CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter details the market and technology assessments that the U.S. Department of Energy (DOE) has carried out in support of the energy conservation standards rulemaking for walk-in coolers and freezers (WICF or walk-ins). Prior to 2007, walk-in coolers and freezers had never before been the subject of energy conservation regulations at the federal level.

This chapter consists of two sections: the market assessment and the technology assessment. The goal of the market assessment is to develop a qualitative and quantitative characterization of the WICF industry and market structure, based on publicly available information as well as data and information submitted by manufacturers and other stakeholders. Issues that are addressed include manufacturer characteristics and market shares, existing regulatory and non-regulatory efficiency improvement initiatives, equipment classes, and trends in equipment markets and characteristics. The goal of the technology assessment is to develop a preliminary list of technologies that could be used to improve the efficiency of walk-in coolers and freezers.

As discussed in Chapter 2 of the preliminary Technical Support Document (TSD), DOE is considering setting standards separately for the two overall components of a walk-in: the envelope and the refrigeration system. DOE's market research found that the majority of small manufacturers in the WICF industry manufacture either envelope or refrigeration, but not both. On the other hand, DOE found that large manufacturers or parent companies tend to manufacture both envelope and refrigeration. Accordingly, DOE conducted the MTA by examining manufacturers of envelope only, refrigeration only, and both envelope and refrigeration.

3.2 MARKET ASSESSMENT

The following market assessment identifies domestic manufacturers of walk-in equipment, manufacturer market share, the manufacturer trade association, regulatory programs, and non-regulatory initiatives; defines equipment classes; provides historical shipment data and equipment lifetime estimates; and summarizes market performance data.

3.2.1 Manufacturers and Market Share

DOE identified 47 manufacturers of walk-in envelopes (listed in Table 3.2.1), 8 manufacturers of walk-in refrigeration systems (listed in Table 3.2.2), and 9 manufacturers of both envelopes and refrigeration (listed in Table 3.2.3). Parent companies are shown in parentheses.

Table 3.2.1 Manufacturers of Walk-in Equipment (Envelope Only)

*Advanced Refrigeration Technology	*Dade Engineering Corporation a.k.a. Daeco	*Refrigeration Gaskets of Texas, Inc.
*Aircooler Corporation	*Duracold Refrigeration Manufacturing Company	*Refrigerator Manufacturers, Inc.
*American Cold Storage, Inc	*General Restaurant Equipment Co, Inc.	*Rudy's Commercial Refrigeration
*American Cooler Technologies	Hussmann Corporation (Ingersoll-Rand)	*Snowman Cooler LLC
*American Insulated Panel Co.	*Imperial Manufacturing	*Southeast Cooler Corporation
*Amerikooler, Inc	*Kool Star (Standex International Corporation)	*Storflex Fixture Corporation
*Arctic Industries, Inc	Kysor Panel Systems (Manitowoc)	*Superior Commercial Coolers, Inc
*Artic Temp Inc	Leer Limited Partnership (Dexter Apache Holdings, Inc.)	*T.M.P. Company, Inc. (Tafco)
*Bush Refrigeration	*Louisville Cooler Manufacturing Company	*T.O. DeVilbiss Manufacturing Co.
Carroll Coolers Inc. (Dexter Apache Holdings, Inc.)	*Mr. Winter/Isopanel	ThermalRite (Rainey Road LLC)
*Chrysler & Koppin Company	*National Cooler (Dover Corporation)	*Thermo-Kool/Mid-South Ind, Inc
*Clark Manufacturing (Southern Stainless Equipment Co.)	*North Star Refrigerator Co., Inc	*U.S. Cooler Company, Inc. (Craig Industries)
*Commercial Cooling (PAR Engineering, Inc.)	*Pacific Refrigerator Company	*W.A. Brown & Son, Inc.
*Cool Solutions Panel Manufacturing LLC.	*Penn Refrigeration Service Co.	*Worldwide Refrigeration
*Crown Tonka Walk-ins (Rainey Road LLC)	*Polar King International, Inc.	*Yenlin Li Refrigeration Company
*Custom Cooler, Inc.	*Polar Panels Mfg. LLC	

*Small business manufacturer

Table 3.2.2 Manufacturers of Walk-in Equipment (Refrigeration Only)

*Century Refrigeration (RAE Corporation)	Krack (Ingersoll Rand)	Tecumseh Products Company
Heat Transfer Products Group a.k.a. Russell (United Technologies Corporation)	*LRC Coil Company a.k.a. S&S Refrigeration Corp	Trenton Refrigeration Products (National Refrigeration and Air Conditioning Products Inc.)
Heatcraft Refrigeration Products, LLC (Lennox International)	*Peerless of America, Inc.	

*Small business manufacturer

Table 3.2.3 Manufacturers of both Envelope and Refrigeration

*Advance Energy Technologies, Inc.	*Bally Refrigerated Boxes, Inc	Kolpak (Manitowoc)
*Airdyne Refrigeration (ARI Industries)	Harford Duracool, LLC (Manitowoc)	Master-Bilt Products (Standex International Corporation)
*American Panel Corporation	*International Cold Storage (Rainey Road LLC)	Nor-Lake, Inc. (Standex International Corporation)

*Small business manufacturer

As illustrated in these tables, the walk-in market is characterized by a large number of small companies and a small number of large companies. In general, the large companies tend to be part of public corporations while the small companies tend toward private ownership. For small companies, DOE gathered company information including revenues from Hoovers. DOE also analyzed financial information for all publicly traded manufacturers of walk-ins by examining SEC 10-k reports. The total walk-in market, including envelope and/or refrigeration equipment, is valued at roughly $800 million to $1 billion in annual revenue. No single company controls the market, although the several large companies together represent roughly half of the annual revenue. This diversity reflects the wide range of end-users that make up the customer base: larger manufacturers tend to serve chain and brand name stores in the grocery, supermarket, and convenience store markets while smaller manufacturers may be preferred by regional non-chain convenience and grocery stores.

DOE estimated that the envelope-only manufacturers have combined total revenues of approximately $367 million. DOE is aware that there may be additional small envelope-only manufacturers not listed in any of the tables above or in publicly available documents or websites.

Though DOE identified several companies that only manufacture refrigeration equipment, the market is dominated by a few large players. United Technologies Corporate (UTC), Lennox International Inc (LII), and Tecumseh make up a majority of sales in the market through their subsidiary brands. Those brands include Russell, Heatcraft, and Tecumseh Cool Products, respectively. Public data for both Lennox International Inc and Tecumseh provided revenue for commercial refrigeration, and public data for United Technologies Corporate provided revenue for cooling equipment in general, including air conditioning. Thus, DOE was unable to determine the exact percentage of WICF market share attributed to each company because the revenue data does not explicitly break out revenue from WICF refrigeration sales.

Likewise, of the manufacturers that manufacture both refrigeration and envelopes, the market was dominated by the large companies: Ingersoll-Rand (subsidiary brands are Hussman and Krack), Standex International Corporation (subsidiary brands are Master-Bilt and Nor-Lake), and Manitowoc (subsidiary brands are Harford Duracool, Kysor Panel, and Kolpak). These large companies tended to break out food service equipment in their public revenues reports, but similarly to refrigeration equipment, this could include types of equipment other than walk-ins, such as commercial refrigerated display cases, reach-ins, and refrigerated beverage vending machines. Walk-in specific revenues were embedded in these data within the public revenue reports, but were not broken out specifically.

3.2.2 Small Businesses

DOE is considering the possibility that small businesses would be particularly impacted by the promulgation of energy conservation standards for walk-ins. The Small Business Administration (SBA) lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). The size standard for an industry is the largest that a for-profit concern can be in that industry and still qualify as a small business for Federal Government programs. These size standards are generally expressed in terms of the average annual receipts or the average employment of a firm. DOE matched walk-in coolers and freezers to NAICS code 333415, Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing, which has a size standard of 750 employees. DOE realizes that this code may be appropriate only for manufacturers of walk-in refrigeration systems and may not apply to manufacturers of walk-in envelopes. DOE also realizes that a different metric than size (for instance, annual receipts) may be more appropriate for characterizing small manufacturers of walk-in equipment. DOE will consult with the SBA in the next stage of the rulemaking to determine the best way to characterize small manufacturers in the walk-in industry.

Manufacturers classified as small businesses according to the NAICS code assumed for the industry are indicated in Table 3.2.1 through Table 3.2.3 with a *.

DOE will study the potential impacts on these small businesses in detail during the manufacturer impact analysis, which will be conducted as a part of the notice of proposed rulemaking analysis.

3.2.3 Trade Associations

There is no single unifying trade organization representing manufacturers of WICF. Rather, the industry is segmented by equipment type and end use. Several refrigeration system manufacturers are represented by a single association. Also, some walk-in manufacturers belong to a trade association that represents manufacturers of foodservice equipment. No association represents manufacturers of envelopes specifically, although several organizations represent manufacturers of different types of foam used in WICF envelopes.

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is one of the trade associations representing walk-in cooler and freezer manufacturers.[i] AHRI primarily represents refrigeration manufacturers, although some of these companies also make the envelopes used in WICF. Manufacturers of walk-ins and walk-in components with membership in AHRI include:

- Carrier Corporation
- Emerson Climate Technologies
- Heatcraft Refrigeration Products, LLC
- Heat Transfer Product Group (also known as Russell)
- Hill PHOENIX
- Honeywell International, Inc.
- Hussmann Corporation
- Kysor/Warren
- Master-Bilt Products

As an organization, AHRI is subdivided into divisions that represent various parts of the refrigeration market. One of these is the Commercial Refrigerator Manufacturers Division (CRMD). Originally founded in 1933 as a separate trade association, CRMD was established within AHRI with the purpose of developing and implementing a certification program for commercial refrigerators, commercial freezers, and commercial refrigerator-freezers. Technical activities of CRMD include:

- Harmonization of international equipment standards;
- Development of industry performance standards for commercial refrigeration equipment;
- Updating of industry guidelines for retail store fixture installation, design, energy conservation, electronic case controls, and specifications for equipment installation;
- Maintaining liaison with refrigerant suppliers and government agencies on environmentally acceptable chlorofluorocarbon (CFC) alternatives; and
- Providing input to government agencies concerning regulations affecting the industry.

The North American Association of Food Equipment Manufacturers (NAFEM) represents manufacturers of foodservice equipment. Several WICF manufacturers who sell equipment to the foodservice industry belong to NAFEM, including:

- American Panel Corporation
- Arctic Industries, Inc.
- Bally Refrigerated Boxes, Inc.
- Hussmann Corporation
- Imperial Manufacturing
- International Cold Storage
- Kolpak Walk-ins
- Kool Star
- Leer, Inc.
- Master-Bilt Products
- Nor-Lake, Inc.
- Penn Refrigeration Service Corporation
- Polar King International, Inc.
- Tafco – TMP Company
- ThermalRite
- Thermo-Kool/Mid-South Industries Inc.
- U.S. Cooler Company

The envelope segment of the walk-in industry has no single organization serving in an umbrella role. Reflecting the diversity of products available, several trade associations represent manufacturers of specific foam types within the WICF industry.

- Polyurethane Manufacturers Association (PMA, www.pmahome.org) comprised of numerous suppliers, distributors and contractors of polyurethane foam insulation.
- Extruded Polystyrene Foam Association (XPSA, www.xpsa.com) comprised of Dow Chemical, Owens Corning, and Pactiv, the main manufacturers of extruded polystyrene foam insulation.
- Spray Polyurethane Foam Alliance (SPFA, www.sprayfoam.org) comprised of contractors, chemical manufacturers, and distributors of spray polyurethane foam insulation. Chemical manufacturers include: BASF Polyurethane Foam Enterprises LLC, Gaco Western, Honeywell, Huntsman Polyurethanes.

- Polyisocyanurate Insulation Manufacturers Association (PIMA, www.polyiso.org) comprised of manufacturers, suppliers, and brand relabelers associated with the polyisocyanurate foam insulation industry. Arkema, Inc. is a member.

3.2.4 Industry Consolidation

The consolidation of major manufacturers through mergers and acquisitions is an industry trend. In some cases consolidation serves to expand vertical reach, such as the acquisition of an envelope manufacturer by a refrigeration manufacturer, while in other cases consolidation creates companies with a more dominant market share in a similar manufacturing process. For example:

- In 1995, commercial refrigeration manufacturer Manitowoc acquired walk-in manufacturer Kolpak.
- In 2000, Hill PHOENIX (Dover Corporation) acquired National Cooler Corporation, a manufacturer of walk-in coolers and freezers.
- In 2000, refrigeration and envelope manufacturer Hussmann was acquired by Ingersoll Rand.
- In 2003, Standex International Corporation acquired Nor-Lake, which manufacturers walk-in envelopes. In 2005, the company acquired Kool Star, a refrigeration manufacturer for walk-in end uses. Standex International also owns Master-Bilt, a major refrigeration and envelope manufacturer.
- In 2008, Manitowoc went on to buy Enodis, PLC in 2008. Enodis owned another envelope manufacturer, Kysor Panel Systems.
- In 2009, Rainey Road, LLC, owner of CrownTonka Walk-ins and ThermalRite, purchased another envelope manufacturer, International Cold Storage, from Carrier Commercial Refrigeration, Inc, (Carrier Corporation).

3.2.5 Equipment Classes

3.2.5.1 Refrigeration

Refrigeration systems of walk-in coolers and freezers can be divided into various equipment classes categorized by key physical characteristics that affect the efficiency of the equipment: the operating temperature, the location of the walk-in (i.e., indoors or outdoors) and the type of condensing unit (i.e., whether the system has a dedicated condensing unit or is connected to a multiplex system).

The condensing unit type has a significant impact on utility and energy use. DOE is considering two classes of equipment associated with the condensing unit type: dedicated condensing (DC) systems and multiplex condensing (MC) systems. In a dedicated condensing system, there is only one condensing unit (consisting of one or more compressors and condensers) that serves a single walk-in. In a multiplex condensing system, the unit cooler inside the walk-in envelope is connected via a refrigerant line to a system consisting of several condensers and compressors in parallel; the set of condensers and compressors serves both the walk-in and other equipment, which may include other walk-ins or other types of refrigeration equipment such as reach-ins. Walk-in units that are connected to a large supermarket compressor rack fall into this category. Multiplex condensing equipment is typically more efficient than dedicated condensing equipment because it uses compressors of varying capacity and cycles them on and off as needed to avoid excess capacity in operation. Compressor racks and condensers of multiplex systems are outside the scope of this rulemaking.

For dedicated condensing units only, the location of the condensing unit, indoors or outdoors, affects the characteristics with regard to energy consumption. Indoor units are assumed to operate at a consistent ambient temperature, while outdoor units are assumed to experience varying temperatures throughout the year. The proposed test procedure accounts for this variation by requiring outdoor condensing units to be tested at three ambient temperatures. This gives credit for certain energy-saving technologies that may allow the compressor to use less energy at lower ambient temperatures. Therefore, DOE intends to create separate classes for refrigeration equipment with indoor (I) and outdoor (O) condensing units.

The operating temperature for walk-ins determines whether the equipment is a refrigerator (medium or high operating temperature) or a freezer (low operating temperature). Because different types of merchandise require different temperatures (e.g., chilled or frozen), operating temperature is a necessary class distinction. Furthermore, EPCA specifically divides walk-in equipment into coolers (above 32 °F) and freezers (at or below 32 °F). The larger temperature differences and thermodynamic behavior of refrigerants means that equipment with lower operating temperatures runs less efficiently than equipment with higher operating temperatures. Thus, DOE is considering separate classes for refrigeration equipment that is medium-temperature (M), operating above 32 °F; and low-temperature (L), operating at or below 32 °F.

Using all combinations of condensing unit types, location and temperature, 6 equipment classes are possible for walk-in cooler or freezer refrigeration systems. DOE also developed a lettering system to simplify discussion of equipment classes. The lettering designation for a particular equipment class consists of the lettering abbreviations for the condenser type, location and temperature, separated by periods. A complete list of equipment classes with lettering designations is shown in Table 3.2.4.

Table 3.2.4 Equipment Classes for Refrigeration Equipment

Condensing Type*	Operating Temperature	Condenser Location	Class
Multiplex	Medium	-	MC.M
	Low	-	MC.L
Dedicated	Medium	Indoor	DC.M.I
	Low		DC.L.I
	Medium	Outdoor	DC.M.O
	Low		DC.L.O

***Note:** For each of the six equipment classes, two analysis points will be used, corresponding to small and large representative units.

3.2.5.2 Envelope

Likewise, DOE also divided envelopes into different equipment classes, as shown in Table 3.2.5.

DOE is considering creating separate equipment classes for display (D) and non-display (ND) walk-ins (that is, walk-ins with and without glass). Glass is necessary for displaying products, but also has a significant effect on energy consumption because of substantial heat loss through the glass. To achieve significant energy savings, transparent glass doors could be replaced by standard foam insulated doors. However, this directly impacts the utility of this product, which is specifically designed to ensure an unobstructed view through the doors. This requirement means that walk-ins with glass doors are inherently less energy efficient. Therefore, to avoid unfairly penalizing display walk-ins by requiring the same energy standard to be met for both display and non-display, DOE created a separate class for non-display products.

DOE also intends to create separate classes for coolers (C) and freezers (F). Coolers and freezers have different insulation requirements under EPCA. Like display and non-display products, freezer and coolers have distinct design requirements; for example, freezers must have door heater wires to prevent entry doors from freezing closed. In addition, EPCA specifically divides walk-in equipment into coolers (above 32 °F) and freezers (at or below 32 °F).

Outdoor units were not considered as a separate product class since there are limited design options available to reduce energy consumption. Manufacturers typically sell indoor units as outdoor units by including roofing or other weatherization systems to prevent rain from entering panel-to-panel interfaces. In addition, the proposed WICF test procedure does not provide a means of testing variation in due external temperature for outdoor units. 75 FR 186.

Table 3.2.5 Equipment Classes for Envelopes

Display Type*	Operating Temperature	Class
Non-Display	Cooler	ND.C.
	Freezer	ND.F.
Display	Cooler	D.C.
	Freezer	D.F.

***Note:** For each of the four equipment classes, three analysis points will be used, corresponding to small, medium, and large representative units.

3.2.6 Equipment Lifetimes

3.2.6.1 Refrigeration

DOE reviewed available literature and consulted with experts on walk-in refrigeration equipment in order to establish typical equipment lifetimes. The literature and individuals consulted estimated a wide range of typical equipment lifetimes, as shown in Table 3.2.6.

A 2008 report by The Freedonia Group suggested that custom-made walk-in refrigeration units are typically used by the food production/distribution sectors. As these units are not seen by consumers but are made for durability, efficiency and dependability, there is little attention paid to aesthetics in design. U.S. tax depreciation schedules (which allow depreciation over a 5-year period for retail fixtures, including walk-in refrigerators and freezers)[ii] may be one driver for regular replacement of walk-in refrigeration equipment in the United States.

Table 3.2.6 Lifetime of Refrigeration Equipment

Lifetime (in years)	Reference
7-15	Mark Ellis & Associatesiii, New Zealand Minimum Energy Performance Standards for Commercial Refrigeration Cabinets
15	Foster-Miller (2001)[iv]
15-20	EPA (2001)[v]
15	Arthur D. Little (ADL) (2002)[vi]
7-10	Intergovernmental Panel on Climate Change (IPCC) 2001[vii]

Some literature reviewed suggested longer lifetimes of up to 20 years or more for walk-in refrigeration equipment. Many of the studies cited here related to examination of environmental impacts of refrigerant emissions and therefore may not always clearly distinguish between the lifetime of the case and the lifetime of the compressor racks.[viii] However, consultation with experts in the field suggested that smaller, independently owned grocery stores were more likely to keep equipment longer than larger chain stores.

3.2.6.2 Envelope

Unlike motorized or electrical equipment, a walk-in envelope may not have a clear point of failure. In some instances, panel and/or door failure may be obvious, such as in the cases of a severe puncture or freeze-thaw distortion of panel shape. However, it is more common that box components fail from an insulation perspective long before they exhibit any visual forms or signs of failure. Even if the envelope box appears structurally intact, its ability to insulate effectively may have been diminished substantially by diffusion, water absorption, or wear and tear.

Owing to this visual ambiguity, and the wide variety of material properties and environmental conditions that may impact the envelope, walk-in lifetimes may have a wide range. Envelope lifetimes across a variety of sources cited a range of 12-25 years that was first referenced in the widely referenced commercial refrigeration equipment industry report by Arthur D. Little, Inc. (1996). Anecdotal evidence suggests that some walk-in envelopes remain operational for years longer.

In addition, since there is possibly a large discrepancy between when the envelope fails and when the envelope is replaced, all following analysis for the envelope is based on estimated replacement rates.

3.2.6.3 Used or Refurbished Equipment

Several industry experts suggested there is a significant used/refurbished equipment market. However, the size of the used market relative to the new market was not determined.

Those consulted generally agreed that the salvage value of used equipment was very low compared to the initial purchase price. This is due to both cosmetic concerns and the custom nature of much of the equipment. Additionally, the difficulty in collecting used equipment of the same "look" for planned display case line-ups was cited as another reason for the low price of used equipment. A survey in the Pacific Northwest reported that for small, independent grocery stores (<20,000 square feet) and for independently owned convenience stores, the fraction of owners who would consider purchase of refurbished equipment was 25 and 16 percent, respectively. For larger, regional chains, this fraction was approximately 11 percent. None of the large grocery chains surveyed had plans to purchase refurbished equipment.

3.2.7 Shipments

Table 3.2.7 shows the forward-looking trend in values of walk-in coolers and freezers shipments beginning in 1993, as estimated by the Freedonia Group in a 2008 report.

Table 3.2.7 Value of Shipments of Walk-In Coolers and Freezers (in millions)

Years	1993	1998	2003	2008	2013
Walk-In Cooler/Freezer Shipments	$390	$680	$620	$800	$1,000

Source: The Freedonia Group, Inc. (2008)

The walk-in industry lacks aggregated data on actual shipments of walk-ins. Table 3.2.8 summarizes DOE estimates of historical shipments of envelope and refrigeration equipment.

Table 3.2.8 Estimated Shipments of Envelope & Refrigeration Equipment, 1998-2009

	Envelope			Refrigeration		
Year	Coolers	Freezers	Total	Multiplex	Dedicated	Total
1998	74,481	29,220	103,701	243,114	43,472	286,586
1999	74,379	29,262	103,641	243,409	43,599	287,007
2000	74,277	29,304	103,582	243,704	43,725	287,429
2001	74,175	29,347	103,522	243,998	43,851	287,850
2002	74,074	29,389	103,462	266,935	22,339	289,274
2003	73,149	29,035	102,185	266,219	22,033	288,252
2004	73,104	29,059	102,162	266,382	22,103	288,485
2005	73,058	29,082	102,140	266,545	22,173	288,718
2006	73,012	29,105	102,118	266,708	22,242	288,950
2007	72,967	29,129	102,095	266,217	21,963	288,180
2008	72,582	28,964	101,546	266,147	21,579	287,726
2009	72,335	28,858	101,193	265,873	21,557	287,430

3.2.8 Barriers to Efficiency Improvements

As the primary barrier to widespread deployment of energy efficient technologies, first cost is reflected across the walk-in market in several different ways.

The structure of the walk-in market is largely responsible for the emphasis on first cost.

The highly competitive market consists of many suppliers, none of whom has a dominant market position, meaning that first cost is a primary basis of differentiation between competitors. Purchasing decisions may not take lifecycle cost or payback considerations into account because in many cases, a general contractor oversees the purchasing of parts and their assembly, which incentivizes the selection of lowest cost equipment in terms of capital expense. The multitude of supply chain options confounds these issues and the lack of coordination between manufacturers of the envelope and refrigeration means that efficient technologies may get overlooked. Cash flow can further sway a decision away from energy efficient technologies that may have a higher first cost. For example, the uncertain long-term prospects for new restaurants, a major end-user of walk-in technologies, often leads to the selection of lowest-cost equipment.

Assessing lifecycle costs associated with walk-in equipment options can be very challenging for end-users. In particular, refrigeration systems and commercial electric rate structures are highly complex and variable. Electric rate structures differ across utilities and states, making lifecycle cost calculations a challenge even for chains planning to implement standard design specifications. These factors create a difficult environment for energy efficient technologies; operating savings related to lifecycle costs are often the only way to differentiate for customers if the more efficient technology has a higher first cost than its conventional counterparts.

The market structure hinders increased use of energy saving technologies for walk-ins. Several of the technologies discussed represent additional complexity for the refrigeration system and its control. Training would be required for most refrigeration service technicians providing service for walk-in systems.

3.2.9 Regulatory and Non-Regulatory Initiatives

The prescriptive standards for WICF set out in EPCA and any standards established by DOE during the WICF rulemaking process preempt state standards established for the same equipment. Exceptions include any state standards established for equipment not regulated by the federal government and state standards that supersede those established by the federal government. The following sections detail existing state standards for WICF thatmeet or go beyond the EPCA requirements.

3.2.9.1 California Energy Commission

The California Energy Commission’s tiered specification regulates the minimum energy performance of equipment sold in California. As of January 6, 2006, walk-in coolers and freezers have been regulated by the California Appliance Efficiency Regulations. The most recent version, published in August 2009 lists the latest requirements for walk-ins sold in California after January 1, 2009, which are identical to the standards established at the federal level by EPCA for all WICF for which federal standards have been established.

Additionally, California has established standards for freezers with volumes exceeding $30ft^3$, wine chillers that are consumer products, commercial refrigerators including but not limited to refrigerated bottled or canned beverage machines, commercial refrigerator-freezers, commercial freezers, commercial ice-markets, and water dispensers. These standards are described in Table 3.2.9.

Table 3.2.9 Requirements for Walk-ins Sold in California

Motor Type	**Required Components**
All	Automatic door closers that firmly close all reach-in doors
All	Automatic door closers on all doors no wider than four foot or higher than seven foot, that firmly close walk-in doors that have been closed to within one inch of full closure
All	Envelope insulation >R-28 for refrigerators
All	Envelope insulation >R-36 for freezers
Condenser Fan Motors < 1 HP	(i) Electronically commutated motors (ii) Permanent split capacitor-type motors, (iii) Polyphase motors >1/2 HP, or (iv) Motors of equivalent efficiency as determined by the Executive Director
Single-phase Evaporator Fan Motors < 1 HP and < 460 volts	(i) Electronically commutated motors (ii) Permanent split capacitor-type motors,
Single-phase Evaporator Fan Motors < 1 HP and < 460 volts	(i) Electronically commutated motors or (ii) Permanent split capacitor-type motors
Walk-ins Coolers and Walk-in Freezers with transparent reach-in doors	(i) Triple-pane glass with heat-reflective treated glass or gas fill, (ii) If appliance has anti-sweat heater without anti-sweat heat controls, then: the appliance must have a total door rail, glass, and frame heater power draw of no more than 40 W (freezers) or 17 watts (refrigerators) per foot of door frame width; and (iii) If appliance has anti-sweat heater with anti-sweat controls, and the total door rail, glass, and frame heater power draw is no more than 40W (freezers) or 17W (refrigerators) per foot of door frame width, then: the anti-sweat controls shall reduce the energy use of the anti-sweat heater in an amount corresponding to the relative humidity in the air outside the door or to the condensation on the inner glass pane.

3.2.9.2 Other U.S. States

Connecticut, Maryland and Oregon have recently set up energy efficiency standards for walk-ins. Connecticut and Oregon's standards were implemented in 2008 while Maryland's was introduced in 2009. It is unlikely that these standards will have much impact given that they will be quickly preempted by the design requirements in EPCA. However, the legislation may prepare any manufacturers or consumers in these states for compliance with the federal standards.

3.2.9.3 Australia & New Zealand

The National Appliance and Equipment Energy Efficiency Committee (NAEEEC) establishes minimum energy performance standards (MEPS) for a variety of technologies manufactured and sold in Australia and New Zealand. Its standards are based on the North American work of the Canadian Standards Association, the California Energy Commission, and the U.S. ENERGY STAR program.

MEPS for remote and self-contained commercial refrigeration are defined in AS1731.14, which targets refrigerated display cabinets used in retail applications[ix]. These standards specifically omit walk-ins.

3.2.9.4 Japan

Japan's Top Runner program targets energy efficiency standards for a wide range of appliances. Although Top Runner sets standards for commercial refrigerators and freezers, units produced for industrial use are not included.

3.2.10 Market Performance Data

Natural Resources Canada (NRCan) provides estimates of the installed number, sales and energy consumption of WICF equipment on an annual basis, summarized in Table 3.2.10.

Table 3.2.10 Summary of Walk-in Cooler and Freezer Data Compiled by NRCan[x]

Equipment Type	Total Installed	Annual Sales (New or replacement)	Annual Energy Consumption (kWh)
Refrigerator (15 m2)	-	-	16,200
Freezer (15 m2)	-	-	21,400
Refrigerator-Freezer (31 m2)	-	-	30,200
Total	96,000	3,300	-

DOE was unable to find a source that compiled WICF data in the U.S. Therefore, DOE gathered its own industry data by sampling equipment of each class for both envelopes and refrigeration systems. The results are shown in sections 3.2.10.1 and 3.2.10.2

3.2.10.1 Envelope

In DOE's research, it was unable to find equipment energy ratings for each equipment class or analysis point. This is likely due to the fact that the industry does not yet have a uniform method for rating products, but this will likely change with the publication of the WICF test procedure NOPR and Final Rule. In the absence of product data, DOE made estimates of envelope energy performance using the envelope engineering analysis (described in Chapter 5 of the preliminary TSD) with various product sizes. Figure 3.2.1 through Figure 3.2.4 show the resulting calculations for each of the four product classes described in Table 3.2.5. The data are plotted on a log scale to facilitate comparison between sizes. Without this scale, the energy performance range within each product class would make the ranges for smaller sized analysis points unreadable.

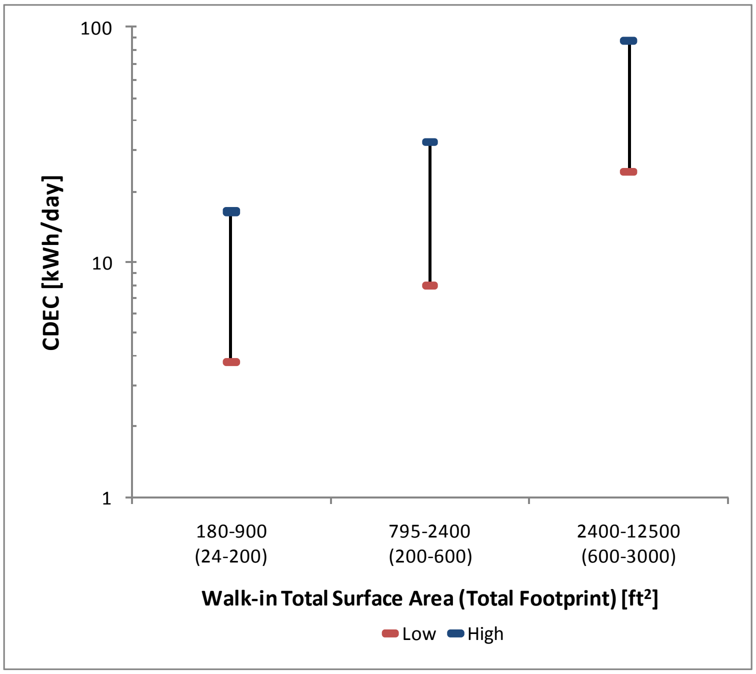

Figure 3.2.1 Market Performance Data for the ND.C Equipment Class

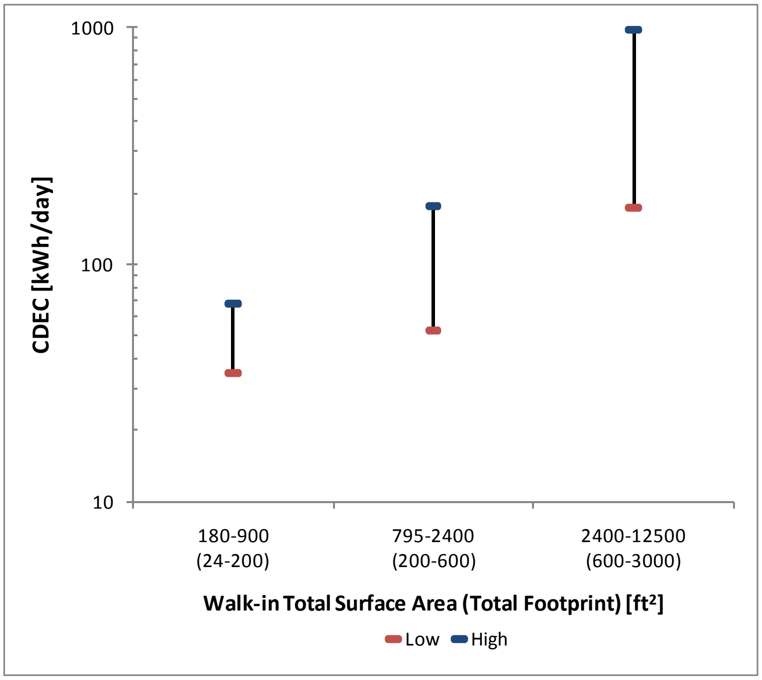

Figure 3.2.2 Market Performance Data for the ND.F Equipment Class

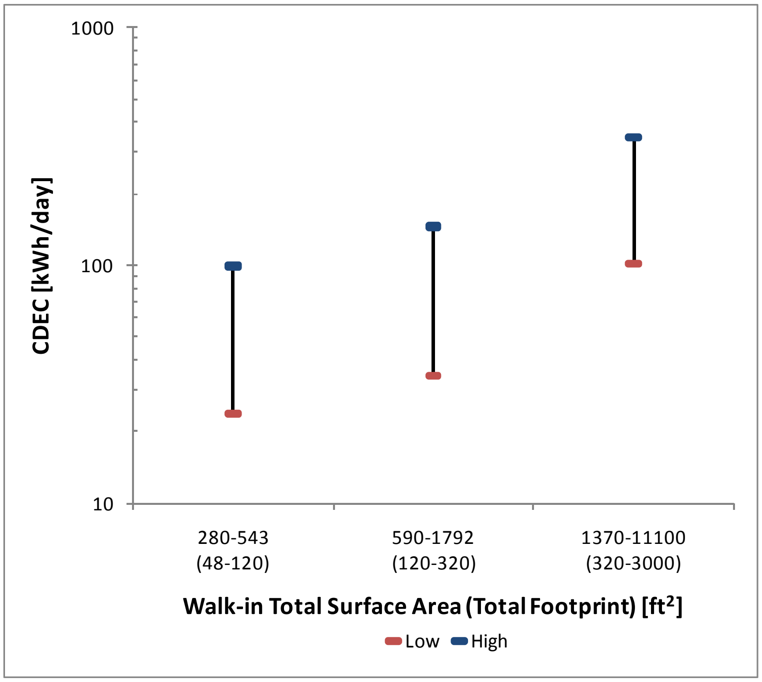

Figure 3.2.3 Market Performance Data for the D.C Equipment Class

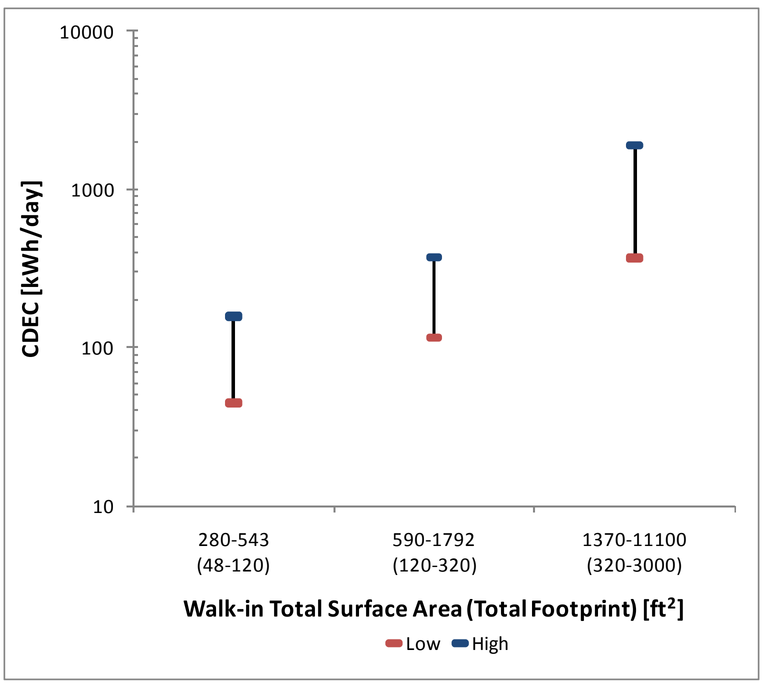

Figure 3.2.4 Market Performance Data for the D.F Equipment Class

3.2.10.2 Refrigeration

As of now, DOE is not aware of any published market performance data for WICF refrigeration. Because there has not been a test procedure in place in this industry, there is no established industry-wide metric for performance of equipment as it relates to energy consumption. However, this may change with the recent publication of AHRI 1250. Manufacturers' specification sheets typically provide only information relevant to the end user or contractor: refrigeration capacity, dimensions, electrical characteristics, etc.

In order to gather energy consumption data for refrigeration systems, DOE examined manufacturers' specification sheets and estimated the energy consumption of the system by entering the information into DOE's engineering spreadsheet. The engineering spreadsheet uses the calculation methodology contained in AHRI 1250 to calculate energy consumption of the system. DOE examined 10 systems in each class that encompass a range of efficiencies that are currently on the market. Figure 3.2.5 through Figure 3.2.10 show graphs of the results.

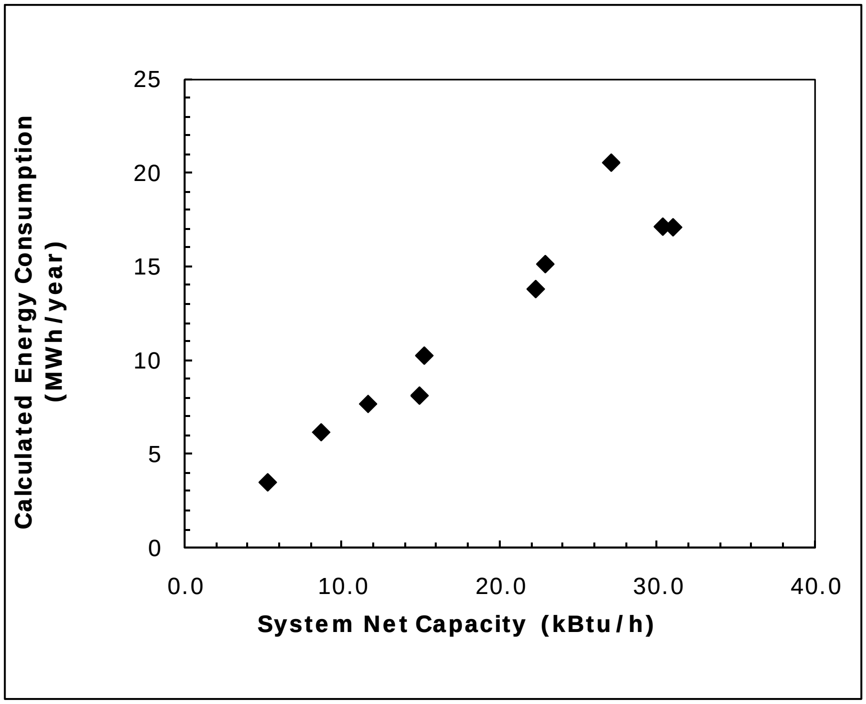

Figure 3.2.5 Market Performance Data for the DC.M.I Equipment Class

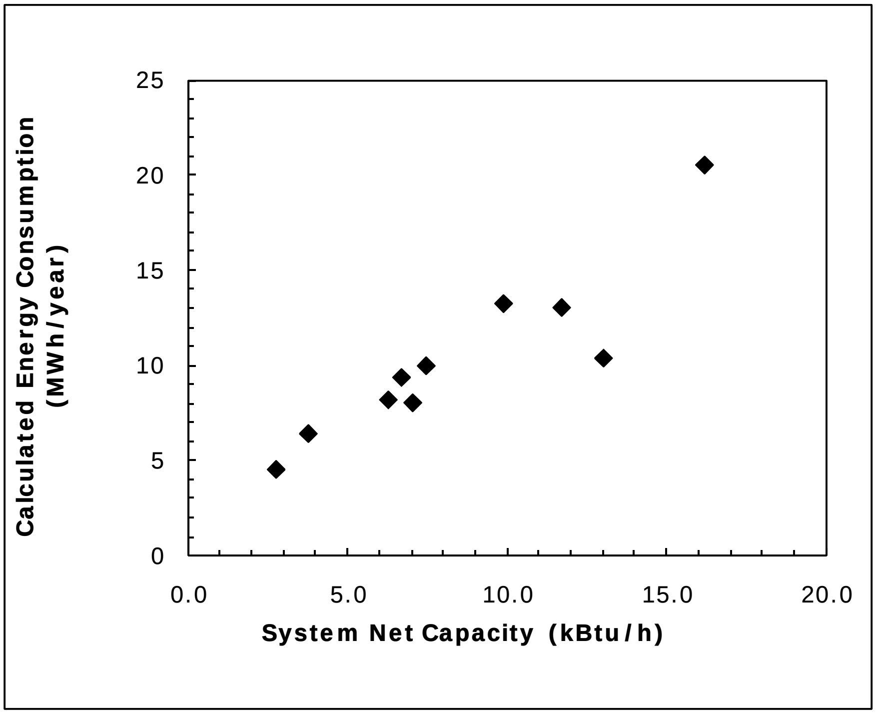

Figure 3.2.6 Market Performance Data for the DC.L.I Equipment Class

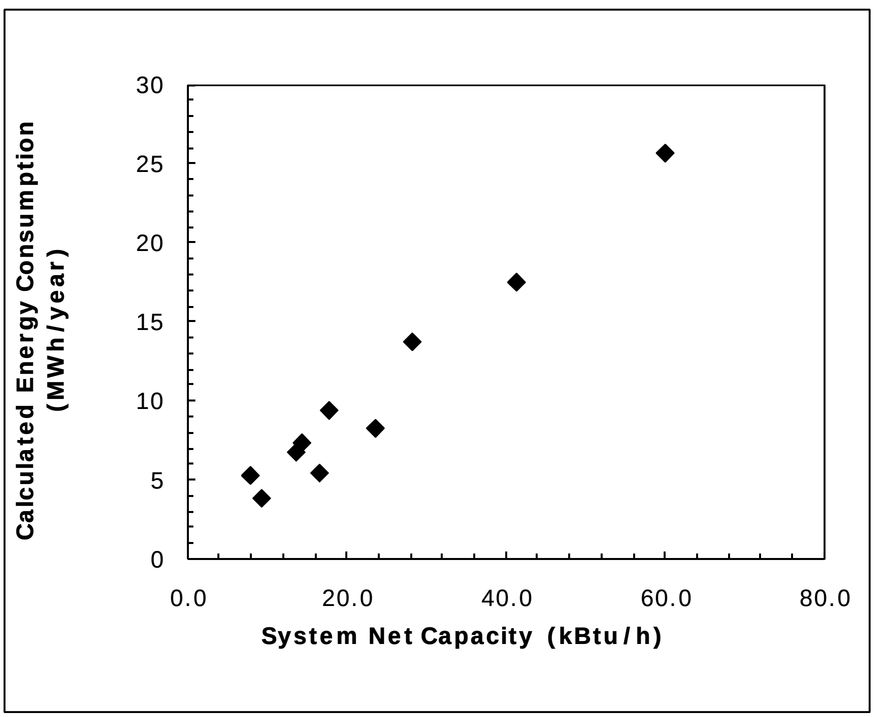

Figure 3.2.7 Market Performance Data for the DC.M.O Equipment Class

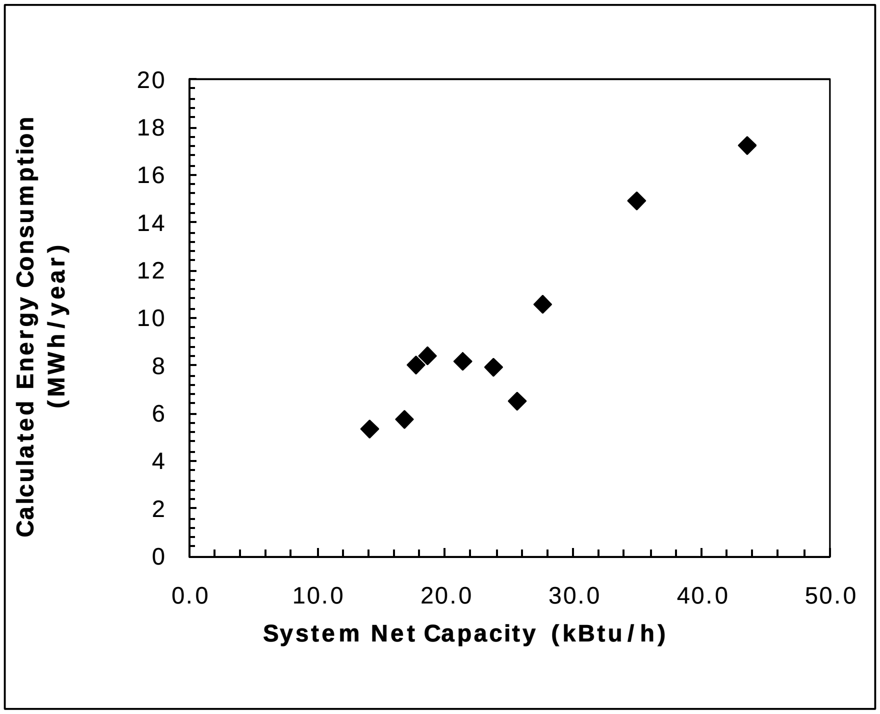

Figure 3.2.8 Market Performance Data for the DC.L.O Equipment Class

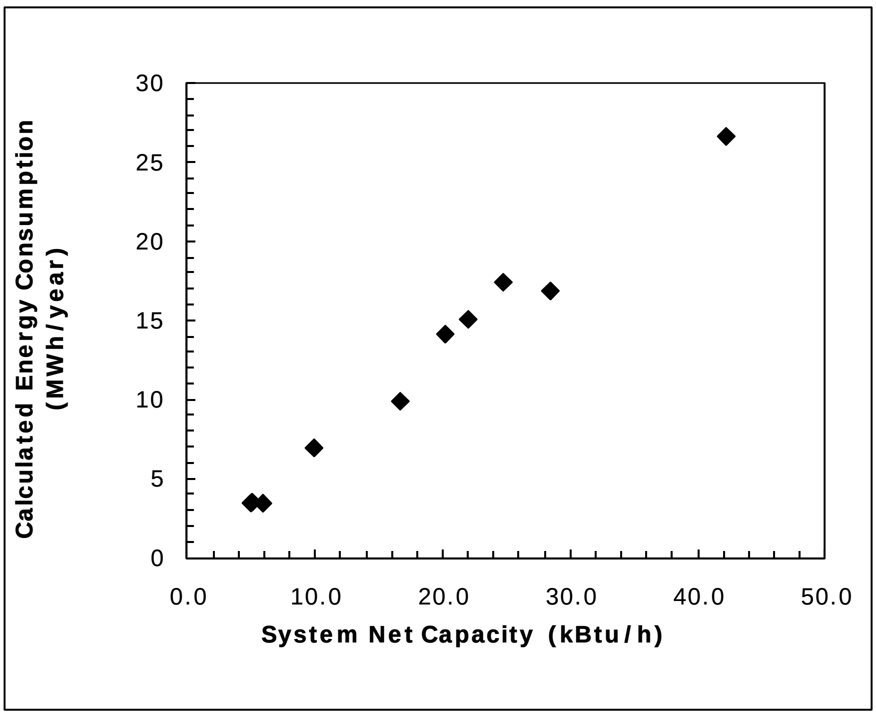

Figure 3.2.9 Market Performance Data for the MC.M Equipment Class

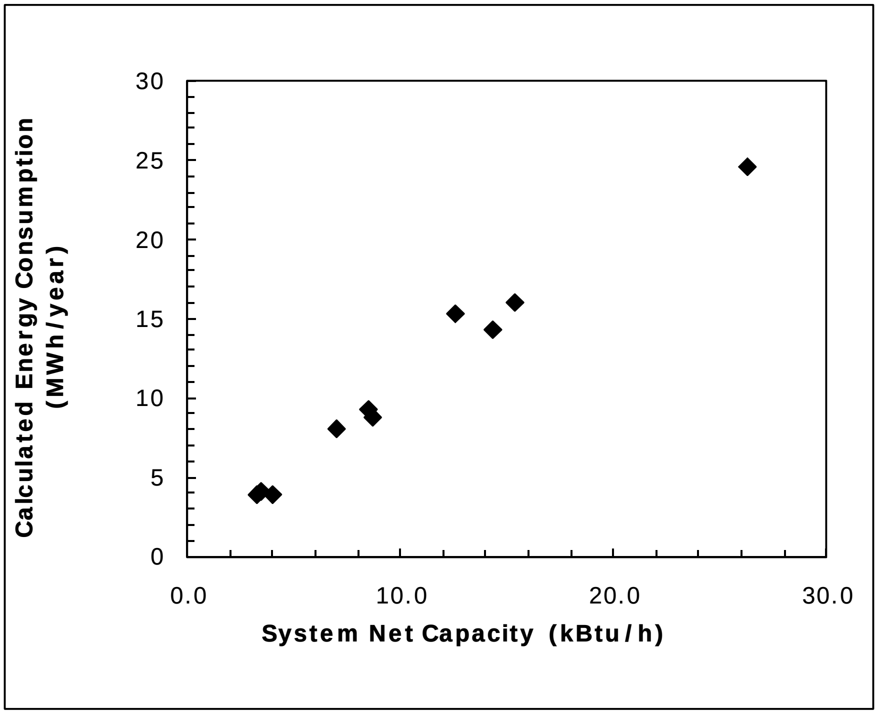

Figure 3.2.10 Market Performance Data for the MC.L Equipment Class

3.3 TECHNOLOGY ASSESSMENT

The function of the technology assessment is to develop a preliminary list of technologies that could potentially be used to reduce the energy consumption of walk-in coolers and freezers, as well as to highlight the developments within those technology categories and their applicability to these product classes. Walk-in coolers and freezers present a wide variety of design options which could lead to energy savings if implemented in production models. The diversity of these options is compounded by the large number of components and corresponding energy loss pathways present in this equipment.

Each unit can be broken down into two components: the envelope and the mechanical refrigeration system. Each of these presents specific energy-loss issues which can be addressed through new technologies. Within the refrigeration system, most energy loss and waste are due to inefficiencies in the components, including the compressor, motors, and fan blades. Advanced designs can lead to both direct energy savings, as well as reduction of waste heat discharged into the refrigerated space which must be removed. The envelope presents another group of energy loss pathways altogether, including the conduction of external heat through insulated walls, as well as infiltration of outside air into the refrigerated space and electricity consuming devices such as lights and anti-sweat heaters.

Certain types of walk-in coolers and freezers may also exhibit further means through which energy loss occurs. For example, units with the case located outdoors are exposed to increased fluctuations in temperature and increased heat load on the surface of the unit due to sunlight, and display units exhibit pronounced energy losses due to conduction through and opening of the glass doors, as well as the presence of anti-sweat heating devices. The following assessment provides descriptions of technologies and designs that apply to all equipment classes for envelope and refrigeration, designs that apply only to particular classes for envelope and refrigeration.

3.3.1 Technologies and Designs Relevant to All Envelope Equipment Classes

3.3.1.1 Wall, Ceiling, and Floor Insulation

Most walk-in cooler and freezer envelopes are constructed from panels known as Structurally Insulated Panels (SIPs), which are comprised of a sandwich of metal skins encapsulating an insulating material. Most walk-ins currently manufactured and installed use traditional foam materials as insulation. Their main purpose is to reduce heat transfer from the external environment to the internal conditioned space of the walk-in.

Improvements to the insulating capacity of the envelope could be achieved through a number of methods. The most basic of these would be increased insulation thickness using existing foam insulating materials. Another option would be the incorporation of insulating materials that have higher thermal resistance per inch thickness. One such technology is the Vacuum Insulated Panel (VIP), which consists of an outer air-tight membrane surrounding a core material. The inner core is evacuated to remove air from the material. This greatly reduces heat conduction on a per inch basis compared to foam materials. Other options include the incorporation of aerogels, a low-density and low heat conducting material.

3.3.1.2 Door Gaskets

All walk-in doors utilize seals to prevent air exchange with the surroundings when the door is closed. These seals typically consist of rubber gaskets which are compressed when the door latch is closed, or magnetic, vinyl-coated systems used display glass doors. Improvements in these systems and the seal materials could result in greater insulating capacity as well as less air leakage, reducing energy loss due to both conduction and air infiltration.

3.3.1.3 Panel Interface Systems

Panel interface systems include the methods and materials designed to seal the panel-to-panel, panel-to-floor, and other interfaces present. Use of improved materials, geometries, and manufacturing techniques could serve to further reduce infiltration and conductive losses and improve the overall insulating capacity of the envelope, meaning that less energy input would be required by the refrigeration system.

3.3.1.4 Electronic Lighting Ballasts and High-Efficiency Lighting

Many fluorescent lighting systems currently in use to illuminate the interior of walk-ins employ traditional magnetic ballasts. These ballasts generate significant amounts of heat due to resistive losses incurred in the circuit. This results in increased energy consumption to power the lights, as well as an increase in the cooling load to remove the waste heat generated by the ballasts. Solid state electronic ballasts serve to reduce this waste heat, as the integrated circuits employed produce very low resistive losses. These advanced ballasts also lead to more efficient operation of the fluorescent lamps, thereby reducing the electricity consumption of the lights. Moving the ballasts away from the lamps entirely, to a location outside of the refrigerated space, is another option. This would ensure than any waste heat produced would be discharged to the surroundings, rather than to the refrigerated space, where it would have to be removed by the cooling system.

In addition to fixtures and ballasts, new advanced lights such as light emitting diodes (LEDs) and organic light emitting diodes (OLEDs) offer significant increase in efficacy. Compared to standard fluorescent systems, the electricity consumption and waste heat generated are far lower. Nearly every major display door manufacturer offers LED lighting as design option. LED bulbs that fit in Edison type fixtures are also widely available.

3.3.1.5 Occupancy Sensors

One major source of energy consumption in a walk-in is the operation of lighting when it is not needed, primarily due to lights being left on when the unit is unoccupied. Occupancy sensors ensure operation of the interior lighting when an individual is present and working inside the refrigerated space or viewing products in a display type walk-in. When motion has not been detected for a set period of time, the lights are turned off. This would reduce waste due to lights being left on unnecessarily. Moreover, the sensors could also be used to notify personnel of periods when the door is ajar; that is, if the door is open and there has been no one present inside the space for a period of time. This would save energy due to loss of refrigerated air from the interior space.

3.3.1.6 Automatic Door Opening and Closing Systems

Doors left open accidentally by employees can be a major cause of losses from the envelope. To avoid accidental and intentional door opening frequency and duration, especially while products are being loaded into the walk-in, the use of automatic door opening and closing mechanisms can reduce air infiltration. By sensing approaching personnel and through the use of powered door openers, the door can be quickly opened and closed at a rate that both ensures safe movement through the doorway and minimizes the duration of the door opening event. Instead of door propping while loading, the door would only be opened for the short period that a person or forklift needs to pass through the doorway.

3.3.1.7 Non-Penetrative Internal Racks and Shelving

Many manufacturers have noted that end users and customers will install interior shelving units and racks in the walk-ins using penetrative fasteners such as nails and screws. These compromise the inner skin and insulation of the envelope, resulting in reduced insulating capacity and possibly air leakage. The use of freestanding racks and shelving units by end users could be a simple and effective method for reducing losses.

3.3.1.8 Air Curtains

Air curtains consist of fans mounted horizontally or vertically that direct a stream of air across a door opening. When the door is opened, the air current is activated, blowing air perpendicular to direction of air movement into and out of the walk-in. This air barrier greatly reduces unwanted exchange of air while offering unobstructed visual or movement barrier.

Two types of air curtains exist: recirculating and non-recirculating. Non-recirculating units are the most common, as these simply use air from the interior space to form the moving stream. The air then impinges upon the floor and the stream splits. If properly positioned, the systems are very effective at reducing air infiltration. In recirculating units, the stream of air captured through a floor grate and run through the blower again. Manufacturers claim that recirculating units these systems are even more effective than non- recirculating. Air curtains are not standard on most walk-ins, but have been widely available for quite some time and are often installed by end users as an accessory.

3.3.1.9 Strip Curtains

Strip curtains are barriers composed of vertically-oriented strips of plastic, usually clear PVC, which can be suspended in the doorway opening of a walk-in. When undisturbed, the curtain forms a barrier which limits movement of the cooled air out into the environment, yet allows for easy and unobstructed passage through the doorway. These are commonly installed by end users for the intent of saving energy. Generally, strip curtains are used in larger units which experience heavy traffic, such as constant movement of goods using forklifts. However, their proficiency in preventing the loss of chilled air from the inside of the refrigerated space makes them a candidate for use in walk-ins of all sizes and uses.

3.3.1.10 Refrigeration System Override

During periods of high traffic, such as when a shipment of product is received and must be transferred into the walk-in, the door to the cooler or freezer may be repeatedly opened or simply left open for a long period of time. With traditional systems, the thermostat engages the compressor and fans during such periods. However, such operation wastes a large amount of electricity, as the attempt on behalf of the system to cool the interior space is lost via the open door. A better alternative is to simply override the thermostat, turning off the refrigeration system completely during high-traffic periods and reengaging it after the tasks have been performed. Such a simple control would prevent the cooling system from continuously running at maximum capacity in an attempt to bring the inside temperature down to the desired value while continuously ejecting cold air to the surrounding environment. The result would be an immediate and sizeable energy savings.

3.3.1.11 Air and Water Infiltration Sensors

Infiltration of water and/or water vapor into the envelope insulating material may lead to significant reductions in the insulating capacity of the affected regions due to the thermal conductivity properties of water. This sort of infiltration may result from specific incidents, such as punctures or damage or a steady-state process occurring over a long period of time. A water condensate or vapor sensor, implanted within the insulating material would allow for early detection of damage to the insulating material. This would prevent continued operation with a damaged unit and would provide notification of the need for repairs. As a result, the energy wasted during sustained operation of a damaged unit would be conserved. In addition, pressure or flow sensors may be utilized to directly measure walk-in air exchange rates, providing end-users data to use historical air exchange patterns to monitor real-time performance.

3.3.1.12 Humidity Sensors

Humidity of the air is another factor which can influence the performance of the mechanical refrigeration system. As air with a higher humidity has a higher specific heat, it thus requires more energy to cool the air on a day with high humidity. Sensors installed in the system could provide real-time information regarding the outside humidity, which would allow for more informed decisions to be made regarding topics such as the loading and loading of product at certain times. Such intelligently managed use would result in lower infiltration losses due to prolonged door opening on days exhibiting adverse operating conditions.

3.3.1.13 Heat Flux Sensors

As mentioned earlier, damage to the envelope of the walk-in can occur due to many reasons, including penetrative fasteners used to attach shelves or racks and/or long-term degradation of insulation due to gas diffusion or water infiltration. Heat flux sensors are available which use a simple hot plate method to provide real-time information regarding the insulating properties of a wall on which they are mounted. This non-destructive R-value monitoring would provide manufacturers with useful data of walk-in performance as installed in the field and allow end-users to monitor performance of the insulation over time to avoid energy losses incurred due to drop in insulation R-value.

3.3.1.14 Vestibule Entryways

The implementation of vestibule or air-lock doors would greatly reduce the losses that arise as a result of opening the doors for entry. This type of entry system is typically used in larger building entrances to prevent heat loss due to door opening air infiltration. The doors open and close sequentially during entry and exit, never allowing direct air exchange. Instead, only a small amount of air would move with the user into the small space between the two doors. This would significantly reduce the increase in interior temperature that occurs each time the door is opened, as well as the corresponding amount of energy required to cool that space back down to the desired set point.

3.3.1.15 Revolving Doors

Another provision for the reduction of losses from door opening would be the use of revolving doors. Like vestibule entries, revolving door systems are commonly used for the entryways of large buildings. Similarly, they prevent direct exchange of air and reduce the rate of infiltration compared to a standard door.

3.3.1.16 Fiber Optic Natural Lighting

During day light business hours, instead of using electrically powered lighting systems, roof mounted collectors can be used to direct sunlight into fiber optic cables that transmit the light to where it is needed in a walk-in cooler resulting in immediate energy savings. Artificial lighting, such as in the form of the high-efficiency lighting systems mentioned previously would also need to be present, as walk-in coolers and freezers are generally accessed at all hours in many applications.

3.3.1.17 Energy Storage Systems

Thermal energy storage systems could be utilized to levelize cooling demand on the compressor and associated refrigeration system, allow the system to operate only during optimal environmental conditions and shift electrical demand to off-peak hours to achieve cost savings. For example, the refrigeration equipment could cool a large mass during the night when outdoor temperatures are lowest and electricity prices are cheapest. During the daytime or periods of peak demand, this stored energy could then be utilized. Storage would allow for systems to be designed for steady-state operation rather than being over sized for "worst-case" weather or product loading scenarios. Generally, the more time the system operates at 100% capacity efficiency increases cost of operation decreases.

3.3.2 Technologies and Designs Relevant to Display Envelopes Only

The following technologies are relevant only to walk-in coolers and freezers which also feature display fronts: display and window glass system insulation performance, anti-sweat heater controls, non-electric anti-sweat systems, no anti-sweat systems, and automatic insulation deployment systems.

3.3.2.1 Display and Window Glass System Insulation Performance

The glass display door heat transfer losses for represents 30-40% of walk-in energy consumption. While current regulation prescribes minimum standards for number of panes, gas fill and low emissivity coatings, there is significant opportunity for improvement. In addition, windows used in non-display doors also contribute to energy consumption but on a much lower percentage basis.

Improvements to reduce heat transfer performance could include the use of additional panes of glass and expanded use of inert gas filled panes using argon, krypton or xenon. The treatment of the window glass with advanced low emissivity coatings and increasing the number of coated surfaces could also reduce losses due to radiation heat transfer. The result of these improvements would include both direct energy savings, through reduced conduction losses, and an indirect reduction in energy consumption due to reduced anti-sweat heater demand.

3.3.2.2 Anti-sweat Heater Controls

In display units, the glass door external surface may experience temperatures below the dew point of the ambient air with which they are constantly in contact. As a result, condensation can form in on the surface of the doors, reducing visibility of the product and also possibly leading to ice buildup or pools of condensate forming at the base of the glass door. This phenomenon is known as “sweating”. To prevent this, anti-sweat heaters are generally employed in order to ensure that the external glass temperature is sufficiently high to avoid sweating.

Generally, electric heater wire, in contact with the door perimeter, is energized to continuously heat the glass. However, anti-sweat heat may only be required during particularly humid environmental conditions or walk-in temperatures. Control devices are available that sense external humidity and temperature regulate anti-sweat heater wire use on demand. These systems significantly reduce the required daily electrical demand.

3.3.2.3 Non-Electric Anti-sweat Systems

While conventional anti-sweat heaters operate using separately powered electric resistance heater wire, any heat source capable of bringing the door surfaces to temperature could also serve this purpose. It may be possible, similar to hot-gas defrost, to utilize the waste heat generated by the mechanical refrigeration system to provide the required glass door heating. In these non-electric systems, a heat transfer fluid could be used to absorb heat from the refrigeration system and reject heat to the glass doors. By utilizing waste heat that is readily available a major source of electrical energy consumption in display units may be entirely eliminated.

3.3.2.4 No Anti-sweat Systems

Another option for addressing the issue of sweating is the use of static systems that prevent the phenomenon from occurring. These include multi-pane glass doors which have greater insulating properties, preventing the exterior temperature from becoming low enough for sweating to occur. Another option may be advanced hydrophobic materials that prevent condensate from attaching or lingering on the glass surface and therefore prevent the formation of water droplets that may obscure a customer’s view of a product.

3.3.2.5 Automatic Insulation Deployment Systems

In many businesses, such as convenience and grocery stores with limited hours of operation, glass display doors are not utilized during non-business hours. In such applications, automatic insulation deployment systems could be put in place to lower a layer of insulation over the interior or exterior surface of the glass doors during non-business hours, thus increasing the thermal resistance of the door and, correspondingly, the net insulating capacity of the entire envelope. This would greatly reduce conduction losses and lead to a direct energy savings.

3.3.3 Technologies and Designs Relevant to All Refrigeration Equipment Classes

3.3.3.1 Evaporator and Condenser Fan Blades

Conventional fans have sheet metal blades mounted to a central hub, and are generally not optimized for the specific application in which they will be used. Instead, they are designed for mass production and scalability in order to minimize production cost and waste. Optimization of fan design for specific applications could significantly reduce input energy needed in order to perform the necessary work. Higher efficiency fan blades are capable of moving more air at a given rotational speed when compared to traditional fan blades. This means that a smaller motor can be used, or the existing motor can be run at a lower speed, resulting in direct energy savings. The improvements described here would be applicable to both evaporator and condenser fans, though evaporator fans would likely stand to earn greater efficiency gains due to the fact that sheet metal fans are poorly suited to the higher pressure drops encountered in this application.

3.3.3.2 Improved Evaporator and Condenser Coils

The effectiveness of the refrigeration system in moving heat from the temperature-controlled space to the ambient environment is constrained by the ability of the evaporator and condenser coils to transfer heat. Coils are generally constructed of copper and aluminum, with these materials being chosen for their favorable heat transfer characteristics. Enhancements to both the refrigerant side (inside) and air side (outside) of the coils can improve their heat transfer characteristics, requiring less compressor power and fan energy to achieve the same system capacity. Improvements to the refrigerant side of the coil can include increased tubing passes as well as changes in the geometric profile of the tubing itself. Air-side improvements consist of decreasing the spacing between the fins, thus increasing the number of fins per unit coil length, as well as changes in the fin patterns. Increased overall coil size also improves heat transfer, but this is infeasible in some cases due to space constraints on both the evaporator and condenser coils.

3.3.4 Technologies and Designs Relevant to Dedicated Condensing Refrigeration Systems Only

3.3.4.1 Ambient Subcooling

This process utilizes an oversized condenser or subcooling heat exchanger in order to further cool the condensed refrigerant. The result is a decrease in coolant enthalpy and an increase in specific capacity, meaning that a lower mass flow rate of compressed refrigerant, and thus less compressor power, is needed. Ambient subcooling is only needed when head pressure has been reduced to the lowest allowable value; in any other case, it is more efficient to simply reduce the head pressure. This system then proves effective when the ambient temperature is low enough that the head pressure must be kept at a high level, as is often the case for systems operating in cooler geographical regions.

3.3.4.2 Higher-Efficiency Fan Motors

Two separate sets of fan motors service the evaporator and condenser of the unit, respectively. Their functions are to facilitate heat transfer by moving air across the heat exchangers, in order to move heat out of the refrigerated volume and discharge it to the ambient environment. The current regulations dictate that all evaporator fan motors must be either 3-phase or electrically commutated motors (ECMs), and that all condenser fan motors must be ECMs, permanent split capacitor motors (PSCs), or 3-phase. This eliminates the usage of an older and less sophisticated motor type, the shaded-pole motor. Aside from motor type alone, other design options can be implemented into the motors in order to reduce internal friction and improve operating capacity. The result will be that less electrical energy input will be required to generate the same amount of output shaft work, and less waste heat will be discharged due to friction, reducing electricity consumption directly and, in the case of the evaporator fan motors, reducing the system heat load, thereby reducing the indirect consumption of the system in removing that load.

3.3.4.3 Automatic Evaporator Fan Shut-Off

Typically, evaporator fans run at all times to circulate cool air in the walk-in. This design option consists of a control that would automatically shut off evaporator fans whenever the walk-in door is opened. The result would be that less chilled air would be blown out into the walk-in's surroundings, meaning that less energy would be needed to bring the interior space back down to temperature following a door opening.

3.3.4.4 Evaporator Fan Control

In traditionally operated systems, evaporator fans run at all times, whether or not the compressor is running. In many instances, the evaporator fan motors are running for more time than is actually necessary, resulting in overuse of electrical power. Evaporator fan controls save energy by allowing the evaporator fans to run at variable speed, or cycle on and off, during periods when the compressor is off. These could include timers or sensors which detect conditions inside the refrigerated space and control the motors accordingly.

3.3.4.5 Higher-Efficiency Compressors

The compressor is the component that uses the most power out of all those comprising the refrigeration system, making it a likely and appropriate target for improvement. Even a small percentage increase in compressor efficiency would result in very large energy savings over the life of the product. Currently, several types of compressors are in use for walk-in refrigeration systems. Smaller systems utilize hermetic reciprocating piston compressors, while larger units utilize semi-hermetic compressors. Additional compressor types exist which have not achieved large market share, including scroll compressors, which generally exhibit quite high efficiencies. Moreover, multiple capacity compressors present an opportunity for energy savings as well. These systems can take many forms, including single compressors with multiple stages or variable operating speeds as well as coupled sets of compressors which engage as necessitated by the load on the envelope. These technologies allow for the compressor operating time and power to more closely follow the heat load, resulting in improved performance and decreased energy consumption.

3.3.5 Technologies and Designs Relevant to Low Temperature Refrigeration Systems Only

3.3.5.1 Hot Gas Defrost

As the air in the refrigerated space is cooled, water vapor condenses on the surface of the evaporator coil, and, if the coil temperature is below freezing, ice will form, creating a layer over the surface of the coil. If this layer grows to be too thick, air flow will be decreased and thermal resistance will increase, resulting in reduced cooling performance. Thus the removal of evaporator coil frost is imperative.

Hot gas defrost involves the recirculation of hot gas discharged from the compressor to warm the evaporator. Compared to other defrosting methods, namely electric defrost, energy consumption is much less as the heat comes from an existing by-product of the process. However, sophisticated controls are required, along with complex pipe routing, in order for the system to be effective. A more serious consequence of using this defrosting system is cracking and leaking resulting from thermal stresses induced upon the coolant piping due to alternate exposure to high and low-temperature refrigerant.

3.3.5.2 Defrost Controls

Management of frost buildup on coils is essential in ensuring continued efficient operation of the unit. Traditionally, defrosting systems were run on regular intervals utilizing a simple timer. However, this system has two possible negative consequences in that the defroster may run too often, resulting in wasted energy, or not often enough, resulting in decreased system performance. Current systems allow for control of the termination of defrosting based on temperature; when the coils reach a specified temperature, the defroster is turned off. However, initiation of the cycle still occurs on a periodic basis using a timer.

Control of the defrost cycle requires the use of sensors in order to determine that a defrost cycle is needed. The data collected can consist of either the temperature drop across the coil or detection of the physical thickness of frost buildup using photocells. The first of these two methods is based on the idea that decreased airflow across the coil is a result of frost buildup, meaning that the temperature differential across the coil will increase. However, there are issues in that external factors aside from frost buildup on the coil may be the reason for decreased airflow. The second method is more accurate but requires more sophisticated sensors.

3.3.6 Technologies and Designs Relevant to Outdoor Refrigeration Systems Only

3.3.6.1 Floating Head Pressure

Traditionally, the pressure at which the compressor discharges, known as the head pressure, is kept at a constantly fixed setting in order to enable operation over a variety of environmental temperatures in outdoor units. Generally, this is fixed at a high value in order to ensure that a sufficient amount of refrigerant can flow through the system, which also protects the evaporative condenser against freezing and maintains the necessary pressure difference across the expansion valve.

However, modern technology, in the form of more sophisticated expansion valves, allows for the use of floating head pressure schemes, in which the refrigerant flow is dynamically controlled over a broad range of external temperatures. In this case, condensing temperatures down to 70 degrees Fahrenheit can be utilized, much lower than the temperatures of 90 or 95 degrees necessary for a fixed-head pressure system. In this case, the evaporative condenser is in constant operation, rather than simply turning on and off as needed. This has the potential to generate a significant net energy reduction through a decrease in compressor energy use, and also can reduce the wear induced upon moving parts due to continual starting and stopping.

3.3.6.2 Economizer Cooling

Economizer cooling consists of directly venting outside air into the interior of the walk-in when the outside air is as cold as or colder than the interior of the walk-in. This relieves load on the refrigeration system when pull-down load is necessary.

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