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Executive Summary

The State-of-the-Art of Commercial Refrigeration

A Review of the Current U.S. Commercial Refrigeration Market, Industry Trends, and Areas Needing Additional Research

Introduction

Commercial refrigeration is a technology area of growing importance in the United States. **According to the data published by the Department of Energy (DOE),[1] refrigeration accounts for 4–6% of total energy consumption in all commercial buildings in the United States.** This does not account for additional energy required for refrigerated transport systems needed to move goods between warehouse storage facilities, retail stores, and end users. As the DOE and Environmental Protection Agency (EPA) continue to review refrigeration equipment for efficiency standards and environmental impacts from refrigerant use, it is critical to fully understand the commercial refrigeration market, including the systems, refrigerants, and technologies currently in use and in research and development. As such, the Electric Power Research Institute (EPRI) is conducting market and technology research in order to provide an overview of current trends, state-of-the-art technologies, and research gaps in the U.S. commercial refrigeration industry. The information contained in the full report is meant to aid EPRI and its utility partners in understanding the energy implications of refrigeration systems, markets with the greatest potential for technology improvement and energy savings, cutting edge systems and strategies to provide such improvement and savings, active research areas, and research gaps needing additional attention.

Methodology

The material included in this report was assembled based on the results of internet research, detailed literature review, conference attendance and interviews with industry representatives. A total of 11 interviews were conducted between July and August 2014 with individuals from the following groups:

- Engineering consultants
- Manufacturers
- Manufacturer representatives/wholesale distributors
- System designers/technicians/installers
- Utility representatives

[1] Department of Energy, (2012, March), Buildings Energy Data Book, Chapter 3: Commercial Sector, Retrieved from: http://buildingsdatabook.eren.doe.gov/ChapterIntro3.aspx?3#1.

Commercial Refrigeration Systems and Applications

Three main commercial refrigeration applications were considered for this study, including commercial retail food storage, refrigerated warehouses, and refrigerated transport systems.

Retail Food Storage

Retail food storage applications include a variety of food sales and food service applications such as supermarkets, conveniences stores, and restaurants. Refrigeration systems in the commercial retail food industry include food storage and product display cases, reach-in coolers/freezers, and walk-in coolers/freezers. While most units for small stores and restaurants are unitary systems (also known as packaged or self-contained), systems in larger retail applications, such as supermarkets, are generally engineered and are often combined to create distributed systems capable of reducing energy consumption and better meeting multiple refrigeration loads.

Commercial refrigeration systems used in the retail industry use a variety of refrigerants. A majority of packaged refrigeration systems use halocarbon refrigerants. The use of R22, R134a, R404A, and R507 is common, depending on the system type, size, and application. **The environmental impact of these refrigerants varies considerably, and much work has been done in recent years to identify new, more environmentally-friendly refrigerants, largely in response to government restrictions and requirements for use.** The use of carbon dioxide (CO_2) is gaining popularity, particularly in supermarkets. Hydrocarbons have been proposed for smaller scale appliances, such as small coolers and display cases, but use is pending EPA approval and refrigerant charge will be limited given flammability concerns.

Refrigerated Warehouses

Refrigerated warehouses include both public and private storage facilities and distribution centers where all or a portion of the building may be used to store cooled or frozen products. Warehouses may include unitary equipment, though most large buildings developed for private companies have applied refrigeration systems that are custom designed to meet specific product needs. For buildings not using unitary equipment, larger ammonia systems are fairly common for warehouse applications.

Refrigerated Transport

While refrigerated transport systems may not be of immediate interest to utility companies, the technologies employed are sufficiently relevant. Understanding refrigerated transport and its interaction with and impact on retail and warehouse applications is also important. As refrigerated transport systems improve, and traveling distances increase, warehouse storage can be further consolidated, with the potential to reduce total connected building load. Refrigerated transport systems account for truck/trailer, rail, marine, and air transport. These systems are unique in terms of their operational challenges, as they heat and/or cool at multiple temperature levels, often simultaneously.

Market Overview

Defining the boundaries of the commercial refrigeration market is extremely challenging, making it difficult to obtain reliable information on market size, expenditures, and energy consumption. The US is the world's largest market for commercial refrigeration equipment and is expected to account for nearly a quarter of global sales through 2016.[2] Estimates of market size are generally on the order of $21–26 billion in revenue per year. **Of the three primary applications studied, commercial retail food storage represents the largest market share, at nearly $11 billion, and shows the greatest area for potential energy savings and system improvements.** Refrigerated transport applications are expected to see the fastest growth over the next five years, from roughly $7 billion to nearly $11 billion, due to anticipated increases in international trade and the potential for consolidation of refrigerated warehouse space.

The market for any of the applications is largely divided among many manufacturers. While there are several key companies that represent a sizable portion of the market (generally 20–25%), the remainder is flooded by smaller developers and distributors. Key manufacturers for the foodservice market include True Manufacturing Co., Manitowoc, and United Technologies. United Technologies (Carrier Transicold) is also a key contributor for refrigerated transport systems, along with Ingersoll Rand. Lineage Logistics and Americold Logistics are the top manufacturers in the refrigerated warehouse sector, but this market is particularly unique since most refrigerated warehouse systems are field engineered

[2] *Summary of World Commercial Refrigeration Equipment to 2016*, Polar Technology, Retrieved from: http://refrigerantauthority.com/commercial-refrigeration-equipment-market-forecast-to-reach-32-0-billion-by-2016/

and erected. This has led to the development of a two-tiered market structure in the refrigerated warehouse construction industry, consisting of original equipment manufacturers of individual refrigeration components, and the contractors who assemble the components to build a functioning turnkey refrigeration system for delivery to the final client.

Energy Consumption and Savings Opportunities

Energy Consumption

In addition to dominating sales, the commercial refrigerated retail industry is also the biggest contributor from a connected energy perspective. **The foodservice industry, including both food sales and food service buildings, has the highest energy use per square foot in the commercial sector as a direct result of the need for refrigeration equipment.**[3] Refrigeration accounts for more than 45% of the total energy consumption for food sales buildings[4] and over 15% for food services buildings,[5] which are primarily dominated by cooking. Specifically, refrigeration in commercial retail (food sales and service) buildings consumes five times more energy than in warehouses, as illustrated in Table 1.[6]

Table 1. Energy Consumption Associated with Commercial Refrigeration Equipment

Description	Energy Consumption (trillion Btu)
Refrigeration in Warehouse Buildings	36
Refrigeration in Food Sales and Food Service Buildings	189
Refrigeration for All Commercial Buildings	381

Supermarket equipment specifically, including display cases, compressor racks, condensers and supermarket walk-ins, account for more than half of the energy consumption for commercial refrigeration applications. Energy usage by equipment type is detailed in Figure 1.[7]

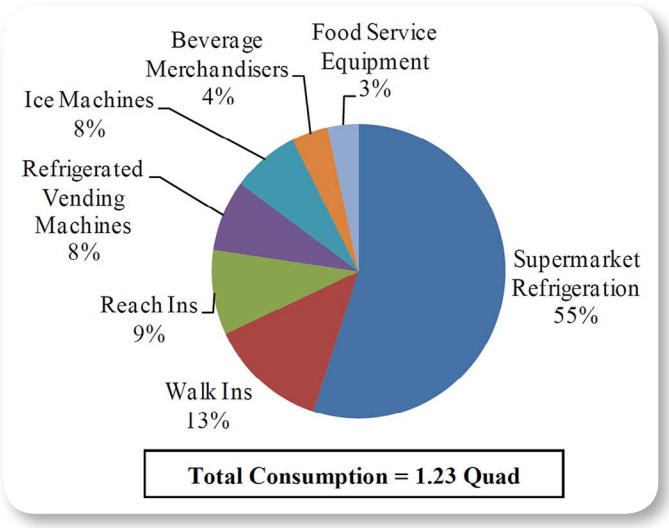

Figure 1. 2008 Annual Primary Energy Usage of Commercial Refrigeration Equipment by Type[8]

Energy Savings Opportunities

There are a number of energy savings strategies that have been identified for commercial refrigeration applications and technologies are readily available to reduce energy consumption and demand. The easiest methods to reduce energy consumption include such measures as:

- Using high efficiency lighting, including LEDs;
- Limiting the use of open display cases (without doors);
- Increasing and/or improving insulation;
- Using variable speed drives; and,
- Improving controls.

Of the energy efficiency measures that have been identified, some commercial refrigeration equipment is better suited to achieve energy savings than others and offer a larger opportunity. This is best depicted in Figure 2.[9] **Supermarkets represent the greatest market share and potential for energy savings, specifically through the optimization of controls and improvements in display cases, walk-ins, and reach-ins, which may either be stand-alone unitary systems, or connected as part of a larger distributed system.** Improvements in packaged, unitary equipment in general

[3] *Status of Energy Regulations for Commercial Refrigeration Equipment*. (2013, January). Emerson Climate Technologies. Pamphlet/brochure.
[4] Defined as retail or wholesale of food products, including grocery stores, food markets, and convenience stores.
[5] Defined as fast food, restaurants, and cafeterias.
[6] Energy Information Administration, (2003), *Commercial Building Energy Consumption Survey*, Office of Energy Markets and End Use.
[7] Note that the total of 1.23 Quad in Figure 1 accounts for electricity generation, transmission and distribution. Energy consumption values provided in Table 1 are site energy only and do not account for source energy.
[8] Navigant Consulting, Inc., (2009, September 23), *Energy Savings Potential and R&D Opportunities for Commercial Refrigeration*, Final Report for the US Department of Energy.

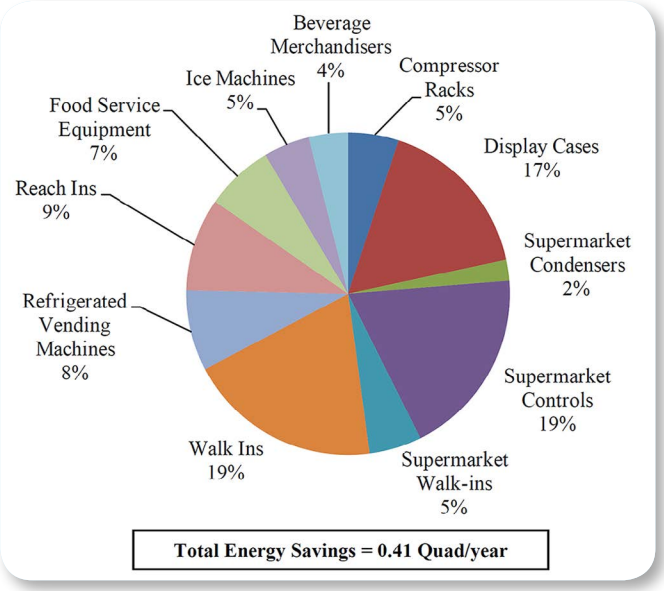

Figure 2. Annual Potential Primary Energy Savings by Commercial Refrigeration Equipment Type

can have a significant impact on energy savings for multiple applications and markets.

While recent DOE and EPA regulations have driven technology development in the industry, energy efficiency still does not seem to be the main concern for a majority of manufacturers or end users. Product presentation and reliability, or keeping product at the correct temperature and getting it to the end user, is the priority of merchandisers.

Research Summary

The primary focus of research in recent years has been on the use and performance of new, alternative refrigerants. As deadlines for existing refrigerant use approach, the industry must respond by finding suitable drop-in replacements and understand what, if any, system modifications must be made to accommodate those replacements. Work has explored a wide range of alternatives, including both "natural" alternatives and chemical refrigerant blends.

In addition to evaluating new refrigerants, recent research has also focused on the operation and incremental improvement of individual system components. Efforts to improve cabinet insulation, reduce lighting consumption, increase heat transfer performance, reduce defrost energy consumption, and optimize system controls have been identified and studied. Work has included analytical modeling and analysis, as well as some experimental testing and validation.

System level research appears to be less of a focus, except for the development of comprehensive modeling tools capable of serving as design and research aids to evaluate alternative component and system configurations. While some field test studies have been conducted, there is little work measuring actual system performance in either a laboratory or installed environment. Modeling efforts are being pursued by multiple research teams, and in a variety of software platforms. Validation work is largely outstanding.

Identified Research Gaps

While there is a considerable amount of research in development associated with the commercial refrigeration industry, a number of topics are not sufficiently accounted for. These include technical areas such as:

- Noise and acoustics;
- New methods of delaying/avoiding frost build-up;
- Minimization of frost through humidity control;
- Identifying alternative defrost strategies and/or improving evaporator design to minimize defrosting;
- Implementation of CO_2 systems;
- Combining refrigeration and HVAC systems;
- Energy savings potential of CHP systems, especially when integrated with emergency power supply;
- Overall assessment of energy savings potential through mathematically rigorous system optimization;
- Overall assessment of energy savings potential as a function of the first cost of better components, controls, etc.; and,
- Assessment of performance potential of non-vapor compression technologies in light of recent advances such as:
  - Electrochemical compression
  - Magnetocaloric cooling
  - Thermo-electrics

As new technologies are introduced to address changes in refrigerant and reductions in energy consumption, manufacturers and distributors have noted that better training is and will be needed for installing technicians.

[9] As in Figure 1, the energy savings total shown in Figure 2 is primary energy, accounting for electricity generation, transmission and distribution.

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