LED Lighting for Low Temperature Reach-in Refrigerated Display Cases

ET 06.06 Report

Prepared by:

Design & Engineering Services
Customer Service Business Unit
Southern California Edison

December 17, 2009

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL® Company

Acknowledgements

Southern California Edison's Design & Engineering Services (DES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technology program under internal project number ET 06.06. DES project manager Scott Mitchell conducted this technology evaluation with overall guidance and management from Ramin Faramarzi and Paul Delaney. For more information on this project, contact *Scott.Mitchell@sce.com*.

Disclaimer

This report was prepared by Southern California Edison (SCE) and funded by California utility customers under the auspices of the California Public Utilities Commission. Reproduction or distribution of the whole or any part of the contents of this document without the express written permission of SCE is prohibited. This work was performed with reasonable care and in accordance with professional standards. However, neither SCE nor any entity performing the work pursuant to SCE's authority make any warranty or representation, expressed or implied, with regard to this report, the merchantability or fitness for a particular purpose of the results of the work, or any analyses, or conclusions contained in this report. The results reflected in the work are generally representative of operating conditions; however, the results in any other situation may vary depending upon particular operating conditions.

ABBREVIATIONS AND ACRONYMS

DAT	Discharge air temperature
EE	Energy efficiency
EMS	Energy management system
ET	Emerging Technologies
LED	Light emitting diode
LT	Low temperature
RTTC	Refrigeration and Thermal Test Center
SCE	Southern California Edison
SCE	Saturated Condensing Temperature
TTC	Technology Test Centers

FIGURES

TABLES

CONTENTS

EXECUTIVE SUMMARY

This project evaluates the energy and demand savings of light-emitting diode (LED) lighting systems and traffic sensitive lighting controllers in low-temperature reach-in refrigerated display cases. The lighting systems were installed in a 35,000 square foot supermarket in West Covina, California. The case lighting in this store was on a timer that turned the lighting off between the hours of 11:00 PM and 6:30 AM. Data was collected for several weeks fore each of three project phases. The first phase monitored the existing T8 fluorescent system with electronic ballasts. The second phase monitored the new LED system operating at full power. The third phase monitored the LED system with a traffic-sensitive controller installed.

Results showed that a 67% reduction in lighting power and energy was achieved by switching from T8 to LED systems. An additional 5% energy savings was achieved with the addition of the traffic sensitive controllers. The controller did not provide significant savings during the middle of the day. Rather, savings were most prevalent during the shoulder periods of 6:30 to 11:00 AM and 8:00 PM to 11:00 PM (Figure 1).

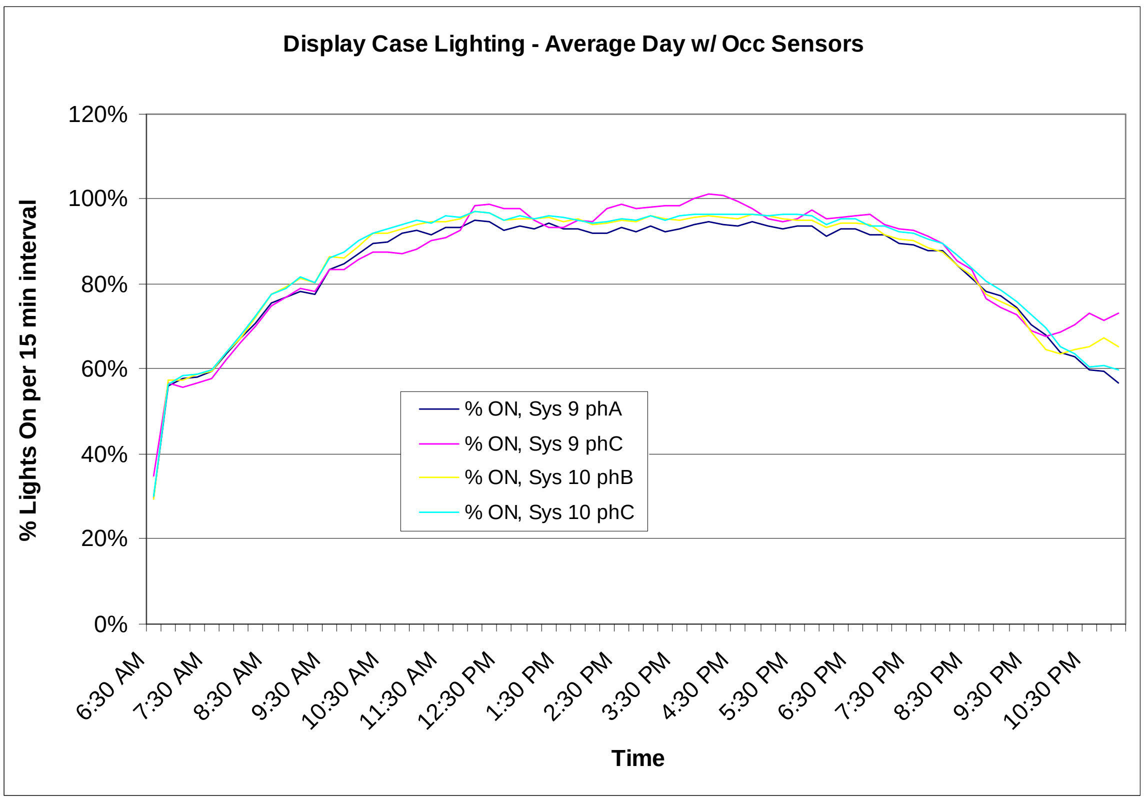

FIGURE 1. AVERAGE DAILY PROFILE OF LED POWER WITH OCCUPANCY CONTROLLER

Estimated direct lighting consumption for each phase is shown in Figure 2 along with the estimated secondary refrigeration energy consumption due to decreased cooling load in the case. Direct power and energy were reduced by 67% with the installation of the LED system at full power. An additional 5% energy savings was realized with the addition of the traffic-sensitive controller. On the refrigeration side, 30% savings were estimated over T8 for both the LED and the controller. These savings are dependent on characteristics of this particular store and may not translate directly to other locations due to variations in shopper traffic patterns and type of equipment in place. However, there may be additional opportunities to leverage the occupancy controllers, such as in demand response programs.

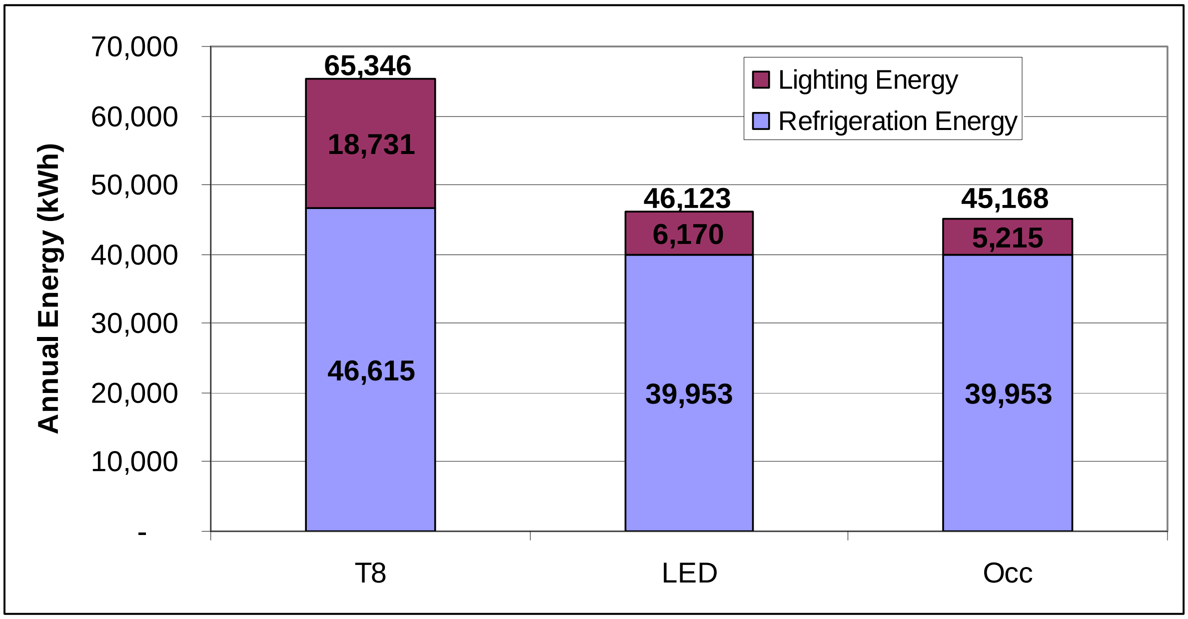

FIGURE 2. COMBINED LIGHTING AND REFRIGERATION ENERGY CONSUMPTION FOR EACH PROJECT PHASE

It is recommended that SCE's energy efficiency programs continue with plans to introduce LED refrigerated case lighting as a rebatable energy efficiency (EE) measure. It would also be wise to explore the possibility of adding a measure for traffic-sensitive controllers for the LED systems. While energy savings may not be large compared to the T8 to LED changeout, the controllers may provide additional benefits not examined here. If these controllers are installed on cases, they may be a good candidate for demand response efforts. Furthermore, as case lighting is readily visible to customers, stores can use the presence of LEDs and lighting controllers as an EE showpiece to expound dedication to greening their operations. Hopefully, this is yet another opportunity to remind consumers of the importance of EE in all aspects of their daily lives.

INTRODUCTION

This project was conducted with $90,000 of Emerging Technology (ET) funds approved for use by the California Public Utilities Commission. The project was funded in December of 2006, and concluded with a final report in the fourth quarter of 2009. This field assessment project was conducted at one of the chain supermarkets located in West Covina, California.

This project investigates the demand reduction and energy savings associated with using new lighting technologies in low-temperature (LT) reach-in refrigerated display cases. Particularly, in this project the existing T-8 fluorescent lamps with electronic ballasts of LT reach-in refrigerated display cases were replaced with a light-emitting diode (LED) system. The LED system was evaluated first at full light output (i.e., without dimming), and afterwards with dimming capability as a function of shoppers traffic in front of the cases.

The evaluation involved measuring key parameters such as lighting system and compressor power and energy requirements. Additional data points included indoor and outdoor dry bulb temperatures and relative humidity, display case temperatures, door openings, as well as the refrigeration operating parameters such as suction and discharge pressures and temperatures.

Typical LT reach-in refrigerated display cases today use T-8 fluorescent lighting systems that introduce a significant amount of heat inside the cases. New lighting technologies, like the LED systems used in this project, require less electrical power to operate while providing better light quality for merchandising products. Subsequently, the LED systems use less energy and introduce less heat inside the LT reach-in cases. Thus, the refrigeration equipment experiences additional energy savings. Additional demand reduction and energy savings can be realized by dimming the LED systems when there is no shopper traffic.

BACKGROUND

Supermarkets and grocery stores represent one of the largest electric energy-intensive building groups in the commercial sector, at 43 to 70 kWh/ft^2 per year.[1] A typical 50,000 ft^2, which is classified as a large supermarket, consumes somewhere between 2 to 3 million kWh per year.[2] About 50% of this energy use is for the refrigeration of food display cases and storage coolers.[1]

Display cases are widely used in supermarkets and grocery stores for merchandising of perishable food products. Depending upon the type of product stored, and its temperature requirements, display cases can be categorized as either medium- or low-temperature. To maintain desired product temperatures, display cases rely heavily on the temperature of air discharged into the case or the discharge air temperature (DAT). For example, medium-temperature display cases are used to merchandise meat, deli, dairy, produce and beverages. The DAT of these types of display cases can range from +24^{o}F to +38^{o}F.[1] On the other hand, LT display cases are used to merchandise frozen food and ice cream. The DAT for LT display cases can range from -24^{o}F to -5^{o}F.[1] Figure 3 shows the distribution of display cases by category in a typical supermarket. As depicted, about one-third of the total refrigerated display cases in a supermarket are LT reach-in.[1,2]

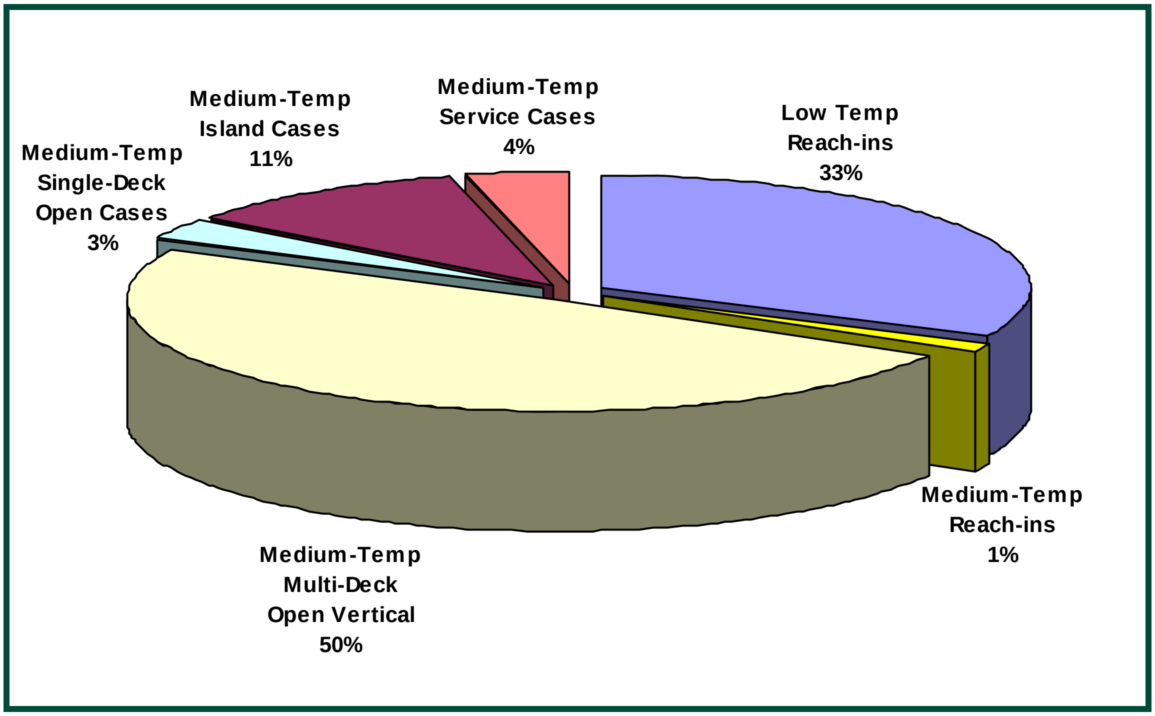

FIGURE 3. PERCENTAGE BREAKDOWN OF DISPLAY CASES BY TYPE IN A TYPICAL SUPERMARKET (SOURCE: BAXTER, V. D., "INVESTIGATION OF ENERGY EFFICIENT SUPERMARKET DISPLAY CASES," ORNL/TM-2004/292. OAK RIDGE NATIONAL LAB, DECEMBER 2004. FIGURE ES-2.)

Presently, the standard LT reach-in refrigerated display cases are equipped with T8 fluorescent lamps and electronic ballasts. The T8 lighting system consumes roughly 67 watts/door and contributes to about 10% of refrigeration load of these cases.[3] The light output from these fluorescent lamps is not optimally directed on the products but partially wasted on the glass doors and floor. Fluorescent lamps also typically have reduced life in cold environments and must be overdriven to prevent flickering.

As energy prices have increased over the past several years, grocery store operators have become very interested in technologies that can help reduce their energy consumption. Historically, they have focused on space lighting improvements because of the ease of installation and readily available energy savings data. The industry, however, seems much slower to adopt new technologies when it comes to refrigeration. This is because of the high costs of implementation and uncertainty of effects due to the complexity of refrigeration systems. In the recent past, several new technologies have arrived on the market that address lighting in display cases. These technologies claim to use less energy to provide equivalent light, as well as reducing interactive load on the refrigeration system.

One of these new technologies in LT reach-in display case application is the LED system. Although LED systems require less power than fluorescent systems, not all LEDs are equal in terms of power usage and efficacy. A laboratory assessment project conducted by Southern California Edison's (SCE's) Technology Test Centers (TTC) explored the performance differences between various generations of LED systems in terms of power usage and efficacy, among other key parameters.[4] This study evaluated and compared seven 5-foot long LED systems from six manufacturers. The results indicated that the power usage of tested LED systems varied from 46 watts to 128 watts for a 3-door LT reach-in display case. The efficacy of these LED systems varied from 26 to 59 lumens per Watt.

Another laboratory assessment project conducted by SCE's TTC looked at performance differences of 5-foot long T8 fluorescents with 5-foot long LED strips in a 3-door LT reach display case.[5] The results of this investigation indicated that both lighting systems provided sufficient light to illuminate the products. Although the LED system provided less total light output in terms of luminance than fluorescent, the LED system achieved more even light distribution across the product facing than fluorescent. The LED system drew 43% less power than T8 fluorescent lighting. Subsequently, the cooling load reduction of the 3-door LT reach-in display case was 255 Btu/hr or 85 Btu/hr per door for the LED system. In addition, the LED system was anticipated to reduce the total combined lighting and compressor annual energy usage by 18%.

PROJECT GOALS AND OBJECTIVES

The objective of this project was to quantify the power and energy implications of installing LED display case lighting systems in a supermarket in the field. This included both the demand of the lighting system itself and indirect effects on the refrigeration system. This was accomplished by comparing the new LED system with the baseline fluorescent system both on the refrigeration and lighting power and energy usage. The same information was achieved for the traffic-sensitive LED dimming controller.

MARKET POTENTIAL

The primary market for the technology in its current form is small, medium, and large size grocery stores and supermarkets, including convenience stores. While the current study specifically addresses LT reach-in refrigerated display case (freezer case) installations where the LED is installed vertically in the cases between doors, similar systems can be used for other types of refrigeration equipment such as medium temperature cases, and walk-in coolers and freezers. There are products introduced on the market very recently that address some of these applications. For example, several display case manufacturers are now offering horizontally-mounted LED lighting options for open vertical display cases. However, because of the different system configurations and lighting needs, the savings reported here may not directly transfer to these other applications. Further investigation is necessary to quantify savings for applications outside the scope of this test.

MARKET SIZE

Table 1 summarizes the number of grocery stores located in SCE service territory and the state of California according to their annual energy consumption or store size classification.[6] It is estimated that there are about 6,900 grocery stores with annual energy usage greater than 1.6 million kWh in California, of which 2,800 are in SCE's service territory. Medium size grocery stores that consume between 190,000 kWh and 1,600,000 kWh annually, number 12,000 in California, of which 5,000 are in SCE's service territory.

TABLE 1. MARKET SIZE FOR SMALL, MEDIUM, AND LARGE CATEGORIES OF GROCERY STORES IN SCE SERVICE TERRITORY AND THE STATE OF CALIFORNIA

GROCERY STORE SIZE CATEGORIES	ANNUAL ENERGY USAGE (KWH / YEAR)	SCE SERVICE TERRITORY (NO. OF STORES)	STATE OF CALIFORNIA (NO. OF STORES)
Small Size	Less than 190,000	2,905	7,158
Medium Size	Between 190,000 and 1,600,000	5,057	12,460
Large Size	Greater than 1,600,000	2,798	6,893
Total		**10,760**	**26,511**

The focus of this technology is on medium and large size grocery stores. A typical medium size grocery store on the average has about 35 LT reach-in glass doors.[3, 7,8] The number of LT reach-in glass doors in a typical large grocery store can range between 65 and 100, or on the average about 80 doors. This information along with the number of stores presented in Table 1 are used to estimate the total number of LT reach-in glass doors.

Table 2 outlines the estimated number of LT reach-in glass doors in SCE service territory and California for medium and large size grocery stores. As shown, the total number of LT glass doors in California is approximately 987,000, of which 400,000 are located in SCE service territory.

TABLE 2. NUMBER OF LOW-TEMPERATURE REACH-IN GLASS DOORS IN CALIFORNIA AND SCE SERVICE TERRITORY BY GROCERY STORE SIZE CLASSIFICATION AND TOTAL

SERVICE TERRITORY	MEDIUM SIZE STORES (NO. OF GLASS DOORS)	LARGE SIZE STORES (NO. OF GLASS DOORS)	TOTAL (NO. OF GLASS DOORS)
SCE	176,995	223,840	400,835
State of California	436,100	551,440	987,540

TEST PLAN

This project was separated into three phases. Phase 1 captured the performance of the existing T8 fluorescent lighting system. Phase 2 captured the performance of the new ElectraLED LED lighting system operating at full power and light output according to the same operation schedule used for the fluorescent system. Phase 3 captured performance of the LED system as controlled by the WattStopper traffic controller. The original plan envisioned collecting data for a minimum of four weeks for each phase. This approach allowed proper quantification and attribution of energy and demand savings between the LED system itself and to the traffic-based controller.

TEST SITE

The test site was a 35,000 square foot supermarket located in West Covina, California originally built in 1986. This location was chosen due to the presence of single compressor per lineup refrigeration system and its physical proximity to the Refrigeration and Thermal Test Center (RTTC).

The store layout consisted of four rows of LT reach-in display cases (Figure 4). The south end of the store housed the produce section, which was bordered by a 20-door LT lineup. The next aisle had 20 doors on one side served by System 9 and 23 doors on the other served by System 10. Finally, 23 doors shared an aisle with dry goods. Each endcap had a two-door case as indicated by cases E and K. The store’s hours of operation were 6:30 AM to 11:00 PM. The case lighting was controlled to operate between these hours for all phases.

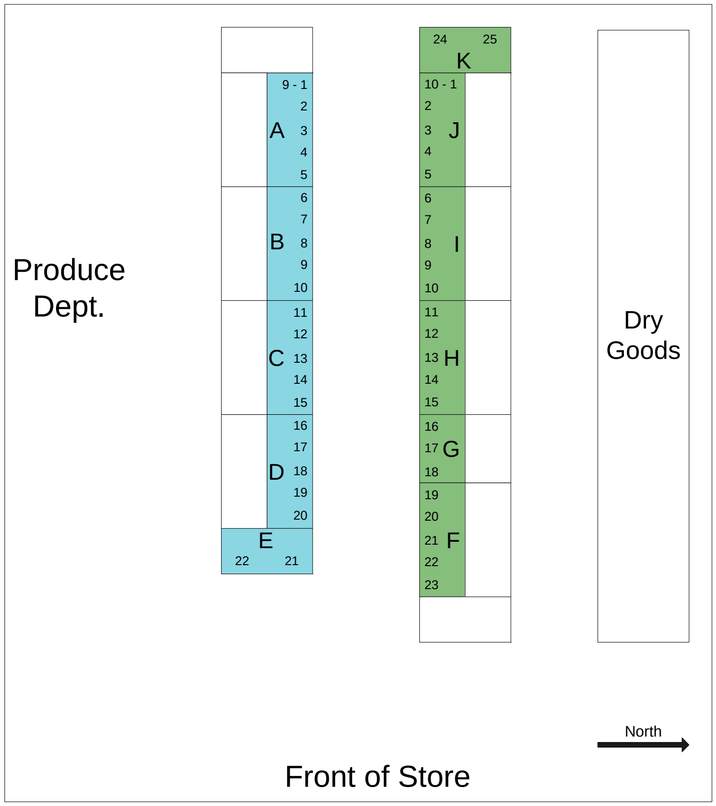

FIGURE 4. LT REACH-IN DISPLAY CASE LAYOUT

TEST PERIOD

All monitoring equipment was installed and data collection on the fluorescent baseline began April 20, 2009 and was expected to last 1 month. During the original baseline period, there was an unexpected change out of the system 9 compressor on June 10. This change was not related to any of the investigations required for this test. Fortunately, a delay in selection of the LED product to be tested meant that sufficient data was collected after the compressor change out so that a complete set of data existed with the new compressor in place. All data presented in the following sections is based on the post-compressor change out performance of system 9.

The data collection periods for all three phases are listed in Table 3.

TABLE 3. DATA COLLECTION PERIODS

PHASE	DESCRIPTION	DATA COLLECTION PERIOD
1	T8 Fluorescent	June 11 – July 8, 2009
2	LED at full power	July 23 – August 24, 2009
3	LED with Dimming	August 26 – October 22, 2009

TECHNOLOGY DESCRIPTION

LEDs are semiconductor devices that emit light when there is a proper amount of current in the semiconductor material. An LED driver is required to properly regulate the current to the LED, similar to ballast for a fluorescent system. The LED light can vary in color and for white LED, color quality as well. There are two ways to achieve white light for LEDs. One way is to use a mix of red, green, and blue LEDs. The most popular way to produce white light, however, is to use blue LED with a phosphor. This is the case for the LED lighting system under evaluation. Like all semiconductor materials, LEDs work better in cooler temperatures. The heat produced by the LED is not good for the performance of the LED. This heat is typically dissipated through a heat sink. Some products have integrated heat sinks that use the fixture itself as the heat sink material.

The LED system in this project was chosen by the host supermarket after conducting several field visits of other installed LED brands. The LED light fixtures were ElectraLED ELS LED series. The LED fixtures or strips were 5-feet long. In order to create even light distribution through the case, each center strip had 20 LED chips and each end strip had 10 LED chips. The power supplies were Osram Sylvania's OT75/120-277/24E. Each power supply drove either three center LED strips or two center LED strips and two end LED strips.

The LEDs were dimmable up to 20% of full output based on occupancy sensors that use passive infrared technology. Specifically, the FSC2 occupancy sensor from WattStopper that provided a 180° horizontal coverage was used to control the lighting levels. One occupancy sensor was used for each of the 5-door, 3-door, and 2-door freezer cases served by systems 9 and 10. The sensors were installed on the top of the cases in the center position. The controller was designed to maintain 20% output and ramp up to full output within two seconds of detecting motion, then dim back to 20% after 30 seconds of no traffic.

Two sets of power measurements were taken for the LED system. One set was with the LEDs at maximum power and full light output. Another set was after activating occupancy sensors with dimming capabilities. Table 4 summarizes key specifications provided by the manufacturer for the center and end LED fixtures.

TABLE 4. KEY MANUFACTURER SPECIFICATIONS FOR THE CENTER AND END LED FIXTURES

MODEL NUMBER	DESCRIPTION	TOTAL LUMEN OUTPUT	LIFE (HOURS)	COLOR RENDERING INDEX	POWER (WATTS) HIGH / LOW	DIMENSIONS (L x W x D)
ELS-C5-3500K	60" light fixture – center	1,700	64,000	80	24.5 / 15.9	57" x 2.76" x 0.85"
ELS-R5-3500K	60" light fixture – right end	850	64,000	80	12.3 / 7.9	57" x 1.80" x 0.85"
ELS-L5-3500K	60" light fixture – left end	850	64,000	80	12.3 / 7.9	57" x 1.80" x 0.85"

MONITORING PLAN

The monitoring plan was developed based on the information gathered during the walk-thru of the project site. The project plan was to replace the existing T8 fluorescent lamps with electronic ballasts (Phase 1) with an LED system. Data was to be collected first with LED at full light output (Phase 2), then with added traffic sensitive dimming capabilities (Phase 3).

Accordingly, a monitoring plan was developed that focused on power demand of the lighting and refrigeration components during all three phases of the project. In addition to power demand of refrigeration components and total refrigeration, variables and factors affecting operation of the refrigeration systems were captured. These included items like indoor and outdoor temperature and humidity, and shopper traffic. The power demand of the store's air conditioning system was also monitored. Although the total building power demand and energy usage was not monitored on-site, it was extracted from SCE's EnergyManager® website. The following subsections detail the monitoring points for both pre- and post-retrofit systems.

Figure 5 illustrates the monitored LT reach-in display case lineups that were served by refrigeration systems 9 and 10, as well as the approximate location of individual sensors. System 9 serves four 5-door and one 2-door LT reach-in display case, a total of 22 glass doors. System 10 serves four 5-door, one 3-door and one 2-door LT reach-in display case, a total of 25 glass doors. Each of these systems (systems 9 and 10) were served by a single compressor that eliminates any complexities associated with multiplex systems with multiple compressors tied to common suction and discharge lines to serve several loads.

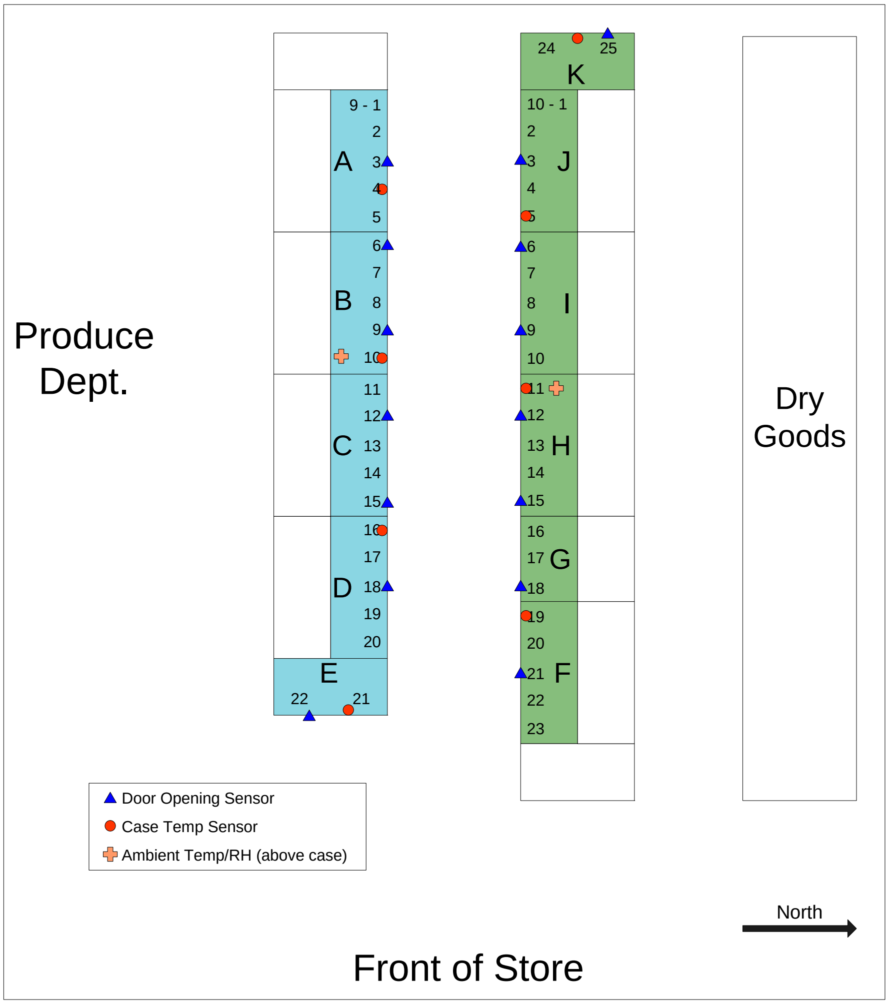

FIGURE 5. LAYOUT OF MONITORED LOW-TEMPERATURE REACH-IN DISPLAY CASES

LIGHTING

Lighting power was measured for display cases served by Systems 9 and 10. Initially, one power sensor was used to measure both systems simultaneously. With one week left in Phase 1, it was decided to split the monitoring into four different channels to allow greater visibility after the controllers were activated. The following data summarizes the number of light fixtures for both baseline and post-retrofit systems.

- Baseline display case lighting:
  - System 9: 27 T-8 fluorescent lamps
  - System 10: 31 T-8 fluorescent lamps
- Post-retrofit display case lighting:
  - System 9:
    - 17 center sticks (or full strips) with 20 LED chips
    - 10 end sticks (or half strips) with 10 LED chips

- System 10:
  - 19 center sticks (or full strips) with 20 LED chips
  - 12 end sticks (or half strips) with 10 LED chips

Sales area lighting power was also monitored in this project. Due to the physical location of some lighting circuits, it was not possible to measure all lighting loads. However, this was not a critical parameter for this project and a sufficient percentage of the lighting was captured to ensure there was not a major shift between the different project phases.

REFRIGERATION

The complexity of supermarket refrigeration systems makes field monitoring an inherently difficult task, and this project was no exception. There are many variables that can impact the refrigeration system's power and energy consumption. For instance, the number and duration of door openings, fluctuating outdoor temperature, and fluctuating indoor temperature and humidity can all have an impact on the refrigeration system operation. The monitoring plan used here attempted to capture data on as many of these operational variables as reasonably possible.

In addition to the display case lighting power, the power demand of various components of the LT reach-in display cases were captured. This included evaporator fans, defrost heaters, and anti-sweat heaters. A portion of the electric connected load of these components, however, becomes the cooling load of the display cases. Eventually, this cooling load will be removed by the compressors to maintain target product temperatures.

Compressor power was recorded for refrigeration Systems 9 and 10 separately. The total refrigeration system power was also captured. Additionally, the compressor's suction and discharge pressures and temperatures were monitored for systems 9 and 10.

The compressor power demand is partially dependent on the saturated condensing temperature (SCT). For an evaporatively-cooled condenser, SCT is a function of the outdoor ambient wet bulb and dry bulb temperatures. The outdoor ambient conditions were monitored using a logger located on the roof in the vicinity of the evaporatively-cooled condenser. For the analysis presented below, data collected at a nearby SCE weather station was used because a full year's worth of data was required.

Indoor (sales area) ambient temperature and humidity was monitored by three loggers. One logger was located above System 9 freezer cases, and one above System 10 freezer cases. The third logger was located in a non-refrigerated area, away from any refrigerated display case. The indoor ambient temperature and humidity have an impact on the total cooling load of the display cases. This is because as the shoppers open and close the glass doors, the surrounding warm and moist air enters the case while the cold air of the case spills out onto the floor. This cooling load will ultimately be removed by the compressors to maintain target product temperatures.

The air temperature in the freezer cases was also monitored via loggers located at the return air grille of freezer cases. Four loggers were used to measure case temperatures for System 9 and four loggers for System 10.

Customer traffic was monitored both at the main entry and exit point of the store, and on the glass freezer doors. Door opening sensors were placed on every third door for System 9 and on every fourth door for System 10. These sensors reported the percent of time open for each 15-minute interval. The same information was also collected for the entry and exit automatic sliding glass doors at the front of the store.

RESULTS

LIGHTING

As mentioned above, the store's Energy Management System (EMS) controlled the display case lights to turn off during closed hours of 11:00 PM and 6:30 AM for all phases of the project. Data presented in the following sections focus only on the store's hours of operation. The average lighting power for fluorescent was 3.110 kW, or 54.5 watts per door. Switching to the LED system provided a 67% reduction to 1.024 kW (18.0 watts/door) and the dimmable controller provided an additional 5% reduction to 0.866 kW (14.9 watts/door).

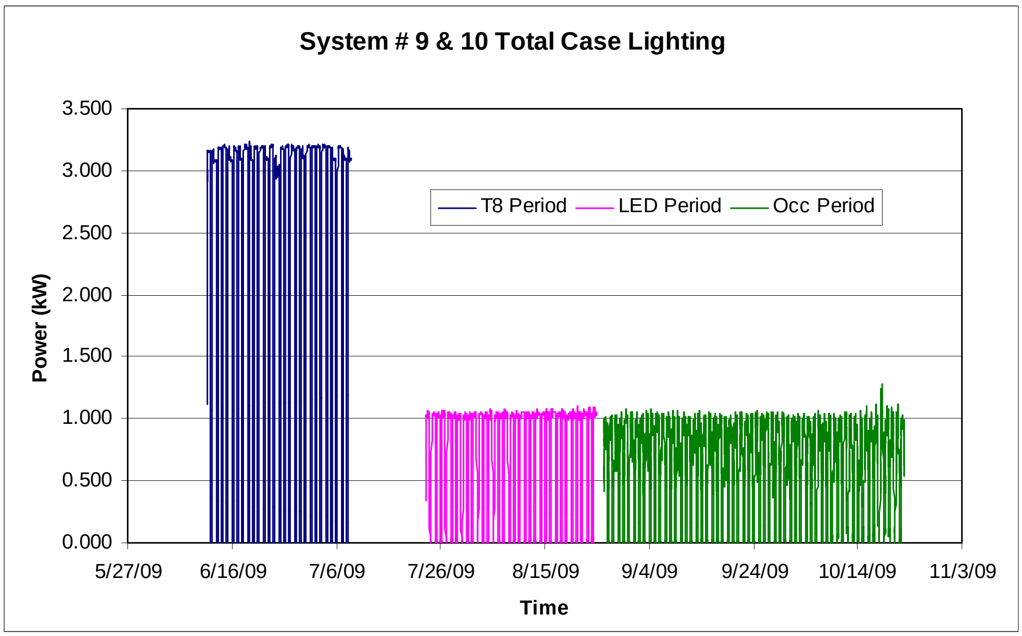

FIGURE 6. TOTAL SYSTEM 9 & 10 LIGHTING POWER

For Phases 1 and 2, no occupancy sensors were employed and the lighting power draw remained relatively constant during all "on" times. Figure 7 depicts the daily lighting power profile for representative days during each test phase. With the occupancy sensors activated on the LED system, Phase 3 experienced a distinctly different usage pattern, as illustrated by the green line.

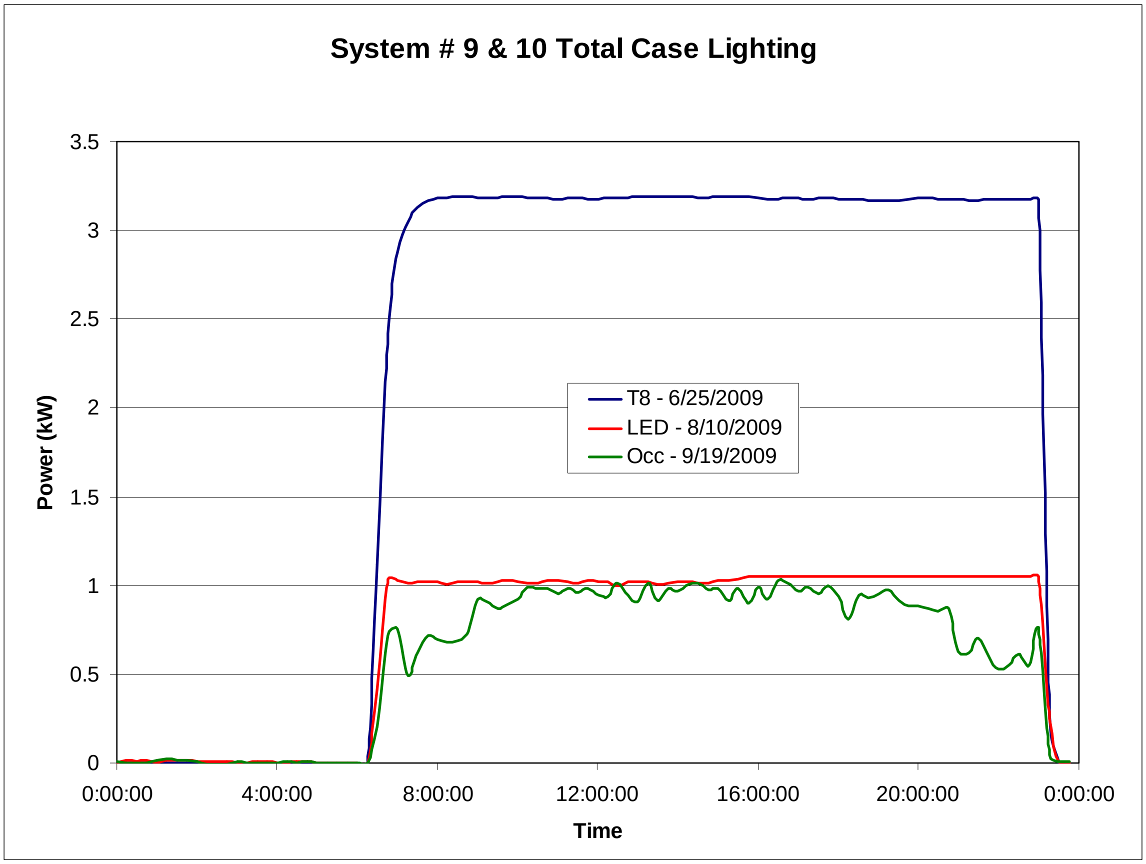

FIGURE 7. REPRESENTATIVE DAILY LIGHTING POWER PROFILE FOR ALL THREE SYSTEMS

Figure 8 depicts the average daily lighting power profile for each of the four measured lighting circuits with occupancy sensors activated. This graph was created by taking the average of all daily measurements for a given time (i.e., 6:30 AM for all 58 days of Phase 3) and dividing it by the average full brightness LED power measured during Phase 2. The trend shows that only 5-10% savings were realized during the high traffic hours (roughly 11:00 AM to 8:00 PM). Significant savings up to 60% were realized during the "shoulder" hours of 6:30 AM to 11:00 AM and 8:00 PM to 11:00 PM).

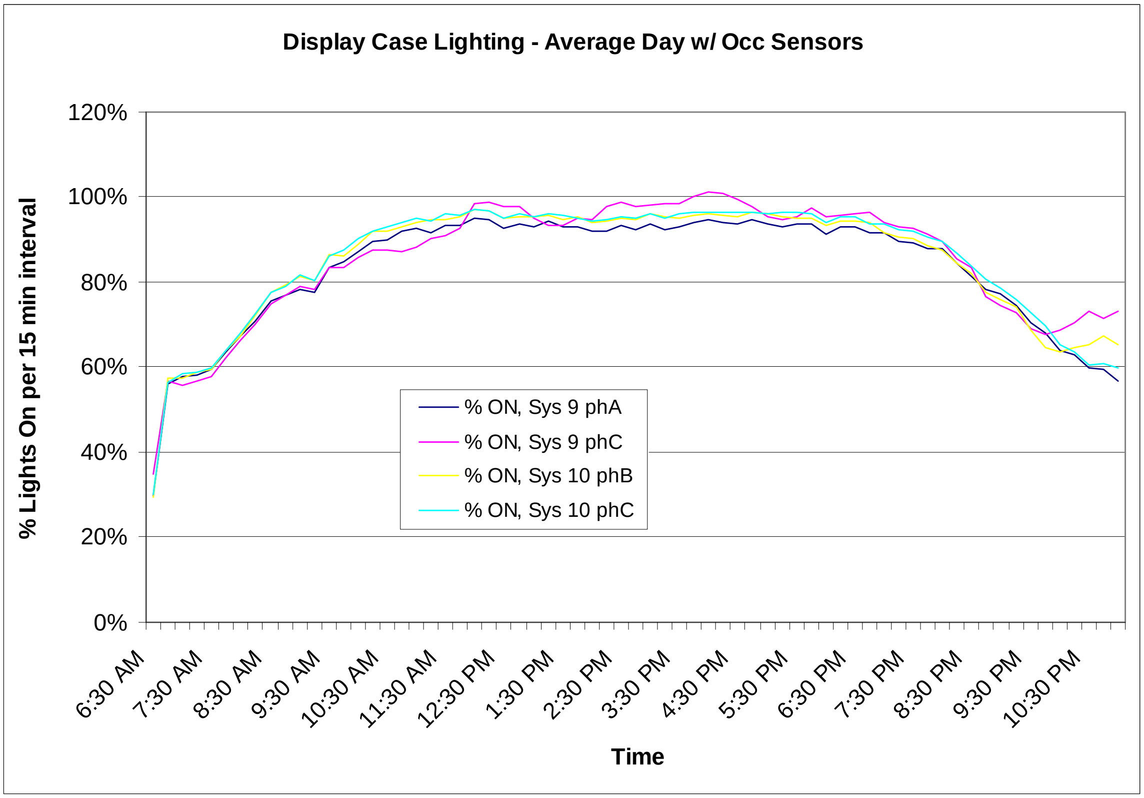

FIGURE 8. DAILY ON-TIME PROFILE OF LED WITH OCCUPANCY SENSOR

Average display case lighting power demand and annual energy consumption are summarized in Table 5.

TABLE 5. TOTAL DISPLAY CASE LIGHTING POWER AND ANNUAL ENERGY CONSUMPTION

PHASE	TOTAL LIGHTING POWER (KW)	ANNUAL LIGHTING ENERGY (KWH)
T8	3.110	18,731
LED	1.024	6,170
Occ	0.866	5,215

One caveat to this finding is that it is extremely dependent on traffic patterns. Traffic can be affected by many factors that are difficult to control such as socioeconomic makeup of the surrounding neighborhood, types of surrounding buildings, size of the store, length of freezer aisles, among others. It cannot be said with certainty that other stores would have the same traffic patterns or realize the same degree of savings.

REFRIGERATION

The refrigeration system was tied to an evaporatively-cooled condenser sitting on the roof of the store. Thus, head pressure and compressor power are a function of the outdoor ambient wet bulb temperature. Figure 10 depicts the relationship between measured wet bulb temperature and head pressure across all test phases for Systems 9 and 10, respectively.

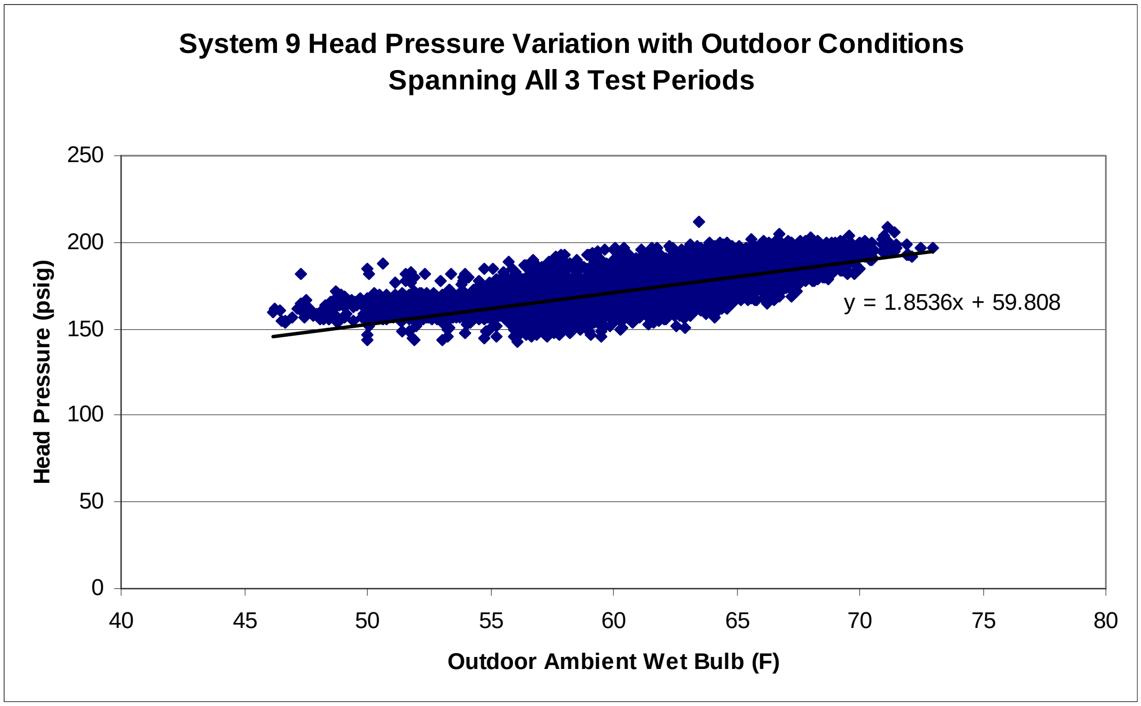

FIGURE 9. OUTDOOR WET BULB AND HEAD PRESSURE RELATIONSHIP FOR SYSTEM 9

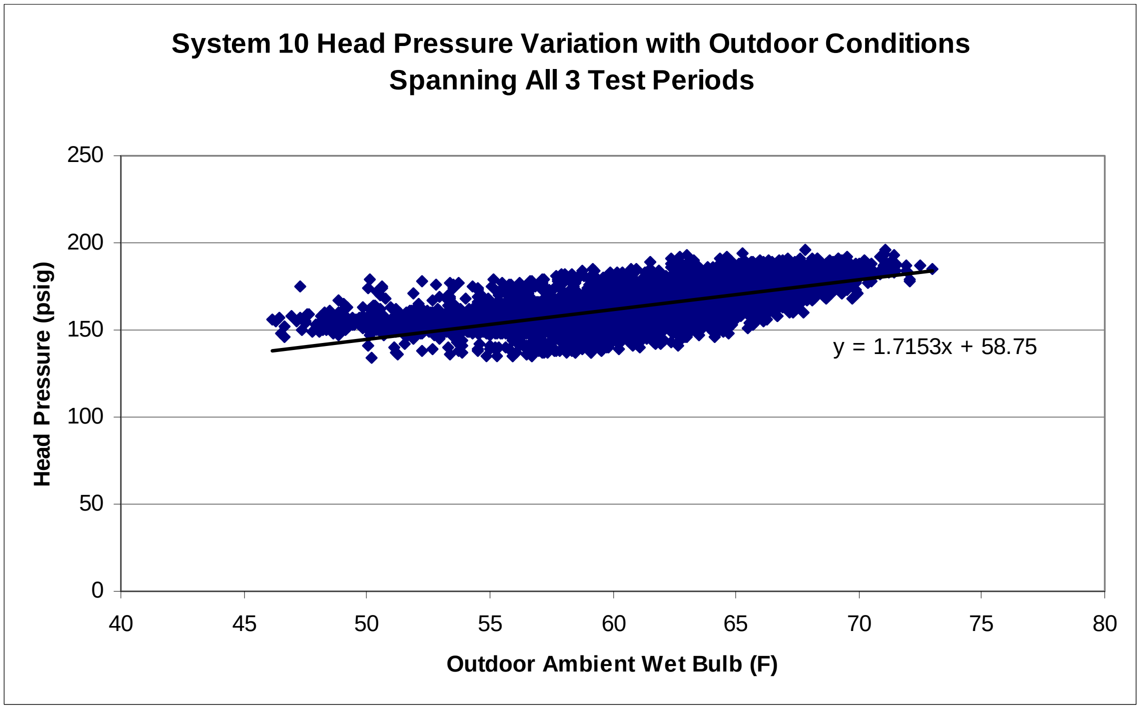

FIGURE 10. OUTDOOR WET BULB AND HEAD PRESSURE RELATIONSHIP FOR SYSTEM 10

Figure 11 relates the measured head pressure to measured compressor power for compressor 9 during Phase 1. This only includes measurements made during times the case lights were on. A few outliers, likely caused by maintenance work on the system and defrost heaters, were removed. Similar plots were made for the other phases of the project (see Appendix A).

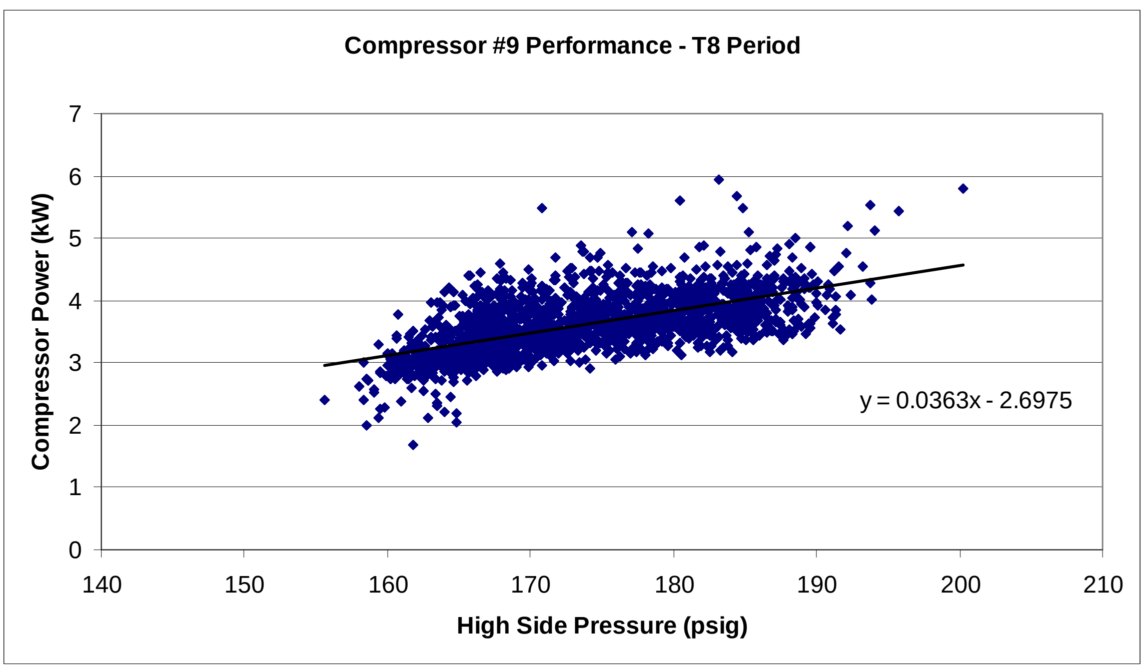

FIGURE 11. COMPRESSOR POWER

Table 6 summarizes the compressor performance characteristics derived from all six of these plots. Each of the compressor curves is plotted for a range of outdoor ambient wet bulb temperatures in Figure 12. The two thicker lines represent an average between the compressor power for the LED and occupancy periods of each system. It also depicts the relationship between outdoor ambient wet bulb temperature and head pressure of each system.

TABLE 6. COMPRESSOR POWER (CP) AS A FUNCTION OF HEAD PRESSURE (HP) FOR BOTH COMPRESSORS ACROSS ALL PHASES OF THE PROJECT

PHASE	SYSTEM 9	SYSTEM 10
T8	CP = 0.0363 * HP – 2.6975	CP = 0.0763 * HP – 7.4179
LED	CP = 0.0297 * HP – 2.1756	CP = 0.0642 * HP – 6.1551
Occ	CP = 0.0276 * HP – 1.8386	CP = 0.0576 * HP – 4.9765

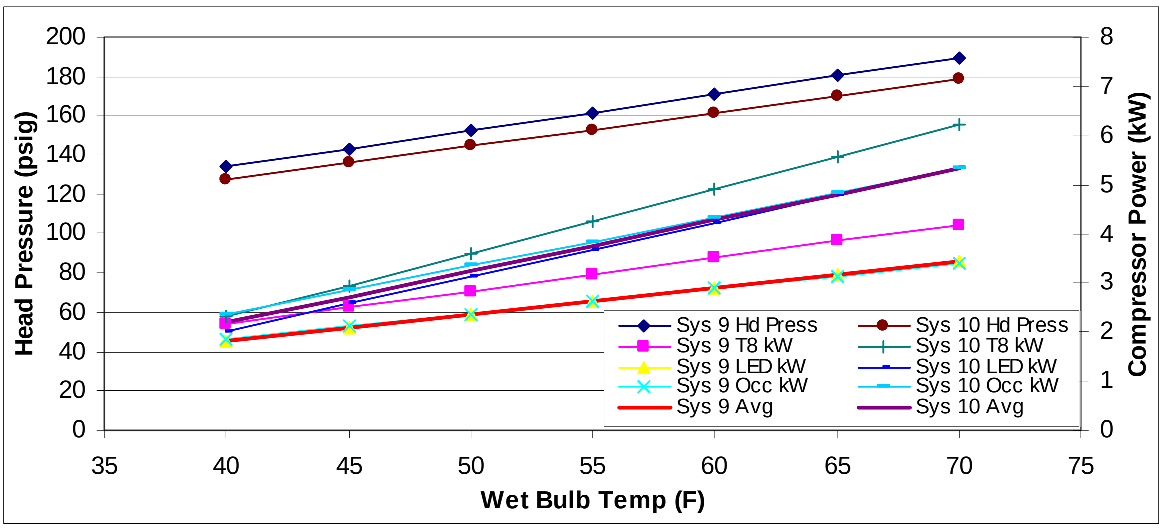

FIGURE 12. HEAD PRESSURE AND COMPRESSOR POWER AS A FUNCTION OF AMBIENT WET BULB

By using an entire year's worth of SCE weather data and the curves above, the wet bulb temperature can be used to calculate the corresponding head pressure and compressor power consumption over the entire year. This analysis ignores the time period between 11:00 PM and 6:30 AM, as there would be no difference in compressor operation when the case lights are turned off. The average compressor power curves were used for both the LED and occupancy sensor periods. These plots were necessary because the slight difference in the equations above made it appear that there was slightly more compressor energy consumption for the occupancy sensor period than LED period. Figure 13 shows the estimated annual compressor consumption for each scenario.

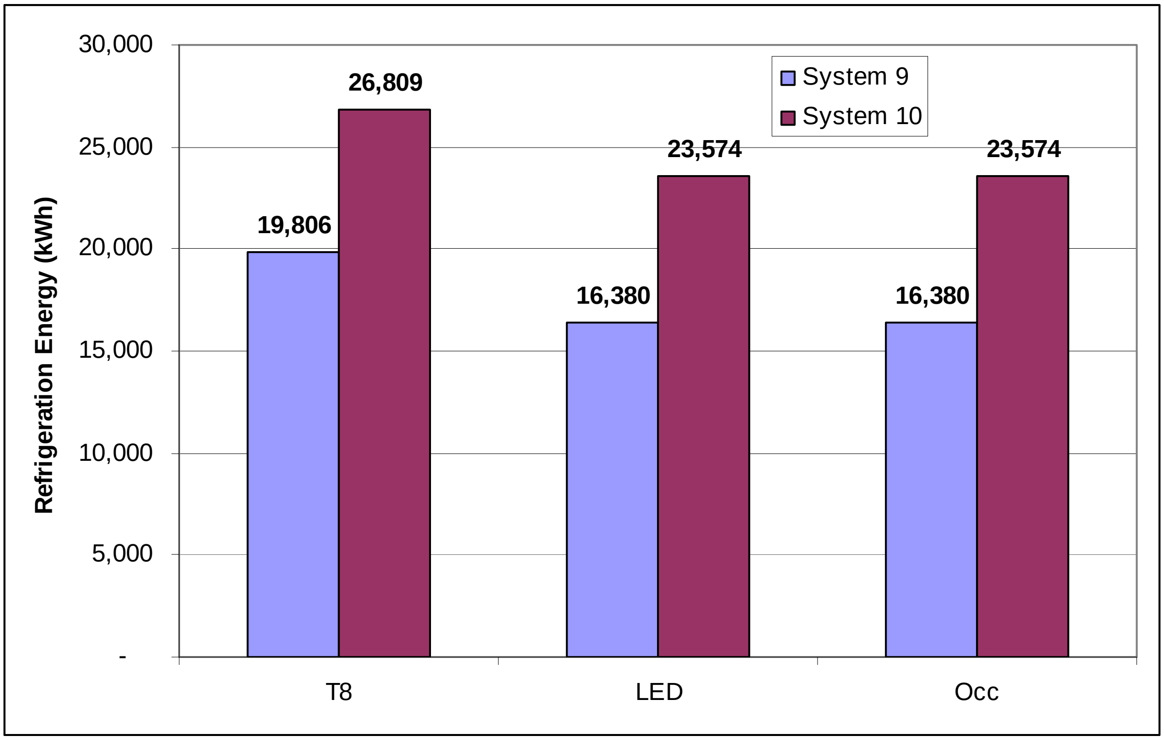

FIGURE 13. ESTIMATED ANNUAL REFRIGERATION ENERGY FOR LIGHTING ON PERIODS

Thus, combining the lighting and energy consumption values results in a 30.1% reduction for both the LED and occupancy sensor periods (Figure 14).

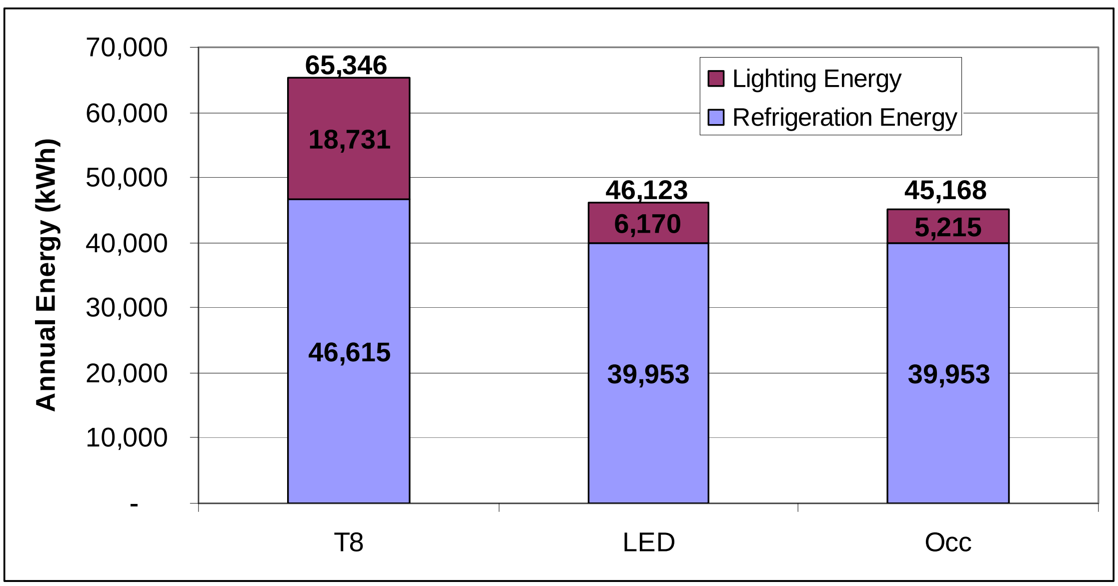

FIGURE 14. COMBINED LIGHTING AND ENERGY CONSUMPTION FOR EACH PROJECT PHASE

Several other factors were monitored primarily to ensure that there was consistent operation of the display cases across the three phases. Table 7 shows the average power draw for other case components for all of Systems 9 and 10.

TABLE 7. AVERAGE COMPONENT POWER CONSUMPTION FOR SYSTEMS 9 AND 10

PHASE	CASE DEFROST POWER (KW)	CASE FAN POWER (KW)	CASE ASH POWER (KW)
T8	20.0	2.69	2.18
LED	21.1	2.72	2.26
LED w/ Occupancy Sensor	20.8	2.72	2.11
Total	20.6	2.71	2.18

Table 8 shows the average case temperature measured throughout each phase of testing. Cases A, D, H, F, and K all maintained fairly constant temperature for all periods. Cases E and J experienced a decrease of 2 and 3 degrees, respectively. It is unclear exactly why this was the case, but it could have partly been the result of lower lighting cooling load in the cases. The temperature sensor in Case B stopped functioning after phase 1 was completed. The problem was not realized until data was collected at the end of the project.

TABLE 8. AVERAGE DISPLAY CASE TEMPERATURE

	AVERAGE CASE TEMP (°F)							
	SYSTEM 9				SYSTEM 10			
PHASE	CASE A	CASE B*	CASE D	CASE E	CASE J	CASE H	CASE F	CASE K
T8	4.53	7.01	4.40	8.16	7.41	5.14	7.75	7.67
LED	4.90	---	4.36	7.45	3.24	4.84	8.66	6.85
LED w/ Occupancy Sensor	4.28	---	4.33	6.15	3.33	4.25	7.89	6.54
Total	4.57	---	4.36	7.25	4.66	4.74	8.10	7.02

**The sensor in Case B malfunctioned and did not collect data during the second and third phases.*

Table 9 presents the percent of time each monitored reach-in door was open during all three time periods. There are some small differences, but none so drastic as to suggest significantly different cooling loads.

TABLE 9. DOOR OPEN % FOR EACH MONITORED DOOR

	AVERAGE % OF TIME DOOR IS OPEN							
	SYSTEM 9							
PHASE	DR 3	DR 6	DR 9	DR 12	DR 15	DR 18	DR 21	
T8	0.1%	0.4%	0.2%	0.9%	1.2%	0.6%	0.9%	
LED	0.1%	0.4%	0.2%	0.7%	1.9%	0.7%	1.1%	
LED w/ Occupancy Sensor	0.2%	0.4%	0.2%	0.7%	1.5%	0.8%	1.0%	
Total	0.1%	0.4%	0.2%	0.8%	1.5%	0.7%	1.0%	
	SYSTEM 10							
PHASE	DR 3	DR 6	DR 9	DR 12	DR 15	DR 18	DR 21	DR 25
T8	0.3%	0.1%	0.8%	0.9%	0.7%	0.9%	0.8%	1.1%
LED	0.2%	0.4%	0.8%	0.7%	0.7%	1.3%	0.8%	0.8%
LED w/ Occupancy Sensor	0.2%	0.3%	0.8%	1.1%	0.7%	1.2%	1.0%	0.8%
Total	0.3%	0.3%	0.8%	0.9%	0.7%	1.1%	0.9%	0.9%

CONCLUSION

The LED lighting system realized approximately 67% direct energy savings and 30% secondary savings on the refrigeration system, over the T8 fluorescent system. With the addition of a traffic-sensitive controller, an additional 5% direct and very minimal secondary savings were achieved. These savings are highly dependent on characteristics of the store in which the system is installed and may vary significantly from one installation to another.

RECOMMENDATION

It is recommended that SCE's energy efficiency programs continue with plans to introduce LED refrigerated case lighting as a rebatable energy efficiency (EE) measure. It would also be wise to explore the possibility of adding a measure for traffic sensitive controllers for the LED systems. While energy savings may not be large compared to the T8 to LED changeout, the controllers may provide additional benefits not examined here. If these controllers are installed on cases, they may be a good candidate for demand response efforts. Furthermore, as case lighting is readily visible to customers, stores could use the presence of LEDs and lighting controllers as an EE showpiece to expound dedication to greening their operations. Hopefully, this is yet another opportunity to remind consumers of the importance of EE in all aspects of their daily lives.

APPENDIX A

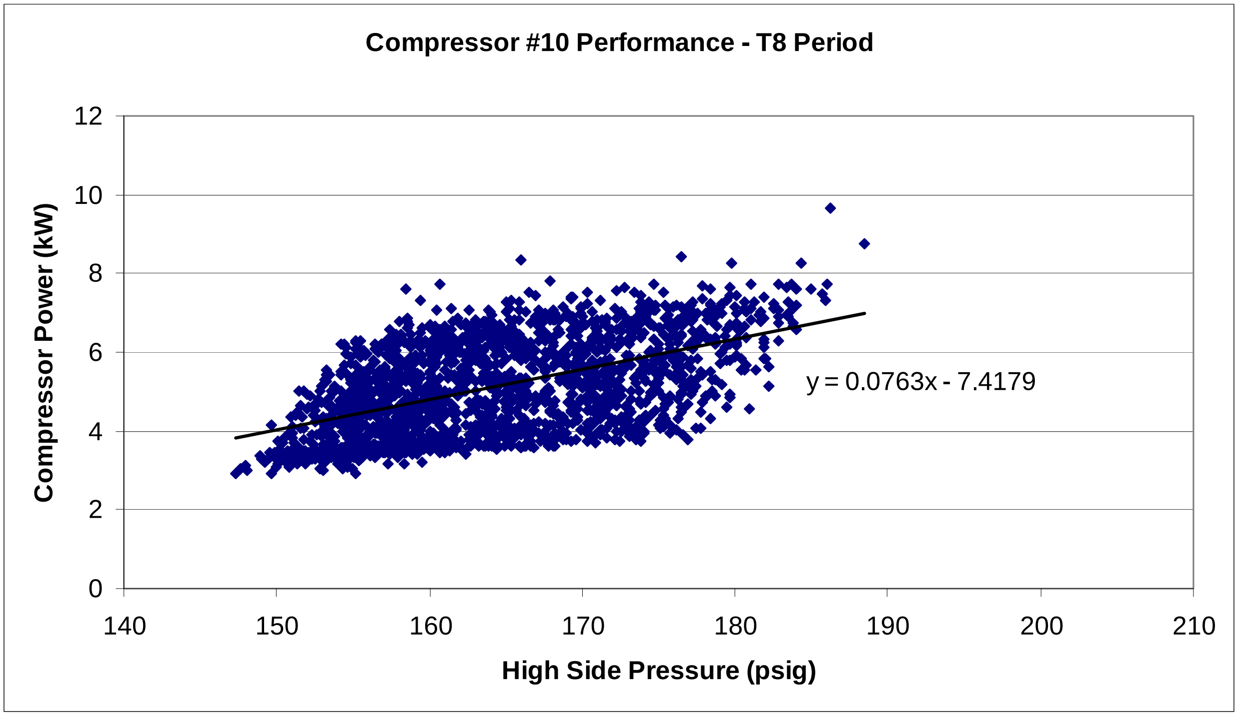

FIGURE 15. COMPRESSOR POWER – SYSTEM 10, T8 PERIOD

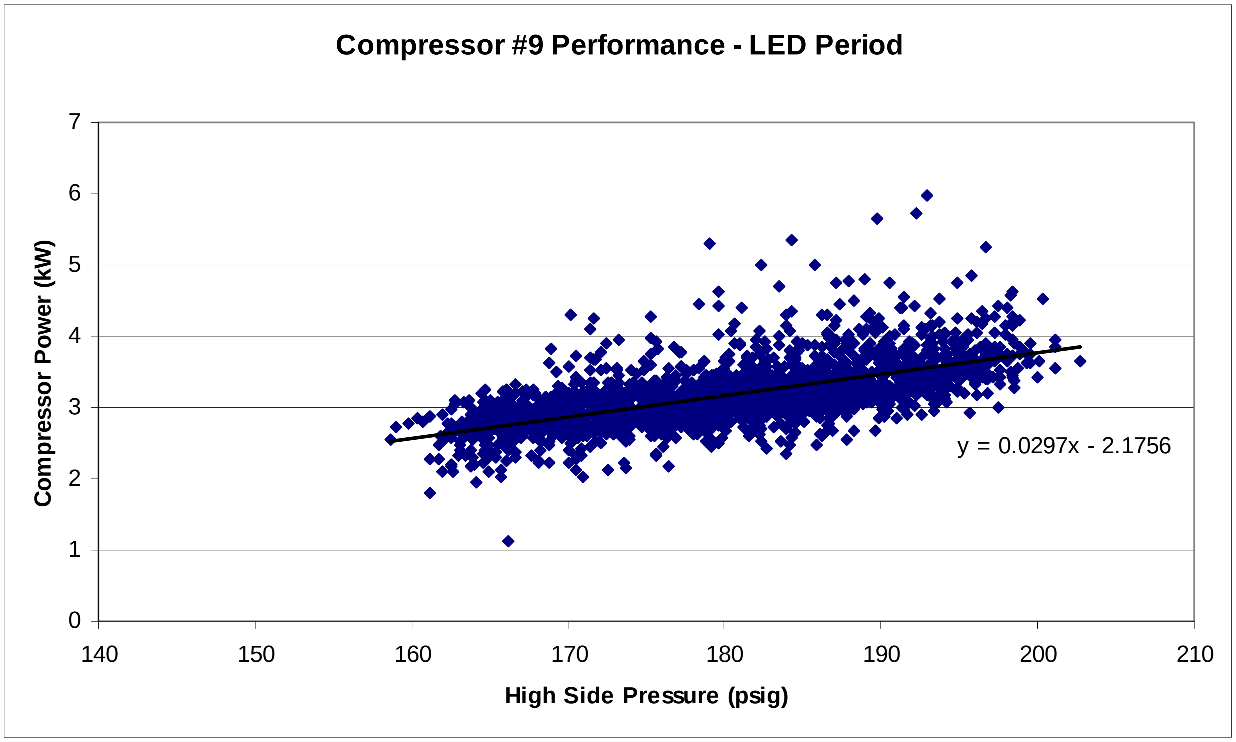

FIGURE 16. COMPRESSOR POWER – SYSTEM 9, LED PERIOD

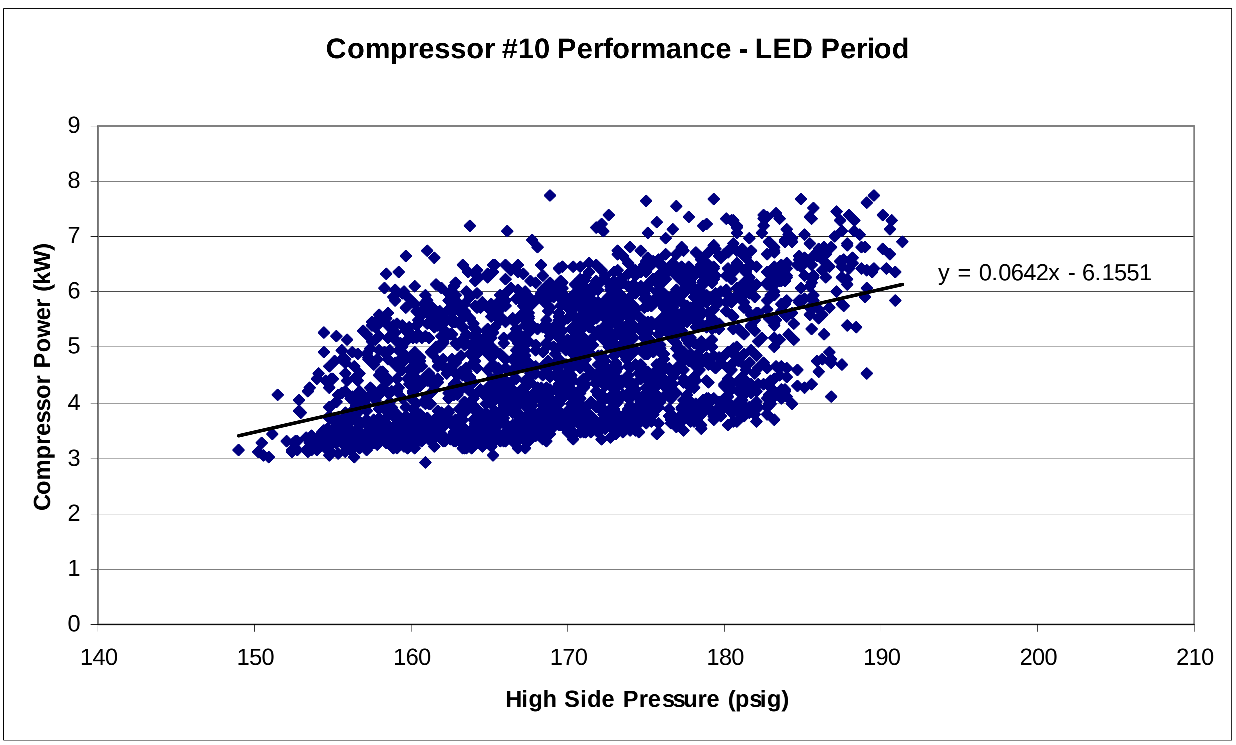

FIGURE 17. COMPRESSOR POWER – SYSTEM 10, LED PERIOD

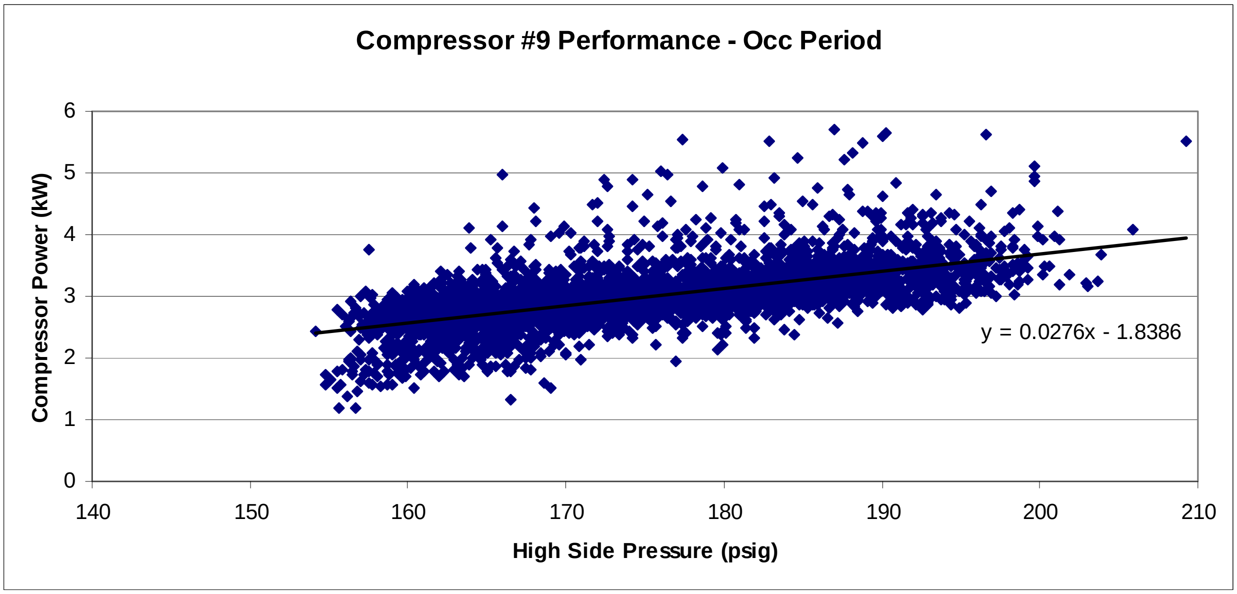

FIGURE 18. COMPRESSOR POWER – SYSTEM 9, OCCUPANCY SENSOR PERIOD

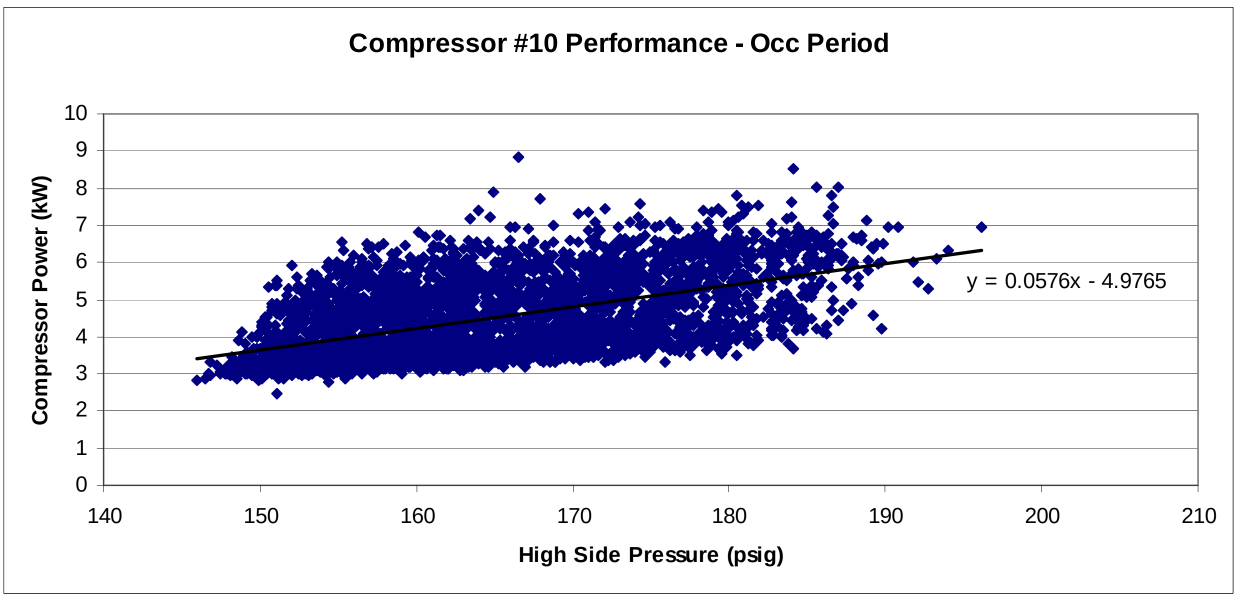

FIGURE 19. COMPRESSOR POWER – SYSTEM 10, OCCUPANCY SENSOR PERIOD

REFERENCES

[1] American Society of Heating, Refrigeration and Air-Conditioning Engineers, Refrigeration Handbook, Chapter 46 – "Retail Food Store Refrigeration and Equipment," 2006.

[2] Baxter, V. D., "Investigation of Energy Efficient Supermarket Display Cases," ORNL/TM-2004/292. Oak Ridge National Lab, December 2004.

[3] Southern California Edison. "Fiber-Optic Lighting in Low Temperature Reach-in Refrigerated Display Cases," ET 05.04. December 2006.

[4] Southern California Edison. "Photometric Analysis of Multiple Generations of LED Lighting Systems for Low Temperature Reach-in Refrigerated Display Cases," ET 08.14. December 2008.

[5] Southern California Edison. "Evaluation of Fluorescent, LED and Fiber Optic Lighting Systems in Low Temperature Reach-in Freezer Display Cases," ETO 06.03. December 2007.

[6] Itron. "California Commercial End-Use Survey: Consultant Report," CEC-400-2006-005. March 2006.

[7] Southern California Edison. Final Report In Progress. "LED in Low-Temperature Reach-in Refrigerated Display Cases". ET 06.06.

[8] Southern California Edison. 2001, Unpublished Survey. Refrigeration and Thermal Test Center's Survey of Grocery Stores.