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# The Impact of Control Technology on the Demand Response Potential of California Industrial Refrigerated Facilities Final Report

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# Executive Summary

Demand response is a set of actions taken to shift or reduce a facility's normal operating electric load in response to a signal, such as market utility pricing or a request from a grid operator responsible for grid stability. Industrial refrigerated warehouses are ideal candidates for implementing demand response strategies due to a unique combination of factors: refrigeration loads account for a significant portion of the facilities' total energy usage, their usage is often greatest during utility peak periods, and the thermal mass of the stored product in the insulated spaces can often tolerate reduced cooling capacity for a few hours when needed.

While the demand response potential of this market segment in California is large (43-88 MW of theoretical potential based on an installed load of 360 MW), there has not been significant participation by the industry in demand response or automated demand response activities to date. It is only recently that industrial refrigerated facilities have drawn the attention of researchers seeking to understand what is necessary to leverage the curtailment potential of this segment. This report builds on prior demand response research efforts (Lekov, May 2009) by the Industrial Demand Response Team (part of the Demand Response Research Center at Lawrence Berkeley National Laboratory).

The primary objective of this report was to provide an overview of the variety of industrial refrigerated facilities, refrigeration systems, and control systems found throughout California. Since robust control systems are considered key to reliable and safe demand response participation, an evaluation of nearly three hundred facilities was undertaken to identify the current landscape of industrial refrigeration control systems found in the state. The evaluation included review of the information database developed to characterize these facilities as well as phone conversations with several facility managers.

In addition to a review of existing refrigeration and control systems, the second objective of this report was to identify the challenges to maximizing the demand response potential related to: facility types, operational factors and product quality, refrigeration system configurations and control system architectures.

The report was structured with sections addressing each of the primary objectives. The information presented in this report is intended to set the stage for future development of a set of specific demand response guidelines for the various types of industrial refrigerated facilities. This future effort would provide facility owners and operators managers with detailed, actionable demand response control options to apply in their individual facilities.

*Key Findings*

The survey of facility managers and analysis of the facility database yielded the following information concerning the current state of industrial refrigeration controls in California:

- 61% of the two hundred ninety-four surveyed industrial refrigerated facilities have integrated control systems where each component of the refrigeration system is under the supervisory control of a central controller. Integrated control systems are viewed as the most desirable starting point for control upgrades needed for demand response functionality.
- 33 of the 44 facilities known to participate in demand response activities have integrated control systems.
- Facilities with integrated control systems tend to be more efficient than their peers; three-fourths of the facilities with integrated control systems were judged to be moderate- to high-efficiency.
- All facility managers surveyed indicated an integrated control system is key to successful and safe demand response participation.
- Most of the facility managers surveyed were able to shut off all their cold storage areas for 3-6 hours without negatively affecting product.

# Introduction

## Background and Overview

In the May 2009 LBNL-1991E report, Lekov et al. noted that while there is significant demand reduction and energy efficiency potential in industrial refrigerated facilities (43-88 MW of theoretical demand response potential based on an installed load of 360 MW in California), actual participation by these facilities in such activities has been limited. It detailed the energy efficiency and demand response measures often implemented in these facilities such as load reductions accomplished through a combination of strategies, including shedding cold storage, reducing lighting and HVAC loads in non-essential areas, shifting cold storage loads through pre-cooling, and rescheduling battery chargers load to off-peak hours. These demand response strategies can be implemented with varying degrees of automation: manual demand response refers to load reductions effected via direct human intervention, semi-automated demand response refers to load reductions effected by personnel triggering pre-programmed control strategies, and fully automated demand response refers to load reductions effected by pre-programmed control strategies with no human intervention, though in many cases the participants have the choice to opt-out of events if desired. The report also identified some of the common facility and control system characteristics.

The current report seeks to present additional detail regarding the landscape of control systems found in California's industrial refrigerated facilities, including details of the common control devices and control architectures.  Also considered and presented are the pitfalls and barriers to demand response due to facility type, refrigeration system characteristics, or control system shortfalls and identifies how an integrated control design can be used to overcome these challenges.

## Key Research Questions

This research effort was focused on achieving two primary goals:

1. Evaluate the current state of industrial refrigerated facility control systems in California, and describe the various types of control systems
2. Identify how control technologies relate to the inherent demand response potential in the subject facilities and address the current barriers to successful implementation

# I. Current State of Industrial Refrigerated Facility Controls in California

## Overview

One of the challenges of characterizing the state of industrial refrigerated facility control systems in California is the wide variation due to key factors such as facility size, type, and vintage. While there are commonalities, facilities are unique and employ wide mix of controls systems. This section describes the facility, refrigeration system, and control system categories identified through the course of the survey to define the landscape of industrial refrigerated facility controls in California. After describing these common categories, the survey methodology and survey results are presented along with a number of key observations of industrial refrigerated facilities.

## Facility Types

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) defines refrigerated facilities as "any building or sections of a building that achieve controlled storage conditions using refrigeration." While the term refrigerated warehouse often brings to mind a facility wherein the sole purpose is to maintain the storage conditions of its product, many refrigerated warehouses are coupled with production facilities. The temperature ranges maintained in refrigerated warehouses are roughly classified as cooler facilities above 28°F and freezer facilities below 28°F. Many facilities have a combination of cooler and freezer spaces.

The survey of refrigerated warehouses identified two primary categories of facilities: pure refrigerated cold storage, and facilities which combine food processing and cold storage. The survey excluded facilities that performed only processing or lacked refrigerated building spaces for product storage.

### Refrigerated Cold Storage Facilities

In California, a facility with a refrigerated area larger than 3,000 square feet is considered a refrigerated warehouse under the Title 24 building standards (California Energy Commission, May 2009).

Refrigerated facilities include private warehouses, which store product the company distributes or produces elsewhere, and public refrigerated warehouses (i.e. privately owned, but offering short or long-term storage to multiple customers), which store product for others. Increasingly, public warehouses provide extensive logistics services and may also have blast freezing capabilities. Private facilities often have a similar mix of products and loads throughout the year, whereas public warehouses can see significant variations throughout the year and from year to year. Distribution centers for supermarkets are a noteworthy sub-category of these refrigerated warehouses, due to their large size and high product turnover rate (often less than 24 hours for some perishable products).

Most refrigerated facilities are single-story structures with shipping and receiving docks, and often pallet racking as near to the ceiling as possible to maximize storage space. Newer facilities are more likely to use mid-rise or high-rise design with automated or semi-automated material handling to increase product storage density or reduce labor costs. Some spaces will be designed for specific purposes, such as fast cooling and freezing or controlled-atmosphere conditions.

The types of refrigeration systems used by refrigerated warehouses vary greatly depending upon the storage temperature range, stored product, facility design, and facility size. Specifics of different refrigeration systems are discussed in more detail in the following section. Pure refrigerated cold storage facilities generally have sufficient refrigeration capacity to accommodate demand response activities while maintaining product integrity.

### Combined Processing and Storage Facilities

Combined storage and processing facilities are roughly divided into agriculture, food, and beverage facilities. Agriculture facilities pre-cool and package freshly harvested fruits and vegetables before storing them for distribution. Food facilities cover a wide variety, processing prepared foods, meats, bread, or dairy products and storing them before shipping. Finally, beverage facilities process juice, beer, wine, or carbonated drinks.

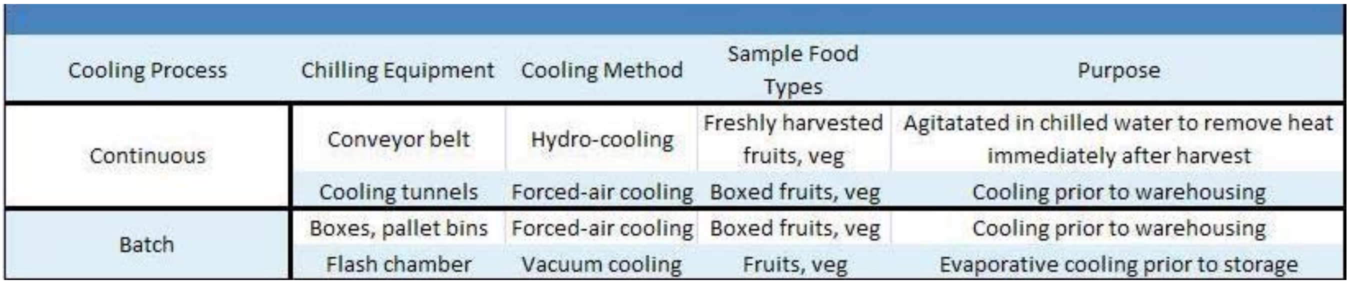
#### *Agricultural (Ag) Processing Facilities*

Fruits and vegetables begin to lose moisture and quality following harvest. Agricultural processing facilities are designed to rapidly cool freshly picked produce to a specified temperature before storing it in a constant temperature space. This process of rapidly removing field heat is referred to as pre-cooling.

There are three main processes used for pre-cooling fruits and produce: hydro-cooling, forced-air cooling and vacuum cooling. Hydro-cooling is a continuous process in which commodities are placed on a conveyor belt and sprayed with chilled water or immersed in an agitated bath of chilled water. Forced-air cooling drives chilled air through produce packed in boxes or pallet bins. It is most often a batch process where specified numbers of pallets are cooled at one time, but it can also be a continuous process where produce is automatically conveyed through cooling tunnels. Finally, vacuum cooling is a batch process in which products to be cooled are loaded into a flash chamber where the internal pressure is reduced to remove air and allow water contained on the products to evaporate and condense on cooling coils, cooling the products in the process (O'Neal & Aguilo, 2010).

After the commodities are pre-cooled to the desired temperature, they are placed in temperature and humidity-controlled storage spaces. Most vegetable and fruits are stored in conditions within the 32°F to 64°F or the 90% to 100% relative humidity range (Thompson & Singh, 2008). While pre-cooling operations generally cannot be interrupted (some can be deferred in certain cases), the cold storage areas of the Ag processing facilities can often be used to participate in demand response activities.

**Table 1. Summary of Common Chilling Systems Used by Agricultural Processing Facilities**



| Cooling Process | Chilling Equipment | Cooling Method | Sample Food Types | Purpose |
|---|---|---|---|---|
| Continuous | Conveyor belt | Hydro-cooling | Freshly harvested fruits, veg | Agitatated in chilled water to remove heat immediately after harvest |
|  | Cooling tunnels | Forced-air cooling | Boxed fruits, veg | Cooling prior to warehousing |
| Batch | Boxes, pallet bins | Forced-air cooling | Boxed fruits, veg | Cooling prior to warehousing |
|  | Flash chamber | Vacuum cooling | Fruits, veg | Evaporative cooling prior to storage |

#### *Food Processing Facilities*

Because food processors' operations span a wide range of foods and types of preparation, the methods, refrigeration systems, and processes used also vary considerably; however, they can be generally grouped into batch processes or continuous processes. Batch processes consist of discrete chilling or freezing periods when products are cooled to specified temperatures. Continuous processes integrate chilling or freezing into a continuous production line, which is most common for large volume production.

Continuous chilling systems can involve elaborate mechanical conveying systems, such as conveyor belts, tumble systems, and power drive rakes (O'Neal & Aguilo, 2010). Facilities with batch cooling processes often have a dedicated holding space for the product being processed, such as a blast freezer room or shipping containers. The primary cooling methods used in either continuous or batch processing are contact, spray, or forced air. For example, poultry carcasses can be chilled continuously by being pulled through troughs containing agitated cool water and ice slush, cooled with cryogenic gases in an insulated tunnel, or blasted with chilled air while moving on conveyor belts (O'Neal & Aguilo, 2010). In another example, small quantities of beef carcasses are often sprayed with chilled water or brine for up to 3-8 hours inside a chiller room until the surface temperature drops between 35°F and 45°F (O'Neal & Aguilo, 2010). While the number of cryogenic cooling installations is limited, there may be longer term opportunity to consider dual cryogenic and mechanical cooling systems as a means to manage demand, since cryogenic fluids (i.e. $CO_2$ and nitrogen) are stored in insulated tanks requiring little or no electric energy.  Additional examples of cooling processes used in food processing facilities are found in Table .

**Table 2.  Summary of Common Chilling Systems Used by Food Processors**

| Cooling Process | Chilling Equipment | Cooling Method | Sample Food Types | Purpose |
|---|---|---|---|---|
| Continuous | Conveyor belts | Contact, cryogenic | Poultry | Chilling of raw carcasses |
| | Tumble systems | Spray | Poultry | Chilling of raw carcasses |
| | Power-driven rakes | Ice contact | Poultry | Chilling of raw carcasses |
| | Directed flow | Contact | Milk, butter | Pasteurization |
| Batch | Shipping container | Ice contact | Fish | Chilling of raw carcasses |
| | Chilling room | Forced air | Meat | Chilling of raw carcasses |
| | Chilling room | Spray | Meat | Chilling of raw carcasses |
| | Holding tank | Contact | Milk, butter | Pasteurization |
| | Storage room | Forced air | Egg | Chilling received and packaged eggs |
| | Storage room | Contact | Baked goods | Dough and bread cooling |

Freezing systems share many of the same characteristics of chiller systems. There are continuous or batch systems, whose main methods of cooling are forced air, contact, or sometimes cryogenic (O'Neal & Aguilo, 2010). Freezing systems are much more commonly used by prepared or precooked food processors than other types of food processors. For example, after cooking, assembling, and packaging, completed prepared dinners are placed on straight multi-pass belts, where cold air is blasted over the products till they are frozen. Numerous other continuous freezer systems exist. Some use spiral belts that are wrapped cylindrically, one tier below the next, and others use cryogenic gases such as nitrogen or liquid oxygen as the refrigeration medium. Small scale ice-cream producers often freeze their products in batches via contact plate freezers. The products are pressed between metal plates that contain channels for recirculating direct-expanded refrigerants. Some common freezing processes used by food processors are summarized below in Table 3.  Similar to Ag processing facilities, the cold storage areas of food processing facilities can often be used to participate in demand response activities, while it is less likely that production activities can be suspended.  However, some batch processes may be deferred in certain situations.

**Table 3. Summary of Common Freezing Processes Used by Food Processors**

| Cooling Process | Chilling Equipment | Cooling Method | Sample Food Types | Purpose |
|---|---|---|---|---|
| Continuous | Straight or spiral belt | Forced air | Prepared food | Finished goods freezing |
| | Fluidized beds | Forced air | Prepared food | Finished goods freezing |
| | Fluidized belts | Forced air | Prepared food, poultry | Finished goods freezing |
| | Carton | Forced air | Prepared food | Finished goods freezing |
| | Contact belt | Contact | Prepared food, ice cream | Finished goods freezing |
| | Automatic plate | Cryogenic | Prepared food | Finished goods freezing |
| | Straight spiral belt | Cryogenic | Prepared food | Finished goods freezing |
| | Air-blast tunnel | Forced air | Poultry, fish | Finished goods freezing |
| Batch | Cold storage room | Forced air | Processed food | Finished goods freezing |
| | Stationary blast cells | Forced air | Processed food | Finished goods freezing |
| | Push-through trolleys | Forced air | Processed food | Finished goods freezing |
| | Manual horizontal/vertical plate | Contact | Processed food, ice cream | Finished goods freezing |
| | Batch cabinet | Cryogenic | Processed food | Finished goods freezing |

*Beverage Production Facilities*

Beverage facilities also utilize a variety of different refrigeration processes to produce fruit juice, beer, wine, and carbonated drinks and store their products prior to distribution. To provide fresh juice year round, juice processors often freeze and store fresh juice, or store it in an aseptic environment right above freezing point (O'Neal & Aguilo, 2010). Juice facilities often store finished product in three different temperature ranges: 0°F, 15°F, and 30°F. Drums of highly concentrated juice are usually stored in the lower temperature ranges while juice in retail packages is often stored at the higher temperature ranges.

Breweries utilize cooling processes at several points during beer production. Wort is liquid extracted from the mashing process of grains and contains the necessary sugar and starch for fermentation. Breweries often cool down boiling wort from the kettle (at roughly 160°F) to between 45°F and 55°F in a continuous process, first by using potable water and then by direct expansion of refrigerant, or with an intermediate medium such as chilled water or glycol. During the fermentation process, refrigeration is used to control the rate of fermentation. After fermentation, facilities typically cool the beer to the desired range of 29°F to 45°F in a batch fashion before it goes into storage (O'Neal & Aguilo, 2010).

Wineries use fermentation temperature control processes similar to a brewery; however, they also utilize unique refrigeration processes such as must cooling and juice cooling. Must is freshly pressed grape juice with the grape skins that can be cooled down in a continuous or batch process before being introduced to a juice-draining tank. Similarly, the juices separated and filtered from the must are usually cooled down to between 35°F and 75°F in a continuous fashion, depending on the type of wine being made (O'Neal & Aguilo, 2010). While they include a combination of batch and continuous processes, beer and wine production (before storage of finished product) is very time and temperature dependent, and not very conducive to interruptions for demand response.

## Types of Refrigeration Systems

Industrial refrigeration systems found in refrigerated warehouses and production facilities are typically one of three main varieties: split systems, packaged rack systems or built-up systems.

**Split Systems**

Split systems consist of a condensing unit (a condenser with compressor(s) combined into one package) piped to one or more direct-expansion evaporator coils located within the refrigerated space (Figure 1). Split systems are most often used in smaller facilities due to their lower initial cost (at the expense of energy efficiency and operating cost) compared to packaged rack systems or built-up systems.

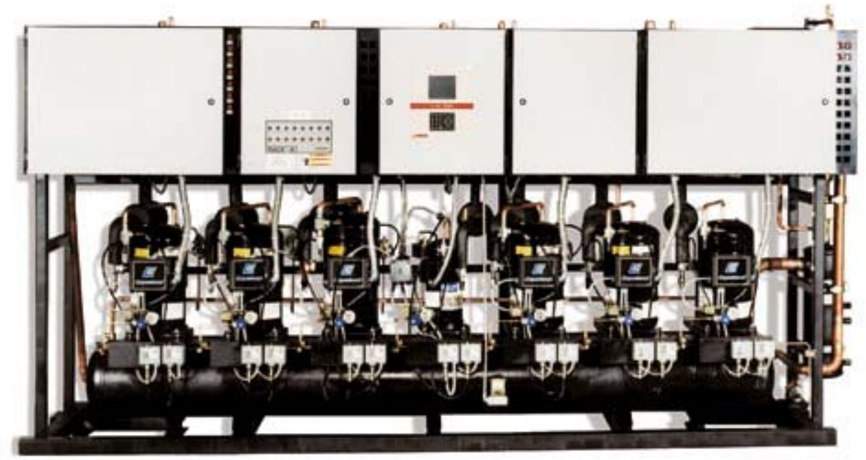
Air cooled condensers are most common and essentially all split systems utilize halocarbon refrigerants. These systems have limited capacity modulation and typically use on/off control of the compressor to maintain temperature. Larger condensing units (>50 BHP of compressors) may feature compressor unloaders for compressor capacity modulation.

*(Courtesy National Refrigeration and Air Conditioning Products Canada Corp.)*

**Figure 1. Example of a Condensing Unit for a Split Refrigeration System**

**Packaged Rack Systems**

Packaged rack systems (Figure 2) are also halocarbon systems that typically utilize multiple small screw compressors or semi-hermetic reciprocating compressors in a parallel configuration. Most often, they serve direct expansion evaporators in the facility's spaces, and the condensers can be either air-cooled or evaporative-cooled. Parallel systems inherently have more steps of capacity and may have unloading capability on individual compressors; they typically range from 50 BHP to 500 BHP in compressor power (Wylie, May 2008). Packaged rack systems more readily accommodate controls for energy efficiency than split systems, such as floating head pressure, floating suction pressure, and variable speed evaporator fan control.



*(Courtesy Hussmann Corporation)*

**Figure 2. Example of a Parallel Rack Refrigeration System**

**Built-Up Systems**
Built-up systems (Figure 3) are typically what are envisioned when industrial refrigeration is mentioned. As the name implies, system equipment such as evaporators, compressors, and condensers are selected individually to meet the needs of the customer and integrated by a system designer who also sizes the interconnecting piping and valves. The system components are assembled in the field. Because the system is customized, the controls are also customized. Built-up systems range from 300 BHP to over 10,000 BHP of compressor power. Halocarbon refrigerants can be used in built-up systems but ammonia is the primary refrigerant, particularly on large systems.

Not surprisingly, custom built-up systems exhibit the widest variability in system configuration. Systems can be single stage (one stage of compression between the evaporators and the condensers) or two stage (where a booster compressor discharges to the suction level of a high stage compressor). Single stage systems can also have multiple suction groups (a group of compressors operating at a common suction pressure) depending on the nature of the loads. One example might be a refrigerated warehouse with both 34°F and 0°F spaces; with a suction group serving the 0°F spaces and another serving the 34°F spaces.

Built-up systems most frequently use evaporative-cooled condensers, although air-cooled condensers are possible. The system evaporators can be direct expansion, flooded, or pump recirculated.

**Figure 3. Example of a Custom Built-Up Refrigeration System**

## Types of Industrial Refrigeration Control Systems

Refrigeration control systems have evolved significantly in recent decades. Due to the long lifespan of most refrigerated facilities, it is not uncommon to see several vintages of equipment and controls arranged in different configurations at a single facility. The evolution of refrigeration control systems has also resulted in a blurring of the distinction between systems historically defined as distributed control systems (DCS) or as supervisory control and data acquisition systems (SCADA). Adding to the confusion is the fact that the term distributed control system is also used in the refrigeration industry to describe control architectures where multiple standalone controllers are networked together under a master scheduler controller.

Rather than attempting to resolve these varying control definitions, the first step in understanding industrial refrigeration control systems was to address the following question:

> *How many distinct controllers or control devices would require individual signals to in order to achieve the desired results in a demand response event?*

The answer to this question led to the recognition of two macro categories: standalone controls and integrated controls. A standalone control system requires an automated demand response (Auto-DR) request to be sent to multiple devices in the same facility, while a facility with an integrated control system needs one point of connection with the Auto-DR signal.

Note: The above designation refers only to control of the refrigeration system and directly related loads. Few facilities, even those with integrated controls, incorporate non-refrigerated processes, lighting or HVAC controls with the refrigeration system controls.

## Standalone Controls

For industrial refrigeration systems, standalone controls cover a broad range of control devices and levels of complexity. At the most basic level of electro-mechanical devices, thermostats, timers and pressure switches are used to start and stop equipment. These mechanical devices are inherently independent and have no ability to communicate with a master controller.

An example with much greater control sophistication is the microprocessor control panel (micro panel) used on nearly all screw compressors. The micro panel automatically operates the compressor capacity controls and commonly provides extensive data to a central operator interface. While the micro panels often have the ability to do a higher level of control or be part of a supervisory compressor-group control strategy, it is very common to find individual compressors set to "local" control mode, with operators determining the required compressor "mix"; thus the compressors micro panels are functionally standalone controls.

Regardless of their relative sophistication, standalone systems are individual silos of control. They execute actions based on their control inputs and function but have no visibility to other areas of the refrigeration system or facility and do not receive direction from a supervisory controller. Facility operators or maintenance contractors make adjustments and changes as needed to individual controls.

### *Electro-Mechanical Devices*

Electro-mechanical control devices, such as pressure or temperature switches, are commonly found in industrial refrigeration systems. Historically, these devices would be used to provide primary control of key system components such as compressors and defrost cycles. These devices can be found today in many smaller facilities using split systems or condensing units; however, in large central plant systems they are more commonly found providing redundant safety or backup operation for equipment controlled by an integrated control system. Next to life safety, product quality is the most important objective of a facility operator, so even the most sophisticated integrated control system will commonly have provisions allowing the operators to run equipment without the control system if necessary.

Figure 4 shows two common examples of mechanical pressure switches in industrial refrigeration systems. The upper photo shows pressure switches on a reciprocating compressor. The lower photo shows a row of pressure switches used to control evaporative condenser fans in a large refrigerated warehouse.

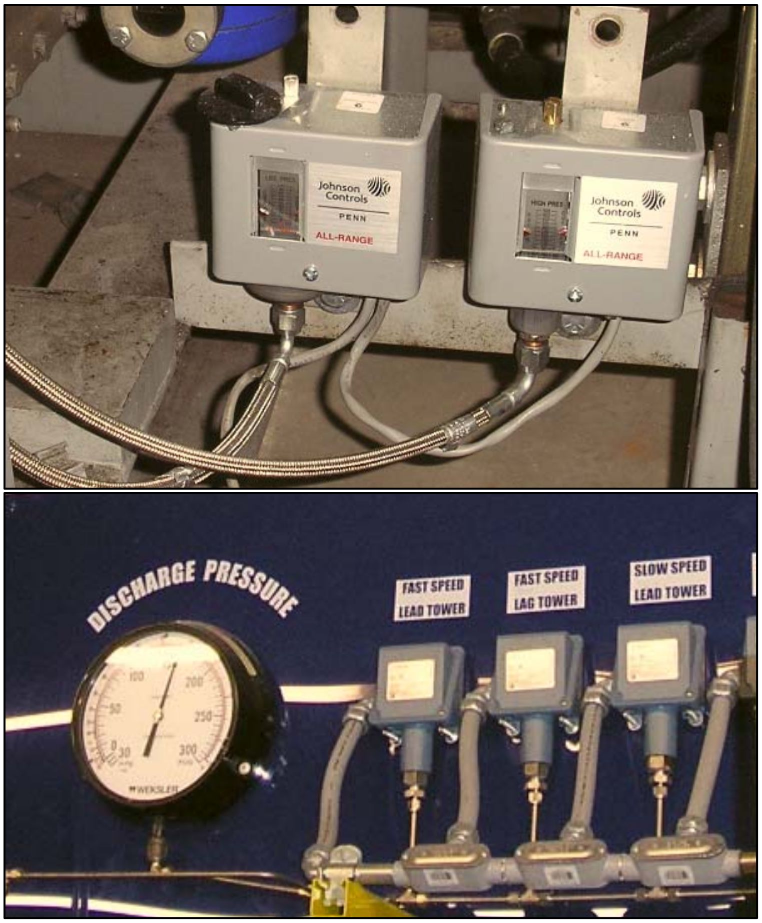


**Figure 4. Examples of Mechanical Pressure Switches**

Figure 5 shows a panel with mechanical time clocks wired to the evaporator fans and control valves in a cold storage facility. The start times and durations set on the clock activate the devices in the proper sequence to accomplish the periodic defrosting of the evaporator coil. While most of these clocks have been replaced with PLC control in modern facilities, they can still be found in smaller and older plants.

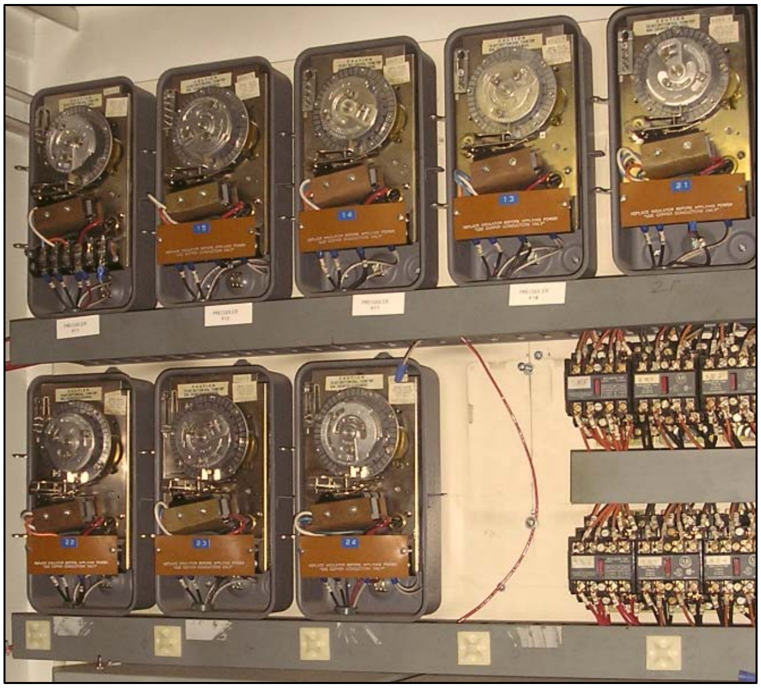
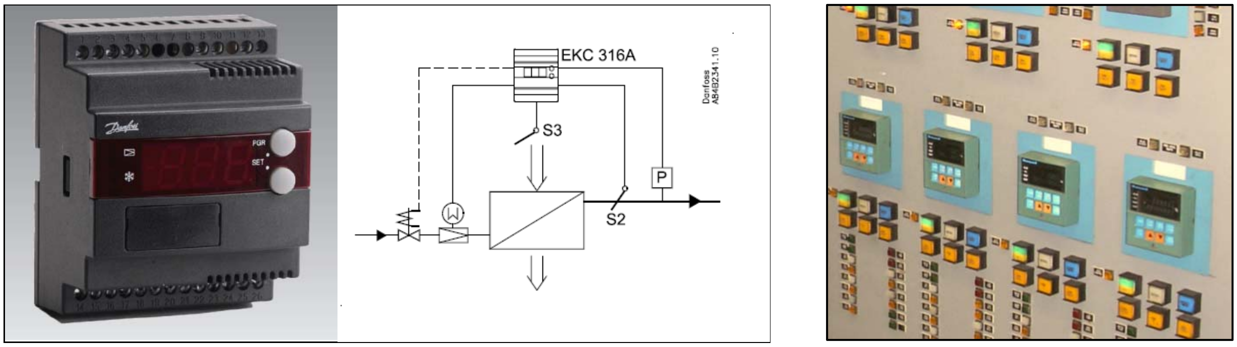


**Figure 5. Example of Mechanical Time Clocks**

*Closed-Loop Temperature or Valve Controllers*

Standalone closed-loop controllers are found less often in industrial refrigeration systems but are still common enough to bear mentioning. Typically, these controllers perform one primary control function such as temperature control, although some can provide an additional function. Some of the newer controllers can communicate with a supervisory control system, but most operate autonomously.



*(Courtesy Danfoss North America)*

**Figure 6. Example of Closed-Loop Valve and Temperature Controllers**

Figure 6 shows a photo and a control diagram on the left of a standalone electronic temperature/superheat controller that could be used on a split system. The right-hand photo shows a panel with a number of individual temperature controllers on a large central system, with each controller monitoring the zone temperature associated with a given evaporator and modulating a pressure regulator to maintain the zone temperature setpoint. In both instances, the controllers provide standalone control, and may or may not have communications with a central user interface.

*Variable Speed Drives*

Variable speed drives (VFDs) are most often implemented in a system with integrated controls, where a supervisory controller takes inputs from various sensors or devices and sends a desired speed reference signal to the VFD. In some instances, the variable speed drive itself may provide the "intelligence" for the required control, in this case by varying the condenser fan speed.

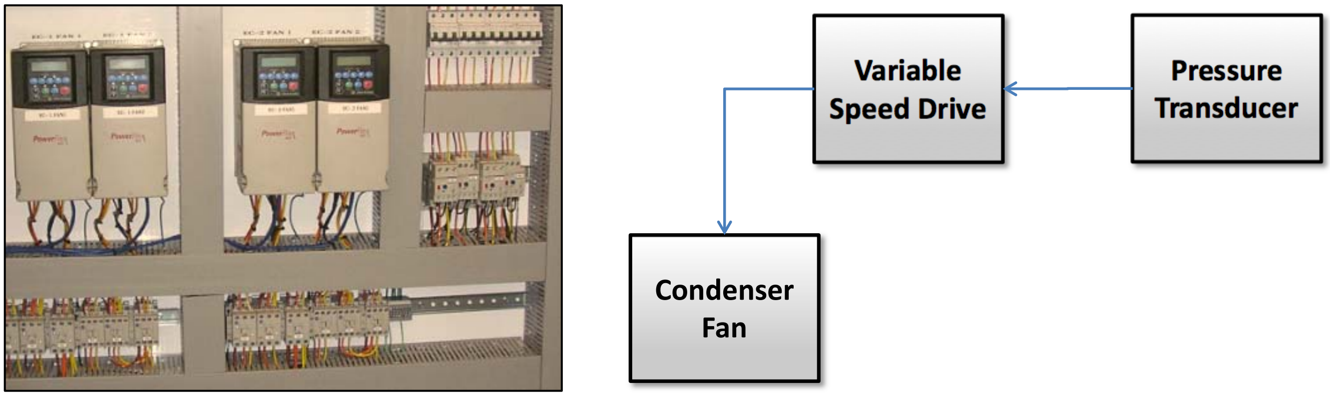


**Figure 7. Example of Variable Speed Drives**

*Split System and Condensing Unit Controllers*

Split systems (a condensing unit with one or more remotely connected evaporators) are most commonly controlled using pressure switches and thermostats to start/stop the system compressors and fans and to maintain space temperature. Defrost is often accomplished using mechanical time clocks. However, many manufacturers offer electronic controllers for split systems (Figure 8), which help improve visibility into system operation.

*(Courtesy Heatcraft Refrigeration Products LLC)*

**Figure 8. Example of Condensing Unit Controller Interface Panel**

In addition, California's Title 24 building standards for refrigerated warehouses, implemented in 2010, require systems serving spaces greater than 3,000 square feet to have floating head pressure controls and variable speed condenser fan controls. Split system controllers are available that incorporate this required head pressure control for improved efficiency as well as electronic expansion valve control, demand defrost controls, evaporator duty cycling controls, and compressor capacity modulation. A small facility would often have multiple split systems, each with its own standalone controller.

*Compressor Micro panels*

Industrial screw compressor control panels have evolved significantly over the last 30 years, from basic gauge and electro-mechanical panels to sophisticated compressor controllers that are self-contained and manage everything needed to operate a refrigeration compressor, including monitoring pressures, temperatures, and even vibration. These controllers monitor suction pressure and perform start, stop, load and unload functions in order to maintain the suction pressure setpoint.

(Courtesy GEA FES, Inc.)

**Figure 9. Examples of Screw Compressor Micro panels**

Newer compressor micro panels, such as the two seen in Figure 9, can communicate with a supervisory controller in an integrated control system. These panels can also be used to control a compressor variable speed drive, which varies speed to meet the target suction pressure.

### Integrated Controls

Since industrial refrigeration systems are generally unique and customized for each facility, the integrated control systems are similarly customized and can take a variety of forms. This is true for field erected built-up systems, skid-mounted industrial packages and light industrial parallel rack systems. Even when cataloged split systems are used, the quantity and combinations of components and controls are different for each application. This section of the report will discuss some of the common control system components and control architectures found in the field. Control system components can be generally grouped into three categories: processors/controllers, visualization, and input/output hardware. Control architectures are either centralized, distributed, or a hybrid of the two.

In considering added demand response capability at a facility, a key consideration is the effort required to make changes to an existing control system, as well as the degree to which end uses can be effectively controlled.

### *Control System Components: Processors/Controllers*

There are many types of controllers used in refrigeration control systems. A common choice is to use programmable logic controllers (PLCs) made by companies such as Allen-Bradley, GE, Siemens, etc. These are general purpose industrial controls used widely in a many industries. Programming requires specialized skills but can be provided by numerous integrators, control manufacturers, contractors or end users. PLCs commonly employ "ladder logic" or other standard forms, with the program logic accessible, allowing the owner to make changes when needed, making the application logic essentially non-proprietary. Some manufacturers refer to their processors by different names, such as PAC (programmable application controller), which in this report will all be grouped and referred to as PLCs. It is important to note that the PLC manufacturers do not provide the refrigeration control programs, only the "blank" controllers and the software for others to use in developing the actual control logic.

Changes to an existing industry-standard PLC program are typically made by using the manufacturer's standard programming software; compared with a proprietary controller where the logic may be either "canned" or otherwise not accessible, except by the manufacturer. However, many existing PLC programs are poorly documented and have evolved over time, and may be the product of a programmer who is no longer available. The flexibility and accessibility of PLC controls means that almost anyone can program a PLC, and existing control systems certainly reflect this fact. Moreover, PLCs are often integrated with safety systems (important for all facilities, but ammonia plants in particular), requiring considerable investigation and possible upgrading before demand response features can be added. The PLC programming software, visualization software runtime and programming software versions, PC operating system and operator interface PC itself are often "tied" together at a certain vintage of technology. With all of these factors, it is very common for a small change to precipitate an extensive (and expensive) upgrade to hardware, software and programming.

Several control manufacturers who focus on the industrial refrigeration industry offer systems with varying combinations of standard and proprietary hardware and/or software, often developed to meet the needs of a particular food or beverage sector. Several industrial refrigeration compressor manufacturers provide branded controllers, with "canned" software and networking capability. In this report, these will be termed proprietary controllers. *It can be noted that the PLC programming software and the operating program within a PLC is certainly proprietary, but the reasoning for this definition is that this software from large, general industrial control manufacturers is likely to always be accessible to owners and integrators, making the resultant logic effectively non-proprietary.* Making changes to these proprietary controllers is far less certain than with PLCs. Changes must be made by the manufacturer, who sometimes may not be in business or may no longer support the subject controller. If the desired feature is available on a more current program chip (or via download), the change can be easy and inexpensive. If new programming is required, the cost and time required can be prohibitive.

A few companies use personal computer (PC)-based control logic (termed "soft logic" control), often in conjunction with industrial I/O (input/output) hardware, combining one PC to provide the control logic and run visualization software. The underlying software is proprietary. Changes typically must be made by the control vendor, but changes may often be relatively easy to implement compared with PLC ladder logic control code.

### *Control System Components: Visualization*

Visualization into the control system operation is frequently comprised of a single workstation or a client-server arrangement and is often referred to as the human-machine-interface (HMI). In both structural arrangements, the HMI is used to view the status of the controlled devices, change setpoints in the controller(s), monitor system alarms, and review operational data trends. Most of the time, the visualization is located on a separate computer from the controllers; in the event of a HMI computer failure, the refrigeration system processors will continue to run unaffected with the last received setpoints from the HMI.

A single workstation is often a desktop PC or a panel-mount PC running the visualization software and is directly connected to the processor(s). The PC is often located close to the refrigeration engine room or maintenance office. While this is a simple and cost-effective approach, a potential drawback is that system information is only available to a maximum of two users at a time: at the visualization panel and via remote access over the plant network.

A client-server HMI system is more costly due to additional hardware and software licenses but provides greater flexibility in viewing system information. Data is exchanged between the system controller(s) and a HMI server, which runs the visualization software and stores trend data. Clients are computers located anywhere in the facility running the HMI client software. When a user logs in to the system via the client, the current system data and setpoints are sent from the server to the client. Multiple clients can be logged in at the same time, allowing personnel from different departments to view system information. Client-server arrangements are also useful in large facilities where equipment may be spread out over a large area; clients can be installed at key locations near important equipment to facilitate maintenance, diagnostics, and monitoring capabilities.

*Control System Components: Input/Output Hardware*

Regardless of whether the control system uses a PLC or PC-based processor, most integrated control systems use standard off-the-shelf input/output (I/O) hardware from one of the major PLC manufacturers (such as Allen-Bradley, GE, or OPTO-22). Input/output hardware is comprised of five categories; digital inputs, digital outputs, analog inputs, analog outputs, and communications modules.

The hardware is typically purchased in the form of cards or modules that serve a particular function and plug into a rack that provides the physical mounting, communications, and power link between the processor and the cards. Figure 10 shows an example of a control panel containing a rack with a PLC and various I/O modules. The PLC provides the processing and executes the control program while the I/O modules are the interface to the controlled devices.

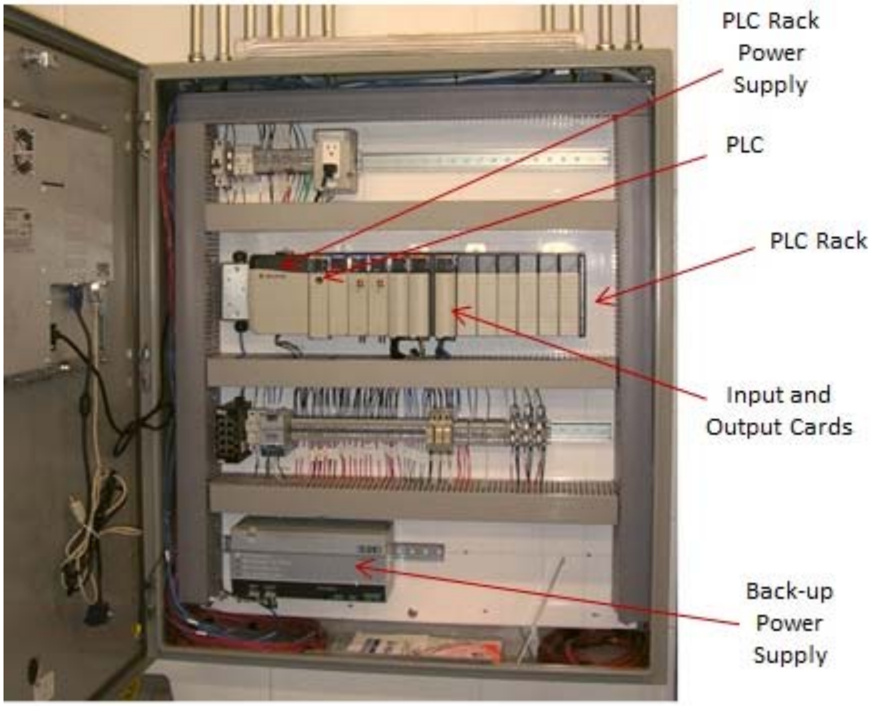


**Figure 10. Sample Industrial Control Panel with PLC Rack and IO Modules**

The I/O hardware can be directly connected to (in the same rack as) the processor or located on a remote rack closer to the controlled devices and connected via a communications link (remote I/O). Many times, a facility will utilize both; however, the same controller is managing the I/O.

A number of proprietary control systems utilize various forms of printed circuit boards for controllers, I/O or a combination of both. Individual panels or modules typically have defined functions, i.e. condenser controllers or evaporator controllers. Typically the control functions are distributed and can be either stand-alone or networked. These systems seem to have diminished use, particularly with the increased complexity associated with energy efficiency features in the last ten years, but there are many existing facilities with legacy controllers of this type.

### *Common Integrated Control System Architectures*

In the field of industrial refrigeration, integrated control architectures are typically a central control configuration, a distributed control configuration, or a hybrid of the two.

A central control configuration has one primary processor controlling individual devices via I/O, similar to the simple example system shown in Figure 11. Control of the condensers and evaporators consists of monitoring pressure and temperature sensor inputs and device status feedback, and then enabling/disabling system valve solenoids and fan starters or VFDs based on the program logic. The interface with the compressor micro panels is often a combination of hard-wired I/O (digital inputs/outputs, analog inputs/outputs) and communications such as Ethernet or Modbus. While the micro panels manage some of the compressor package safeties and alarming, the primary control of the compressors resides at the PLC with respect to starting, stopping, loading, and unloading the compressors for optimal efficiency. The system suction setpoint and any floating suction controls would reside at the PLC level as well. If the controller were to fail, the system devices would have to be operated manually. Due to the reasonably high reliability of PLCs and the capability to run the facility manually if necessary, many facilities are comfortable having a single, central PLC and the ability to manage their usage with less control hardware cost.

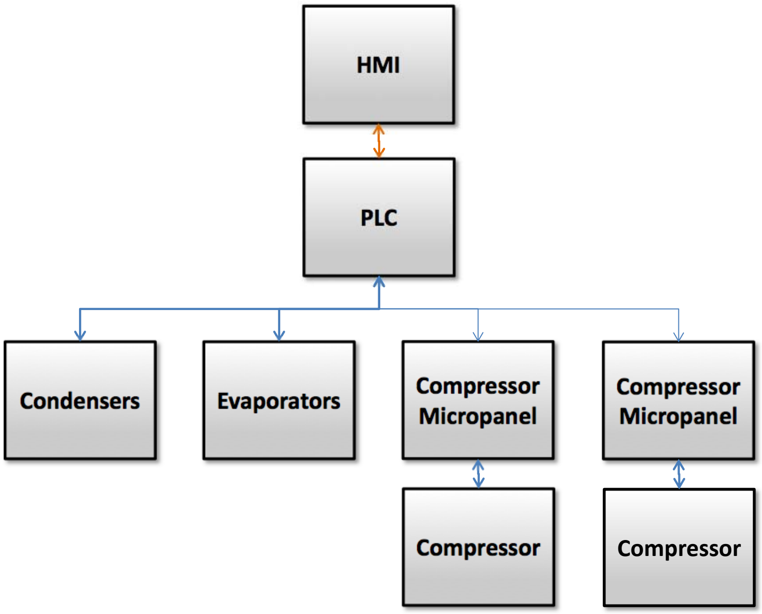


**Figure 11. Example of a Central Control System Configuration**

In the context of industrial refrigeration control systems, a distributed control configuration has one supervisory processor interfacing with multiple standalone controllers. While this is more hardware and software intensive, it provides a degree of redundancy that certain facility owners feel is necessary. In the event the supervisory controller fails, each standalone controller continues to operate with the last received data from the supervisory processor, and perform its programmed control and energy efficiency functions.  The supervisory controller typically provides master scheduling (including demand response) for the various processors and their controlled devices, as well as a common platform for overall visualization, setpoint modification, alarming, and trending.

Figure 12 shows an example of a distributed control configuration that might be found in a smaller warehouse with multiple split systems.  Use of distributed controls in conjunction with distributed individual refrigeration systems has obvious consistency in terms of maintaining the advantage of individual units—one failure does not affect other systems.

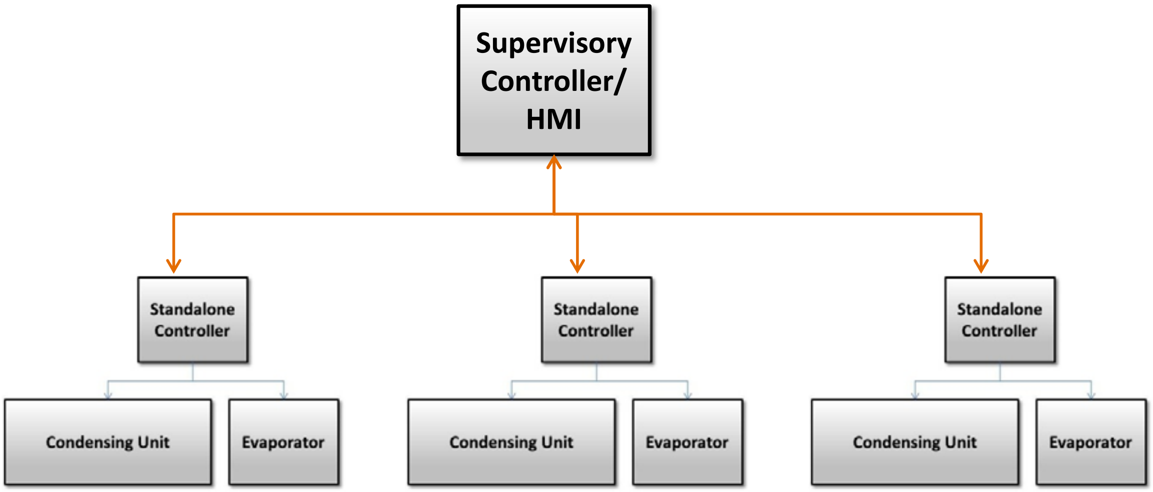


**Figure 12.  Example of a Distributed Control System Configuration**

Each standalone controller performs all the necessary control functions to cool a given zone to its setpoint based on its associated sensors and inputs.  Energy efficiency measures such as floating head pressure, demand defrost, and off-cycle evaporator fan control would also be handled by the standalone controllers.

Many control systems are a hybrid of central and distributed control configurations as a result of facility expansion over time and available financial resources at each phase of the expansion.  In addition, acquisitions and mergers between companies with differing controls standards also results in configuration changes.

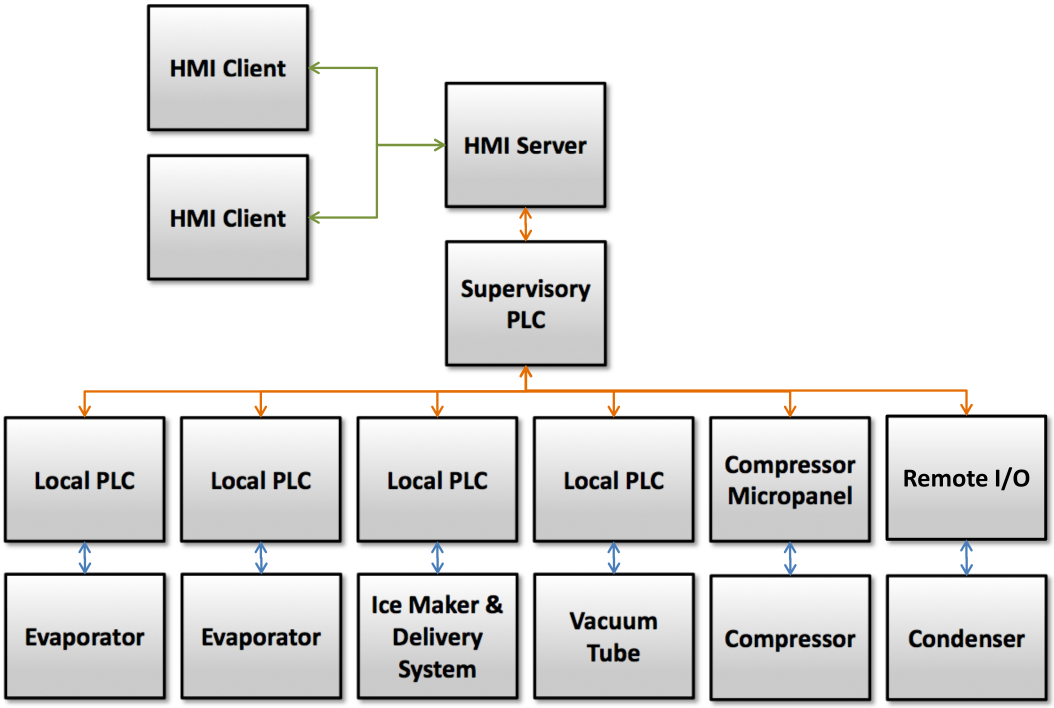


**Figure 13. Example of a Hybrid Control System Configuration**

Figure 13 provides an example of a hybrid configuration where various standalone PLCs control the evaporator, ice maker, and vacuum tube systems, and interface with a supervisory PLC that directly controls the compressor and condenser control functions. For reference, an example of a client/server HMI configuration is also included.

## Common Facility Configurations

The variety and vintage of facility types, system types, and control systems can be a challenge to understand, especially in the context of the relative effect of each permutation on a given facility's ability or willingness to participate in demand response programs.

The following table (Table 4) is an effort to identify typical refrigeration and control systems for various refrigerated facility types. While there are numerous exceptions, the intent is to help frame the landscape of industrial refrigeration controls in California.

**Table 4. Cross Reference of Common Facility and Control Configurations**

| | Common Refrigeration System Types | | | | Control System Types | |
|---|---|---|---|---|---|---|
| | Halocarbon | | | Ammonia | | |
| Refrigerated Facility Type | Split System | Parallel Rack System | Custom Built-Up System | Custom Built-Up System | Standalone | Integrated |
| Small Warehouses | √ | | | | √ | |
| Medium Warehouses | √ | √ | √ | | √ | √ |
| Large Warehouses | | | √ | √ | | √ |
| Small/Med Ag Processors | √ | | √ | | √ | √ |
| Large Ag Processors | | | √ | √ | | √ |
| Small/Med Food Processors | √ | | √ | √ | √ | √ |
| Large Food Processors | | | √ | √ | | √ |
| Small/Med Bev Producers | √ | √ | | | √ | √ |
| Large Bev Producers | | √ | √ | √ | | √ |

Although not called out in the table above, the facility vintage plays a role in the style of controls found in the different facilities. In general, the older the facility, the more likely it is to have standalone controls or a mixture of standalone controls and some limited PLC integration.

## Facility Control Survey

VaCom Technologies utilized its existing resources to compile a database comprising a significant number of existing industrial refrigerated facilities in California, including many facilities built or expanded in the last fifteen years. Data resources included information from site visits at many of these facilities, completed detail analysis of the potential for energy efficiency through control system upgrades, and in some instances, access to facility management who provided detailed insight into the system, facility, and controls characteristics.

Facilities were divided into the categories of Ag Processors, Food Processors, Warehouses, and Beverage Producers. The control systems were identified as to whether they were Integrated (Proprietary and Non-Proprietary) or Standalone (Partial PLC/Electromechanical Controls, Basic Non-Integrated Controls, or Mix of Control Systems).

A number of the listed categories have been discussed earlier in the report; however, for clarity's sake, the following definitions were used for the above categories:

*Facility Types:*

1. Ag Processors- storage facilities that pre-cool and process fruits and vegetables
2. Beverage Producers-storage facilities that make beer, wine, or other consumer drinks such as sodas
3. Food Processors- storage facilities that produce or process any other food product not included in 1 or 2
4. Warehouses- facilities that have no production, but only store products from categories 1, 2, or 3

*Integrated Control Systems:*

1. Proprietary- integrated control systems with proprietary hardware/software that would require an end-user to go back to the controls provider to get changes made
2. Non-Proprietary- integrated control systems with industrial standard platforms that can be modified by a knowledgeable programmer or controls integrator

*Standalone Control Systems:*

1. Partial PLC/Electromechanical Controls- system with some components under PLC or supervisory control and others running on electro-mechanical controls, such as pressure switches or thermostats

2. Basic Non-Integrated Controls- system with no supervisory control at all
3. Mix of Control Systems- applies mainly to facilities with multiple refrigeration systems, where the systems have different types of controls (one could even have supervisory control) that are not integrated together at the facility level.

When it was known, the refrigeration system type, relative capacity, and potential for energy efficiency improvements were noted to provide additional insight to the variety of facilities. Current participation in demand response activities was included as well.

## Facility Control Survey Results

Just under three hundred (294) facilities were evaluated to develop the landscape of industrial refrigerated facility controls in California. Facility locations ranged the entire length of the state (Figure 14), with expected concentrations in the San Joaquin and Salinas valleys as well as the major metropolitan areas surrounding San Diego, Los Angeles, and San Francisco.

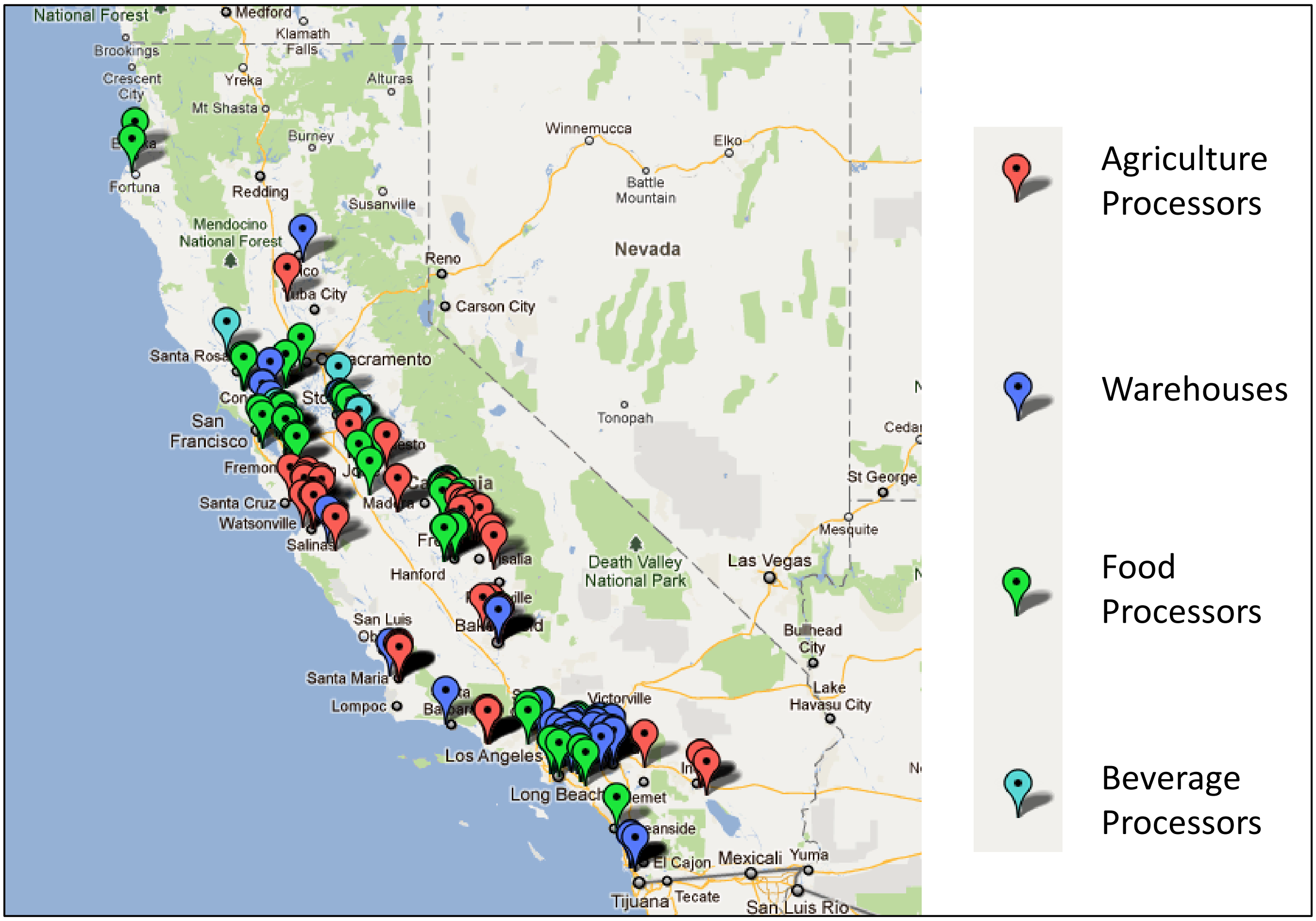


**Figure 14. Locations of Surveyed Facilities in California**

Figure 15 provides a pictorial representation of the current state of control systems in California industrial refrigerated facilities. For the four defined types of facilities, the graph shows the percentage of the facilities that currently have one of the five categories of control systems. The size of each bubble reflects the quantity of surveyed facilities in that category; consistent with the values also shown in Table 5. The data labels show those quantities as well.

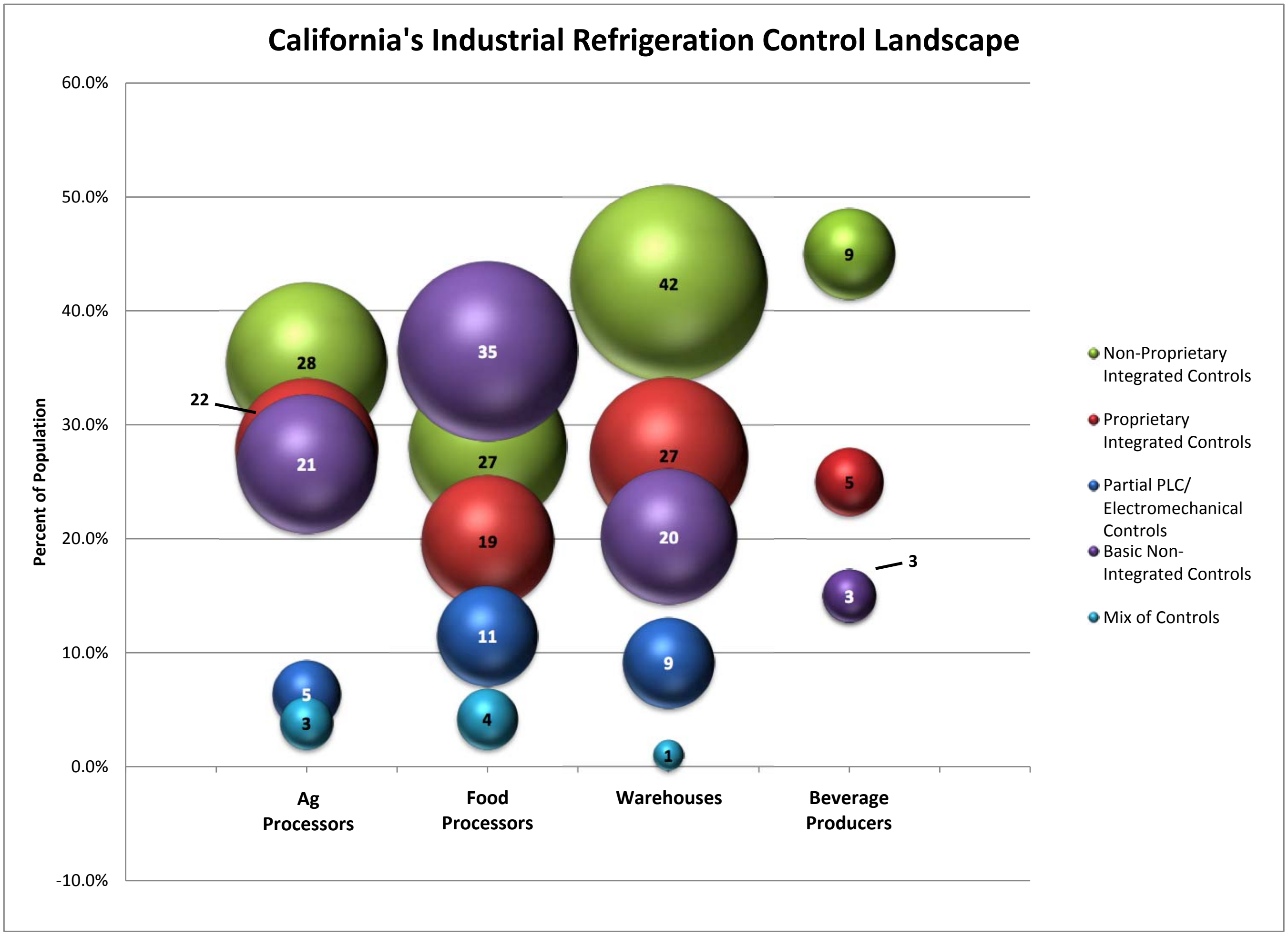


**Figure 15. Landscape of Industrial Refrigeration Controls in California**

The survey data was also captured in Table 5 for ease of comparison.

**Table 5. Summary of Facility Control System Survey Data**

| Quantity and Categories of Facilities Surveyed | | | | | |
|---|---|---|---|---|---|
| | Facility Types | | | | |
| **Control Type** | **Ag Processors** | **Food Processors** | **Warehouses** | **Beverage Producers** | **Total** |
| **Integrated Control Systems** | **50** | **46** | **69** | **14** | **179** |
| Non-Proprietary Integrated Controls | 28 | 27 | 42 | 9 | 106 |
| Proprietary Integrated Controls | 22 | 19 | 27 | 5 | 73 |
| **Standalone Control Systems** | **29** | **50** | **30** | **6** | **115** |
| Partial PLC/ Electromechanical Controls | 5 | 11 | 9 | 3 | 28 |
| Basic Non-Integrated Controls | 21 | 35 | 20 | 3 | 79 |
| Mix of Controls | 3 | 4 | 1 | 0 | 8 |
| **Total** | **79** | **96** | **99** | **20** | **294** |

## Discussion of Results and Additional Observations

*Key Findings*

Of the three hundred facilities, nearly 61% had an integrated control system that would provide a single interface point to the refrigeration system for demand response activities (with of course appropriate programming changes and control extensions). A majority (59%) of these integrated systems utilized a non-proprietary control platform; non-proprietary control systems increase the potential pool of controls providers that a facility could use to make programming additions required to implement demand response (DR) or Auto-DR.

With the exception of Food Processors, two-thirds of the remaining three categories of facility types each had integrated control systems (Table 6).

**Table 6. Percentage of Integrated Control Systems by Facility Type**

| Facility Type | Percent with Integrated Controls |
|---|---|
| Ag Processors | 63% |
| Food Processors | 48% |
| Warehouses | 70% |
| Beverage Producers | 70% |

Forty facilities were known to be currently participating in some type of a DR program. Of the forty, nearly 83% (33 sites) had an integrated control system. While not as large of a sample size as the overall survey, the high percentage indicates a potential correlation between integrated control systems and a facility's likelihood of participating in demand response activities. This was further reinforced with feedback from a number of facility managers, which is discussed in the next section of this report.

Approximately 58% of the facilities known to be participating in demand response were larger refrigeration systems with greater than 300 tons of refrigeration capacity. The following table (Table 7) provides some additional information on these facilities.

**Table 7. Summary of Facilities Known to Participate in Demand Response**

| Facility Type | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | Ag Processors | Food Processors | Warehouses | Beverage Producers | Total |
| **Participants by Facility Type** | 8 | 9 | 18 | 5 | **40** |
| **% of all Facilities of this Type** | 10% | 9% | 18% | 25% | |

| Refrigeration System Type | | | | | |
|---|---|---|---|---|---|
| | Ammonia Central Plant | Halocarbon Central Plant | Rack or Skid Systems | Split Systems | Total |
| **Participants by System Type** | 31 | 6 | 3 | 0 | **40** |
| **% of all Systems of this Type** | 20% | 18% | 17% | 0% | |

The high number of warehouses participating in demand response is particularly interesting, given the focus on these types of industrial refrigerated facilities for their perceived DR potential.

*Additional Observations*

Two-hundred and twenty-four (224) facilities out of the total 294 had additional details that were available beyond the information about the facility type and control system.

Table 8 identifies the breakdown of the various refrigeration system types and associated refrigerant use. The majority (69%) of the systems are custom built-up systems using ammonia as the refrigerant. Each of the facilities in the “Mix of Systems” category has at least one ammonia system. Non-ammonia systems use HCFC-22 or HFC refrigerants. HCFC-22 was for many years the only alternative to ammonia in large industrial systems, but as an ozone depleting substance is being phased out and can no longer be used in new construction. Zero chlorine HFC alternatives include R404A, R-507 and more recently a number of R-407 blends. These HFCs are greenhouse gases with high global warming potential which is leading to increased regulation, increasing cost and expected phase-down over time. Various system alternatives are emerging, including indirect fluids such as glycol or phase-change $CO_2$ or cascade systems using $CO_2$ compressors, coupled with lower-charge primary systems using ammonia or HFC refrigerant. Numerous options to HFC refrigerants are being studied and promoted, including HFO blends with moderate or low global warming potential (GWP). Many of these new refrigerants are unsuitable for large industrial systems due to high cost or incompatibility with recirculated system design. Nonetheless, various pressures and market actions to reduce greenhouse gas emissions and change refrigerants will result in a large investment in new equipment and technology which may constitute an opportunity for improved control and demand response integration.

**Table 8. Summary of Facility Refrigeration System Types**

| Refrigeration System Type | Quantity | Refrigerant |
|---|---|---|
| Split Systems | 18 | 22, 404A, 507 |
| Rack or Skid Systems | 18 | 22, 404A, 507 |
| Halocarbon Central Plant | 33 | 22, 507 |
| Ammonia Central Plant | 146 | NH3 |
| Mix of Systems | 9 | |
| Unknown | 70 | |
| **Total** | **294** | |

One of the drivers of the high percentage of integrated control systems is undoubtedly the high percentage of ammonia systems. Improper operation of an ammonia system can lead to product loss and even loss of life; therefore, control systems in these facilities must incorporate or properly respond to safety-related inputs, which generally dictate the use of an integrated control system, with a single or primary controller.

An additional interesting observation was made with respect to the relative efficiency of the surveyed facilities; facilities with integrated control systems have a higher likelihood of being more efficient than their peers. Of the 179 facilities with integrated control systems, 48 were unknown with respect to their relative efficiency. For the remaining 131 facilities, 74% (97 facilities) had an energy efficiency improvement potential of less than 10% of their total refrigeration usage. For reference, an older facility with standalone controls can often expect approximately 18% in refrigeration energy usage savings by upgrading to an integrated control system and implementing efficiency measures such as floating head pressure, compressor sequencing, and evaporator and condenser fan VFDs[1]. The potential energy savings determinations of the surveyed facilities were a combination of locations where analysis had been completed, facilities where post-efficiency project savings have been monitored, and facilities whose potential was estimated based on site surveys and comparison to similar facilities. Table 9 identifies the efficiency profile of the facilities with relevant available data.

**Table 9. Summary of Relative Facility Efficiency**

| Efficiency Improvement Potential | Quantity |
|---|---|
| Up to 5% Refrigeration Usage | 47 |
| 5%-10% of Refrigeration Usage | 76 |
| Over 10% of Refrigeration Usage | 101 |
| Unknown | 70 |
| **Total** | **294** |

The relative capacities of the various systems were identified when known. Although it does not provide any value in quantifying the potential power that could be reduced for demand response,

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[1] *Author's note: The 18% average figure is based on a review of past experience with refrigerated facility energy modeling and supported by select post-installation monitoring of system energy efficiency and usage.*

Table 10 shows that 50% of the 224 facilities were greater than 300 tons of refrigeration capacity.

**Table 10. Summary of Refrigeration System Capacities**

| Quantity of Facilities by Relative System Size | | | | | |
|---|---|---|---|---|---|
| **Relative System Capacities** | **Ag Processors** | **Food Processors** | **Warehouses** | **Beverage Producers** | **Total** |
| 0-100 Tons of Refrigeration | 9 | 8 | 6 | 1 | 24 |
| 100-300 Tons of Refrigeration | 16 | 30 | 34 | 7 | 87 |
| Over 300 Tons of Refrigeration | 36 | 42 | 27 | 8 | 113 |
| Unknown | 18 | 16 | 32 | 4 | 70 |
| **Total** | **79** | **96** | **99** | **20** | **294** |

## Discussion of Survey Sample Size and Bias

Due to the variety of industrial refrigerated facilities, there is no single resource that provides an exhaustive compilation of the refrigeration systems in California. A few industry organizations have data concerning their members, but are not necessarily representative of all facilities nor focused on control system capabilities.

However, one of the more comprehensive nationwide surveys of refrigerated facilities is undertaken by the United States Department of Agriculture (USDA). In 2009, USDA surveyed 2,572 firms throughout the nation that normally stored food products for more than 30 days at 50°F or lower. The surveyed facilities included both cold storage and production, although facilities who rotated their total inventory more than once per month were excluded.

The latest survey results released in 2010 (USDA National Agricultural Statistics Service, January 2010) breaks down the quantity and storage capacity of refrigerated facilities by state and is summarized below in Table 11.

**Table 11. Summary of USDA Refrigerated Facility Data**

| USDA Summary of California Refrigerated Warehouses | | | | |
|---|---|---|---|---|
| | | | | |
| | **Public** | **Private & Semi-Private** | **Apple & Pear Storage** | **Total** |
| **Quantity of Refrigerated Warhouses** | 119 | 124 | 23 | **266** |
| | **Public** | **Private & Semi-Private** | **Apple & Pear Storage** | **Total** |
| **Usable Storage Space (cu ft)** | 280,714,000 | 128,501,000 | Included in prior groups | **409,215,000** |

The industrial refrigerated facilities surveyed by VaCom were not excluded or sorted by product turnover rates like the USDA survey, but there is undoubtedly some overlap as both surveys targeted the same general demographic. It is interesting to note the total number of California facilities in the VaCom survey (294) is very similar to the quantity of refrigerated facilities identified by the USDA survey (266).

### Survey Bias

The sites surveyed by VaCom are generally biased towards larger facilities and refrigeration systems which often use ammonia as the primary refrigerant. While a number of smaller refrigerated warehouses with smaller systems are included, the survey very likely understates the number of facilities with rack systems and multiple split systems.

## Conclusion

While the landscape of industrial refrigerated facility controls is as varied as the types of facilities and refrigeration systems, the majority of the facilities have integrated control systems that can upgraded and expanded to implement demand response activities. As expected, facilities with a priority on energy efficiency and cost management are also likely to have integrated control systems; facilities with large ammonia central plant systems are also likely to have integrated control systems.

# II. Energy Management Potential of Industrial Refrigeration Control Systems

## Overview

Prior efforts by the Industrial Demand Response Team (part of the Demand Response Research Center at Lawrence Berkeley National Laboratory) have led to preliminary findings of the significant potential for demand response and energy management savings in industrial refrigerated warehouses. The Lawrence Berkeley National Laboratory (LBNL) report LBNL-1991E (Lekov, May 2009) provides an overview of common control strategies for energy efficiency and automated demand response (Auto-DR) in refrigerated warehouses. The prior section of this report provides additional detail of the current state of control systems in California industrial refrigerated facilities and the common system and facility types.

This portion of the report focuses on the second objective of the project: identifying the opportunities and challenges to leveraging the existing state of controls to implement DR, and ultimately Auto-DR effectively in these facilities. Integrated control systems have already been used successfully to address facility, refrigeration system, and control system challenges while helping facility managers achieve their primary objectives of safety, product quality, and regulatory compliance. Therefore, there seems to be potential for them to contribute to achievement of DR. This report also includes a subjective evaluation of the demand response potential of various facility and control system combinations, as well as feedback from a number of facility managers that were contacted to provide additional insight on how controls are currently enabling demand and energy management.

## Background: Energy Cost Management

As utility rate structures continue to evolve from time-of-use (TOU) to real-time or market pricing, facilities are under increasing pressure to control both their energy usage *and* demand in order to minimize their overall energy costs. This is certainly one of the forcing functions that have driven the adoption of improved, integrated control systems in refrigerated facilities. Utility incentive programs have often been used by facilities to offset the cost of upgrading control systems in the last fifteen years. A number of utility programs throughout California have focused on improving energy efficiency through control strategies in new and existing refrigerated facilities, while others have focused on reducing demand and adding demand response capabilities. Many of the programs treat energy efficiency or demand response as separate silos; however, minimizing overall utility cost requires balancing energy efficiency and demand response. The facility control system serves as the logical fulcrum for achieving this balance. With an integrated control system, facility management has the ability to see and monitor refrigeration plant and control system performance over time as well as the data necessary to evaluate and minimize energy costs.

### Energy Management Hierarchy

Facility energy management comes in three primary forms. A refrigerated facility can permanently reduce overall energy usage through energy efficiency, permanently shift demand to lower cost periods, or actively manage demand as needed for demand response events. The priority that these three options should be given is typically set by the total usage hours or the cost benefit of the management option to the facility (Figure 16).

**Figure 16. Hierarchy of Energy Management Strategies**

For existing facilities seeking to minimize utility costs, energy efficiency should be the first order of business, as the energy savings benefits the facility every hour of the year and inherently includes some peak demand savings as well. In new refrigerated warehouses permitted in California after January 1, 2010, energy efficiency measures and controls that significantly reduce usage versus prior industry practice are now required by the Title 24 building code. As described in more detail in LBNL-1991E (Lekov, May 2009), refrigeration energy efficiency measures normally involve the use of control methods to reduce the difference in system suction and discharge pressures and to improve part load performance through sequencing, capacity modulation, and/or the use of variable speed drives.

Maximizing a facility's refrigeration system efficiency often helps enable the facility to consider permanent load shifting or demand response, as the controls needed to implement the efficiency measures usually provide the customer with excellent system visibility as well as the means to safely and reliably shed load. Furthermore, the installation of variable speed drives (VFDs) on equipment such as evaporator fans provide the customer with additional demand response flexibility; without VFDs, a facility only has the option of turning certain equipment completely off. A facility with VFDs has the ability to run at reduced speeds during demand response events, limiting usage but still providing some cooling for critical areas.

Permanently shifting overall demand can benefit a facility between 600-900 hours a year, depending on the particular rate tariff, and often requires operational changes, additional equipment, and programming additional control strategies. Depending on their ice storage capacity, some facilities may defer using ice-making equipment to mid or off-peak hours. Other facilities inhibit charging of electric forklift batteries during on-peak hours. Although there are similarities between demand response (DR) and permanent load shifting (PLS), there are some important considerations when implementing one or the other. While most facilities could probably inhibit forklift battery charging three to four times per summer for a couple hours, significantly fewer facilities would be able to turn off their chargers every weekday during on-peak hours. Many times, the age and quantity of batteries would prevent a facility from participating in PLS, although demand response could be accommodated. Similarly, many facilities with variable speed control of evaporator fans could limit and reduce fan speeds during a demand response event (or shut off zones entirely), but may not have sufficient capacity to do the same every on-peak weekday.

Control automation is the key in both examples, as the facility could have different stages of demand reductions that adjust to the current facility conditions. A few battery chargers could be left on to maintain some critical batteries while the other chargers participate in PLS or DR reductions. It is always important to balance the permanent load shifting with energy efficiency for each specific facility, as overly aggressive demand shifting can result in the refrigeration system being unable to meet the accumulated cooling demand, offsetting any energy efficiency gains and potentially affecting product quality due to higher average zone temperatures. An integrated control system provides the facility manager with the ability to balance these goals and minimize overall energy costs.

Demand response, of which automated demand response is a sub-category, is usually an occasional and relatively large demand reduction in response to a utility request. While certain facility loads, such as lighting, may be relatively simple to curtail, most custom industrial refrigeration systems require an integrated control system and additional programming to be able to safely and reliably curtail demand without significant operator involvement and system or product risk. Future applications of current Auto-DR pilot programs are facility demand management in response to real-time pricing signals and automated curtailment for utility grid stability in response to grid operator signals. One goal of demand-side management is to minimize the impact of highly variable renewable generation resources as well as the required online power plant generation capacity.

Demand response programs can range from utility-managed offerings to programs managed by third-party aggregators. Aggregators allow the utility to execute a contract with one entity for demand reduction; the aggregator then manages customer enrollment in demand response programs, executes curtailment events in response to grid operator requests, and coordinates participation incentives.

### The Role of Energy Efficiency

Energy efficiency plays a strong supporting role in enabling DR. As the survey data confirms, the facilities with integrated control systems were often the more efficient facilities. Demand response is a natural bolt-on feature for a facility with integrated controls, especially those with control strategies for energy efficiency. The facility management is often more engaged in managing energy costs and more likely to be supportive of DR or Auto-DR, and the operators are often already familiar with sophisticated control systems and more aware of the interactions between various system equipment. The facility personnel are also able to use the data from the control system to understand how the system behaves during a curtailment event compared to expectations, as well as have the ability to closely monitor product quality throughout the events.

In addition, efficiency measures such as evaporator fan variable speed drives provide efficient systems the additional demand response option of *slowing* fans instead of *stopping* them; this can help address concerns regarding air circulation or product quality while saving significant fan power (a fan running at 50% speed uses approximately 15% power per the fan laws). As the load drops, the associated compressors would unload as well, using less power. Temporarily limiting fans to lower speeds regardless of zone temperatures is one way a large system could reduce load quickly in response to a utility curtailment signal.

Variable speed evaporator fan control has become common practice in California over the past 10-12 years and has often been a primary efficiency measure in customized new construction and retrofit incentives delivered through California utility programs. In a few instances, evaporator fan control has included load shifting or demand response capability along with energy efficiency logic. Refrigerated warehouses permitted and built after January 1, 2010 will most likely have an integrated control system in order to provide the refrigeration efficiency control measures required by the California energy code, which includes variable speed evaporator fan control, floating head pressure with variable speed fans and other measures. Most new construction controls providers will describe their systems as “DR capable;” however, it often requires a custom addition to the programming and HMI interface. In general, energy code requirements such as variable speed control of fans are seen as enabling greater participation in demand response activities. A number of utility companies have a similar opinion, and are pursuing pilot programs to integrate automated demand response with energy efficiency controls in new refrigerated facilities. Designing the refrigeration plant and control system for both demand response and energy efficiency from the beginning can certainly minimize the cost and technical challenges, compared with retrofitting DR capability later on.

## Understanding the Industry: Customer Priorities

Even though minimizing energy costs and demonstrating social responsibility are often important corporate objectives that drive participation in energy efficiency (EE) and demand response activities, they are (at best) the fourth and fifth priorities for most industrial refrigerated facility managers. Without exception, safety-of-life, product quality, and regulatory compliance will trump energy efficiency and demand response goals. To obtain customer buy-in and to successfully implement EE and DR, the proposed changes must not negatively affect these top three priorities.

**Safety**

The large industrial refrigerated warehouses and processing facilities in California using a significant percentage of the sector's power are typically custom, built-up systems using ammonia as the refrigerant. While it is an excellent refrigerant from a thermodynamic and ozone depleting/global warming perspective, ammonia can also be hazardous if released in large concentrations near people. The industry has well established safety processes and training in place, and is very mature with respect to the proper handling, servicing, and operation of these systems. Certain processes, such as hot-gas defrost, must occur in a certain sequence for a certain time to prevent hydraulic shocks from developing in the piping. If the shock is severe enough to burst the piping, the loss of product and, worst-case, the loss of life could occur. Any demand response activities must be executed in concert with full awareness of the current state of the system to prevent the savings coming at the expense of safety.

**Product Quality**

Food processors and refrigerated storage facilities are first and foremost concerned with ensuring product quality. Due to the custom nature of most facilities and the wide variety of cooling and production processes, demand response recommendations and responses need to be tailored to the capabilities of each facility in order to achieve practical, repeatable reductions that preserve product integrity and retain the support of facility management. Demand response must have no adverse impact, or be more cost effective than deferred or lost production, associated personnel overtime costs, or any product quality degradation.

While concern for product quality and temperature maintenance is a high priority, there is nonetheless a marked lack of effective temperature monitoring in most facilities, often with only a single temperature sensor in the return air at the evaporator, assumed to represent the temperature of the entire space. Additional temperature sensors throughout the facility and possible use of product temperature simulators would provide greater understanding and ability to identify "hot spots" that could be addressed through advanced control strategies. Also, experience has shown that more accurate and extensive temperature monitoring improves confidence in product temperatures and reduces the need to run colder than necessary simply as a "safety factor". In some instances temperature setpoints have been increased by 5-10°F as a consequence of improved temperature monitoring. Considering that each degree relates to approximately 2% efficiency, this can be a substantial improvement. Accordingly, a focus on *quality* of air distribution rather than simply quantity of air circulation and better understanding of actual product temperatures are essential to both energy efficiency and use of these facilities as a demand management resource.

**Regulatory Compliance**

In addition to safety organizations, refrigerant management compliance is becoming an important consideration for facility managers. Ammonia systems are primarily regulated from a safety-of-life perspective. However, California legislation continues to increase the regulatory requirements for halocarbon systems due to the environmental impacts of leaked refrigerant. Halocarbon systems encompass many of the small-to-medium industrial refrigerated facilities. Similar to ammonia systems discussed previously, processes such as hot-gas defrost must be executed properly in halocarbon systems in order to prevent burst pipes and the loss of refrigerant.

## Impact of Facility Type on Demand Response Potential

As described in the previous section of this report, the term refrigerated warehouse applies to a number of different types of facilities. The facility type can have a large bearing on its demand response potential.

### Refrigerated Cold Storage Facilities

Pure cold storage warehouses typically receive product at, or near, its desired storage temperature. Barring substantial changes in product mix or quantities over time, the primary change in cooling demand throughout the year is typically due to changes in ambient conditions and the rate of infiltration to the spaces. By reducing the amount of infiltration into the cold storage spaces as much as possible (primarily via minimizing forklift traffic and keeping doors closed), cooler storage areas (greater than +28°F) are often capable of shutting off many, if not all, of their storage zones for a few hours. The duration is heavily influenced by the product mix, facility insulation quality, and product quality requirements. Facilities with evaporator fan VFD controls can also clamp fan speeds during a curtailment event. The demand reduction is less than shutting off the equipment entirely; however, this approach provides a fairly rapid response to a utility request while still providing some amount of cooling for the spaces. In either approach, the reduced load on the refrigeration system will result in fewer compressors needing to run. Freezer storage areas (less than +28°F) offer a similar opportunity to turn off evaporators or clamp fan speeds; due to the thermal mass of the stored frozen product and thicker insulation, they can often curtail for a longer duration.

There are a number of unique facility types within the refrigerated cold storage category, including controlled-atmosphere facilities and grocery distribution centers. Controlled-atmosphere facilities specialize in the long-term storage of produce, which is largely achieved by strict space temperature controls as well as controls on relative humidity and ripening processes. Such facilities may be less able or willing to reduce demand by deferring cooling. One such facility in California, however, processes a few types of fruit that each had a different harvest time in the summer. Depending on the type of fruit being stored at the time, the facility is able to shut off the controlled atmosphere rooms for 2-3 hours.

The warehouse portions of grocery distribution centers are unique in their rapid product turnover. Some facilities will turn more than 90% of the total stored area in under twenty-four hours. Such facilities have significant traffic and infiltration and no opportunity to reduce them by deferring shipping. Some older distribution facilities can struggle to maintain space temperature setpoints during summer months even without curtailment efforts. A realistic strategy for these facilities would be to limit evaporator fan speeds rather than shutting off zones.

### Combined Processing and Cold Storage Facilities

Facilities with combined processing and cold storage usually have, at a minimum, the same opportunities to reduce demand in their cold storage areas as pure cold storage warehouses. The magnitude of reduction can be less as the cold storage areas are typically used for just a few days' worth of production of their own product; however, the majority of their refrigeration power demand is often associated with process cooling loads, so it is important to understand what, if any, of the load can be curtailed.

The primary distinction for determining curtailment potential is whether the production loads are batch or continuous processes. Stopping continuous processes such as hydrocooling or spiral freezing requires an interruption of the production line, sometimes beginning with workers in the field to prevent spoilage of harvested product. This is a significant and costly disruption which also requires advance notice in order to effect demand reduction and is unlikely to garner any support with facility management. There are always exceptions to the rule, as evidenced by one facility that received enough incentive for their significant demand reduction that they chose to delay their entire blast freezing production for a day.

Batch production loads such as pressure cooling, vacuum tube cooling, or room freezing can sometimes facilitate demand reduction due to the cyclical nature of the processes. If a facility has some spare cold storage space to temporarily accommodate arriving product, they may be able to defer pressure cooling operations for a few hours, as observed with one fresh fruit precooler. Similarly, depending on the amount of product needing to be processed in the day, a facility can sometimes delay some of their vacuum tube cooling cycles. In general, once a batch process has started, it is undesirable or even detrimental to product quality to interrupt the process. Certain processes such as cooling for fermentation control are critical processes that cannot be interrupted once begun. As with much of the industry, there are exceptions to this statement as well. Certain batch freezing processes, such as blast freezing a drum of fruit puree or room freezing a tray of baked hamburger buns, may actually benefit or be largely unaffected by an interruption of the process for a couple of hours.

## Impact of System Type on Demand Response Potential

The type, configuration, and vintage of a refrigeration system can provide a number of opportunities as well as challenges for demand response.

One of the first subjects in considering demand response is the installed *and available* refrigeration capacity vs. the required cooling capacity. Shifting load out of a peak period naturally increases the load during other hours. For example, if a facility shuts off its refrigeration plant for six hours, it now has eighteen hours remaining to meet the day's total ton-hours of cooling required to remove heat gain from product, infiltration, equipment, and transmission loads. While some loads are reduced during a demand response event (e.g. fan heat), most of the loads continue and are simply stored in the mass of the building and product. To meet the same load in eighteen hours requires a third more capacity. Study of several facilities that participate in daily load shifting programs has shown a characteristic gradual increase in space temperatures throughout the week. The refrigeration system can usually catch up on weekends, although this scheme is highly dependent on equipment reliability and sometimes on cooperative weather. Two factors have become important after observing these facilities. First, without additional control sophistication, freezers and coolers equipped with variable speed fan control will end up running at 100% fan speed during the reduced operating hours vs. otherwise operating at 60-80% speed when the capacity can be spread over the full day. This increases heat load and energy consumption substantially (particularly since fans reduce power at the "third power" of speed reduction), often with an overall operating cost increase to the owner—which can make demand response under these conditions a false economy. Second, many systems appear to have significant capacity shortfalls; they do not lack capacity on paper, but for various reasons the equipment does not operate at full capacity. Inherently, refrigeration systems are designed with substantial safety factor, and oftentimes the additional capacity in not available due to either lack of maintenance, deterioration in performance over time, or inherent differences in rated vs. applied capacities. Understanding and addressing these factors presents challenges as well as significant opportunities, for both energy efficiency and demand response.

Smaller refrigerated facilities using multiple split systems without integrated control have no real practical ability to modulate the capacity of individual systems in response to a demand response signal; however, there are often multiple units serving the same space. In that case, the zone temperature setpoints could be temporarily increased on as many units as possible in response to the curtailment signal, and the condensing units would pump down and cycle off. Typically, the evaporator fans run continuously, except for defrost of low-temperature units, so there should be adequate air circulation in the space. Certain control systems will duty-cycle the evaporator fans or run the evaporator fans at reduced speeds when the compressors are off, further reducing demand.

Medium-sized facilities with packaged rack systems and medium-to-large facilities with built-up systems nearly always have the ability to modulate capacity and reduce a portion of the load in response to a curtailment signal. This provides the flexibility to reduce demand where possible while still keeping critical processes running. Although it is certainly possible to manually curtail load in such facilities without an integrated control system, it is definitely less reliable from a utility company perspective. As the facility and system size increases, demand response becomes more challenging, and even dangerous, without a proper control system.

The piping configurations of the facility need to be reviewed in order to identify the levels of demand reduction that are possible. For example, a room with four evaporators might have only one control valve group for the four evaporators or as many as one valve group per evaporator. The configuration determines if the entire room will be either on or off or if a fraction of the evaporators could be left on to provide some degree of cooling.

Frequently, large systems (especially large systems that have been expanded over time) can have challenges managing refrigerant even during normal operations. While there are a number of scenarios or potential causes, the fundamental issue is either too much or too little refrigerant at a given location. The most critical concern is preventing liquid refrigerant from entering the compressor suction. One facility that was expanded over time had a particular liquid vessel that was too small for its current function. In order to safely defrost the associated evaporators and not have a refrigerant high level in the vessel (which happened to be one of the primary protection vessels for the compressors) the liquid feed to the recirculator had to be shut down a half hour before the initiation of the hot-gas defrost cycle in order to have room for the refrigerant pumped out from the evaporators. The issue was addressed by an integrated control system, and the facility is also successfully participating in permanent load shifting and demand response activities. Understanding the particular facility’s refrigeration system is vital to determining their particular demand reduction potential and how to execute it safely and reliably via an integrated control system.

In addition to difficulties caused by piping or system design flaws, shutting down even a portion of a large system requires a staged, orderly process. Putting everything into pumpdown mode at one time significantly increases the likelihood of having a vessel high level on the suction side of the system. Staging zone and load shutdowns is necessary to successfully implement demand response. Again, an integrated control system with a master scheduling function is key, as the timing for particular activities can be defined and monitored from one location.

## Impact of Control System Type on Demand Response Potential

There are a number of challenges to taking a one-size-fits-all approach to demand response in this industry; however, combining refrigeration knowledge with the use of system controls can overcome many of the issues and leverage the significant demand reduction potential of this market segment. Of primary importance is utilizing controls to ensure safety-of-life, product quality, and regulatory compliance before, during, and after demand response events.

An integrated control system is the key to enabling each type of facility to participate in demand response activities. With the ability to monitor space temperature profiles and to schedule repeatable curtailment responses to grid operator requests, facility operators have the ability to fine-tune DR activities for their specific facility and process type. This level of control gives facility managers visibility into the state of processes at all times, imparting the confidence to participate and try additional curtailment approaches. Without this level of visibility, the curtailment efforts are likely to be very limited, conservative, or non-existent.

In addition, an integrated control system takes the potential burden of demand response off the shoulders of the operators and facility managers and allows them to continue performing their job functions. If a facility were manually participating in demand response with a standalone control system for a six-hour event, the activity could take up a significant portion of staff time during an eight or ten hour shift, causing maintenance or repair activities to be deferred. Furthermore, integrated controls eliminate one of the inherent risks of manual demand reduction in a large system, which is the ability (or lack thereof) of the system operators. There can be a wide variation in operator skillsets and how well they understand the nuances of their particular system. Shutting down parts of a complex system can bring up situations not commonly seen during normal operation. Systems with ammonia are especially critical due to the potential hazards in the event of a leak.

### Implementing Demand Response with an Integrated Control System

While an integrated control system is certainly the most desired starting platform, successfully implementing demand response in a facility with such a system requires additional effort.

#### *Non-Proprietary Integrated Control Systems*

To enable demand response participation, and most certainly automated demand response, a non-proprietary control system generally requires additional programming. The cost can vary significantly depending on the number of modifications that must be made and whether or not the facility has in-house IT staff or must outsource the job.

Most often, the additional programming is associated with developing a demand response master schedule, which would be enabled either manually (manual DR) or automatically by a DR signal. This master schedule is used to define the time period of the curtailment. In addition, more programming is then needed to define how each zone or component will respond to this master schedule, based on the facility's curtailment plan. For example, if the facility intends to pre-cool certain zones prior to shutting them off for a few hours in the afternoon, capability would need to be added for the user to be able to define the alternate temperature setpoint and when the setpoint would be in effect. Similarly, if the demand reduction plan involves shutting off a significant number of zones in the facility, programming is needed to define when each zone would start pumping down and to stage the zones so there is not too much refrigerant coming back to the engine room at one time. Because the pumpdown process takes time, the schedules need to be carefully timed in order to ensure the facility has curtailed the desired amount of load by the beginning of the demand response period. Following the event, the re-start of the system(s) must include appropriate time delays to prevent system instability due to the rapid addition of load and to help keep the facility from incurring an excessive demand charge as everything comes back online.

With any changes to a comprehensive control system, documentation of the new control functionality and additional training for the system operators and managers is a must. Because the demand reduction plan may need to be modified occasionally based on current production, weather, or other factors, operators need to be comfortable with adjusting the schedules and staging the curtailed loads.

#### *Proprietary Integrated Control Systems*

An integrated control system with a proprietary controller often needs the same functionality added as was just described, but the fact that the code is proprietary adds additional complications. To modify the existing program, the facility owner must contract with the same company that provided the initial programming and is subject to their fees. The demand response functionality would likely be a custom offering and may not even be developed yet for their particular platform. When evaluating whether to interface with the existing system or improve its functionality, it is often more cost effective to bypass the existing controls during a demand response event via a third-party integrator offering, or to completely replace the proprietary control system. Complete replacement may be cost effective if the facility does not have many refrigeration energy efficiency measures in place, especially if the project combines energy efficiency and demand response.

*The Role of Performance Monitoring*

Performance monitoring is an additional layer of integrated control system data acquisition that compiles information and pre-processes it to trend key metrics. Facility power monitoring is the most basic type of performance monitoring and is usually included by a control system integrator providing demand response capability. While this data is beneficial to understanding how much load has been curtailed, it provides little insight into the relative efficiency of the refrigeration system(s) before, during, and after the DR event.

Performance monitoring should combine system data such as equipment status, temperatures, pressures, and power readings with manufacturer's data to calculate component and system *efficiency,* not just power usage. This type of visibility is very helpful in tuning a facility's curtailment response over time and allows the facility to effectively balance energy efficiency and demand response to achieve the lowest operating cost.

### Implementing Demand Response with a Standalone Control System

Standalone control systems are often more complex and costly to implement DR, because safe, reliable DR often requires that a central control system be installed to integrate the varied equipment. Smaller facilities with split systems or small rack/central plant systems *can* manually perform demand response with some degree of repeatability and success as long as they have skilled operators; however, the practicality of safe manual DR decreases as the system size and complexity increases. One large facility with manual and standalone controls on a central ammonia system attempted to manually curtail load one season, but it required the team of operators to rush around in golf carts in what appeared to be a chaotic fire drill. When an integrated control system was installed as part of a combined energy efficiency and DR project, the following DR season's events were much more controlled and safe. The operators simply entered the times they wanted the system zones to shut down and restart and then monitored space and product temperatures during the event.

It is possible to add a controller for demand response that interfaces with the standalone controls only during a demand response event. This type of a controller can support manual or Auto-DR, but does not provide supervisory control. Based on a schedule, DR signal, or manual input, the controller will take a pre-determined action, such as shutting off a piece of equipment or adjusting a suction setpoint. Aside from a power meter input, the controller has limited or no awareness of the state of the refrigeration system. This is a viable solution in a facility with a number of split systems; however, implementing such a solution in a custom built-up ammonia system would require significant operator involvement to ensure system and product integrity.

### Response Time for Curtailment

Due to the complexities of large, custom built-up refrigeration systems, primarily related to safety-of-life and refrigerant management, many facilities will not be able to manage a full system shutdown for demand response when there is less than a 30 minute notification. This is due to the time it takes to stage down and pump out evaporators in a safe, orderly fashion. The few exceptions would be facilities with split systems or a small rack system. Large facilities with evaporator fan variable speed drives *could* respond in less than thirty minutes by clamping fan speeds, though this only reduces a fraction of the total load.

## Evaluation of the Minimum State of Control for Successful Demand Response

The minimum state of control for successful demand response is a very subjective evaluation; a simple light switch could be all the control that's needed to shed lighting load in a facility. As long as there's a responsible individual operating the switch, the demand reduction could be very repeatable and reliable. However, there are a number of general observations that seem to be consistent across the industrial refrigeration industry in California.

Observation: Large, custom built-up refrigeration systems usually require integrated control systems or partially PLC-controlled systems to safely and reliably participate in demand response activities. Fully integrated control systems can be used to schedule load reductions in an organized manner. A system with PLC control of evaporators (but standalone controls on compressors and condensers) can often reliably reduce demand by scheduling off the evaporators using the PLC, and relying on the standalone controls for compressors and condensers to eventually turn off the equipment when sufficient load has dropped.

Observation: Most facilities have some demand response potential (other than the refrigeration system) that is relatively low-cost to automate, and does not require an integrated control system. Many times, a simple relay panel with a micro-controller could be used to interrupt certain lighting circuits, battery chargers, or other curtailable loads in response to a DR signal.

Observation: A phased implementation approach may improve the adoption of Auto-DR in industrial refrigerated facilities. Small, short-notice load reductions are gaining value to grid operators and utility providers, and there are often smaller, non-critical loads in an industrial refrigerated facility that could be integrated into an Auto-DR program with relatively little cost. A positive initial experience with Auto-DR would help develop customer support for additional efforts, such as improving the integrated control system to accommodate Auto-DR with the refrigeration system or incorporating demand control of other facility loads.

Observation: Most facilities have curtailable loads that require different amounts of advance notification. Certain actions could have very short (four minute or less) response times, such as adjusting lighting levels or evaporator fan speeds. Other actions would require more lead time. Maximizing the demand response potential of a given facility will likely benefit from a tiered approach that includes both Auto-DR and manual DR measures. For example, a facility may have twenty-five kW of fast response Auto-DR load, another 200 kW of one-hour advance notification Auto-DR load, and 1,000 kW of manual DR load that requires day-ahead notification to leverage.

## California Industrial Refrigerated Facility Demand Response Potential

Similar to the prior section, evaluating the demand response potential of the different segments of the industrial refrigerated facility landscape in California is somewhat subjective. A significant number of factors come into play when evaluating the costs and benefits of pursuing demand reductions from this industry. However, the various facility and control combinations were given a relative ranking based on hands-on experience implementing control retrofits for energy efficiency and demand response over the last twenty years.

Table 12 below shows a subjective evaluation of the relative demand response potential of each combination for typical facilities in each category. To score as high demand response potential, a facility would typically have over 100 kW of curtailable load, be relatively unaffected (from an operational and product perspective) by participation in a demand response event, and have a higher likelihood of facility management support for demand response activities. As the table shows, warehouses with integrated control systems are likely the most promising candidates, with the potential of each facility type decreasing as the sophistication of the controls decreases.

**Table 12. Summary of the Relative DR Potential of Industrial Refrigerated Facilities**

| Relative Demand Response Potential of Facility and Control Combinations | | | | |
|---|---|---|---|---|
| | Facility Types | | | |
| **Control Type** | **Ag Processors** | **Food Processors** | **Warehouses** | **Beverage Producers** |
| Non-Proprietary Integrated Controls | 9 | 9 | 10 | 7 |
| Proprietary Integrated Controls | 8 | 8 | 9 | 6 |
| Partial PLC/ Electromechanical Controls | 6 | 6 | 7 | 3 |
| Basic Non-Integrated Controls | 3 | 3 | 4 | 1 |
| Mix of Controls | 4 | 4 | 5 | 2 |

**Low** 1 2 3 4 5 6 7 8 9 10 **High**

Due to the time-sensitive nature of their production, beverage producers are seen as the most challenging facility types to pursue, regardless of the sophistication of their controls. While Ag and Food processors also have time-sensitive operations, they often have enough cold storage warehouse capacity to support some demand response activities.

Table 13 below shows the same combinations of facility and control system types, but provides a subjective evaluation of the relative effort needed to implement demand response activities in each case. A facility scored as low effort would be expected to need relatively little capital investment to implement DR participation, possibly only requiring programming modifications to implement the DR strategies safely. The facility would likely also have a high availability when called upon for demand reductions. Similar to the prior table, warehouses with integrated control systems will likely be the most cost-effective to pursue, with Ag Processors and Food Processors with integrated control systems coming in next. As the quality of the existing controls decreases, the cost of implementing demand response increases, since capital investments must be made to first implement the control platforms that would facilitate reliable, safe demand response.

**Table 13. Relative Effort Needed to Leverage the DR Potential of Industrial Refrigerated Facilities**

| Relative Level-of-Effort to Achieve Significant DR Participation | | | | |
|---|---|---|---|---|
| | Facility Types | | | |
| **Control Type** | **Ag Processors** | **Food Processors** | **Warehouses** | **Beverage Producers** |
| Non-Proprietary Integrated Controls | 2 | 3 | 1 | 5 |
| Proprietary Integrated Controls | 3 | 4 | 2 | 6 |
| Partial PLC/ Electromechanical Controls | 6 | 7 | 5 | 8 |
| Basic Non-Integrated Controls | 9 | 9 | 8 | 10 |
| Mix of Controls | 8 | 8 | 7 | 9 |

**Low** 1 2 3 4 5 6 7 8 9 10 **High**

## Facility Manager Feedback on Demand Response and Energy Management

A number of facility managers were contacted to understand what they were doing with respect to demand response and energy efficiency, as well as to obtain feedback on the role of controls in their efforts. The responses included managers of grocery distribution centers, managers of national public refrigerated warehouse companies, owner-operators, and large combined production and cold storage plants.

A number of valuable comments and insights were obtained:

- Without exception, an integrated control system managing their refrigeration systems was cited as the key to providing them the confidence to do demand response safely while maintaining product quality.
- Only one of the managers had experience with Auto-DR; the majority of the facilities participated manually in demand response or in permanent load shifting.
- The primary reason any of the facilities participated in DR or load shifting was to reduce their overall bill. Two facilities were able to stay on a tariff with a lower average cost by participating in DR. A couple of the cold storage-only facilities whose tenants paid for the utilities saw the DR participation incentives as additional revenue helping the bottom line. One facility manager, manually participating in DR across all their facilities, had been approached to switch to Auto-DR; however, the economics of the participation incentives were not sufficiently better than their current manual DR program to offset the increased effort required for establishing an Auto-DR program.
- Most of the managers felt that aggregator demand response programs had fewer events, higher total incentives, and less economic risk than the utility tariff-based demand response programs with a set number of events.
- Most all of the facility managers were wary of a utility signal being able to directly initiate a demand response action at their facility. Many prefer getting an email or text request to curtail. Facilities would be more likely to participate in Auto-DR if the economics were clearly attractive, and they understood their options, e.g. the ability to adjust the level of participation or opt-out in the event production requirements or some other issue prevents them from participating.
- Most of the facilities were able to shut off all their cold storage for 3-6 hours. In some facilities, this meant their entire refrigeration system is off.
- One facility, with significant blast freezing production, tried shifting production work out of the 12 PM to 6 PM time frame but received significant pushback from personnel unwilling to work the late night shifts.
- Participating in demand response in a production facility can have a negative impact on the staff. One facility on a Base-Interruptible utility tariff must shut down production during mandatory curtailments in order to get below their target threshold. For the six hours production is down, they have to send over 1,200 hourly employees home. This results in a large number of people who essentially do not get paid for the day.
- One facility did not participate in a demand response program because they have sufficient refrigeration capacity and can shut off most of their system for six to eight hours each day (permanent load shift). They are still able to recover quickly enough so that the evaporator fans are not always running at 100% speed. With their limited on-peak demand, they do not have much else to curtail during a DR event.
- One facility also shuts off most of their refrigeration system during all on-peak hours, due to the high on-peak demand charges of their rate tariff. They have deferred any investment in efficiency measures such as evaporator variable speed control since the facility is usually heavily loaded (either pre-cooling or recovering) outside of the on-peak period. Interestingly, the facility is considering moving to a direct-access utility agreement to lower their costs and may consider efficiency investments at that time.
- One large cold storage operator noted that their corporate mandates to support their local communities and to maximize efficiency were also drivers in their demand response participation, in addition to utility cost savings.
- One frozen-food storage warehouse manager mentioned that their refrigeration system could be shut down for a few days without any risk to product quality.
- The perceived complexity and the myriad of demand response program options appear to be a current barrier to more widespread participation in demand response activities.

## Demand Response Case Studies

As previously mentioned, the effort needed to implement demand response varies significantly by facility. The following examples illustrate the range of facilities and control systems found in California facilities.

### Refrigerated Warehouse

One example warehouse in California wanted to participate in their utility's demand response program. The facility had recently completed a refrigeration energy efficiency project that installed a new integrated control system. The control system retrofit added floating head pressure controls, supervisory compressor sequencing, and evaporator fan variable speed control. The facility already had variable speed control of the condenser fans. The integrated control system fully automated all the refrigeration system end uses and safeties, and included a scheduling function that allowed the facility to adjust setpoints, limit fan speeds, or shut off equipment for specified intervals.

A company working with the utility provided a demand response interface module that received the demand response signal issued from the grid operator. This company also contracted with the provider of the new integrated control system to modify the system so it would communicate with the demand response interface module. The existing scheduling functions were updated to provide three levels of demand reduction in response to the signal from the DR interface module.

When the DR interface module would send a small, medium, or large demand reduction request to the integrated control system, the control system would execute the pre-programmed reductions based on the rules set up by the facility management. Small reductions would involve limiting evaporator fan speeds to a maximum value for the duration of the event. Medium reductions were programmed to turn off refrigerant feeds to zones in the warehouse while leaving the evaporator fans running at minimum speed. The large reductions used the scheduling function to shut down all zones and evaporator fans in the facility, one after another to prevent any refrigerant management issues. With all zones off, the refrigeration compressors and condensers would also stage off automatically. Programming also ensured the orderly re-start of the system after the demand response event.

### Frozen Food Processor

One facility had two very large ammonia refrigeration systems at their frozen food plant that were controlled by a mix of mechanical and standalone controllers. The facility had been expanded significantly over the prior forty years, before energy efficiency was a priority. The new facility management wanted a comprehensive upgrade of the refrigeration controls so they could better manage their energy usage and improve system safety and reliability. To provide a reasonable project payback, energy efficiency and demand response incentives were pursued simultaneously along with the control upgrade. A computer model was used to simulate the base case refrigeration system operation and energy usage, and to calculate the expected energy savings of implementing condenser fan variable speed control, floating head pressure, supervisory compressor sequencing, and evaporator fan variable speed control. The calculated post-energy efficiency project usage was then used to estimate the expected demand response potential of the facility after the controls upgrade and calculate the combined incentives.

The installation of the control system required close coordination with facility staff and engineering, as systems were moved from mechanical or standalone controllers to the integrated control system. At the same time, safety deficiencies and piping issues had to be addressed to ensure the system operated as intended. After the efficiency improvements were completed, a DR demonstration test was performed to validate the calculated DR savings.

For this facility, demand response could not be implemented consistently or safely without the installation of an integrated control system (they had tried before with limited success), but demand response incentives alone were insufficient to provide a reasonable payback on the control upgrade. However, pursuing both energy efficiency as well as demand response capability provided enough incentive to properly upgrade the controls and provide the facility with complete control over their energy usage. To date, the facility has exceeded the original energy efficiency goals through continuous improvement initiatives that balance energy efficiency, permanent load shifting during summer peak periods, and demand response.

### Large Beverage Producer

One large beverage company had a mix of mechanical controls and standalone controllers on the multiple refrigeration systems in their facility. They had added demand response capability through a controller that only interfaced with the systems during a DR event. However, the demand response capability was usually bypassed, as there was no way for the DR controller to know which plants were performing critical cooling tasks that couldn't be interrupted. In addition, the lack of integrated controls made it difficult to tune the demand reduction response on a system-by-system basis.

A plant-wide integrated control system was installed as part of an energy efficiency upgrade project. In addition to the installation of variable speed drives for condenser fans and trim compressors, programming was added to properly interface with the existing demand response controller. When a demand event is called, the DR controller sent a signal to the integrated control system, which then took the appropriate demand reduction actions based on the rules set up by the facility operators. This allowed for the modification of the demand response plan on an event-by-event basis, depending on what was being processed on a particular day.

## Future Demand Response Systems

Existing industrial refrigeration control logic is based upon a set of rule-based controls. It works well for steady state system behaviors but is rigid and unable to adapt to changing system behaviors. Demand response and auto-demand response events are inherently transient and deviate from normal refrigeration system operation. Research has been done in recent years into the area of predictive control for HVAC systems (Forrester, 1984) and (Cooper & Francis, 2011). Such control could also be applied to industrial refrigeration systems. The control algorithm attempts to answer a set of questions for some period of time in the future through modeling, simulation, or forecasting (Cooper & Francis, 2011). The questions could include:

- How much cooling load is going to be needed?
- What is the effect on product quality?
- What is the total energy cost?

After the control system optimizes a set of operations resulting in the reduction of a collective cost function (taking into account energy cost, product quality, and other relevant parameters for that period of time) it activates the appropriate equipment. It then repeats the optimization process based on new predicted information and adjusts the next set of operations based on the current state of refrigeration system.

One advantage of predictive control is the flexibility given to plant management to trade-off between energy cost and product quality by weighing the cost function more heavily toward either factor. Another major advantage is its ability to react to real-time price signals by incorporating price signals into future energy cost. The drawback of predictive control is the intensive computation capability required for the optimization process. Fortunately, modern micro-processor based devices are increasingly able to effectively solve optimization problems on-line and in real-time. Hence, integrated control architectures may be suitable to implement new technologies such as predictive control to effectively implement demand side management, cost optimization, and especially auto-demand response relative to real-time pricing signals.

## Conclusion

An integrated control system is considered central to implementing demand response activities in general, and automated demand response specifically. The most important driver for businesses to participate in demand-side management is to minimize their energy costs. Furthermore, demand response participation must have no adverse impact, or at a minimum be more cost effective than deferred or lost production, associated personnel overtime costs, or product quality degradation.

## Recommendations for Future Work

Based on the analysis and experience to date, warehouses and the cold storage areas of industrial refrigerated facilities with integrated control systems are thought to be the best initial targets for leveraging the demand response potential of this industry. New refrigerated warehouses constructed under the California 2008 Title 24 code are likely to all fall under this category. In addition, expanding pilot programs to incorporate demand response functionality into the design of new refrigerated facilities (as well as energy efficiency) will likely improve the adoption of demand response. Furthermore, completion of the planned demand response guide would provide a valuable asset for helping facility managers decide to pursue demand response, as it would clearly identify specific recommendations that a facility could implement based on their facility type.

Careful integration of energy efficiency objectives with load shifting and demand response strategies is required if demand response capacity is to be reliable and also yield minimum operating cost for owners. Understanding interactions and minimizing owner cost is essential for the inherent demand control potential of refrigerated warehouses to become a robust, long term resource.

A greater understanding of the demand response potential vs. implementation cost thresholds can be obtained for the subject facilities, to better inform regulators and utility program developers. For example, a graduated form of participation payments may be necessary for a production-heavy facility, which can participate at one level on a routine basis, but might defer production occasionally with greater demand reductions but at much higher cost.

To support a balanced approach to energy efficiency and demand response, future work should identify appropriate performance metrics, commissioning concepts, and point to benchmarking methods for refrigerated facilities and systems. While the wide range of temperatures and operations in refrigerated facilities have historically limited progress in these areas, compared with what has transpired in commercial buildings and HVAC systems, it is essential to demonstrate how owners can establish expectations against which actual performance can be compared.

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