Showcasing Energy Efficiency Solutions in a Cold Storage Facility

Ramin Faramarzi, Southern California Edison
Bruce A. Coburn, Southern California Edison
Rafik Sarhadian, Southern California Edison

ABSTRACT

Refrigerated warehouses have one of the highest electric *energy usage intensities* in the commercial building sector (Leue and Eilert 2000). Their electric usage, often ranges from 40 to 60 kilowatt-hours per square foot per year, with refrigeration accounting for more than 70 percent of overall electric usage. Although refrigeration equipment performance in cold storage facilities is not governed by any efficiency standards, these facilities can benefit significantly from commercially available energy efficiency solutions, which can reduce energy consumption and improve food safety by providing desirable temperatures.

This paper presents the findings of an energy efficiency showcase of a 24,600 square-foot cold storage facility in Ontario, Calif. A short-term end-use monitoring plan was deployed to capture the impact of the following energy efficiency solutions:

- Enclose an open loading dock area and add energy efficient cooling and dehumidification to reduce cooling load.
- Design and implement a new state-of-the-art refrigeration system, with advanced controls; sub-cooling; floating head pressure; high efficiency evaporators, condensers, and motors; and variable speed drives.

At a mild ambient temperature of 65°F, the new system reduced daily refrigeration energy use by approximately five percent, and reduced the facility's peak electric demand by five percent. (The site is, however, exposed to temperatures higher than 65°F during summer.) Additionally, the north and west freezers' storage temperatures dropped by 2.6°F and 5.6°F, respectively. These improvements were achieved despite a 17 percent increase in refrigerated floor space.

Introduction

In early 2000, Southern California Edison initiated this project with one of its refrigerated warehouse customers, as part of the utility's energy efficiency market transformation activities. The premise was to implement an energy efficient and environmentally friendly refrigeration system, while expanding refrigeration capacity and improving product storage temperatures. A short term monitoring plan was designed and implemented to capture the benefits of the new system. Project agreement was signed in March 2000, followed by design engineering. Pre-monitoring began in April and ended in May 2000; construction began in June and ended in August 2000; and post-monitoring began in September 2000 and ended in February 2001. The specific objectives of the project were to:

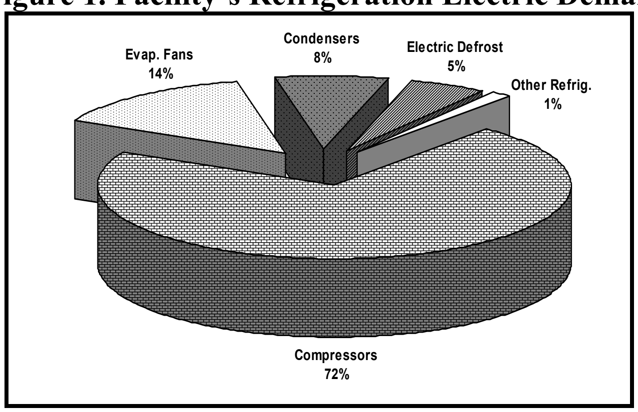
1. Increase energy efficiency by:

    a. Minimizing cooling load
    b. Replacing inefficient equipment with a high efficiency system
    c. Improving system controls

2. Improve product quality by maintaining tighter, lower temperatures
3. Increase refrigeration capacity to include a new zone for ice cream storage and provide cooling in the loading dock, and
4. Improve environmental friendliness with zero-ozone-depleting R-507 refrigerant.

Prior to developing a list of energy efficiency measures and an end-use monitoring plan, a detailed walk-through of the facility was performed. Coupling results from the walk-through and analyzing the facility's billing history paved the way for identifying applicable energy efficiency measures. More than two-thirds of the facility's electric usage was for refrigeration, with compressors contributing more than 70 percent of that, as illustrated in Figure 1.

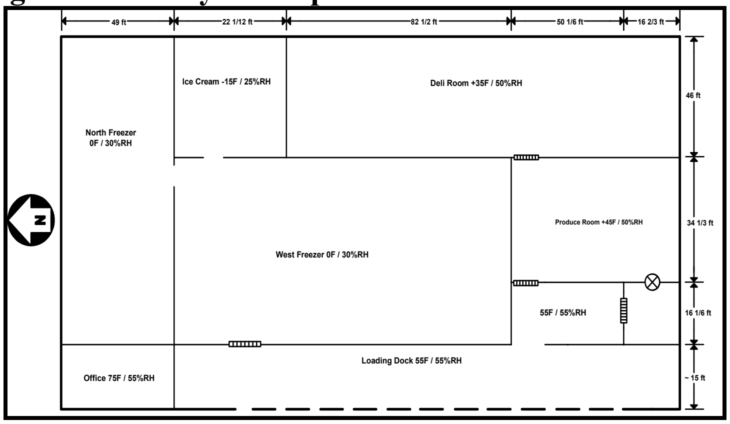
Figure 1. Facility's Refrigeration Electric Demand



Facility Description

The single-story, 24,600 sq-ft refrigerated warehouse with 20-foot ceilings is located in Ontario, Calif. (Figure 2). It comprises low- and medium-temperature zones, with a total of six old and poorly conditioned refrigeration systems serving fan coils in coolers and freezers. The old system did not serve the ice cream and the loading dock zones, shown in Figure 2.

Figure 2. Facility Description



An unconditioned loading dock with 10-foot ceiling separates the refrigerated zones from 12 roll-up doors. Most doors remained continuously open, regardless of shipping and receiving activities (Figure 3a). Most of the roll-up door openings were not fitted with any form of sealing devices to reduce infiltration of warm air into the dock (Figure 3-b).

Figure 3. Loading Dock Area

(a) (b)

Base Refrigeration Systems

Six old refrigeration systems served two freezers, one deli cooler and one produce cooler. All systems suffered from deferred maintenance. Table 1 summarizes the characteristics of each system.

Table 1. Summary of the Old System Characteristics

System	Serves	Compressor Type	Compressor Qty/Cyl	Compressor HP	Capacity Control	Refrigerant	Condenser Qty/ Type	Defrost
A	North Freezer	Reciprocating	(2) 4 Cylinder	50	Pressure Switch	R-22	(2) Air-Cooled	Hot Gas
B	Deli Cooler	Reciprocating	(2) 4 Cylinder	20	Pressure Switch	R-22	(1) Air-Cooled	Electric
C	West Freezer	Reciprocating	(1) 6 Cylinder	30	Pressure Switch	R-402A	(1) Air-Cooled	Electric
D	West Freezer	Reciprocating	(2) 6 Cylinder	30	Pressure Switch	R-22	(1) Air-Cooled	Electric
E	Produce Cooler	Reciprocating	(1) 4 Cylinder	10	Pressure Switch	R-22	(1) Air-Cooled	Time Off
F	No Zone	Reciprocating	(1) 4 Cylinder	7.5	Pressure Switch	R-22	(1) Air-Cooled	Time Off

Figures 4 and 5 show schematic piping diagrams of systems A and B. Both systems operated on fixed head pressure. Most fan coils in both systems were blocked by product racks, which had hampered the airflow and caused severe icing on the coil. Many of the evaporator fan motors were burned out.

Figure 4. Schematic Piping Diagram of System A

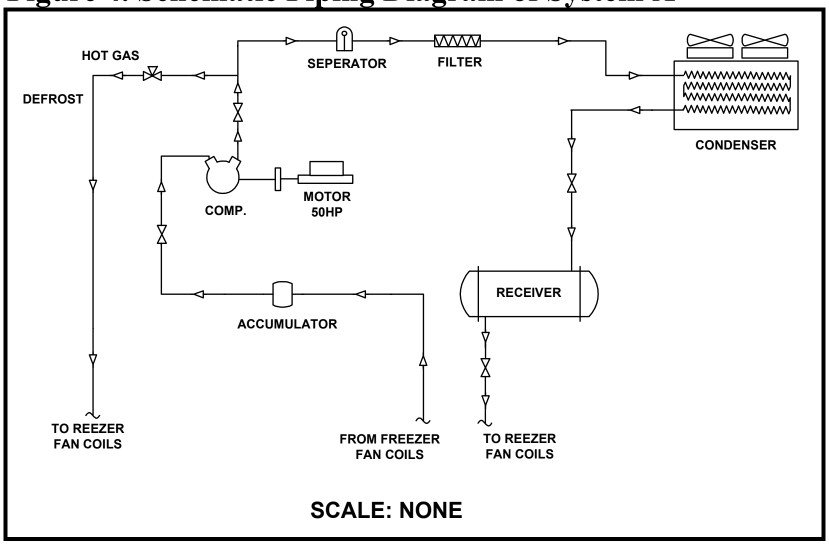
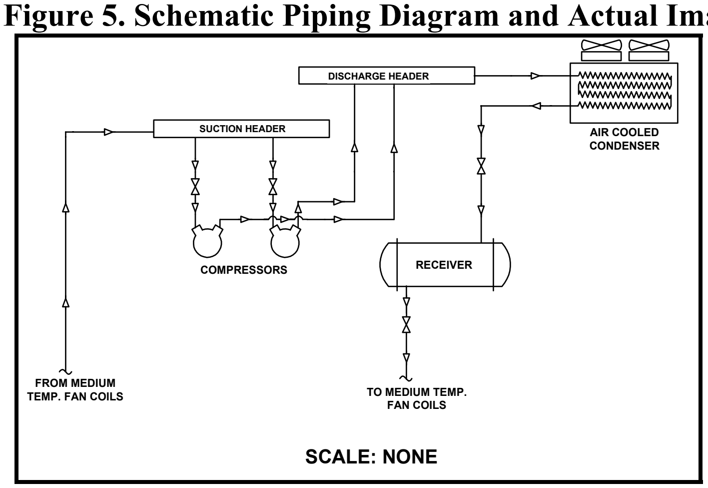
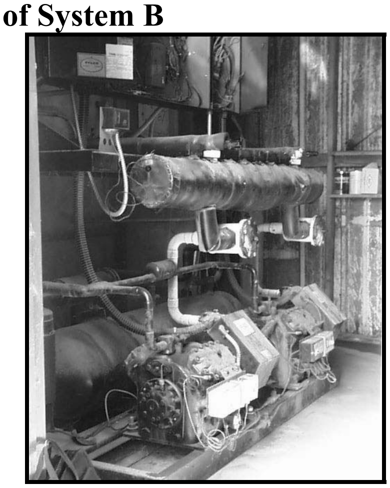


Figure 5. Schematic Piping Diagram and Actual Image of System B





End-Use Monitoring Plan

A carefully designed monitoring plan was developed, based on the on-site audit data, which was collected in five-minute intervals, so both demand and energy use could be analyzed. The project focused on monitoring the most critical points, refrigeration and total electric loads of the building. Monitoring equipment was installed in March 2000. The pre-monitoring periods covered April and May of 2000, while post-monitoring started in September 2000 and ended in February 2001. According to pre-monitoring data, the total electric demand of the facility varied due to fluctuations in total refrigeration systems' electric demand, which clearly seemed to be a function of outdoor ambient temperature (Figure 6).

Figure 6. Pre-Retrofit Electric Load Profiles and Ambient Temperature – April 2000

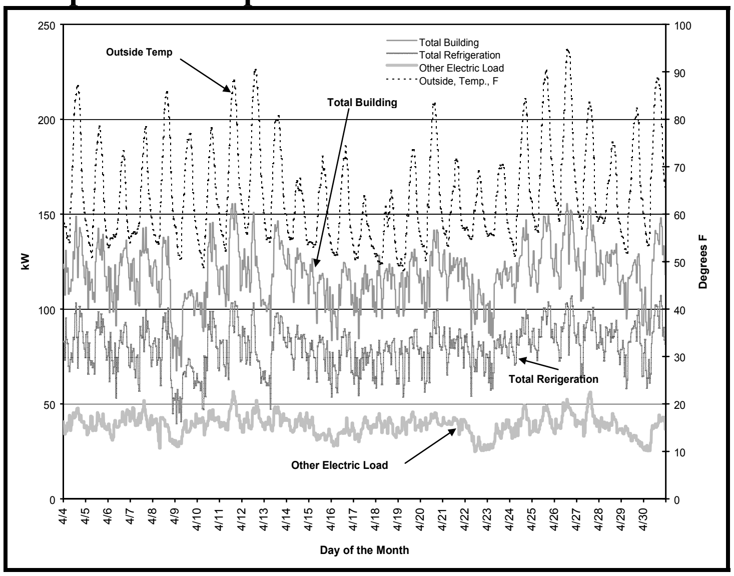
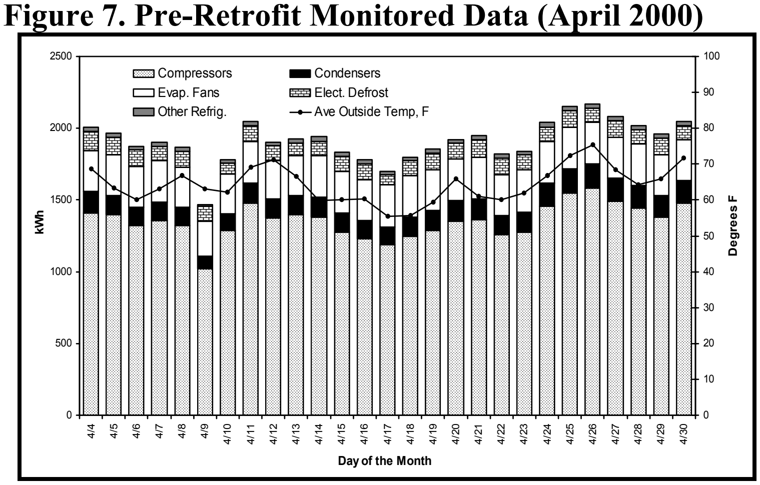


Figure 7 shows the pre-retrofit average daily electric energy of each end-use equipment monitored during April 2000. The average daily total building electric load was 1,914 kWh during this period. Compressor load is the only one that displays large day-to-day variations with respect to temperature changes.

Figure 7. Pre-Retrofit Monitored Data (April 2000)



Energy Efficiency Solutions

Based on the on-site audit results, a series of energy efficiency solutions (EES) were identified to improve and enhance the performance of the refrigeration system:

- **EES-1**: Reduce the cooling load of the facility by minimizing infiltration load through the loading dock.
- **EES-2**: Replace scattered single compressor systems with a centralized high efficiency un-evenly sized multiplex system using R-507, featuring sophisticated

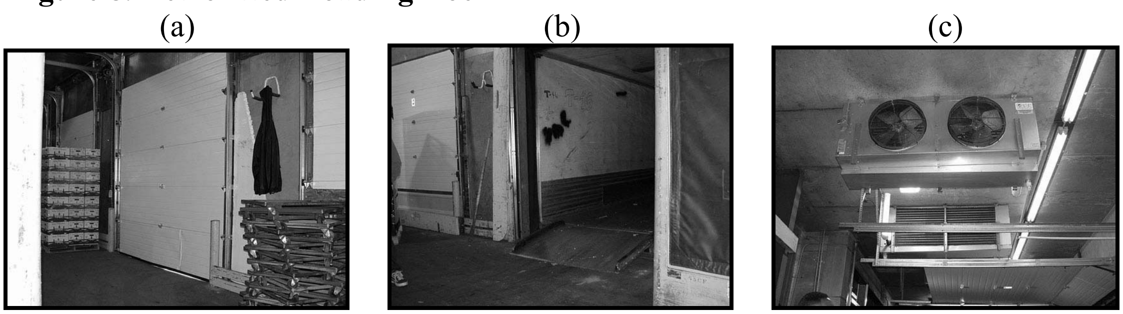
controls, high efficiency compressors with Discus valve, un-loaders for capacity modulation, mechanical sub-cooling, and floating head pressure, using a variable set-point control strategy. The new system serves an additional 3,577 sq-ft of refrigerated space to include the added ice cream freezer and loading dock.

- **EES-3**: Replace all scattered air-cooled condensers with a single high efficiency evaporatively cooled condenser, equipped with Variable Speed Drive (VSD).
- **EES-4**: Replace fan coils with low Temperature Difference (TD) evaporators utilizing hot gas defrost instead of electric. All evaporators will be equipped with dual-port Thermal Expansion Valve (TXV), an Evaporator Pressure Regulator (EPR) valve, and high efficiency fan motors.

Cooling Load Reduction (EES-1)

The open loading dock allowed adverse infiltration of warm and moist air into the refrigerated zones. Door seals and insulated, auto-closing roll-up doors were used to minimize outside air infiltration. As a result, all twelve 8' x 8' un-insulated roll-up doors were replaced with new R-17-insulated units (Figure 8a and b). Two large fan coil systems were added to provide roughly seven tons of cooling (Figure 8c). The new fan coils are served by the same centralized system, which provides refrigeration for the entire facility. The new fan coils provide dehumidification and cooling of the air to 60^{o}F inside the 2,567 sq-ft loading dock area.

Figure 8. Retrofitted Loading Dock



Attention was paid to cooling load analysis of the facility to ensure optimum sizing of the new system. Following guidelines provided by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE 1998), an engineering model was developed to perform the cooling load analysis.

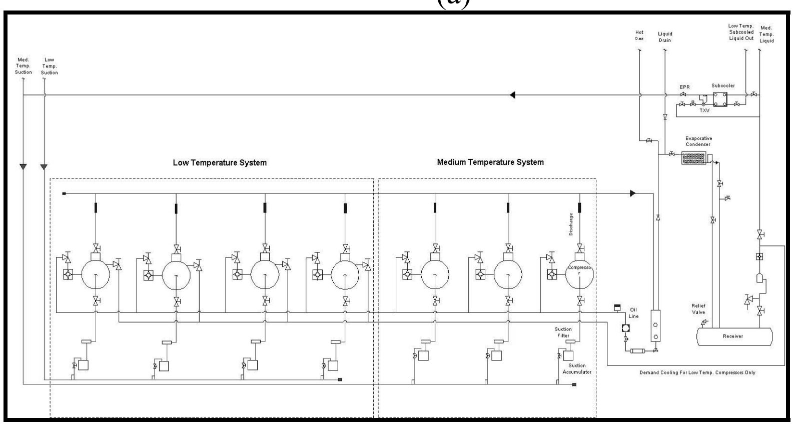
New Centralized High Efficiency Multiplex System (EES-2)

A single centralized multiplex system replaced the six existing scattered refrigeration systems (Figure 9b). The new system, which serves the entire facility including the added zones, is composed of three medium-temperature and four low-temperature compressors, and one dedicated ice cream compressor.

Two separate lines return suction gas from the fan coils to individual headers piped to compressors serving the two temperature groups. Discharge gas from all temperature groups enters a common manifold, which is piped to a single condenser (Figure 9a). During defrost, a portion of high pressure, superheated discharge gas enters the defrost manifold. Through an electronically controlled valve mechanism, discharge gas provides defrost to designated fan coils. All compressors are un-evenly sized and equipped with un-loaders to provide a desirable match between load and capacity under part-load operations. A new dedicated computer-based Energy Management System (EMS) controls the operation of the entire refrigeration system. The EMS also floats the discharge pressure of the compressor system by maintaining a fixed TD above the ambient wet-bulb temperature. Floating the head pressure increases refrigeration capacity, while reducing compression ratio and, thereby, compressor power use. A new medium-temperature system provides sub-cooling for the low-temperature group to increase refrigeration capacity and efficiency.

Figure 9. Piping Diagram and Image of the New Centralized Compressor System

(a) (b)



Ice cream compressor not shown

All compressors are served by environmentally friendly R-507 refrigerant and utilize discus valves, which provide higher volumetric efficiencies than conventional reed valves. Table 2 provides a summary of the new system's specifications.

Table 2. Specification Summary of New Centralized Multiplex System

Refrigerant	Design Suction Temp.	Design Cond. Temp.	Cooling Load (@ peak design)		Compressor Type	Compressor HP	Compressor Quantity	Total Compressor Capacity	Capacity Control	Defrost Type
	(^oF)	(^oF)	(Btu/hr)	Tons		(each)		(Tons)		
R-507	-25	90	73,741	6.1	4 Cyl. / Recip / Discus	15	1	6	unloader	Hot Gas
R-507	-10	90	462,000	38.5	4 Cyl. / Recip / Discus	15	4	45	unloader	Hot Gas
R-507	+25	90	708,000	59.0	6 Cyl. / Recip / Discus	35	1	65	unloader	Hot Gas
					4 Cyl. / Recip / Discus	25	2			

High Efficiency Condenser System (EES-3)

One new evaporative condenser replaced several air-cooled condensers that were distributed throughout the facility. Evaporative condensers provide lower condensing temperatures than air-cooled units in dry climates, such as Ontario, Calif. The surface area of the new condenser is slightly oversized for more efficient heat rejection, while its fan motor is not sized as large. With a larger heat transfer surface, the condenser can operate at lower TDs, which results in operations at lower condensing temperatures. The condenser fan is equipped with a VSD, which is controlled by the EMS to provide optimum conditions for floating the head pressure of the compressors.

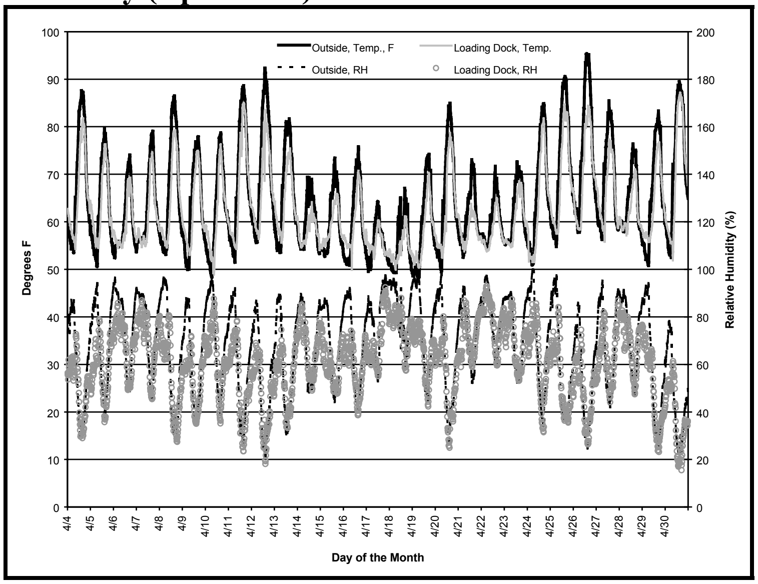
High Efficiency Fan Coil Systems (EES-4)

All fan coils were replaced with new units featuring larger surface area, high efficiency fan motors, EPR valve, and dual-port TXV. The new fan coils operate at lower TDs. As a result, discharge air is colder than that of a conventional evaporator, yet the compressors operate more efficiently. The high efficiency fans reduce heat dissipation to the refrigerated space while consuming less power. The dual-port TXV eliminates the over- or under-sizing effects of the valve, and allows higher refrigerant flow through its larger port during post-defrost periods. Once the superheat set-point is satisfied, the TXV closes the large port and opens the small port for maintaining storage temperatures. The EPR valve ensures that the coils operate at a constant temperature and prevents the evaporator from freezing or operating at undesirably low temperatures.

Discussion of Results

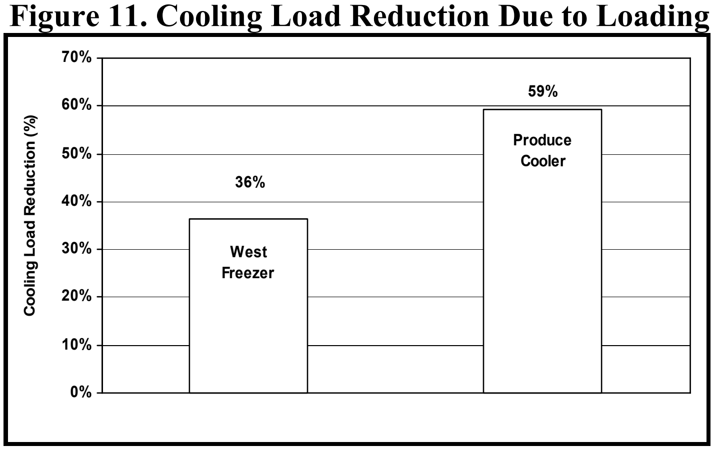
Prior to installing the new loading dock doors and the new cooling system, the temperature and relative humidity of the loading dock area closely tracked outdoor ambient temperature, as depicted in Figure 10. This closeness can be attributed to the loading dock doors remaining continuously open and poor sealing around the doors when closed.

Figure 10. Ambient and Loading Dock Temperature and Relative Humidity (April 2000)



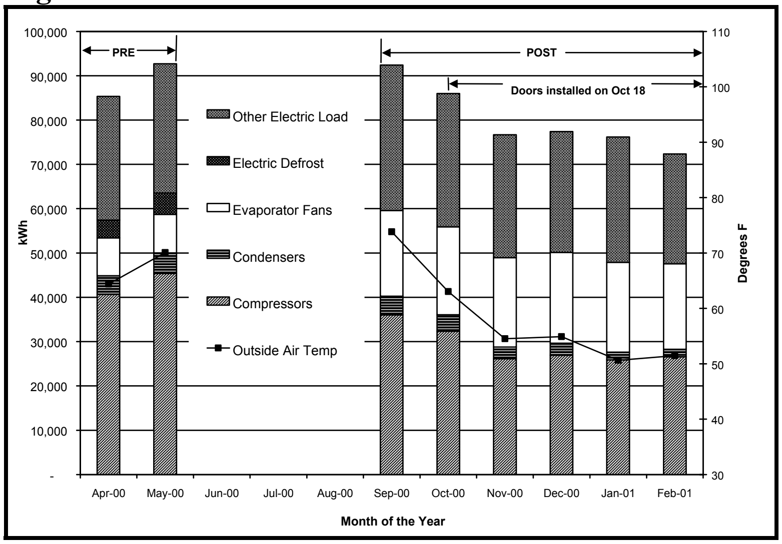
Keeping insulated roll-up doors closed when not in use and installing tight sealing devices reduced the infiltration of warm air into the loading dock area. Coupled with adding mechanical cooling in the loading dock, this reduced the cooling loads of the west freezer and the produce cooler by 36 percent and 59 percent, respectively (Figure 11).

Figure 11. Cooling Load Reduction Due to Loading Dock Retrofit



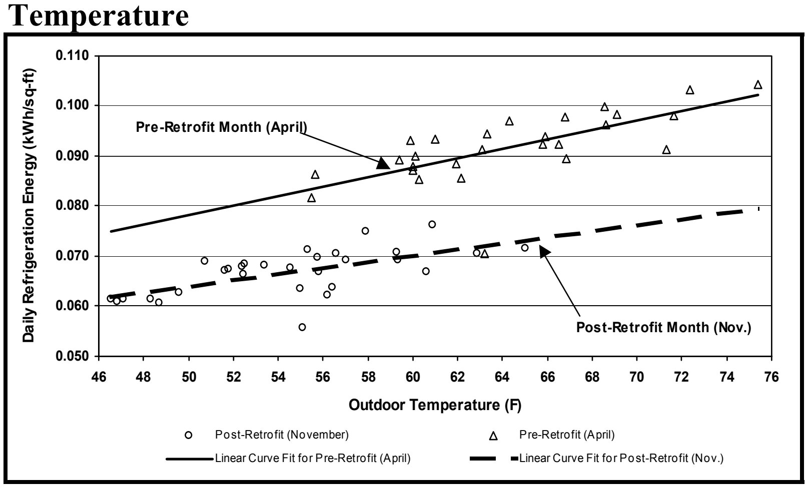
Post-retrofit end-use monitored data indicates a reduction in compressor and condenser energy use (Figure 12). The reduction was even greater in mid-October, when the 12 new insulated roll-up doors were installed in the loading dock. According to monitored data, the facility sustained a relatively constant monthly non-refrigeration electric load of roughly 29,000 kWh during pre- and post-retrofit periods. Post-monitored data indicates the facility's evaporator fan energy increased, which is a result of adding fan coils in the new ice cream freezer and the loading dock. Noteworthy, the lower pre-monitored fan energy includes the evaporator fan motors that were burnt out. As shown in Figure 12, except for September, condenser and compressor used less energy, despite the increased refrigerated floor space.

Figure 12. Pre and Post-Retrofit Monitored Data



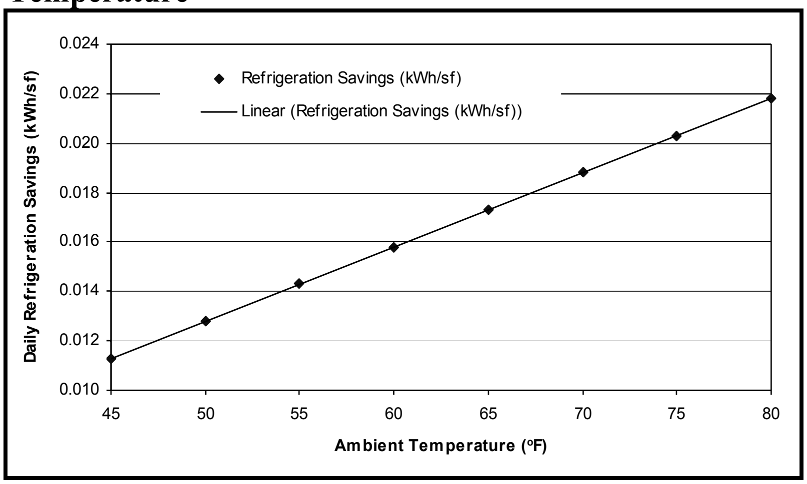
Some of this reduction should be attributed to milder temperatures during post-retrofit periods. Most pre- and post-retrofit comparisons were made using April and November monitored data, respectively. November was the first month that all retrofit technologies were completed. The pre-retrofit data in April was used because that month's cool temperatures most closely resembled November. A correlation between the energy usage during these two pre- and post-retrofit months, with respect to ambient temperature, was developed to create a reasonable comparison platform (Figure 13). As expected, the compressor is the most critical weather dependent component of both refrigeration systems. At higher temperatures, condensers provide higher condensing temperatures. Under these conditions, refrigeration capacity of the compressor drops, while its compression ratio and power usage increase. Therefore, as depicted in Figure 13, the normalized daily refrigeration energy usage (kWh/sq-ft) of both systems increases as a function of ambient temperature. The energy efficient system, however, consumes less energy per square foot than the old system under equal ambient temperatures.

Figure 13. Refrigeration Energy Use as a Function of Ambient Temperature



Daily refrigeration energy savings were estimated using the regression equations developed in Figure 14. At an ambient temperature of 65°F, the new system saves approximately 0.017 kilowatt-hours per day per square-foot, or 102 kilowatt-hours per day in refrigeration use. Figure 14 indicates that, as the ambient temperature increases, the new system tends to generate more refrigeration energy savings. Based on three years of weather data collected by Southern California Edison's meteorological station, located near the project site, the average summer temperature stayed around 72°F. At higher ambient temperatures, the new system maintains lower loading dock temperatures than the old system. Also, the new energy efficient condenser provides lower condensing temperatures than the old system. All of these factors, as well as advanced controls, justify the predicted increased savings of the new system at higher ambient temperatures.

Figure 14. Refrigeration Energy Savings as a Function of Ambient Temperature



Billing data also reveals a reduction of 5 percent in peak electric demand of the facility (Figure 15). With the exception of January, April and May the maximum kW demand of the facility stayed lower during post-retrofit period.

Figure 15. Pre and Post-Retrofit Billing Data

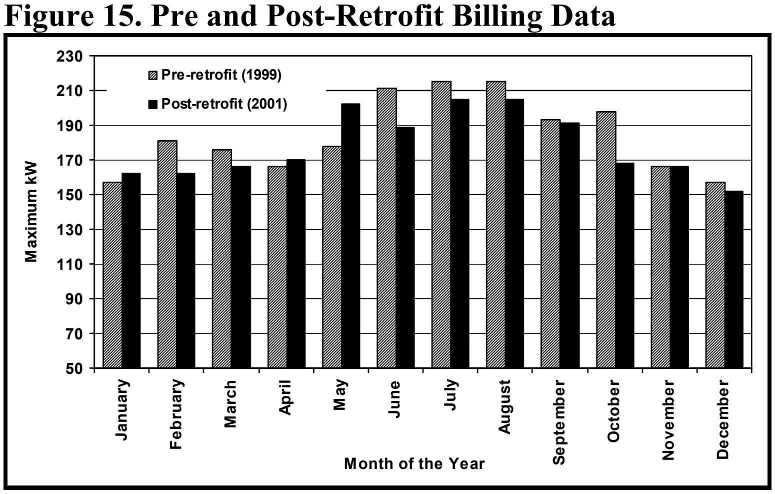
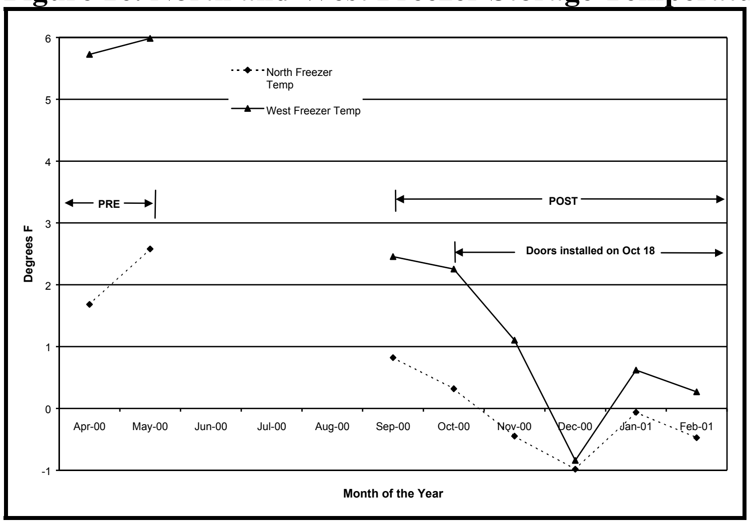


Figure 16 shows an average storage temperature drop of 4.9°F in the west freezer, which is adjacent to the loading dock. This temperature drop can be attributed to lower infiltration load, colder discharge temperatures, tighter temperature controls and improved air circulation. The north freezer also experiences lower storage temperatures, which is primarily due to higher efficiency fan coil systems and improved controls.

Figure 16. North and West Freezer Storage Temperatures



Conclusions and Recommendations

Overall, the new system performed more efficiently than the old system, while it increased the capacity and provided lower storage temperatures. The implemented EESs allowed the new system to operate at higher suction pressures and lower condensing temperatures than the old system. The lower and tighter post-retrofit storage temperatures may enhance product quality and be more economical. Furthermore, the whole system is far more environmentally friendly than its predecessor and offers an improved arrangement for implementing a cost-effective maintenance strategy.

In general, the benefits of these particular energy efficiency solutions will not be captured in the absence of a proper product stacking practice. Blocking fan coils' air passages will hamper system efficiency and nullify the effectiveness of these energy efficiency solutions. Additionally, it is critical to implement a routine and effective maintenance program after investing in energy efficiency.

References

Leue, David and Patrick Eilert. 2000. "Industry Transformation in Refrigerated Warehouses." In *Proceedings of the American Council for an Energy-Efficient Economy*.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). 1998. *ASHRAE Handbook Refrigeration Systems and Applications, Chapter 12.*