater by the total operating time of the heater over a 24-hour period. The total operating time is calculated as the time it would take to evaporate all of the defrost melt water.

5.6.7.2 Compressor Energy Consumption

Compressor energy consumption (CEC) is calculated from the total heat load and one of two compressor models: one version for remote condensing equipment and one for self-contained equipment. Compressor energy consumption for remote condensing equipment is calculated using default efficiency values from ARI 1200. Table 1 in ARI 1200 lists remote condensing compressor EER in Btu/Wh as a function of adjusted dew point temperature.

Adjusted dew point (ADP) temperature (°F) is calculated as:

$$\text{ADP} = \text{SET} - 2°\text{F (for medium temperature)} \qquad \textbf{Eq. 5.1}$$

$$\text{ADP} = \text{SET} - 3°\text{F (for low/ice-cream temperature)} \qquad \textbf{Eq. 5.2}$$

where

SET is the saturated evaporator temperature (°F).

Once ADP is calculated, Table 1 in ARI 1200 is used to find the corresponding EER value. The compressor energy consumption (kWh/day) is then calculated as:

$$\text{CEC} = Q_{tot} \times (24 - t_{defrost}) / (\text{EER} \times 1000) \qquad \textbf{Eq. 5.3}$$

where

Q_{tot} is the total heat load (Btu/hr), and
$t_{defrost}$ is the total defrost time in a 24-hour period (hr).

Compressor energy consumption for self-contained equipment is calculated by using the compressor model described in section 6.4 of ARI Standard 540-2004 (ARI 540), Performance Rating of Positive Displacement Refrigerant Compressors and Compressor Units. This model is based on a 10-coefficient polynomial derived from empirical compressor performance data for power, mass flow, current, and efficiency. The coefficients are derived for each parameter as a function of SET and SCT. Compressor coefficients, or tabulated empirical data (from which coefficients can be derived), are available from compressor manufacturers. Similar to the method used for remote condensing equipment, the EER of any compressor can be determined given a SET and SCT. Using Equation 5.3 above, the compressor energy consumption can be determined.

In the NOPR engineering analysis, DOE revised its rated capacity values for self-contained compressors. In the ANOPR, rated capacity was listed at standard ASHRAE rating evaporator and condenser rating conditions. Because the actual conditions in most commercial refrigeration equipment are not at standard rating conditions, listed capacities differed significantly from capacities at modeled conditions. The compressor model used a look-up function to select the most appropriate compressor based on the total refrigeration load in the case and the compressor oversize factor from the baseline design specifications. Because of the mismatch of capacity at standard conditions and actual modeled conditions, the capacity of the selected compressors was typically overestimated. To compensate, the compressor oversize factor was adjusted to an unrealistic level (typically 1) so the model could select the correct compressor.

In the NOPR, the corrected capacity listings required revising the oversize factor for all self-contained equipment classes to maintain the selection of the correct compressor size. Because no compensation is needed in the updated NOPR model, the compressor oversize factors are more realistic (typically 1.4).

5.6.7.3 Component Load Model

The component load is the sum of the heat each evaporator fan motor, lamp, defrost and drain heater, and anti-sweat heater emits inside and adjacent to the refrigerated space. Each component creates waste heat that is rejected to the refrigerated space and must be removed by the compressor.

DOE assumed that all electrical energy the evaporator fan motors consume ends up as heat inside the refrigerated space. In any electric motor, irreversibilities in the motor windings, bearings, and other mechanical components convert much of the input electrical energy into heat. The rest of the energy is converted to moving air inside the case. This moving air is slowed by friction and eventually converted to heat as well.

For lamps inside the refrigerated space, DOE assumed that all electrical energy the lamps consumed ends up as heat inside the space. For lamps that are outside the refrigerated space (*i.e.*, adjacent to the air curtain), DOE assumed that 50 percent of the electrical energy the lamps consumed ends up as heat inside the space. For ballasts inside the refrigerated space, DOE assumed that all electrical energy the ballasts consumed ends up as heat inside the space. Ballasts outside the refrigerated space do not contribute any heat to the space.

The phase change that occurs when defrost heaters melt the frost from evaporator coils consumes most of the electrical energy that supplied during a defrost period. Over a 24-hour period, the total heat of melting is determined by

$$Q_{melt} = m_{frost} H_{f,water} \qquad \textbf{Eq. 5.4}$$

where

Q_{melt} is the heat of melting (Btu/hr),
m_{frost} is the frost mass in a 24-hour period (lbs/hr), and
$H_{f,water}$ is the heat of fusion of water (Btu/lb).

DOE assumed that all the electrical energy that defrost heaters consume, other than what is used to melt the frost, ends up as heat inside the refrigerated space. For drain heaters, DOE assumed that all electrical energy ends up as heat inside the refrigerated space.

DOE assumed that on average, 70 percent of the electrical energy consumed by anti-sweat heaters adjacent to the refrigerated space (frame, rail, glass, sill and air grille heaters) ends up as heat inside the space.

5.6.7.4 Radiation Load Model

The radiation heat load model accounts for the gray-body radiation between the warm surfaces of the surrounding environment (the test chamber) and the cold inner surfaces of the refrigerated space. For cases without doors, the net radiation is determined:

$$Q_{rad} = \frac{\sigma\left(T_{room}^4 - T_{case}^4\right)}{\dfrac{1-\varepsilon_{room}}{\varepsilon_{room} A_{room}} + \dfrac{1}{A_{room} F_{case-room}} + \dfrac{1-\varepsilon_{case}}{\varepsilon_{case} A_{case}}} \qquad \textbf{Eq. 5.5}$$

where

Q_{rad} is the net radiation load (Btu/h),
σ is the Stefan-Boltzmann constant (Btu/h-ft^2-°F^4),
T_{room} is the temperature of the room walls (°F),
T_{case} is the temperature of the case inner walls (°F),
ε_{room} is the emissivity of the room walls (dimensionless),
ε_{case} is the emissivity of the case inner walls (dimensionless),
A_{room} is the area of the room walls (ft^2),
A_{case} is the area of the interior of the case (ft^2), and

$F_{case\text{-}room}$ is the view factor from the case interior to the room walls (dimensionless).

DOE assumed that the wall temperatures of the case was in thermal equilibrium with the air temperature in the case, and that the wall temperatures of the room were in thermal equilibrium with the air temperature in the room. See Table 5.6.14 for numerical constants pertaining to the radiation model.

DOE made one change to the methodology of calculating the radiation load for cases without doors (VOP, SVO, and HZO equipment families). In the ANOPR, DOE estimated the view factor from the interior of the case to the walls of the test chamber as 0.025, based on data and calculations from the RTTC. This value was kept constant for all cases and sizes, but it is clear this value should change somewhat as the geometry and the overall size of the case changes.

In the NOPR, the view factor is calculated separately for each equipment class depending on the geometry specific to the baseline design specifications of that class. The view factor from the case to the room is calculated as the ratio of total display area (TDA, area of the plane separating the case from the room) to the test chamber wall surface area.

For glass doors and other glass, the net radiation is incorporated into the overall U-value of the door calculated by WINDOW 5 (Table 5.6.7 through Table 5.6.10, and Table 5.6.14). The WINDOW 5 program specified the environmental conditions in the case and the room for cases at medium temperature, low temperature, and ice-cream temperature. See section 5.6.7.5 for a discussion of the calculation of the combined radiation and conduction loads for glass doors and other glass.

5.6.7.5 Conduction Load Model

The conduction load model accounts for the heat conducted through walls and doors. For solid walls and doors, the conduction is given by:

$$Q_{cond} = A_{walls} \frac{T_{room} - T_{case}}{\frac{1}{h_o} + \frac{d_{ins}}{k_{ins}} + \frac{1}{h_i}} \qquad \textbf{Eq. 5.6}$$

where

A_{walls} is the area of the exterior of the case (ft^2),
h_o is the convective film coefficient on the outside of case walls (Btu/h-ft^2-°F),
h_i is the convective film coefficient on the inside of case walls (Btu/h-ft^2-°F),
d_{ins} is the insulation thickness (in), and
k_{ins} is the insulation thermal conductivity (Btu-in/h-ft^2-°F).

Because of its high thermal conductivity, the sheet metal that encloses the insulation has no significant effect on the conduction load, and therefore was not included in the calculation of conduction load. See Table 5.6.14 for numerical constants pertaining to the conduction model.

For glass doors and other glass, the conduction load is incorporated into the overall U-factor of the door assembly or glass calculated by WINDOW 5 (Table 5.6.7 through Table 5.6.10 and Table 5.6.14). The combined radiation and conduction load for glass doors and other glass is calculated as:

$$Q_{glass} = U_{overall} A_{glass} \left(T_{room} - T_{case} \right) \qquad \textbf{Eq. 5.7}$$

where

$U_{overall}$ is the overall U-factor, including convection and radiation (Btu/h-ft^2-°F), and
A_{glass} is the area of the glass (ft^2).

5.6.7.6 Infiltration Load Model

In the ANOPR, infiltration load was calculated using empirical defrost meltwater data obtained from manufacturers' detailed spec sheets. DOE assumed that defrost meltwater could be correlated with infiltration load, given certain known parameters such as ambient relative humidity. This methodology was calibrated with detailed case load data obtained from Southern California Edison for several large-volume equipment classes.

At the ANOPR public meeting, stakeholders commented that using defrost meltwater may not be an accurate way of calculating the infiltration load. They explained that defrost meltwater data was a rough estimate of the amount of infiltrated air, and in many cases could underestimate the infiltration load. DOE agrees with this assessment and altered its methodology accordingly.

In the NOPR engineering design specifications, DOE replaced the defrost melt water (in pounds per hour (lbs/hr)) with infiltrated air (also in lbs/hr) for all equipment classes. DOE estimated infiltrated air by using manufacturers' detailed spec sheets, recognizing that infiltration load is the only load component that cannot be directly calculated. DOE calculated other load components (internal load, conduction load, radiation load) using physical parameters about each case. DOE subtracted these load components from the listed total refrigeration load, and assumed that the remaining load is due to infiltration. Table 5.6.15 provides a summary of changes to the infiltration load for each equipment class DOE examined in the NOPR. This was also used in the final rule.

Table 5.6.15 Summary of Changes to Infiltration Load Calculation in the NOPR and Final Rule

Equipment Class	NOPR Infiltrated Air Mass *(lbs/hr)*	NOPR Infiltration Load *(Btu/hr)*	ANOPR Infiltration Load *(Btu/hr)*
VOP.RC.M	860	16,066	16,050
VOP.RC.L	530	15,643	15,277
SVO.RC.M	590	11,022	10,982
HZO.RC.M	250	4,670	620
HZO.RC.L	140	4,132	1,428
VCT.RC.M	30	524	210
VCT.RC.L	30	865	887
SOC.RC.M	15	267	279
VOP.SC.M	300	5,605	4,224
SVO.SC.M	220	4,110	2,816
HZO.SC.M	100	1,868	620
HZO.SC.L	100	2,951	1,214
VCT.SC.I	15	491	391
VCS.SC.I	15	491	391
HCT.SC.I	3	98	78

5.7 COST-EFFICIENCY CURVES

The result of the engineering analysis is a set of cost-efficiency curves. DOE developed 15 curves representing the 15 directly analyzed equipment classes, using the baseline specifications and design options described above. (See Appendix B for details). The methodology for developing curves started with determining the baseline energy consumption and manufacturer production cost. Above the baseline, DOE implemented design options from lowest to highest payback, and only one design option was implemented at each design option level. Design options were implemented until all technologies were at a maximum level.

ARI created four industry-aggregated curves using an efficiency-level approach. ARI presented these curves to DOE in the form of daily energy consumption and manufacturer list price normalized by TDA. DOE applied the list price discount developed in the markup section (section 5.5) to the industry-supplied curves to arrive at a TDA-normalized MSP.

The 15 cost-efficiency curves are shown in Figure 5.7.1 through Figure 5.7.15 and in Table 5.7.2 through Table 5.7.16 in the form of TDA-normalized daily energy consumption and MSP. Figure 5.7.1 through Figure 5.7.4 and Table 5.7.2 through Table 5.7.5 include the corresponding industry-supplied data for comparison. Table 5.7.1 shows a list of the 15 analyzed equipment classes and their corresponding figure, table, and page numbers. Appendix B provides more detailed results, including the design options used at each design option level in the analytically derived (AD) curves.

Table 5.7.1   Figure, Table, and Page Numbers for Cost-Efficiency Results

Equipment Class	Figure	Table	Page Number
VCT.RC.L*	Figure 5.7.1	Table 5.7.2	5-40
VOP.RC.M*	Figure 5.7.2	Table 5.7.3	5-41
SVO.RC.M*	Figure 5.7.3	Table 5.7.4	5-42
HZO.RC.L*	Figure 5.7.4	Table 5.7.5	5-43
HZO.RC.M	Figure 5.7.5	Table 5.7.6	5-44
VCT.RC.M	Figure 5.7.6	Table 5.7.7	5-45
VOP.RC.L	Figure 5.7.7	Table 5.7.8	5-46
SOC.RC.M	Figure 5.7.8	Table 5.7.9	5-47
VOP.SC.M	Figure 5.7.9	Table 5.7.10	5-48
SVO.SC.M	Figure 5.7.10	Table 5.7.11	5-49
HZO.SC.L	Figure 5.7.11	Table 5.7.12	5-50
HZO.SC.M	Figure 5.7.12	Table 5.7.13	5-51
HCT.SC.I	Figure 5.7.13	Table 5.7.14	5-52
VCT.SC.I	Figure 5.7.14	Table 5.7.15	5-53
VCS.SC.I**	Figure 5.7.15	Table 5.7.16	5-54

* Shown with industry-supplied data.
** VCS equipment family is normalized by volume.

As stated above, DOE used the cost-efficiency curves from the engineering analysis as an input to the life-cycle cost (LCC) analysis to determine the price of commercial refrigeration equipment to the customer (Chapter 8). In the LCC analysis, DOE used industry-supplied curves for the equipment classes that had industry-supplied curves provided. For all other equipment classes, DOE used the AD curves in the LCC analysis.

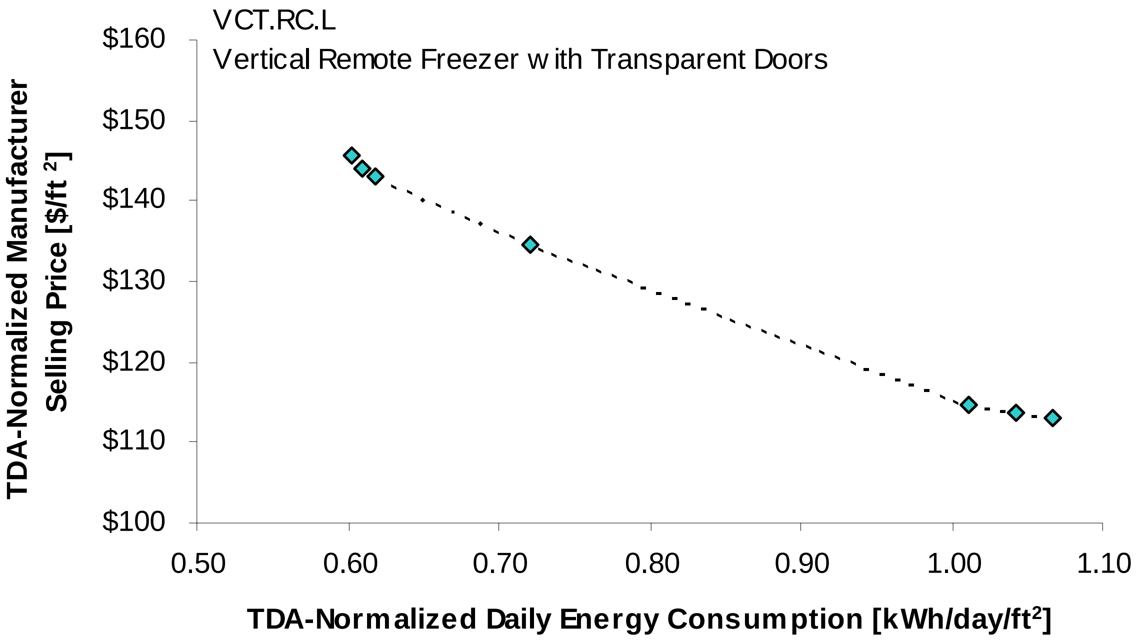

Figure 5.7.1 Cost-Efficiency Curve for the VCT.RC.L Equipment Class

Table 5.7.2 Cost-Efficiency Data for the VCT.RC.L Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	1.07	113.17
AD2	1.04	113.61
AD3	1.01	114.67
AD4	0.72	134.42
AD5	0.62	143.16
AD6	0.61	143.98
AD7	0.60	145.70

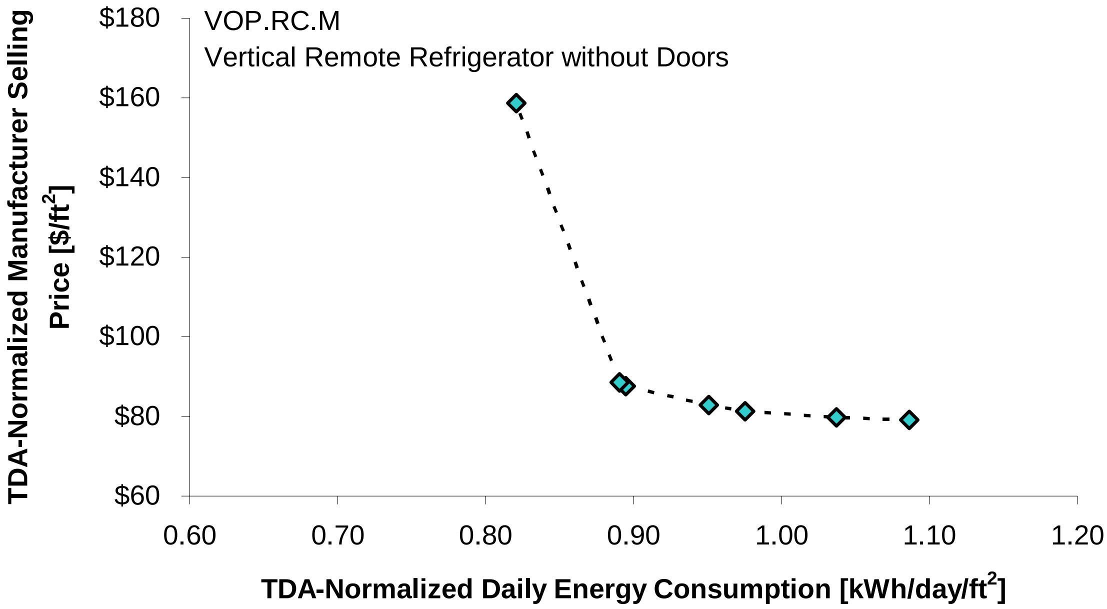

Figure 5.7.2 Cost-Efficiency Curve for the VOP.RC.M Equipment Class

Table 5.7.3 Cost-Efficiency Data for the VOP.RC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	1.09	79.12
AD2	1.04	79.76
AD3	0.98	81.30
AD4	0.95	82.90
AD5	0.89	87.59
AD6	0.89	88.58
AD7	0.82	158.71

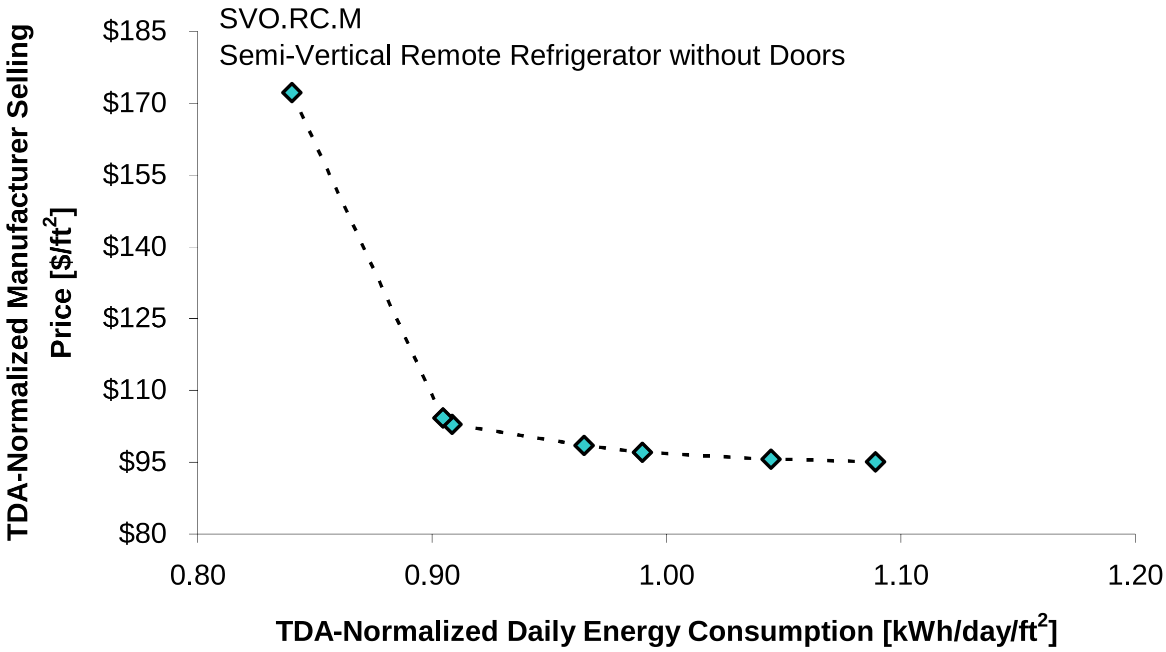

Figure 5.7.3 Cost-Efficiency Curves for the SVO.RC.M Equipment Class

Table 5.7.4 Cost-Efficiency Data for the SVO.RC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption *(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price *($/ft^2)***
AD1	1.09	95.10
AD2	1.04	95.67
AD3	0.99	97.04
AD4	0.96	98.56
AD5	0.91	102.91
AD6	0.90	104.24
AD7	0.84	172.27

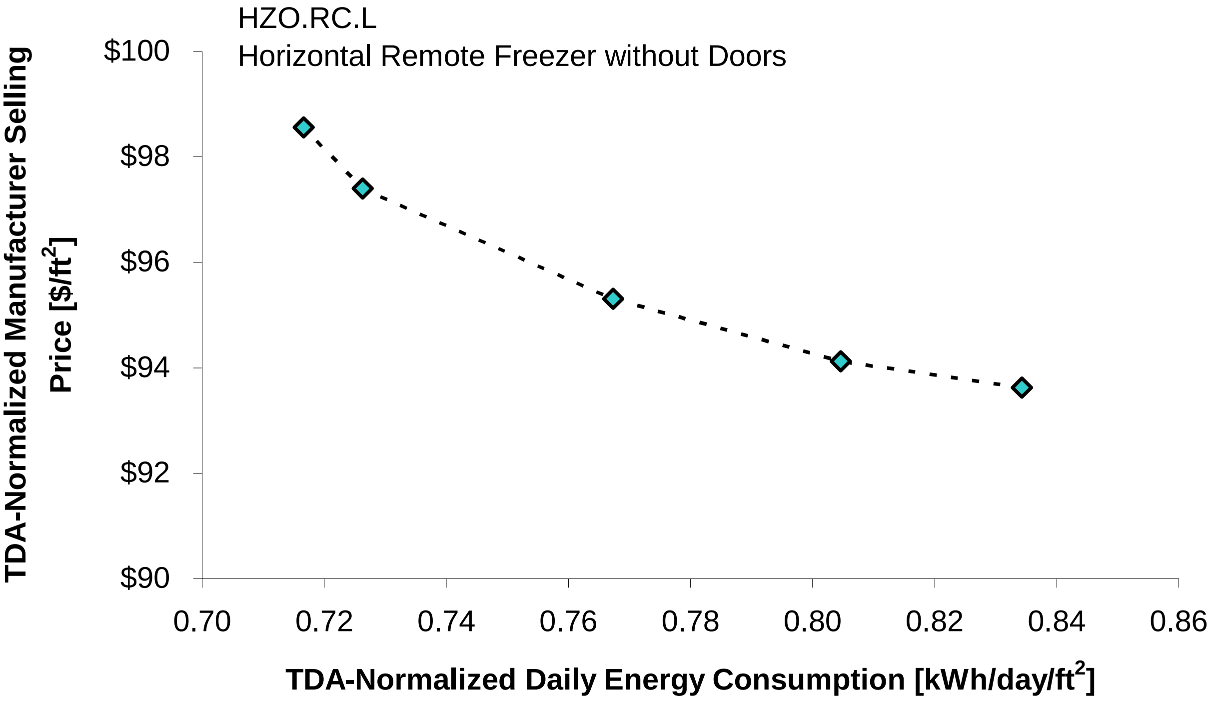

Figure 5.7.4 Cost-Efficiency Curves for the HZO.RC.L Equipment Class

Table 5.7.5 Cost-Efficiency Data for the HZO.RC.L Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption *(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price *($/ft^2)***
AD1	0.83	93.63
AD2	0.80	94.12
AD3	0.77	95.31
AD4	0.73	97.40
AD5	0.72	98.56

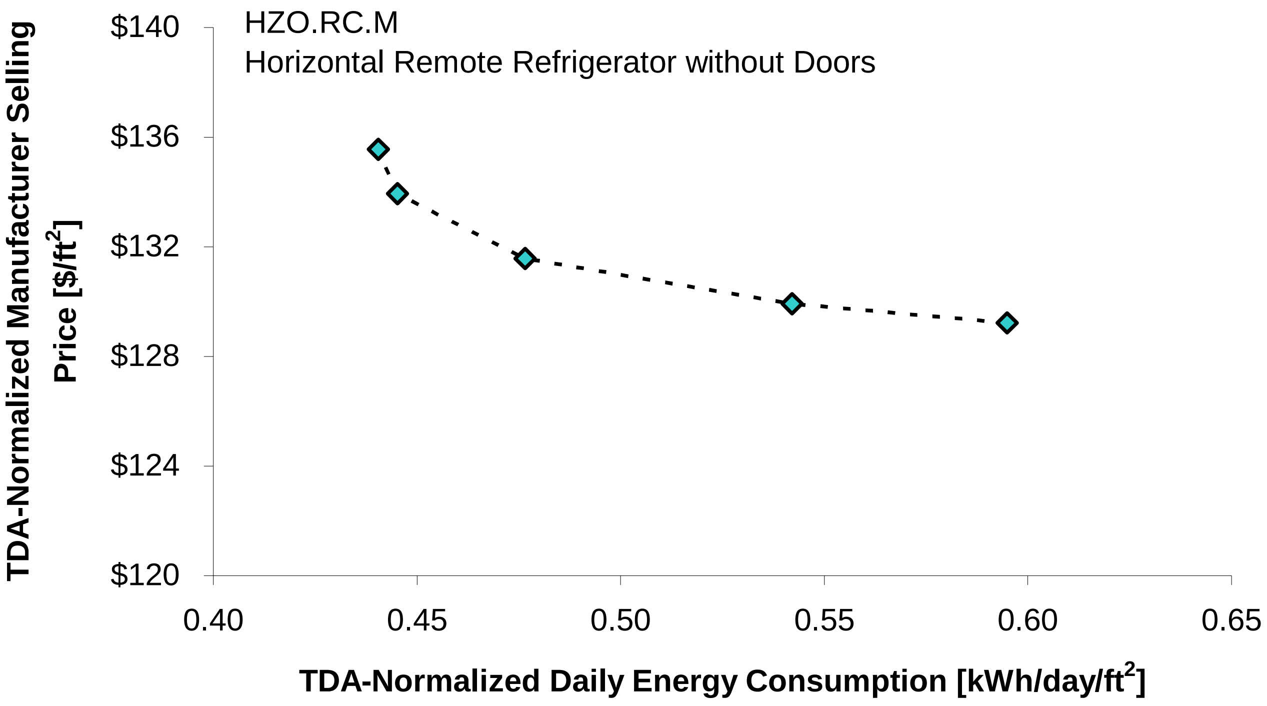

Figure 5.7.5 Cost-Efficiency Curve for the HZO.RC.M Equipment Class

Table 5.7.6 Cost-Efficiency Data for the HZO.RC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption *(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price *($/ft^2)***
AD1	0.59	129.23
AD2	0.54	129.92
AD3	0.48	131.58
AD4	0.45	133.95
AD5	0.44	135.56

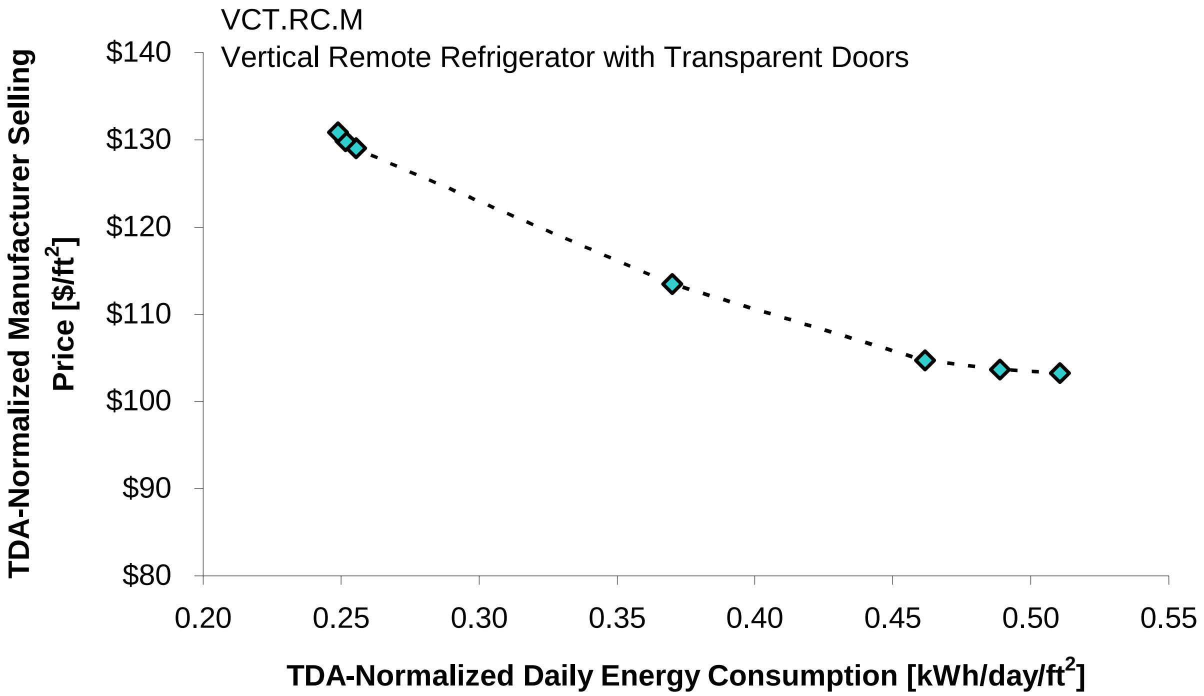

Figure 5.7.6 Cost-Efficiency Curve for the VCT.RC.M Equipment Class

Table 5.7.7 Cost-Efficiency Data for the VCT.RC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	0.51	103.23
AD2	0.49	103.67
AD3	0.46	104.72
AD4	0.37	113.47
AD5	0.26	129.02
AD6	0.25	129.84
AD7	0.25	130.86

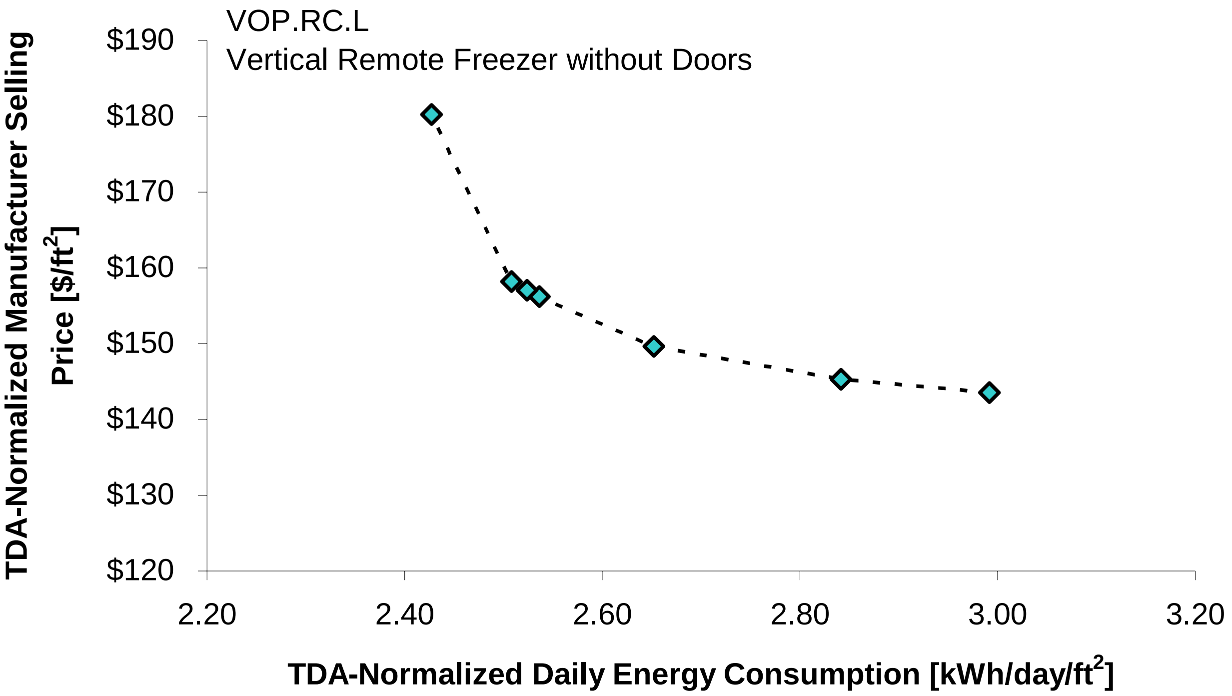

Figure 5.7.7 Cost-Efficiency Curve for the VOP.RC.L Equipment Class

Table 5.7.8 Cost-Efficiency Data for the VOP.RC.L Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption *(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price *($/ft^2)***
AD1	2.99	143.54
AD2	2.84	145.32
AD3	2.65	149.62
AD4	2.54	156.20
AD5	2.52	157.02
AD6	2.51	158.21
AD7	2.43	180.22

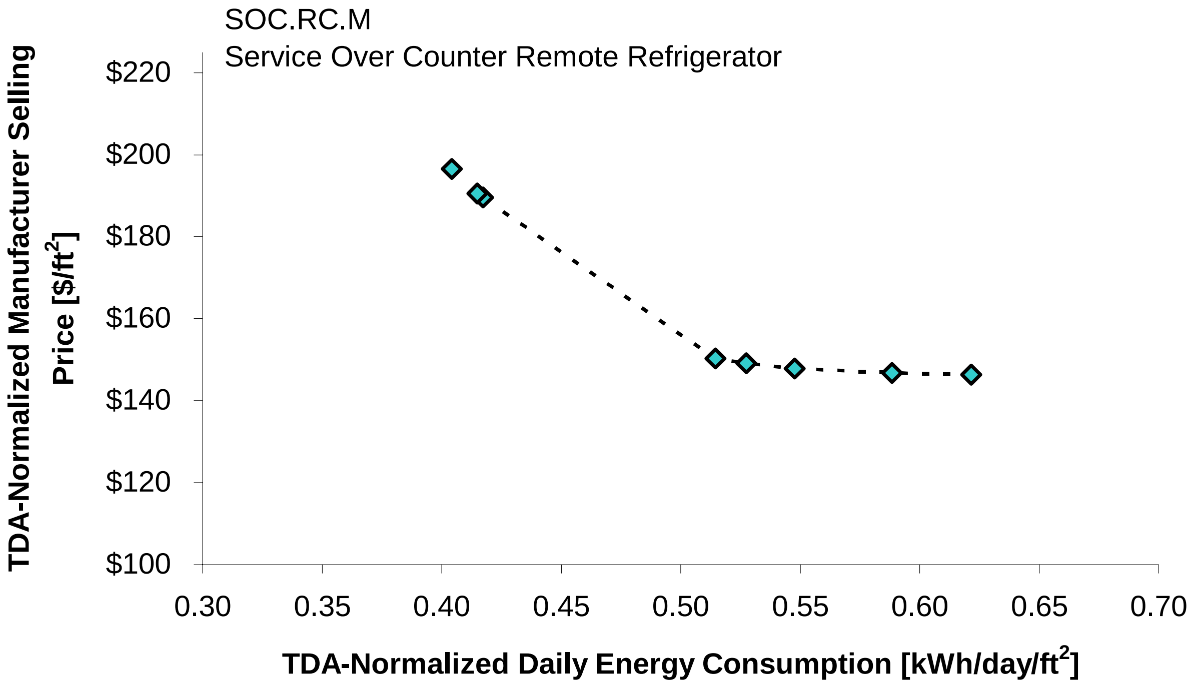

Figure 5.7.8 Cost-Efficiency Curve for the SOC.RC.M Equipment Class

Table 5.7.9 Cost-Efficiency Data for the SOC.RC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption *(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price *($/ft^2)***
AD1	0.62	146.36
AD2	0.59	146.81
AD3	0.55	147.88
AD4	0.53	149.08
AD5	0.51	150.33
AD6	0.42	189.53
AD7	0.41	190.57
AD8	0.40	196.55

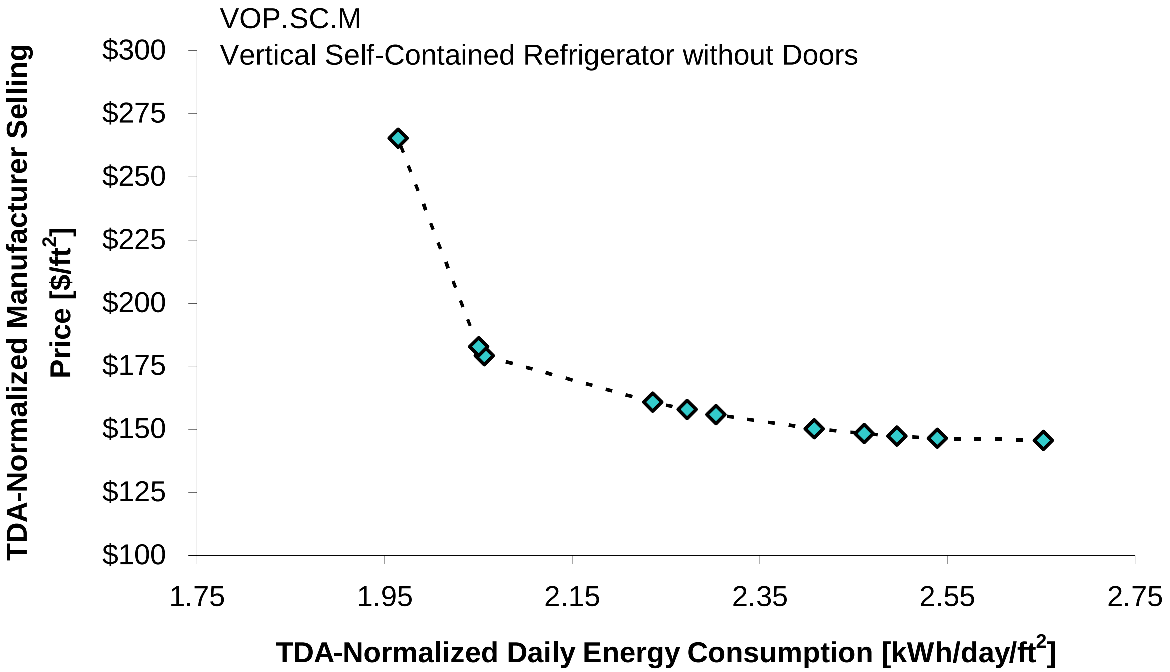

Figure 5.7.9 Cost-Efficiency Curve for the VOP.SC.M Equipment Class

Table 5.7.10 Cost-Efficiency Data for the VOP.SC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft²)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft²)***
AD1	2.65	145.66
AD2	2.54	146.49
AD3	2.50	147.25
AD4	2.46	148.39
AD5	2.41	150.23
AD6	2.30	155.87
AD7	2.27	157.96
AD8	2.24	160.71
AD9	2.06	179.11
AD10	2.05	182.67
AD11	1.96	265.29

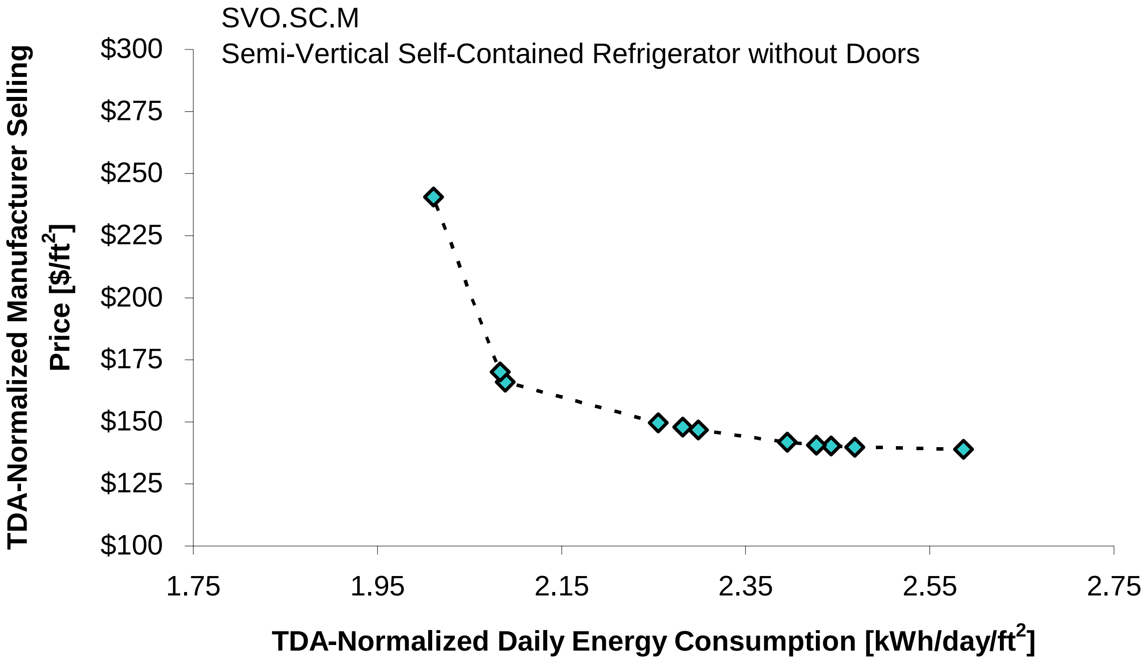

Figure 5.7.10 Cost-Efficiency Curve for the SVO.SC.M Equipment Class

Table 5.7.11 Cost-Efficiency Data for the SVO.SC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	2.59	138.92
AD2	2.47	139.82
AD3	2.44	140.27
AD4	2.43	140.71
AD5	2.40	141.78
AD6	2.30	146.81
AD7	2.28	147.88
AD8	2.26	149.57
AD9	2.09	165.98
AD10	2.08	170.13
AD11	2.01	240.51

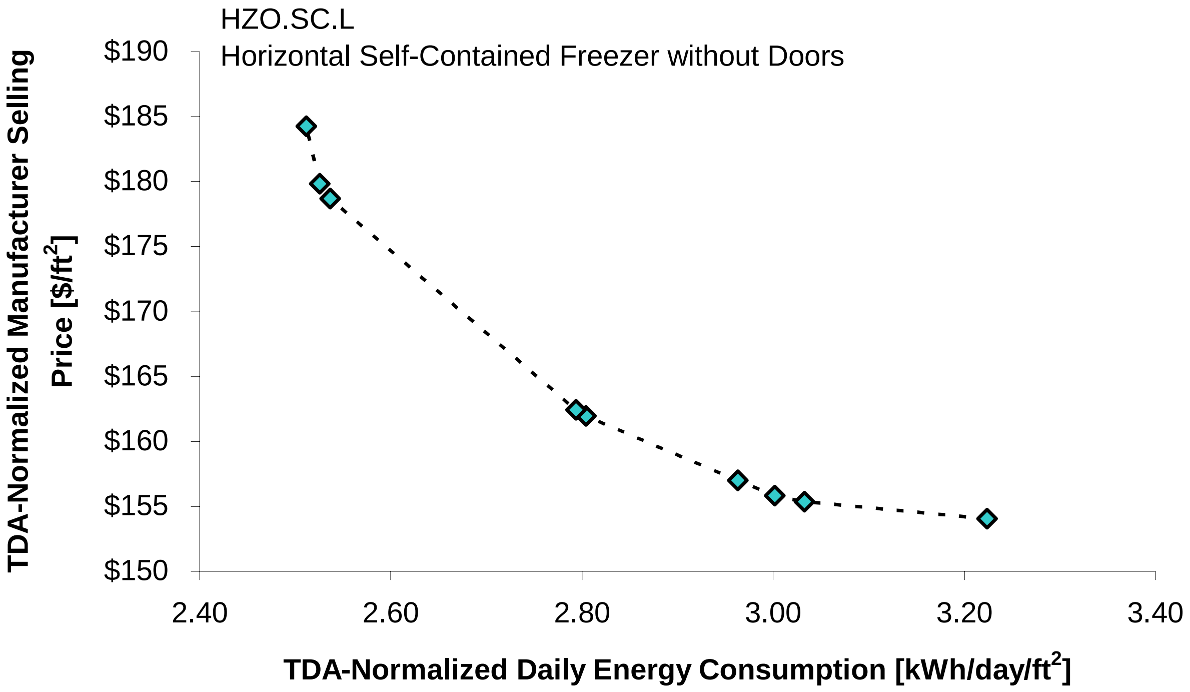

Figure 5.7.11 Cost-Efficiency Curve for the HZO.SC.L Equipment Class

Table 5.7.12 Cost-Efficiency Data for the HZO.SC.L Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	3.22	154.04
AD2	3.03	155.38
AD3	3.00	155.85
AD4	2.96	156.99
AD5	2.80	161.97
AD6	2.79	162.44
AD7	2.54	178.69
AD8	2.53	179.83
AD9	2.51	184.26

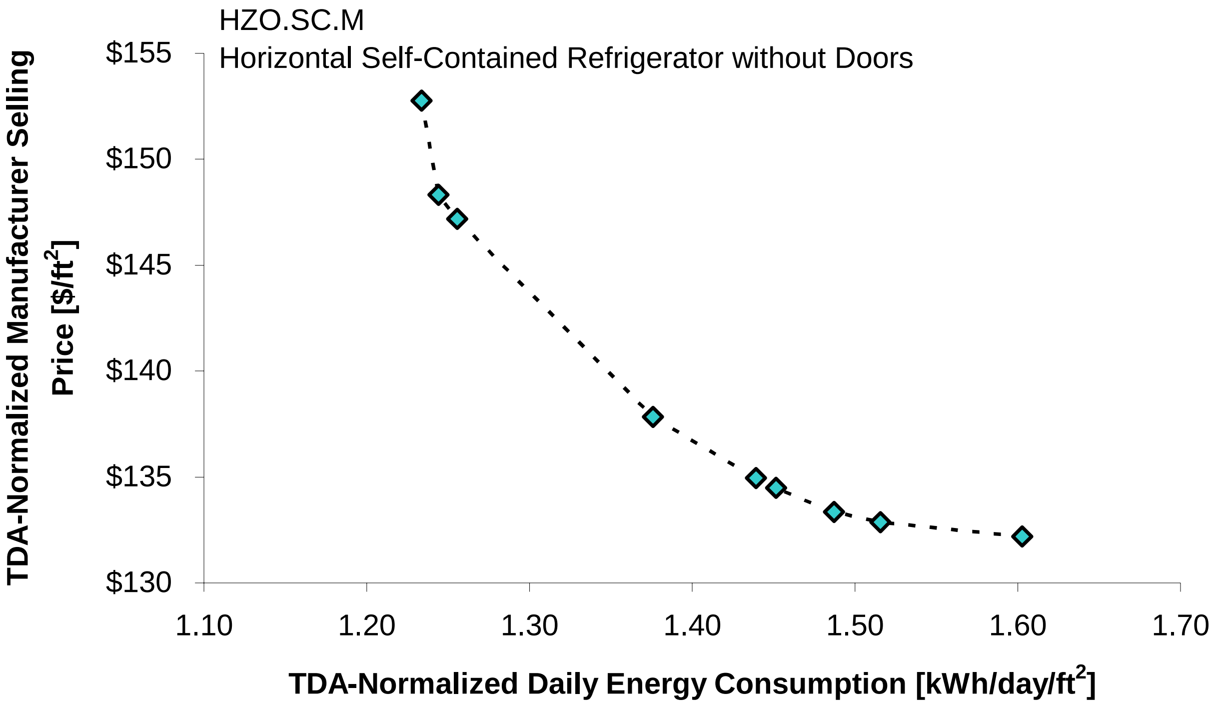

Figure 5.7.12 Cost-Efficiency Curve for the HZO.SC.M Equipment Class

Table 5.7.13 Cost-Efficiency Data for the HZO.SC.M Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption *(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price *($/ft^2)***
AD1	1.60	132.19
AD2	1.52	132.87
AD3	1.49	133.34
AD4	1.45	134.48
AD5	1.44	134.96
AD6	1.38	137.83
AD7	1.26	147.19
AD8	1.24	148.33
AD9	1.23	152.76

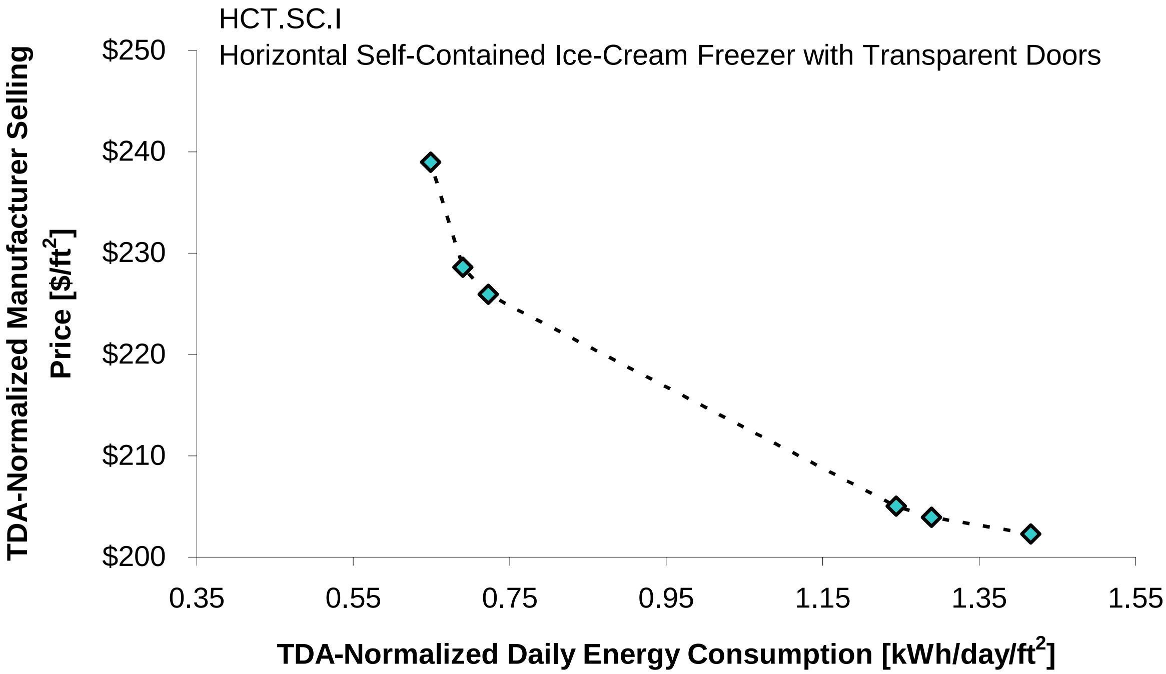

Figure 5.7.13 Cost-Efficiency Curve for the HCT.SC.I Equipment Class

Table 5.7.14 Cost-Efficiency Data for the HCT.SC.I Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	1.42	202.29
AD2	1.29	203.93
AD3	1.24	205.04
AD4	0.72	225.93
AD5	0.69	228.61
AD6	0.65	239.00

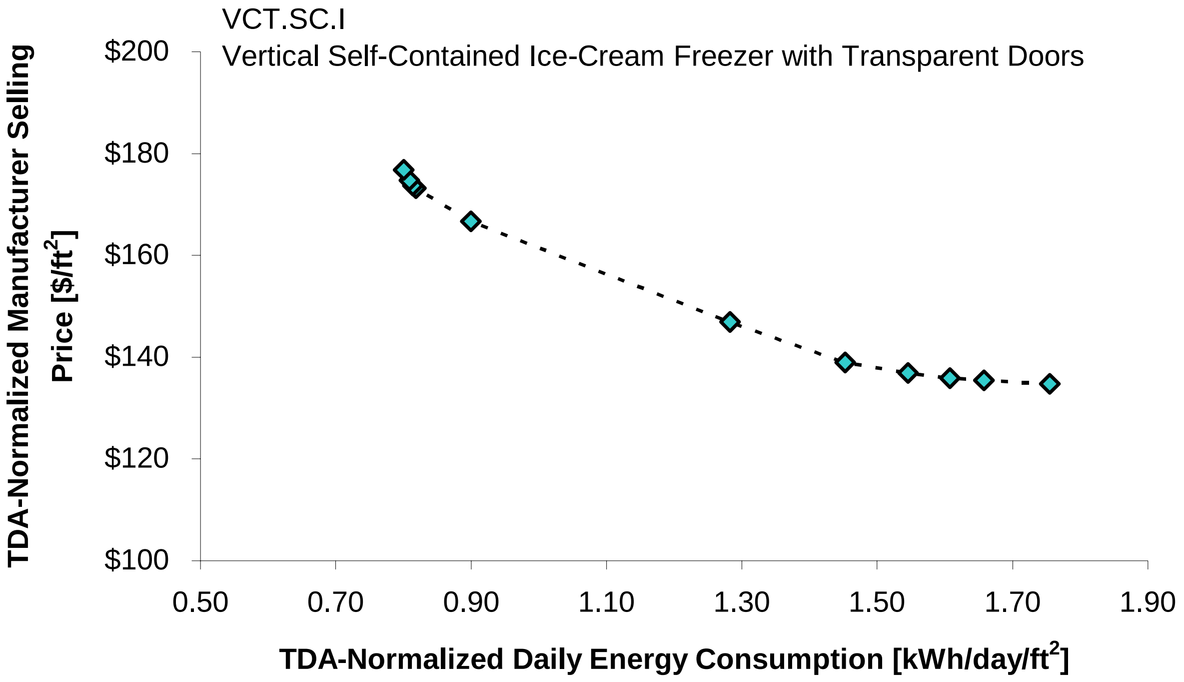

Figure 5.7.14 Cost-Efficiency Curve for the VCT.SC.I Equipment Class

Table 5.7.15 Cost-Efficiency Data for the VCT.SC.I Equipment Class

DOE Analytically Derived Data		
Design Option Level	**TDA-Normalized Daily Energy Consumption** ***(kWh/day/ft^2)***	**TDA-Normalized Manufacturer Selling Price** ***($/ft^2)***
AD1	1.76	134.76
AD2	1.66	135.45
AD3	1.61	135.88
AD4	1.55	136.94
AD5	1.45	138.95
AD6	1.28	146.92
AD7	0.90	166.68
AD8	0.82	173.24
AD9	0.81	173.67
AD10	0.81	174.73
AD11	0.80	176.77

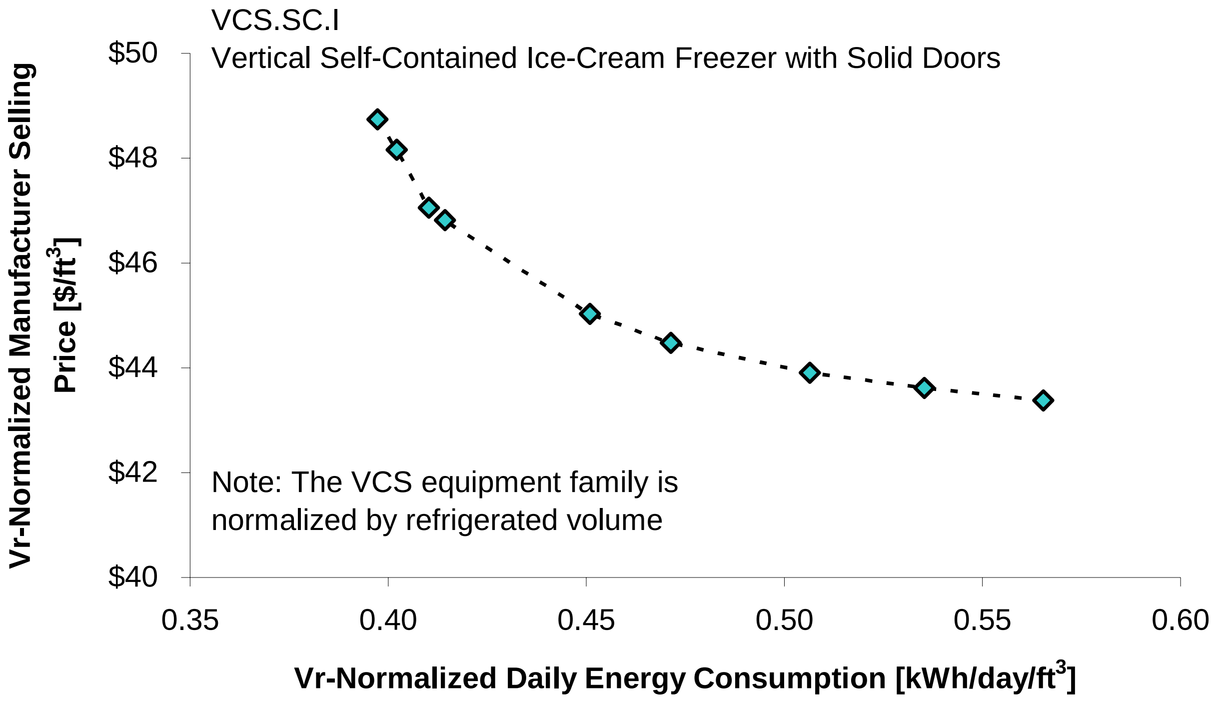

Figure 5.7.15 Cost-Efficiency Curve for the VCS.SC.I Equipment Class

Table 5.7.16 Cost-Efficiency Data for the VCS.SC.I Equipment Class

DOE Analytically Derived Data		
Design Option Level	**Vr-Normalized Daily Energy Consumption** ***(kWh/day/ft^3)***	**Vr-Normalized Manufacturer Selling Price** ***($/ft^3)***
AD1	0.57	43.38
AD2	0.54	43.61
AD3	0.51	43.91
AD4	0.47	44.48
AD5	0.45	45.03
AD6	0.41	46.82
AD7	0.41	47.06
AD8	0.40	48.17
AD9	0.40	48.74

5.8 OFFSET FACTORS

Equipment energy use (CDEC) scales with equipment size, but smaller equipment tends to use more energy per TDA (or per volume) than larger equipment in the same equipment class. This extra energy is attributed to components of case load that do not scale with equipment size. These load components therefore have a disproportionate effect on the energy consumption of small equipment. DOE developed offset factors to account for these load components, commonly referred to as “end effects,” as a way to adjust standards to allow more energy use for smaller equipment.

In the ANOPR public meeting, stakeholders raised concerns that standards developed for large sizes of equipment would be unfair when applied to smaller equipment in the same class, because of the end effects that disproportionately affect smaller equipment. In most equipment classes, larger equipment is more common, especially in those classes that are used in grocery stores (*i.e.,* remote condensing equipment). In its engineering analysis, DOE developed cost-efficiency curves for a single size within each equipment class. The representative TDA[c] selected for each class was toward the larger end of the equipment available within that class. DOE intended for standards to be based on this single point (the point defined by TDA and CDEC). In effect, DOE was proposing in the ANOPR to implement standards by requiring equipment to meet an energy consumption limit defined by a line drawn between the origin and the TDA-CDEC point determined by the engineering cost-efficiency curve. (See the left pane of Figure 5.8.1.) As the right pane of Figure 5.8.1 shows, the offset factor fixes the left end of the standard equation at a fixed offset on the CDEC axis, effectively providing a higher limit on energy consumption for smaller equipment.

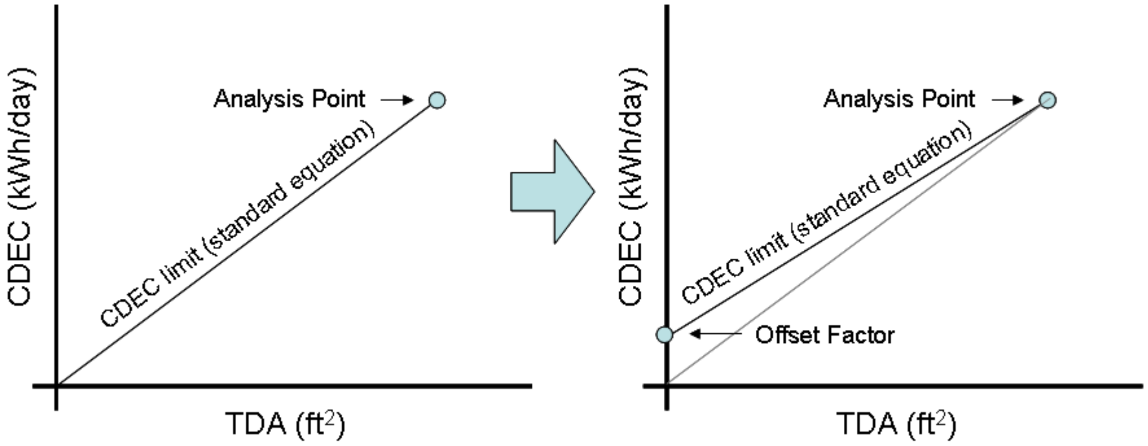

Figure 5.8.1 Illustration of Offset Factor

---

[c] TDA is used here to illustrate the concept of offset factors. However, this explanation also applies to equipment classes that use volume as a normalizing factor.

A standard equation, then, consists of two components: a size-dependent multiplier (slope) and a constant (offset factor). DOE calculated the slope of the standard equation as the difference between the CDEC at the analysis point corresponding to the selected standard level and the offset factor, divided by the TDA at the analysis point:

$$m = \frac{CDEC - b}{TDA} \qquad \textbf{Eq. 5.10}$$

where,

m is the slope of the standard equation, and
b is the offset factor.

The standard equation then takes the form:

$$CDEC_{MAX} = m \cdot TDA + b \qquad \textbf{Eq. 5.11}$$

where $CDEC_{MAX}$ is the maximum allowable energy consumption. This form of the standard equation also applies to equipment classes that use volume as a normalizing factor.

In determining offset factors, DOE considered different end effects for each equipment family. For all open cases (VOP, SVO, and HZO), DOE considered the effects of heat conduction through the case ends, as well as the infiltration load end effects. For vertical closed transparent cases (VCT), the conduction through the ends was taken into account, as well as the heat load and electrical load of one T8 lamp. DOE considered one T8 lamp because there is generally always one more lamp than the number of doors (*e.g.,* six lamps in a five-door case), meaning that in a theoretical case with no doors, there would still be one lamp. In the remaining equipment families (SOC, HCT, VCS), DOE only considered the conduction effects through the case ends.

To estimate the heat load due to conduction through the case ends for each equipment class, DOE used the same methodology that it used to find the conduction through case walls (Eq. 5.6). DOE substituted the area of the case ends for the wall area of the entire case to find only the heat load caused by conduction through the ends. For the open cases, DOE estimated the infiltration load end effects. DOE estimated the infiltration end effects of a VOP.RC.M case as 1,100 Btu/h per end,[10] and then scaled that value for the other open cases based on the air curtain length of each equipment class compared to the air curtain length of the VOP.RC.M case. DOE estimated the heat load due to a lamp as 198.08 Btu/h (section 5.6.7.3).

Once the appropriate heat loads were calculated, DOE summed the applicable heat loads for each class. DOE used the total heat load of each individual equipment class to calculate the daily energy use of the compressor for that class, using the method described in section 5.6.7.2. For all equipment classes except for those in the VCT equipment family, this became the offset factor. For VCT equipment, DOE also considered the amount of electrical energy consumed by lighting. DOE estimated the daily electrical load of lighting as 1.392 kWh/day for one lamp using the method explained in section 5.6.7.1. DOE then summed the energy use of the lamp and compressor for each VCT equipment class to get the total daily energy consumption of a zero-length case for each class. These figures became the offset factors for the various VCT equipment classes. Table 5.8.1 Offset Factors shows the offset factors for the 15 primary equipment classes.

Table 5.8.1 Offset Factors

Equipment Class	**Offset Factor *(kWh/day)***
VCT.RC.L	2.61
VOP.RC.M	4.07
SVO.RC.M	3.18
HZO.RC.L	6.88
HZO.RC.M	2.88
VCT.RC.M	1.95
VOP.RC.L	6.85
SOC.RC.M	0.11
VOP.SC.M	4.71
SVO.SC.M	4.59
HZO.SC.L	7.08
HZO.SC.M	5.55
HCT.SC.I	0.43
VCT.SC.I	3.29
VCS.SC.I	0.88

5.9 EXTENSION OF STANDARDS

DOE did not analyze all covered equipment classes, but focused its analysis on 15 high-shipment equipment classes (Table 5.2.2). DOE developed an extension approach to apply the standards developed for these 15 "primary" classes to the remaining 23 "secondary" classes. This approach involves extension multipliers developed with the 15 primary results and a set of focused matched-pair analyses. In addition, standards for certain primary equipment classes can be directly applied to other similar secondary equipment classes. This section explains each aspect of this approach.

In the final rule, trial standard levels are presented for each of the 15 primary equipment classes in the form of a standard equation. This standard equation consists of a size-dependent multiplier (slope) and an offset factor (section 5.8). The extension multipliers are applied to the slopes and offset factors of the primary standard equations (Figure 5.9.1). In this illustration, a standard is multiplied by an extension factor greater than one, for example in the case of extending a standard from a low-temperature class to an ice-cream-temperature class.

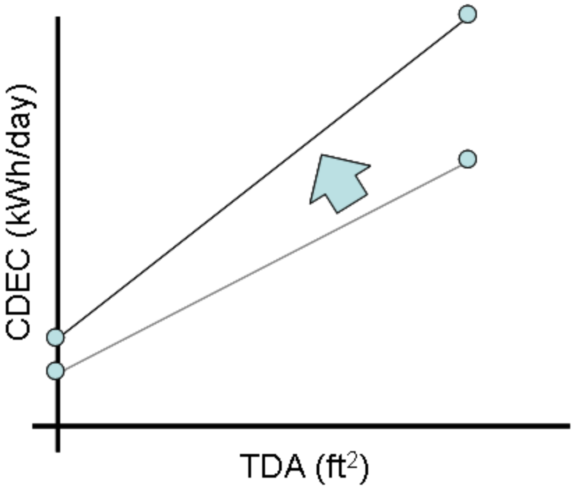

Figure 5.9.1 Illustration of Extension of Standard Level

5.9.1 Extension Multipliers

DOE examined extending standards using the 15 primary equipment classes developed in the engineering analysis. Using the TDA-normalized baseline CDEC values, several trends are apparent for certain sub-groups of equipment. DOE examined several related pairs of equipment classes to develop extension multipliers.

First, DOE examined the CDEC/TDA relationship between remote and self-contained medium-temperature equipment without doors (Table 5.9.1). There is reasonable agreement across equipment families among medium-temperature open equipment, with an average multiplier of 2.51 between remote and self-contained equipment. The differences between remote and self-contained equipment are similar for VOP, SVO, and HZO equipment. In addition to the inclusion of a self-contained condensing unit, which is less efficient than remote condensing systems, self-contained open equipment must have provisions for dealing with defrost meltwater. Because self-contained equipment is designed to be mobile, defrost meltwater must be collected in a drain pan and evaporated using electric-resistance heating. This feature adds considerable energy use to open self-contained equipment. The 2.51 multiplier is also applicable to low- and ice-cream-temperature equipment without doors. The differences in design are similar for low-temperature and ice-cream-temperature equipment, consisting of a self-contained condensing unit and the addition of a defrost meltwater evaporation system. Thus, the 2.51 multiplier is applicable to the following standard extensions:

- VOP.RC.L to VOP.SC.L
- SVO.RC.L to SVO.SC.L
- VOP.RC.I to VOP.SC.I
- SVO.RC.I to SVO.SC.I
- HZO.RC.I to HZO.SC.I

Table 5.9.1 Extension Multipliers for Remote and Self-Contained Equipment Without Doors

Relationship	CDEC/TDA Multiplier
VOP.RC.M to VOP.SC.M	2.431
SVO.RC.M to SVO.SC.M	2.376
HZO.RC.M to HZO.SC.M	2.712

DOE next examined the CDEC/TDA relationship between low-temperature and ice-cream-temperature remote equipment using a focused matched-pair analysis. The focused matched-pair analysis methodology was described in detail in the ANOPR TSD, and establishes a correlation between rating temperature levels and CDEC/TDA, using data collected from manufacturer specification sheets. DOE quantified the differences in energy consumption for matched pairs of equipment classes that are very similar in features and dimensions, but have different operating temperatures. Pairs of units at low- and ice-cream-temperatures were selected from several different manufacturers for comparison. DOE selected identical units from a given manufacturer designed to operate at multiple temperatures to isolate operating temperature as the only variable.

The matched-pair results show that VCT.RC.I units (at -15°F) have on average CDEC/TDA values that are 1.17 times higher than comparable VCT.RC.L units. The 1.17 multiplier is also applicable to other similar equipment types with doors. Differences in design consist of a lower operating temperature (resulting in a lower compressor EER) and higher defrost and anti-sweat heater power. Thus, the 1.17 multiplier is applicable to the following standard extensions:

- SOC.RC.L to SOC.RC.I
- HCT.RC.L to HCT.RC.I

The matched-pair results further show that HZO.RC.I units (at -15°F) have on average CDEC/TDA values that are 1.27 times higher than comparable HZO.RC.L units. The 1.27 multiplier is also applicable to other similar equipment types without doors. Differences in design consist of a lower operating temperature (resulting in a lower compressor EER) and higher defrost and anti-sweat heater power. Thus, the 1.27 multiplier is applicable to the following standard extensions:

- VOP.RC.L to VOP.RC.I
- SVO.RC.L to SVO.RC.I
- VOP.SC.L to VOP.SC.I
- SVO.SC.L to SVO.SC.I
- HZO.SC.L to HZO.SC.I

DOE next examined the CDEC/TDA relationship between remote and self-contained ice-cream-temperature equipment with transparent doors. To make this comparison, DOE used the matched-pair results to estimate the baseline CDEC/TDA values for VCT.RC.I equipment, and compared the results to VCT.SC.I equipment. The comparison showed that CDEC/TDA values for VCT.SC.I equipment are 1.40 times higher than VCT.RC.I equipment. DOE understands that this difference in energy use is due to the differences in efficiency of the self-contained condensing unit, as well as the addition of defrost meltwater evaporation systems. However, in contrast to open equipment, equipment with transparent doors is subject to a much lower infiltration load, and thus a lower melt water evaporation requirement. This leads to a lower multiplier than was seen for open equipment. The 1.40 multiplier can be applied to the following standard extensions:

- SOC.RC.I to SOC.SC.I
- HCT.RC.I to HCT.SC.I
- VCS.RC.I to VCS.SC.I
- HCS.RC.I to HCS.SC.I

Finally, DOE examined the relationship between medium- and low-temperature remote equipment with transparent doors. Both the VCT.RC.M and VCT.RC.L equipment classes were directly examined in the engineering analysis. Using the engineering results, the comparison showed that CDEC/TDA values for VCT.RC.L equipment are 2.10 times higher than VCT.RC.M equipment. This difference is due to the higher defrost heater power and anti-sweat heater power requirements in low-temperature equipment. The 2.10 multiplier can be applied to the standard extension from HCT.RC.M to HCT.RC.L.

Using these extension factors, DOE can extend standards to the 23 secondary equipment classes, as illustrated in Table 5.9.2. Baseline CDEC/TDA values for the 15 primary equipment classes are represented by the letters a through o (in bold for the 15 primary classes) for simplicity, multiplied or divided by the appropriate extension values. Note that the SVO.RC.L baseline CDEC/TDA value is identified as "a," which is the same as the baseline CDEC/TDA value for VOP.RC.L. The baseline CDEC/TDA values for VOP.RC.M (b) and SVO.RC.M (d) are equal, and additionally the CDEC/TDA levels above the baseline are very similar (see detailed cost-efficiency results in Appendix B). The similarities in these two medium-temperature equipment classes would extend to the respective low-temperature versions. Also note that the baseline CDEC/TDA value for the HCS.SC.I equipment class is identified as the letter "o," which is the same value for VCS.SC.I. The orientation has little effect on energy consumption for equipment with solid doors, and standards for all corresponding equipment classes within the VCS and HCS families should be equivalent.

Table 5.9.2 Extension Multipliers by Equipment Class

		RC			SC		
		I	L	M	I	L	M
Open	**VOP**	1.27a	**a**	**b**	1.27(2.51c)	2.51c	**c**
	SVO	1.27a	a	**d**	1.27(2.51e)	2.51e	**e**
	HZO	1.27f	**f**	**g**	1.27h	**h**	**i**
Closed	**SOC**	1.17(2.10j)	2.10j	**j**	1.40(1.17(2.10j))		▨
	VCT	1.17k	**k**	**l**	**m**		▨
	HCT	n/1.40	(n/1.40)/1.17	((n/1.40)/1.17)/2.10	**n**		▨
	VCS	o/1.40	(o/1.40)/1.17	((o/1.40)/1.17)/2.10	**O**		▨
	HCS	o/1.40	(o/1.40)/1.17	((o/1.40)/1.17)/2.10	o		▨

5.10 SENSITIVITY ANALYSES

DOE conducted two sensitivity analyses. The first examined the sensitivity of the cost-efficiency curves to material prices. The second examined the sensitivity of standards to alternative refrigerants.

5.10.1 Material Price Sensitivity

DOE conducted a sensitivity analysis on material prices to examine the effect of spikes in commodity prices that the industry has experienced over the past few years. The analysis compares the 5-year average prices for 2002-2006 (described in section 5.4.3) with the 5-year high price for the same period (2006 is the year with the highest material prices during that 5-year period). The results of this sensitivity analysis are presented in Figure 5.10.1 for the VOP.RC.M equipment class, which has the highest shipment volume of all analyzed equipment classes. Shown for comparison is the industry-supplied data for the VOP.RC.M equipment class.

In addition to adding about 15 percent to the overall cost of the equipment, the large increase in copper prices dramatically raises the cost of the evaporator coil (roughly 50 percent for both the baseline and enhanced evaporator coil). This increase in coil cost reduces the cost-effectiveness of this design option, which can be seen as a change in the slope of the cost-efficiency curve between the third and fourth design option levels above the baseline. For this equipment class, the 5-year average prices produce an analytically derived curve that more closely matches the industry-supplied curve. Based on the assumption that the overall case cost would increase by roughly 15 percent for other equipment classes, the 5-year average prices would also provide a closer match than the 5-year high prices for the other industry-supplied curves (Figure 5.7.1, Figure 5.7.3, and Figure 5.7.4).

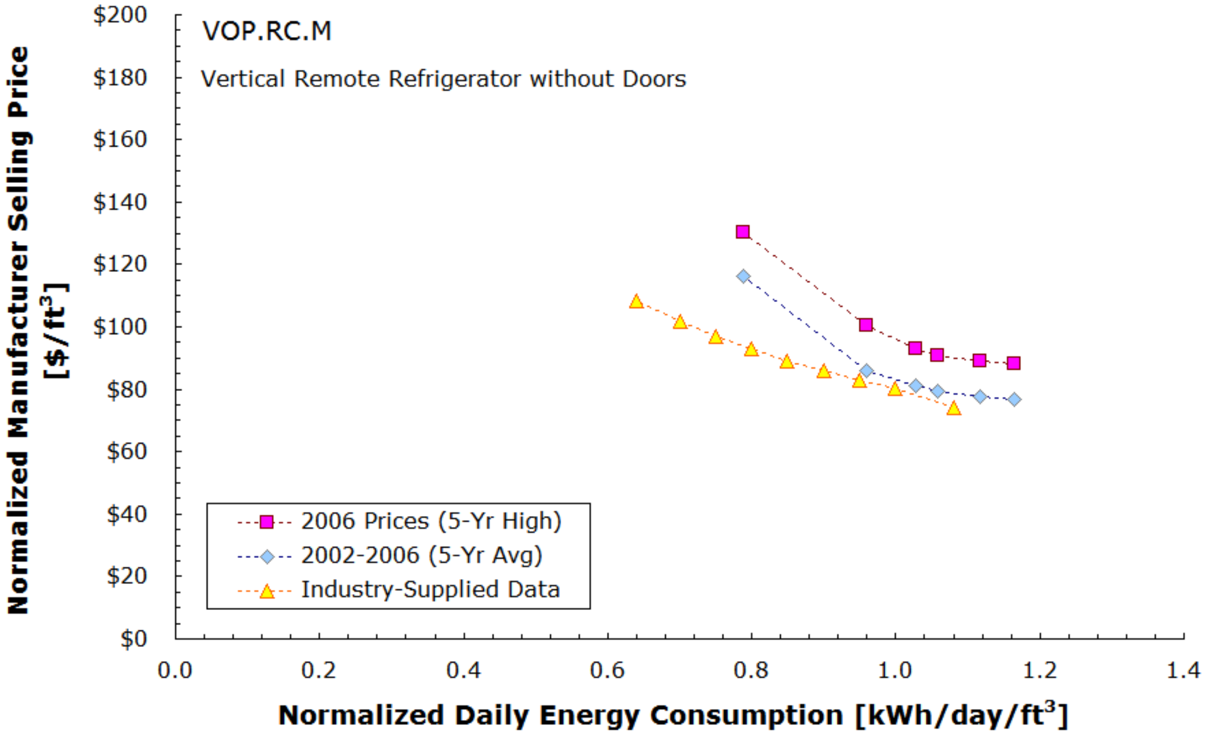

Figure 5.10.1 Material Price Sensitivity for the VOP.RC.M Equipment Class

5.10.2 Alternative Refrigerants

In conducting an engineering analysis, DOE must consider the effects of regulatory changes outside DOE's statutory energy conservation standards rulemaking process that can affect the manufacturers of the covered equipment. Some of these changes can also affect the energy efficiency or energy consumption of the covered equipment. DOE identified such external engineering issues that could affect the engineering analysis. These issues are closely related to the cumulative regulatory burden assessment that DOE carried out as part of the manufacturer impact analysis.

Due to the phase-out of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), the commercial refrigeration industry must transition to non-ozone-depleting refrigerants. As a result, the refrigeration industry is transitioning to hydrofluorocarbon-based (HFC-based) refrigerants in its equipment. For the commercial refrigeration equipment covered in this rulemaking, much of the industry has already been using HFC-based refrigerants for both remote condensing and self-contained equipment. Therefore, DOE considered the effects of HFC-based refrigerants from the outset by using HFC refrigerants in its analyses. For remote condensing equipment, the compressor efficiency values used in its analysis are based on ARI 1200, which uses an HFC-based compressor rack with R-404a refrigerant. Likewise for self-contained equipment, DOE's analysis uses R-134a and R-404a, both HFC-based refrigerants.

5.11 RESULTS

DOE presents more detailed results and supporting data for the engineering analysis in Appendix B of this TSD.

REFERENCES

[1] American Metals Market. 2007. (Last accessed July 11, 2007.) http://www.amm.com/ The July 11, 2007, material from this website is available in Docket # EE-2006-STD-0126. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[2] U.S. Department of Labor, Bureau of Labor Statistics. *Producer Price Indices*. 2007. (Last accessed June 28, 2007.) http://www.bls.gov/ppi/ The June 28, 2007, material from this website is available in Docket #EE-2006-STD-0126. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[3] U.S. Department of Commerce, Bureau Economic Analysis, *Gross Domestic Product Implicit Price Deflator*. 2007. (Last accessed June 28, 2007.) <https://bea.gov/bea/dn/nipaweb/TableView.asp#Mid> The June 28, 2007 material from this website is available in Docket #EE-2006-STD-0126. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[4] David H. Walker, Ramin T. Farmarzi, Van D. Baxter, *Investigation of Energy-Efficient Supermarket Display Cases*. 2004. Oak Ridge National Laboratory: Oak Ridge, TN. Report No. TM-292-2004.

[5] Lawrence Berkley National Laboratory. *Window 5.0*. 2007. (Last accessed June 26, 2007.) http://windows.lbl.gov/software/window/window.html The June 26, 2007 material from this website is available in Docket #EE-2006-STD-0126. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

[6] Refrigeration and Thermal Test Center. *Personal communication*. Southern California Edison. March 29, 2007.

[7] ANSI/ASHRAE. *Standard 72-2005*: *Method of Testing Commercial Refrigerators and Freezers*. 2005.

[8] Electric Power Research Institute. *Supermarket Simulation Tool v3.0*. 2007.

[9] R. Faramarzi. Efficient Display Case Refrigeration. In *ASHRAE Journal*. November 1999.

[10] P. D'Agaro, G. Cortella, G. Croce, *Two- and Three-Dimensional CFD Applied to Vertical Display Cabinet Simulation*, Int. J Refrigeration, Vol. 29, 2, pp. 178-190, 2005.