Permanent Magnet Synchronous Motors in Refrigerated Display Cases

ET17SCE8020 Report

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Disclaimer

EXECUTIVE SUMMARY

In support of California's strategic goals to accelerate the penetration of energy efficiency technologies, Southern California Edison Emerging Products and AESC performed an assessment study of a new display case evaporator fan product. The primary goals were to characterize the refrigerated display case fan market and to quantify the energy savings and demand reduction of a high-efficiency fan with permanent magnet synchronous motors.

A scaled field placement of 208 fan retrofits was performed at four grocery stores in Southern California Edison territory, each in a different climate zone. Fan power, refrigeration system power and temperatures, weather, and case air were monitored for several months of baseline and post-retrofit conditions. In addition to data logging over time, spot measurements of individual fans were taken during the retrofit. To complement the field data, refrigeration system modeling was used to study the interactive effects on the compressors. Finally, a market survey of refrigeration professionals and energy managers was performed to characterize the market and baseline conditions.

The 208 fan retrofits showed clear and consistent improvements in electrical demand, energy usage, and power factor without negatively impacting case operation or compressor power or compression ratios. As seen in the following table, savings were calculated for different baseline conditions: low-temp versus medium-temp cases and shaded pole (SP) versus electrically commutated motors (ECM).

TABLE ES1. SUMMARY OF FAN ENERGY SAVINGS AND DEMAND REDUCTION

BASELINE FAN TYPE	BASELINE FAN POWER (W)	POST FAN POWER (W)	FAN POWER REDUCTION (W)	LOW-TEMP FAN ENERGY SAVINGS (KWH/YR)	MED-TEMP FAN ENERGY SAVINGS (KWH/YR)
ECM	20.2	13.9	6.3 (31%)	54.7	55.2
SP	45.4		31.5 (69%)	273.6	275.9

In addition to fan power savings, the reduced case heat load will result in compressor savings. Refrigeration modeling of the measure was used to determine the interactive effects and total per-fan system savings shown in the following table. Estimated simple payback for the full measure cost was between 1.6 and 9.5 years depending on the case and baseline motor types (at an assumed blended rate of $0.15/kWh). Payback of incremental costs is much quicker and net present value for a total supermarket retrofit is likely tens of thousands of dollars.

TABLE ES2. SUMMARY OF ENERGY SAVINGS AND DEMAND REDUCTION, AVERAGED ACROSS CLIMATE ZONES

BASELINE FAN TYPE	AVG LOW-TEMP INTERACTIVE EFFECT FACTOR	TOTAL SYSTEM ENERGY SAVINGS (KWH/YR)	AVG MED-TEMP INTERACTIVE EFFECT FACTOR	TOTAL SYSTEM ENERGY SAVINGS (KWH/YR)
ECM	1.63	89.2	1.36	75.1
SP		446.0		375.2

The market survey suggested an average baseline blend of 60% ECM and 40% SP while the field sites had a blend of 85% ECM and 15% SP. Using these estimated existing conditions and the calculated savings, the California market potential is estimated to be 252-411 GWh which would equate to 60,500-98,500 metric tons of CO_2e emissions reductions.

Based on the savings results, market potential, and simple implementation, the product appears well-positioned to gain market traction. Targeted utility program support would help hasten and ensure this market adoption by mitigating market barriers such as low product awareness, low customer priority, long baseline effective useful life, and case repair habits.

ABBREVIATIONS AND ACRONYMS

CZ	Climate zone
DEER	Database for Energy Efficient Resources
DHS	Desert Hot Springs
ECM	Electrically commutated motors
EE	Energy efficiency
ET	Emerging technologies
EUL	Effective useful life
GG	Garden Grove
HB	Huntington Beach
IE	Interactive Effects
IPMVP	International performance measurement and verification protocol
LAH	Lake Arrowhead
LT	Low-temp refrigerated cases, fans, compressors, and circuits
M&V	Measurement and verification
MT	Medium-temp refrigerated cases, fans, compressors, and circuits
OAT	Outside air temperature
PF	Power factor
PMSM	Permanent magnet synchronous motors
PSC	Permanent split capacitors

RH	Relative humidity
SME	Subject matter expert
SP	Shaded pole
T/RH	Temperature and relative humidity
SCE	Southern California Edison

CONTENTS

FIGURES

TABLES

INTRODUCTION

This study explores the energy and cost savings, market, and opportunity of a recently commercialized display case fan motor technology called permanent magnet synchronous motors (PMSM). Although this type of motor is not new, it has only recently been commercially available in small motor sizes and designed specifically for display case evaporator fan use and form factors. A scaled field placement of 208 replacement fans at four sites, market surveying, and refrigeration system modeling were performed to quantify the opportunity and ascertain market trends and barriers.

Studies of commercial refrigeration systems estimate that about 30,000,000 GWh of site energy is consumed by motors in in the United States every year (Fricke & Becker, 2015) (NCI, 2013). Although each display case evaporator fan is small, their large numbers present a significant opportunity for energy footprint reduction through effective efficiency measures and market transformation. At the same time, the opportunity exists in one of the most energy intensive commercial building sector. While the average California commercial building has an energy use intensity of 13 kWh/ft^2-yr, supermarkets and grocery stores have an average electrical energy use intensity of 44 kWh/ft^2-yr (Lawrence Livermore Laboratory, 2016). Furthermore, California convenience stores which also typically have refrigerated case systems have an even higher average electric EUI of 51 kWh/ft^2-yr.

This study was performed by Alternative Energy Systems Consulting on behalf of Southern California Edison (SCE) Emerging Technologies program. In part, the Emerging Technologies program strives to increase the exposure and success of emerging and underutilized energy efficiency and demand side management technologies in California.

TARGET MARKET AND SETTING

Refrigerated display cases in retail food businesses come in a variety of designs with any combination of the following features: open or closed with door access, single or multideck, various air distribution paths (e.g. baffles), electric, bypass, or hot gas defrost, antisweat heaters, linear fluorescent or LED lighting, and others (ASHRAE, 2014). Additionally, cases are typically either low-temperature freezers (LT) or medium-temperature (MT). Refrigerated cases and their features are selected based on the store's refrigeration system design, refrigeration loads, product, store aesthetics, and other design considerations.

Each case has evaporator coils and fan boxes, almost always at the bottom of the case, underneath the lowest product rack. Each evaporator fan is typically powered by a small, fractional horsepower motor which rotates the fan blades, moving air across evaporator coils. For the purposes of this report, a fan will refer to the assembly consisting of the fan blades and driving motor. The continuous air movement maintains a constant, well-distributed temperature throughout the case.

The refrigeration load of these display cases consists of product load, defrost heating, antisweat heaters, lighting, infiltration, radiation, conduction from the exterior, and the heat output of the fans. One source states that the heat output of evaporator fans accounts for about 2-5% of the refrigeration load for open cases (ASHRAE, 2014) (Faramarzi, 1999). The fraction of the total system load would typically be somewhat lower for a supermarket since refrigeration systems often serve both display cases and walk-ins simultaneously.

Figure 1 shows an open MT case with fans drawing air down into the fan box, across the coils, and circulated out from behind the product.

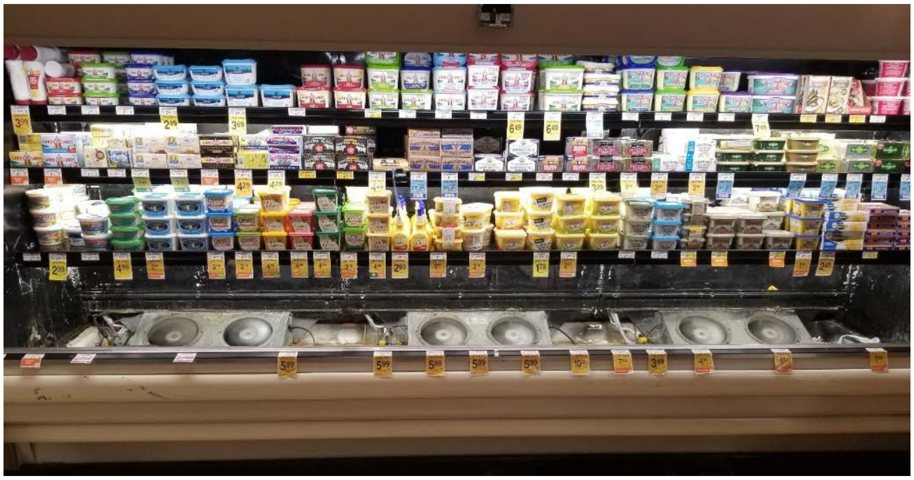


FIGURE 1. OPEN MED-TEMP DISPLAY CASE WITH FAN BOXES

The vast majority of refrigerated case evaporator fans use 9-12 watt motors, rated for their output power, not input. However, smaller cases and walk-ins can often have other size motors, such as 4-8 watt motors in smaller deli cases or 38-50 watt motors in walk-in coolers or freezers. This study is limited to the display case 9-12 watt size, but the technology could be similarly applied to other refrigeration fan sizes. Manufacturers do offer 38-50 Watt models which should incur similar percentage savings found in this report.

There are approximately 27,693 buildings in the California's food retail sector including supermarkets, grocery stores, convenience stores, specialty food stores, liquor stores, and drug stores (US Census Bureau, 2013). Table 1 lists this building sector breakdown along with the estimated number of evaporator fans (Fricke & Becker, 2015). From this, the total estimated California 9-12 watt fan base is about 2,000,000 fans. Supermarkets and grocery stores account for about 90% of the total baseline evaporator fan energy consumption and demand within these customer types.

TABLE 1. CALIFORNIA MARKET SIZE (VALMIKI & CORRADINI, 2016)

Facility type	NAICS Code	California Establishments	4-8W Motors per Site	9-12W Motors per Site	38-50W Motors per Site
Supermarkets and other grocery stores	44511	8,805	80	216	63
Convenience stores	44512	2,373	4	7	9
Specialty food stores	4452	2,896	20	50	16
Liquor stores	4453	3,815	0	2	15
Drug stores	44611	4,435	0	8	0
Gas stations w/ convenience stores	44711	6,089	8	2	6

Operation and maintenance of refrigerated cases is often supplied by contracted service providers not associated with the design of the refrigeration systems while some larger supermarket chains will employ their own internal refrigeration service department. Maintenance calls are typically made when a system component fails or when case temperatures and refrigeration control systems send alerts or alarms. Evaporator fan fault detection diagnostics are extremely uncommon, at best. As a result, evaporator fans can operate with degraded performance resulting in higher energy costs over time and can stay broken and unrepaired for extended periods. They are typically only repaired or replaced when a failure is noticed due to noise or temperature alarms.

Evaporator fans typically use electrically commutated motors (ECM), shaded pole motors (SP), or permanent split capacitor motors (PSC). Although ECMs are mandated code for fans in walk-in freezers and refrigerated warehouses, there are no existing California codes for display case evaporator fans. That said, federal code for display case efficiency virtually ensures that all new cases will use ECM fans (U.S. Department of Energy, 2012). As will be shown later, market surveying suggests that ECMs are industry standard in new case installations but not in fan replacements which still rely on both ECM and SP motors (see Figure 6). Regardless of motor type, virtually all display case fan motors operate at constant speed and are only turned off during defrost cycles[1] (Karas, 2006). As such, display case fans have a constant load profile except during uncommon maintenance shutdowns and regular defrost periods in LT cases.

California's Database for Energy Efficiency Resources (DEER) and active deemed workpapers estimates the effective useful life (EUL) of display case fans and their motors is 15 years.

INCUMBENT TECHNOLOGY

Historically, asynchronous induction SP motors have often been used for refrigerated case fans due to their low cost, simplicity, and availability for the required motor size. However, these advantages are accompanied by relatively poor motor efficiency of about 20% (NCI and PNNL, 2011). This low efficiency means input fan energy is higher than alternative technologies and increases the thermal load in the refrigerated cases. While SP motors are still commonly found in refrigerated display cases, they are not industry standard practice any longer and are being phased out towards more efficient alternatives despite the large existing installed population.

Permanent split capacitor motors are a slightly more efficient but less common fan motor technology. This motor type is able to realize efficiency improvements over SP motors due to the addition of a small start-up winding. Once the motor reaches steady-state, the smaller winding becomes auxiliary, thereby approximating two-phase operation. Because of this design, PSC motors achieve improved motor efficiencies of about 29% (NCI and PNNL, 2011). Despite this, PSC motors represent a very small fraction of the market due to the historical use of SPs and emergence of ECMs which rapidly overtook any incremental market opportunity PSCs had. No PSC motors were found in any of the cases that were retrofit in this study. Nor were any PSCs found in the 173 fans that were retrofit in a similar 2016 SDG&E study (Valmiki & Corradini, 2016).

[1] Some new technologies offer evaporator fan speed control, but as an emerging technology have little-to-no market adoption rate as of the writing of this report.

Currently, the typical high-efficiency option is the ECM. This motor technology first rectifies the supplied AC current to DC current, which is then commutated, or switched, by digital signals from simple rotor position sensors to an individually wound stator. This creates a magnetic field that rotates in sync with the motor. ECMs also make use of permanent magnets which eliminate the need for magnetizing current and decreases the overall energy use. Due to these design improvements newer ECMs achieve efficiencies of up to 66% (NCI and PNNL, 2011). Although it is industry standard practice to include ECMs in new cases, the installed fan population in California is roughly 60% ECMs according to the market survey of refrigeration industry subject matter experts.

Figure 2 shows several baseline fans removed from one of the host sites.

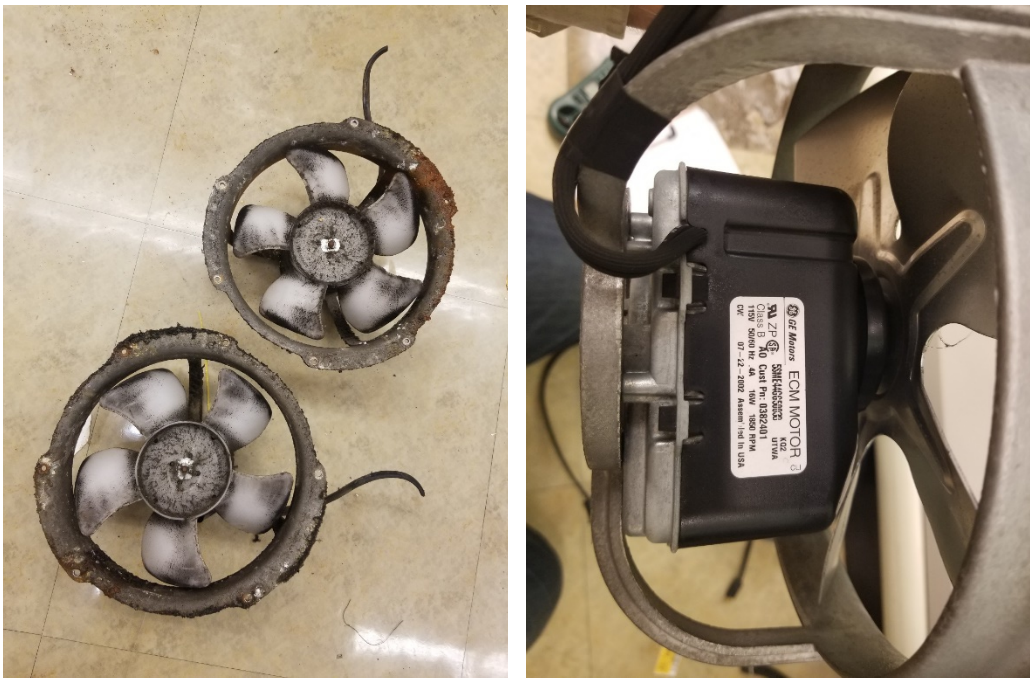


FIGURE 2. INCUMBENT BASELINE FANS AT THE HOST SITE

EMERGING TECHNOLOGY BACKGROUND

The technology examined in this study is an evaporator fan that uses a permanent magnet, synchronous motor. These motors are inherently more energy efficient than all the previously discussed motor technologies - SP, PSC, and ECM - due to a number of design improvements. Figure 3 shows the installation of a PMSM replacement fan at one of the host sites.

FIGURE 3. INSTALLATION OF A RETROFIT PMSM FAN

First, energy savings are realized through the use of permanent magnets which reduce the power necessary to operate the motor. Similar to ECMs, the use of permanent magnets eliminates the need for magnetizing current and shaft brushes. Secondly, unlike an ECM, this new synchronous motor runs off existing AC current without the need to rectify the current to DC. The elimination of the rectifying electronics further improves energy efficiency and power factor (PF). The elimination of the electronics also decreases the motor complexity while increasing the reliability and service life of the motor (Fricke & Becker, 2015).

As of the publishing date, it appears there is a single manufacturer offering this type of PMSM display case fan motor. During the market survey, one subject matter expert who previously worked for a refrigeration system manufacturer indicated that this may be due to perceived low market opportunity. Although only a 6-12W model was used in the study, the technology is scalable to smaller and larger size applications and commercially available in the typical walk-in 38-50W size.

The PMSM display case fan technology has been studied in several field demonstration studies. The savings from these studies have been consistent as seen in Table 2.

TABLE 2. PMSM SAVINGS FROM PREVIOUS STUDIES

NUMBER OF FANS (STUDY)	BASELINE TYPE	SAVINGS SOURCE[2]	ENERGY SAVINGS (KWH/YR)	ENERGY SAVINGS (%)	DEMAND SAVINGS (KW)	PF IMPROVEMENT[3]
173 Fan Retrofit (Valmiki & Corradini, 2016)	Blend (92% ECM, 8% SP)	Fan + Refrigeration System	73.6	37%	.0085	0.32
12 Fan Retrofit (Becker & Fricke, 2016)	ECM	Fan Only	-	34%	.0087	0.24
2 Fan Retrofit (Becker & Fricke, 2016)	SP	Fan Only	-	79%	.0457	0.14
2 Fan Retrofit (Fricke & Becker, 2015)	ECM	Fan Only	-	27%	.0062	0.34

Table 3 presents costs based on available literature and costs incurred for this study. Average baseline measure costs are difficult to ascertain. A 2014 ex ante report identified that ECM replacement costs vary wildly, between $27.25 and $304.84 in the evaluated DEER years (Itron, Inc., 2014), pointing to challenges in identifying a basis for fair cost comparison. Online vendor ECM list prices can be far higher than those for bulk purchases and refrigeration equipment distributors that service providers rely upon. Based on survey respondents, manufacturer input, and an approved Regional Technical Forum (RTF) measure, the cost for a PMSM retrofit is roughly equivalent to the cost of an ECM replacement. This is borne out by the data shown in Table 3.

TABLE 3. MEASURE COSTS PER FAN (DIRECT FROM PMSM MANUFACTURER)

COST ITEM	COST	SOURCE
Installation Cost	$33.10, $47.00, $53.50 (Avg $44.53)	(Regional Technical Forum, 2019) and costs from this field study
SP Equipment Cost[4]	$32.49	(Regional Technical Forum, 2019)
ECM Equipment Cost[5]	$56.50, $60.00 (Avg $58.25)	(Regional Technical Forum, 2019)
PMSM Equipment Cost	$62.50	Bulk purchase direct from manufacturer
Full PMSM Measure Cost[6]	$107.03	PMSM equipment and installation costs
Incremental PMSM Cost	$4.25 (Near cost parity)	Over ECM baseline

[2] Savings can be either just fan input energy or also account for estimated compressor savings due to reduced heat load in the display case from retrofit.

[3] Units are of actual PF improvement. For example, 0.34 improvement would be from a baseline PF of 0.54 to a retrofit PF of 0.86.

[4] Note that SP and ECM material costs are only for a replacement motor while PMSM costs are for the entire fan assembly. This reflects the expected existing case retrofit scenario.

[5] These costs are similar to those listed in another outdated resource which suggested average ECM costs of $61.71 (Navigant, 2009).

[6] This is similar to the per-unit cost of $116 incurred for the 208 retrofits in this field study.

Since the available PMSM prices are only direct from the manufacturer, there will likely be added distributor markup costs in the future. The authors could only identify a single source for expected distributor markup, estimated to be 1.672 for the refrigeration industry (Navigant, 2009). Table 4 lists full and incremental measure costs for this assumed distributor markup scenario.

TABLE 4. MEASURE COSTS PER FAN (AFTER ASSUMED DISTRIBUTOR MARKUP)

COST ITEM	COST	SOURCE
PMSM Equipment Cost (adjusted)	$104.50	After assumed distributor markup for fair market comparison based on (Navigant, 2009)
Full PMSM Measure Cost	$149.03	PMSM equipment and installation costs
Incremental PMSM Cost	$46.25	Over ECM baseline

MARKET SURVEY

AESC conducted a market survey to better understand the current state of display case fans in California supermarkets and grocery stores. A total of 31 subject matter experts and end-users responded to solicitations to answer questions regarding display cases, fans, and the new technology. The respondents were either interviewed via phone or could respond via an online survey instrument. Subject matter experts in supermarket corporate headquarters and consultants with a large customer base were targeted in order to achieve a reliable understanding of the entire California market. The participants were asked to limit their responses to the California marketplace as much as possible and to give average, representative answers.

The market survey was designed to address a variety of information gaps, including:

- ECM, SP, and PMSM market trends and market share
- Installed fan base (i.e. what is the existing baseline?)
- Industry standard installation and replacement practices
- Measure costs
- Market barriers to adoption of high-efficiency display case options

The following chart shows the survey participant industry roles.

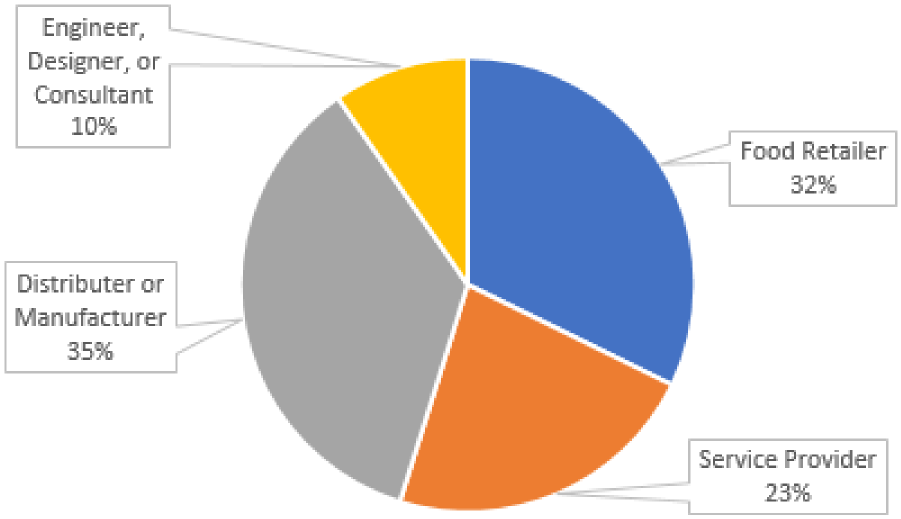


FIGURE 4. RESPONDENT SELF-CLASSIFICATIONS

When asked about the number of display cases in their stores, the food retailers estimated 19 LT and 42 MT cases per store on average. Assuming an average of 4 doors per case and one fan per door, this translates to roughly 76 LT and 168 MT evaporator fans per store, totaling 244 fans. This corresponds closely to Oak Ridge National Lab's estimate of about 225 fans in a typical grocery store (Fricke & Becker, 2015).

As seen in Figure 5, respondent answers suggested about 42% LT and 58% MT. Although the respondents estimated that about 59% of MT cases do not have doors, one subject matter expert (SME) described the rapid adoption rate of case doors and estimated that about 75% of MT cases would have doors in 2023.

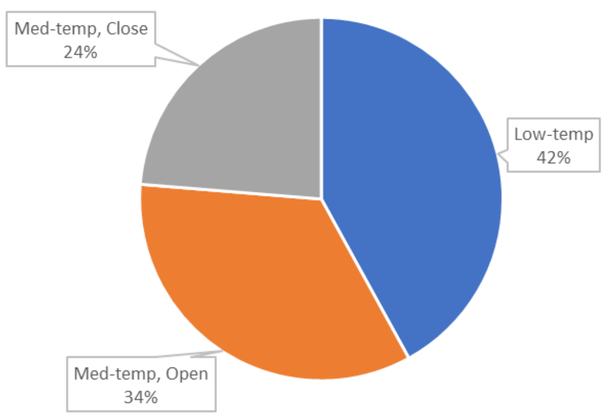


FIGURE 5. EXISTING MARKET CASE TYPE BREAKDOWN

It should be noted that this contrasts somewhat with the ASHRAE Refrigeration Handbook's description of roughly 75% MT cases and 25% LT cases (ASHRAE, 2014). This is the same as existing deemed workpaper breakdowns as determined from the Energy Smart Grocer Program (PECI, 2014).

The fan motors are typically a combination of ECMs and SP with a negligible fraction of PSC motors. To find out the existing market share of each fan, the survey participants were asked to approximate the breakdown of ECM vs. SP in display cases. Figure 6 shows that respondents estimated that roughly 60% of existing fans were ECMs and 40% predominantly SP. Similarly, about 56% of replacement fan sales are ECMs, representing retrofit patterns. In new cases, the respondents estimated about 90% would use ECM evaporator fans.

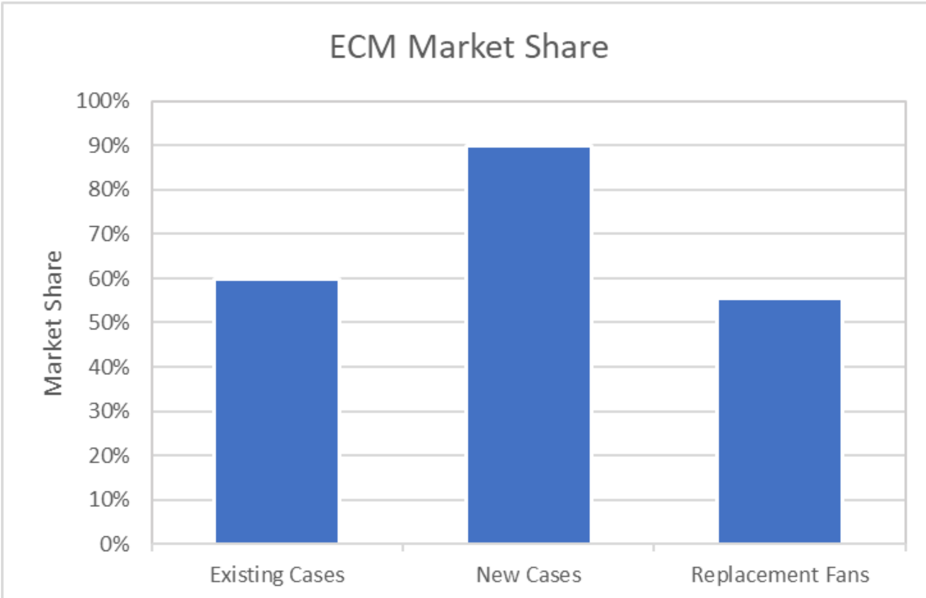


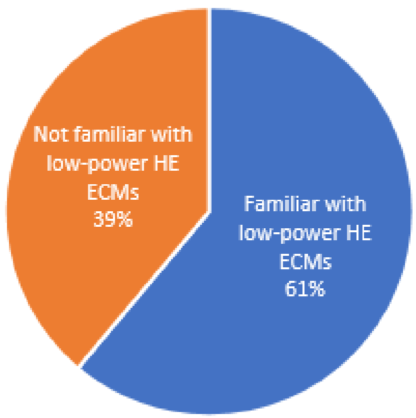
FIGURE 6. ECM MARKET SHARE IN EXISTING CASES, NEW CASES, AND OEM REPLACEMENT FAN SALES

Average installed cost of an ECM fan, motor, bracket assembly was reported to be $116. This self-reported estimate aligns well with estimates in the literature which were ultimately used to estimate measure cost and payback.

Although ECMs are mandated code for in walk-in freezers and refrigerated warehouse fans, there are no existing California codes for display case evaporator fans. From the survey results, however, it is evident that ECMs are considered industry standard practice and code baseline for new refrigerated cases.

Electrically commutated motors can come in a range of efficiencies depending on the quality and cost. The estimated existing market share of high-efficiency tier, lower-power ECMs was reported to be about 29%. In this survey, 61% of respondents were aware that high-efficiency ECMs could be selected. One SME suggested that the primary reason there are varying efficiencies in ECM fans is due to manufacturing standards, country of origin, and vintage, all of which are not controlled in the market.

About 56% of those who answered said they had heard of PMSM fan options, indicating a growing familiarity with this new fan option. However, it should be noted that SMEs in this survey are more likely to be familiar with PMSM fans than the typical service provider or industry professional since they were targeted for their expertise and knowledge base technology.



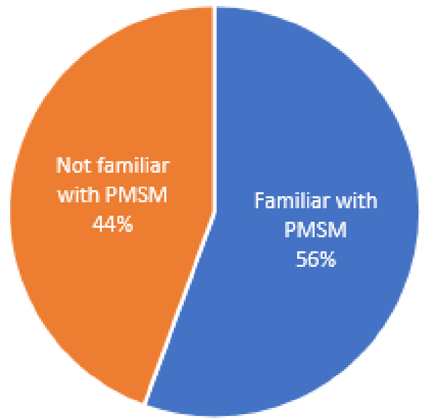


FIGURE 7. HIGH EFFICIENCY MOTOR FAMILIARITY

Evaporator coil and fan maintenance is often overlooked, causing the fans to be serviced or replaced only when noticed after failure. When asked if the fans are regularly serviced and replaced, only three of the surveyed respondents answered that they did perform routine maintenance and proactively replaced motors before failure. In most cases, the fans are replaced only when they fail or when service is required. The others stated that the timing of replacement was "up to the warehouse's stock" or the replacement was "recommended to the customer, but only when called out [on a service call]."

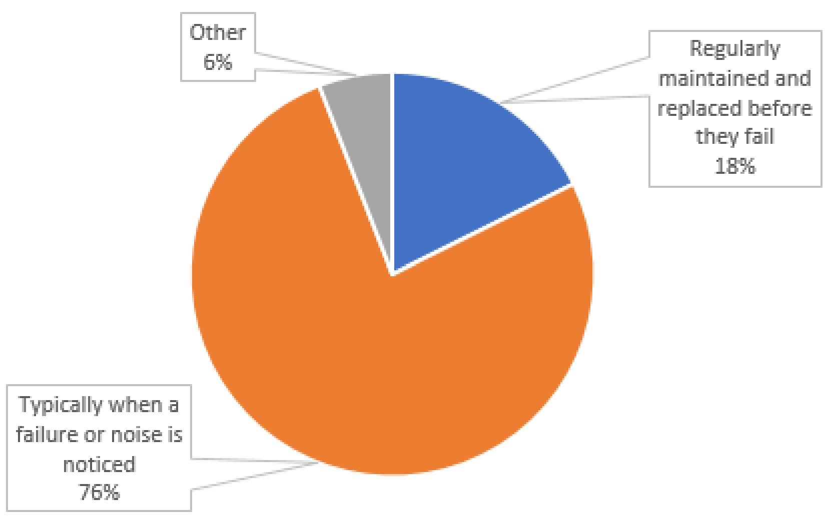


FIGURE 8. DECIDING FACTORS FOR REPLACING REFRIGERATED CASE FANS

Additionally, the 56% of respondents said that decisions on replacement fan types are made by the service provider while 38% said by customer's company policy. When company policy does not exist or it is not enforced, the refrigeration service provider is the one making the choice on the type of fan; this decision is also based on availability in stock to restart operation as quickly as possible and low cost. This standard practice was confirmed by SME interviews.

When asked what might prevent adoption or installation of efficient fan alternatives, respondents primarily focused on cost premiums and reliability concerns as shown in Figure 9. A variety of other comments were submitted (see Appendix C).

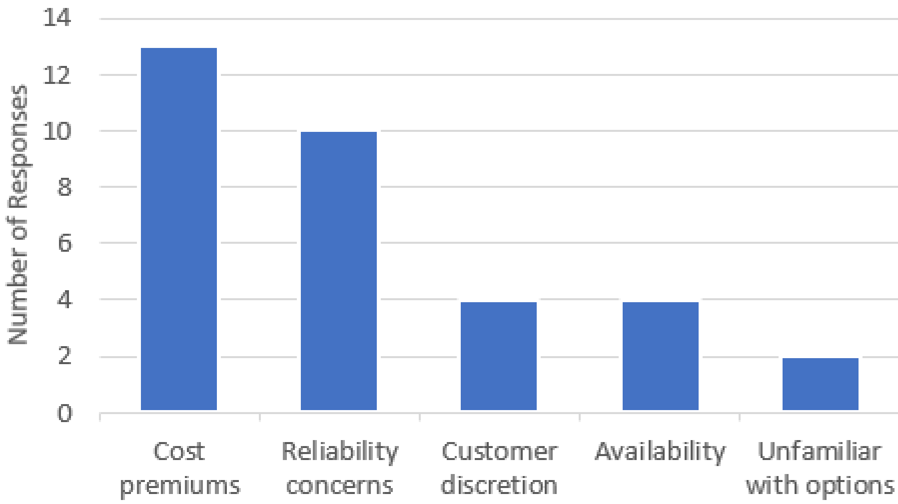


FIGURE 9. BARRIERS TO ADOPT MORE EFFICIENT FANS

Finally, the survey participants were asked to rank the importance of fan selection criteria. As seen in the average rankings in Figure 10, efficiency is not the primary concern when choosing a replacement motor. Unsurprisingly, reliability and cost were rated highest in importance with manufacturer and recognition least important. These rankings were similar the barriers shown in Figure 9 with a slight difference. Whereas cost premiums were listed as the top barrier to selection of premium efficiency options, reliability was considered the most important when selecting case fans.

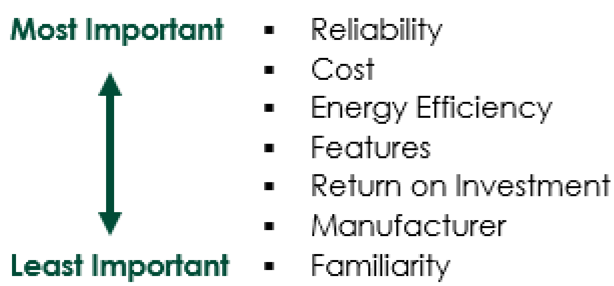


FIGURE 10. FAN SELECTION CRITERIA IMPORTANCE

In addition to above survey results, some SMEs engaged in phone discussions about the retrofit market, ECMs, and PMSMs. These conversations yielded additional important information and feedback on the emerging technology and program support. The details of the conversation as well as the survey questions and responses are included in Appendix C.

ASSESSMENT OBJECTIVES

The goal of this technology assessment is to identify the demand reduction, energy savings, market characteristics, and operational benefits of a new PMSM fan design in supermarket refrigerated display cases. To this end several objectives were established:

- Evaluate existing refrigerated case fan demand, energy usage, and power factor to establish a baseline case.
- Document and research existing motor base to establish industry standard practice and existing baseline.
- Study market barriers and trends by surveying of customers, subject matter experts, and refrigeration service professionals.
- Upgrade to PMSM fan and motor assemblies at each site across a variety of case types.
- Monitor fan energy, compressor energy, and operating conditions to ensure fair pre-post comparison and compressor interactive effects.
- Quantify and verify energy savings resulting from the technology during a post-installation period.
- Quantify effect of retrofit on refrigeration system efficiency, energy consumption, and demand.
- Generate an assessment report that can be used as a case study for future upgrade opportunities, deemed workpaper development, and utility incentive program design.

In order to accomplish these objectives, AESC designed a measurement and verification (M&V) plan adhering to IPMVP principles. The M&V plan is outlined in the following section and was designed to directly measure energy effects and the relevant factors and performance characteristics.

TECHNICAL APPROACH & TEST METHODOLOGY

TEST PLAN

A test plan was derived to answer the questions listed in the Assessment Objectives. To achieve the objectives, the test plan included a scaled field placement with measurements at four host sites, refrigeration modeling, and a market survey.

The measurement and verification included data collection at four supermarket sites following IPMVP Option A (Retrofit Isolation: Key Parameter Measurement). Supermarkets were targeted since they account for about 90% of the installed 9-12W fan base in the state. Sites in SCE territory were recruited and selected in order to gather data across a variety of operating conditions. A field study was selected over a laboratory study in order to gain insight into the actual installation process and to allow measurement of the compressors and refrigeration equipment.

Criteria for site selection included:

- Number of cases across category and fan type (open/closed, MT/LT, ECM/SP/PSC)
- Refrigeration system type (evaporative/air-cooled, compressor arrangement, control parameters, etc.)
- Store location, hours, and cooperation to minimize time burden
- Electrical circuits ideally dedicated to evaporator fans only
- Compatibility with data logging equipment and locations

The population of measured refrigerated cases was selected to have an even distribution of case types. Each store had roughly one-fourth of the total field placement, with case type breakdowns evenly distributed as much as store arrangements will allow.

The test plan also included refrigeration modeling in eQuest to estimate interactive effects at the compressors. The modeled building was similar to the prototype used in existing workpapers and used the fan power measurements from the field to adjust the input fan powers in the models.

Finally, the test plan included market surveying of subject matter experts, end-users, and refrigeration service providers in California to gather information on the market trends and baseline conditions.

HOST SITES

Four grocery stores located in different SCE territory climate zones (CZ) were selected as host sites for this study: Huntington Beach (HB), Garden Grove (GG), Desert Hot Springs (DHS) and Lake Arrowhead (LAH), which are located in climate CZ06, CZ08, CZ15 and CZ16, respectively. At all host sites, the supermarket staff performs restocking and refrigeration system maintenance outside of business operating hours. All MT cases operate 24/7 (8,760 hours per year). The LT freezers undergo defrost cycling each day resulting in an average an average of 8,685 fan operating hours per year. The defrost type and period varies between four sites.

The building characteristics and refrigeration system of each site are summarized in Table 5.

TABLE 5. HOST SITES BUILDING CHARACTERISTICS AND CENTRAL REFRIGERATION SYSTEM

Characteristic	HB	GG	DHS	LAH
Building Type	Supermarket	Supermarket	Supermarket	Supermarket
Zip Code	92646	92845	92240	92352
Business Hours	5AM -1AM , Sun-Sat	5AM -2AM , Sun-Sat	6AM -11PM, Sun-Sat	6AM -11PM, Sun-Sat
Approximate Area (sq.ft.)	54,400	56,500	31,400	25,500
CA Climate Zone	CZ06	CZ08	CZ15	CZ16
Number of Reciprocating Compressors	11	15	13	11
Type of Condenser	Air-cooled	Air-cooled	Evaporative Cooled	Air-cooled
Number of Condensers	3	2	1	2
Defrost Type and Period	Defrost Cycle with Fans ON (Electrical Heat Defrost)	40 Minute Defrost Cycle with Fans OFF (Hot-Gas)	Electric Defrost Cycle with Fans On for 40 Minutes, then 15 Minutes Fans and Defrost OFF	Electric Defrost Cycle with Fans On for 40 Minutes, then 10 Minutes Fans and Defrost OFF

Figure 11, Figure 12, Figure 13, and Figure 14 show the store layouts for each of the host sites as well as the case lineups that were targeted for retrofit.

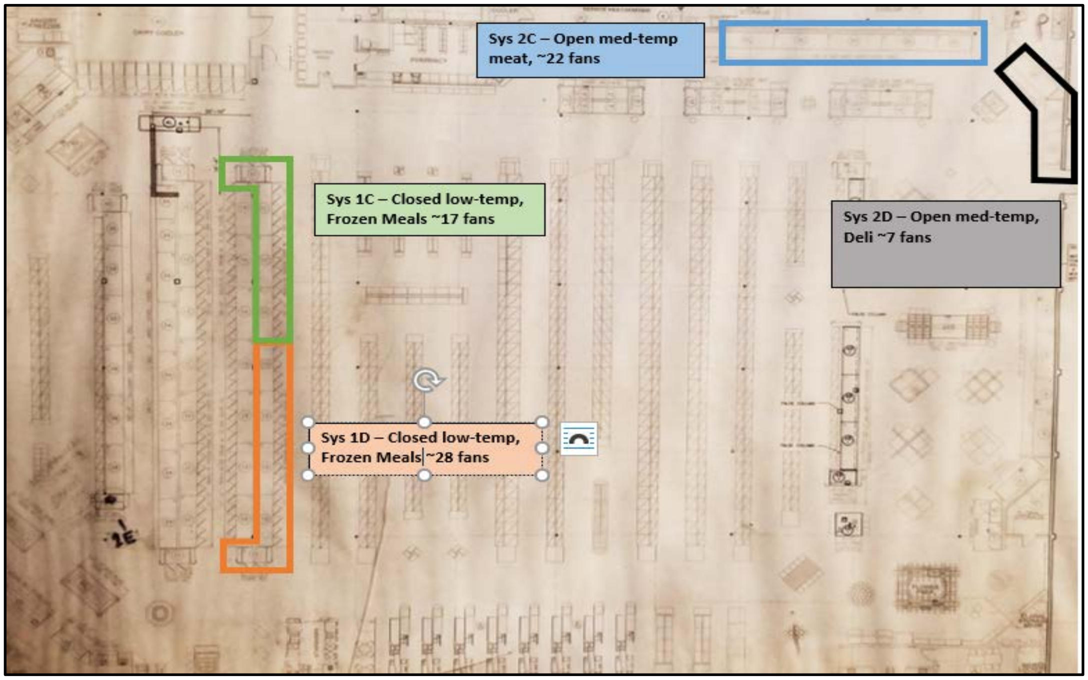


FIGURE 11. STORE LAYOUT WITH TARGETED CASES – HB

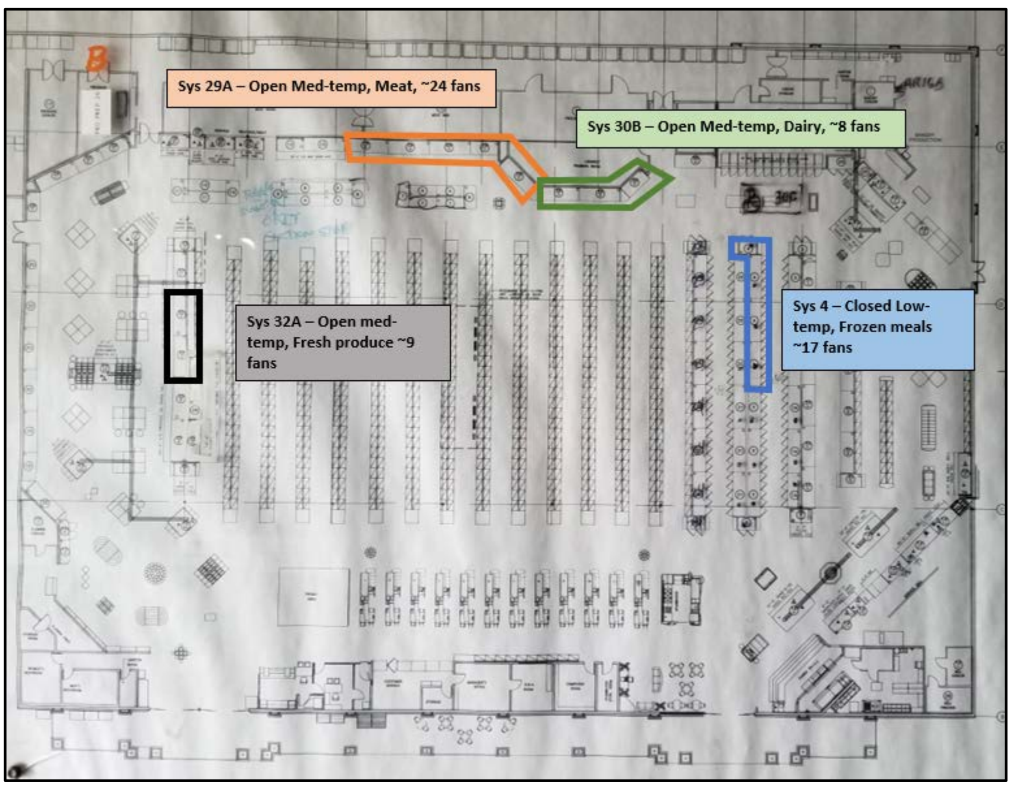


FIGURE 12. STORE LAYOUT WITH TARGETED CASES – GG

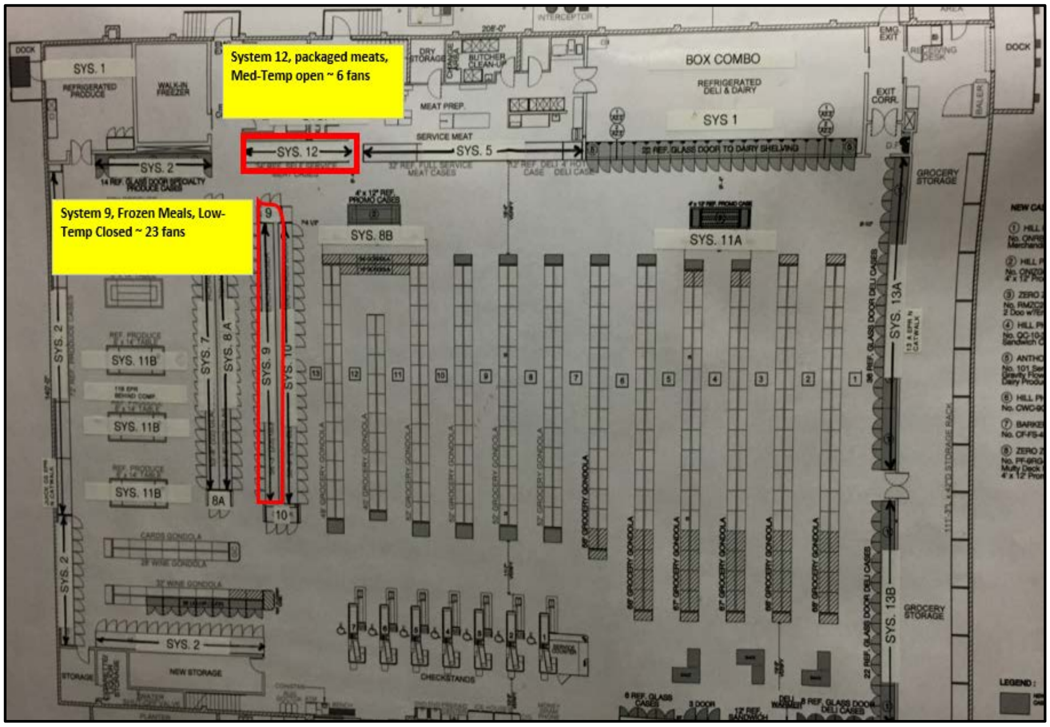


FIGURE 13. STORE LAYOUT WITH TARGETED CASES - DHS

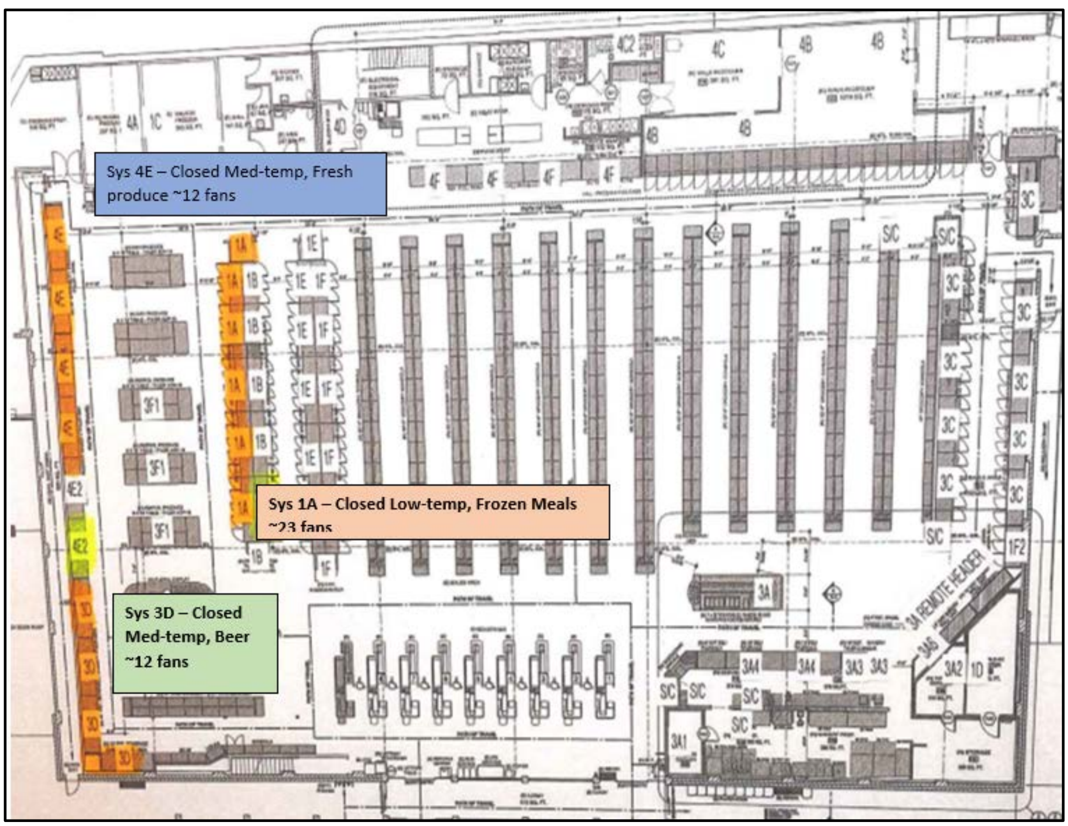


FIGURE 14. STORE LAYOUT WITH TARGETED CASES - LAH

The retrofitted display case system number, type, content, and associated quantity of 208 fans at each store are listed in Table 6. Originally, 239 total fan assemblies were retrofitted, but 31 fans were noted as poor application as elaborated in the Discussion & Conclusions section. Hence, these fans were not counted in the analysis. Of these 208 total fan assemblies retrofitted, 30 had SP baseline motors while the remainder had ECMs. Baseline fan motor size, including both ECM and SP, ranged from 20 watts to 45 watts and 85% of the baseline motors were ECMs. The remaining, untargeted cases in each store were not retrofitted due to the sensitive nature of the case contents and to limit project costs and time. A whole-store retrofit or future operations and maintenance (O&M) efforts could certainly target these additional units.

TABLE 6. RETROFITTED DISPLAY CASE LINEUPS

Site Name	System Number	Case content	Number of Fans (Retrofitted)	Type
HB	1C	Frozen Meals	17	LT Closed
	1D	Frozen Meals	28	LT Closed
	2C	Packed Meat	22	MT Open
	2D	Deli	7	MT Open
GG	4	Frozen Meals	17	LT Closed
	29A	Packed Meat	24	MT Open
	30B	Dairy	8	MT Open
	32A	Fresh Produce	9	MT Open
DHS	9	Frozen Meals	23	LT Closed
	12	Packed Meat	6	MT Open
LAH	1A	Frozen Meals	23	LT Closed
	3D	Beer	12	MT Closed
	4E	Fresh Produce	12	MT Open

Figure 15 and Figure 16 show several of the refrigerated cases at the host sites.

FIGURE 15. DAIRY CASES AND FROZEN FOODS CASES (GG LEFT AND HB RIGHT)

FIGURE 16. DELI CASES AND FROZEN FOOD CASES (DHS LEFT AND LAH RIGHT)

INSTRUMENTATION PLAN

Power monitoring over the entire study period was performed using Dent ElitePro energy meters. The Dent meters were installed at the electrical distribution panels that supply power to each fan circuit, compressor(s), and condensing fans. Additionally, Onset HOBO data loggers were placed in a sample of the cases throughout the four sites to measure the case bulk air temperature and relative humidity (T/RH) conditions (N=34 cases). Inside and outside air temperature and relative humidity (RH) were also measured. Finally, compressor suction and discharge temperatures were monitored as well. The summary of instrumentation used in this study is listed in Table 7.

TABLE 7. MONITORING INSTRUMENTATION

MEASUREMENT POINTS	UNIT	INSTRUMENT	ACCURACY	LOGGING INTERVAL
Fan Circuits, Compressors, and Condensers	kW, kVA, A, V, pf	Dent ElitePro Onset CTV-C	<1% ±4.5%	
Inside and Outside Air	T/RH	HOBO U12	±0.63°F, ±2.5% RH	
Inside and Outside Air	T/RH	HOBO UX100-011	±0.38°F, ±2.5% RH	1 minute
Display Case Air	T/RH	HOBO MX2301A	±0.45°F, ±2.5% RH	
Compressor Suction and Discharge Temperatures	T	Onset TMCx-HE	±0.45°F, ±2.5% RH	

Figure 17 shows example metering installations for fan power, compressor suction and discharge temperatures, and case air.

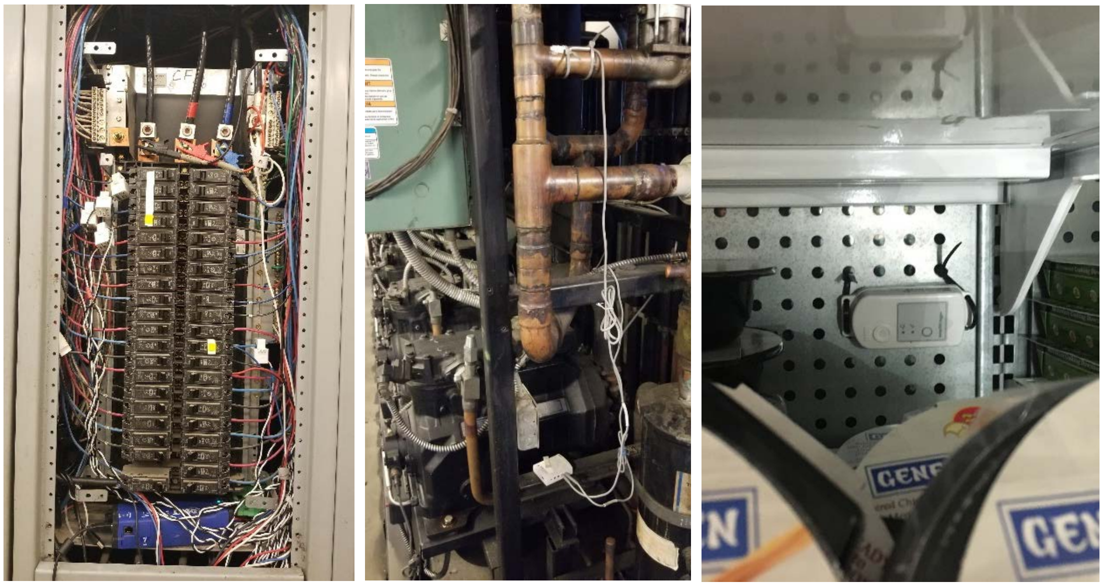


FIGURE 17. FAN CIRCUIT DENT POWER METERING, COMPRESSOR SUCTION AND DISCHARGE METERING, AND CASE AIR METERING

Additionally, spot measurements were taken at the baseline and retrofit fans during the installation at two of the host sites as shown in Figure 18. These included fan power measurements of every baseline and retrofit fan. The instrumentation for the spot measurements is listed in Table 8.

TABLE 8. SPOT MEASUREMENT INSTRUMENTATION

MEASUREMENT	INSTRUMENT	ACCURACY
kW, kVA, A, V, pf	Kill A Watt	<1%

FIGURE 18. SPOT MEASUREMENTS TAKEN AT A BASELINE FAN

MODELING PLAN

A modeling plan was designed to ascertain interactive effect savings at the compressors across CZs. The refrigeration module of eQuest modeling software version 3-65-7175 was used to estimate the energy saving potential of PMSM fan assemblies at whole-building level, including the refrigeration system compressor and condenser energy consumption. The software calculates hourly plug loads, HVAC, and refrigeration system energy consumption for the entire year. The CZ2010 weather files published by California Energy Commission were used for the simulations. The baseline model was built upon DEER grocery store model, a prototypical grocery store model provided by the eQuest refrigeration software. This model had been used in previous workpapers. The following table summarizes the major parameters of the DEER grocery store model used.

TABLE 9. EQUEST MODEL CHARACTERISTICS

FIELD	VALUE
Prototype Name	DEER Grocery
Area	50,000 sq. ft.
Occupied Hours	6AM to 10PM, 7 days a week
Lighting Power Density	2.0 W/SF
HVAC System Type	Packaged AC
Refrigerant	R-507
Refrigeration System Type	Multiplex
Number of Suction Groups	2 (LT & MT)
Number of LT Cases	5
Number of LT Case Motors	169
Number of MT Cases	10
Number of MT Case Motors	156

A few modifications were made as necessary to comply with the California Title 24 requirements. Additionally, the baseline case fan energy values for LT and MT cases were modified so that they matched with the field observations.

Since the baseline site had a mix of ECM and SP motors, energy savings were estimated for two baseline scenarios for each CZ. The first iteration is based on a baseline consisting of all ECM motors replaced with PMSMs. The second iteration uses a baseline consisting of all SP motors replaced with PMSMs. The baseline and post-implementation models for each CZ are identical with the exception of different evaporator fan power inputs. Additional information regarding the eQuest modeling, inputs, and compressor performance curves are detailed in Appendix D.

RESULTS

The technology was evaluated with three different complementary approaches: field retrofit data collection, refrigeration system modeling, and market surveying of subject matter experts and end-users. The results of these three approaches are presented below, each of which informs the conclusions and recommendations drawn for this product.

The baseline technology can be considered ECM, SP, or a blend of the two. The blend of baseline fan types can be defined by the following breakdowns which were determined through observation of the participating sites and through the market surveying. Note that the field sites had a fan population similar to that expected for new case installations due in part to their proactive ECM retrofits in the past.

TABLE 10. BASELINE MOTOR TYPE BLEND[7]

	ECM %	SP %
Field Sites Blend	85	15
Existing Cases (Market Survey)	60	40
New Cases (Market Survey)	90	10
Replacement Fan Sales (Market Survey)	56	44

The data collected from the retrofits of 208 fans at the four sites was used to calculate the per-fan power, energy, and savings shown in Table 11. Across all the sites, the average post-retrofit PMSM fan power was 13.9 watts per fan. The annual runtime of 8,685 hours for LT cases is the average observed runtime including defrost cycles. The power, energy, and savings were calculated for each type of potential baseline: ECM, SP, or a blend of the two. Percent demand and energy savings were 31% and 69% for ECM and SP baseline fans, respectively. This aligns with savings found in previous studies listed in Table 2.

TABLE 11. PER-FAN INPUT POWER AND SAVINGS

Baseline Type	Baseline Fan Power (W)	PMSM Fan Power (W)	Fan Power Savings (W)	LT Fan Runtime (hr/yr)	LT Energy Savings (kWh/yr)	MT Fan Runtime (hr/yr)	MT Energy Savings (kWh/yr)
ECM	20.2	13.9	6.3 (31%)	8,685	54.7	8,760	55.2
SP	45.4		31.5 (69%)		273.6		275.9
Field Sites Blend (85% ECM, 15% SP)	23.9		10.0 (42%)		86.9		87.6
Market Survey Baseline Blend (60% ECM, 40% SP)	30.3		16.4 (54%)		142.4		143.7

[7] Note that split capacitor motors were not observed in the field nor claimed to hold significant market share by any survey respondents. There may be a small fraction of the existing base that use split capacitor motors, but their market share is small enough to be negligible for the purposes of this report.

While long-term circuit-level monitoring was performed at all four stores, two of the participating sites allowed for spot measurements during the actual retrofit. Measurements at each fan enabled calculation of the 95% confidence interval for the baseline power and savings for each type of baseline fan. As seen in Figure 19 and Figure 20, the confidence intervals for the measured fan power, power factor, and savings are very good and indicate a clear statistical significance and reliable savings over each type of baseline.

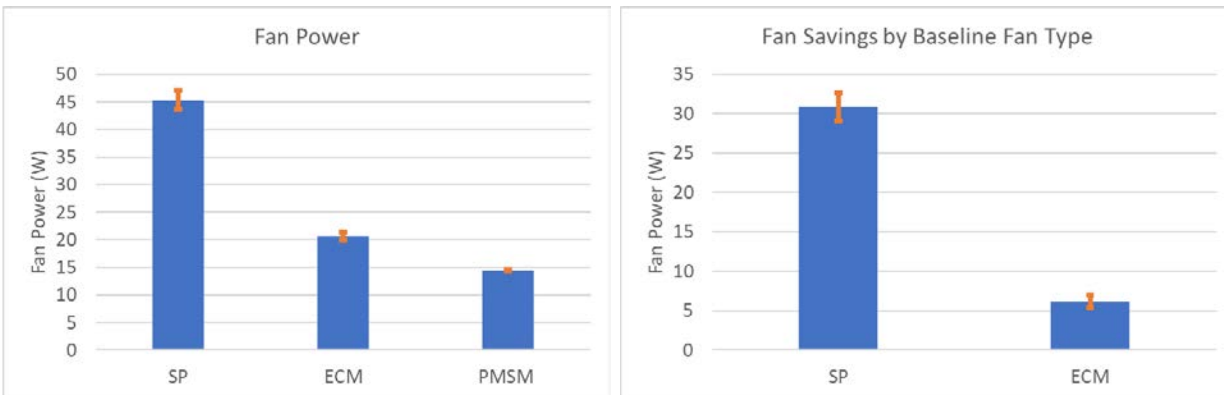


FIGURE 19. FAN POWER AND SAVINGS WITH 95% CONFIDENCE INTERVALS

Additionally, PF improved from 0.52 for ECMs and 0.66 for SPs to 0.86 for PMSMs as seen in Figure 20.

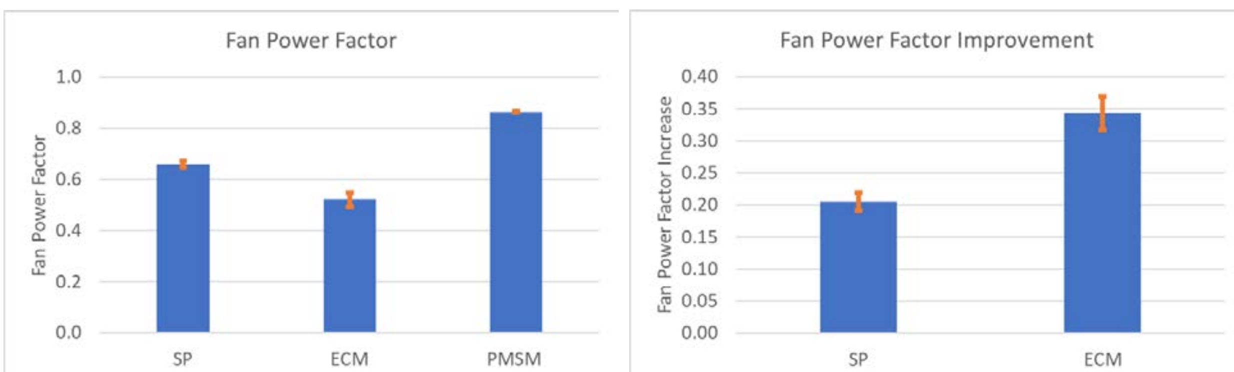


FIGURE 20. FAN POWER FACTOR AND IMPROVEMENT WITH 95% CONFIDENCE INTERVALS

Figure 21 shows the fan circuit power monitoring for each retrofit display case lineup before and after retrofit at the HB site with a clear power drop during the retrofit on the night of July 9th, 2019 indicated by the dashed vertical line.

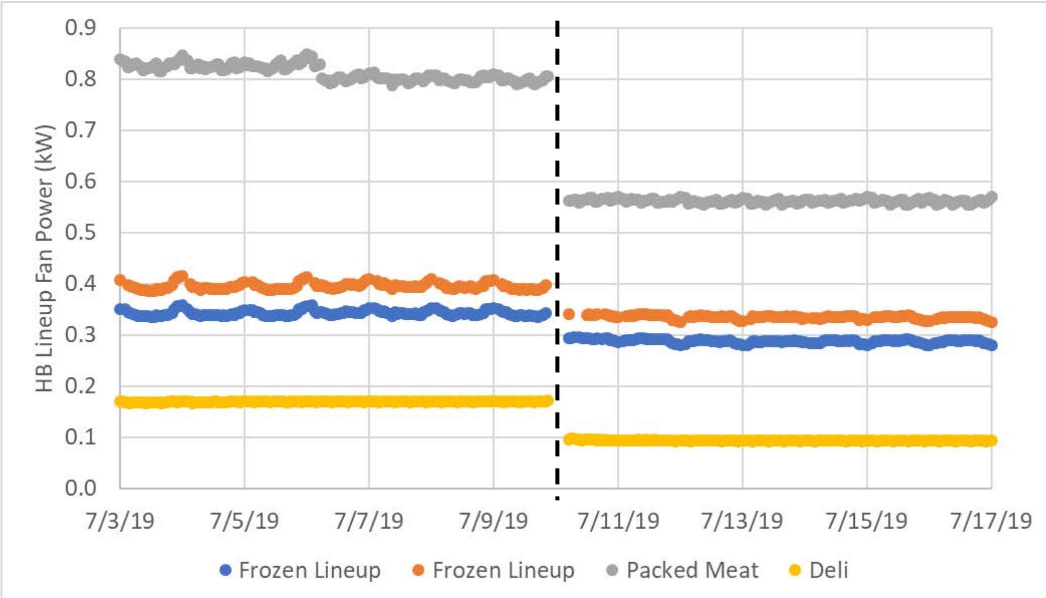


FIGURE 21 . FAN CIRCUIT POWERS BEFORE AND AFTER RETROFIT (HB SITE)

Additionally, long-term monitoring of both case air conditions and compressor power was performed to confirm that the retrofit would not negatively impact case performance or refrigeration system energy consumption.

Figure 22 shows scatter plots of sample compressors at all four sites. Additional plots for all the affected compressors can be found in full in Appendix A. In each case, it is obvious that compressor powers are not negatively impacted by the retrofit. In other words, the compressors are not working harder across the load profile to achieve the same refrigeration effect due to any changes at the evaporator coils. This is important evidence that any airflow changes, although unexpected based on fan curves and monitored data, did not require the compressors to operate at higher pressures or higher compression ratios.

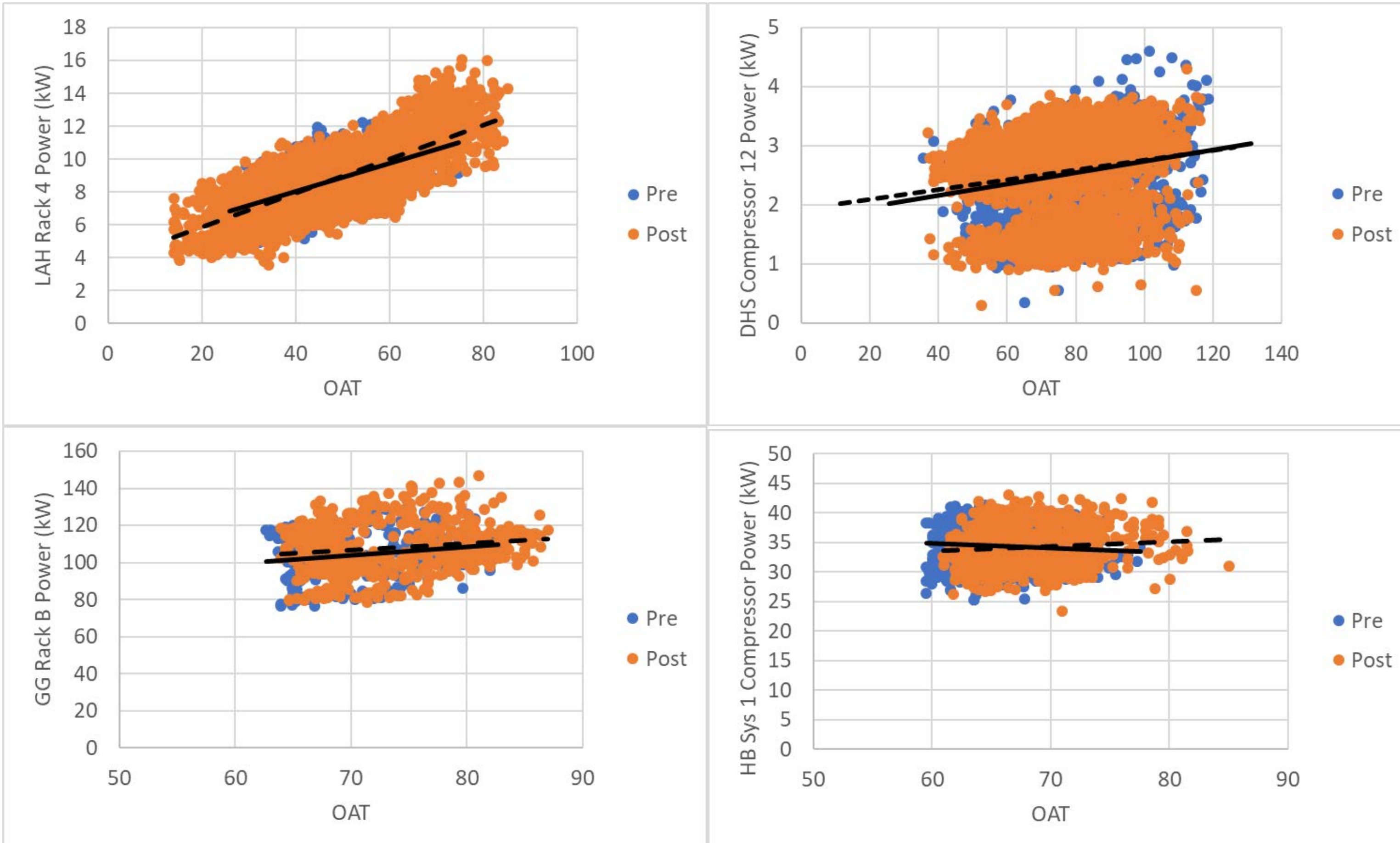


FIGURE 22. EXAMPLE COMPRESSOR MONITORING DATA

To further support this conclusion, monitored data before and after retrofit shows a clear drop in fan power as demonstrated in Figure 21 without any corresponding change in compressor operation as shown in Figure 23 and Figure 24. Both figures include 3-day moving averages for the compressor power and temperatures which stay consistent before and after retrofit. Similar observations were made at all sites as seen in Appendix A.

The absence of increased compressor power or reduced suction temperatures suggests that the fan retrofit did not cause any increase in compression energy. When evaporator coil airflow is reduced significantly, compressor power would be greater since the compressor would have to raise the refrigerant from a lower pressure to the condensing temperature. Since no change in compressor energy or suction pressure was observed, this should alleviate the concern that the retrofit fans may cause increased compressor energy from reduced airflow across the evaporator coils. Becker and Fricke came to a similar conclusion in 2016 by monitoring suction and discharge temperatures of evaporator coils before and after retrofits. (Becker & Fricke, 2016)

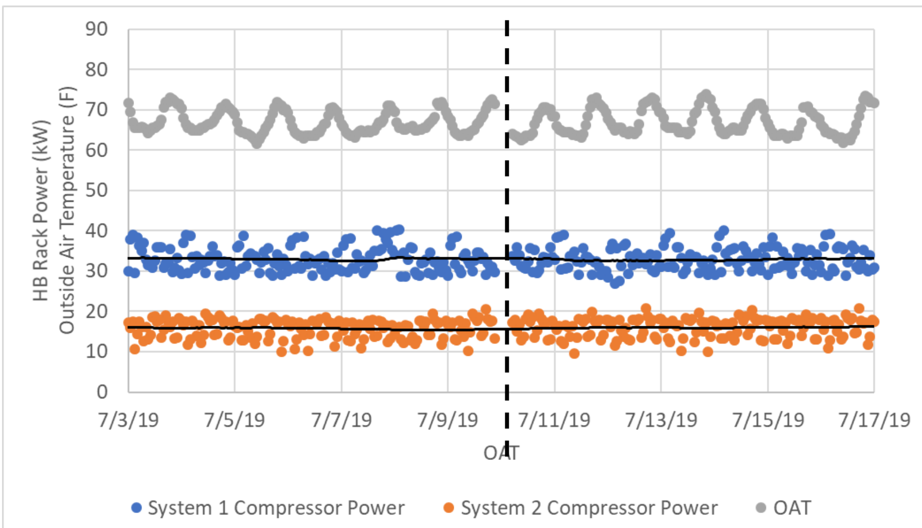


FIGURE 23. COMPRESSOR POWER WITH MOVING 3-DAY AVERAGE BEFORE AND AFTER RETROFIT (HB SITE)

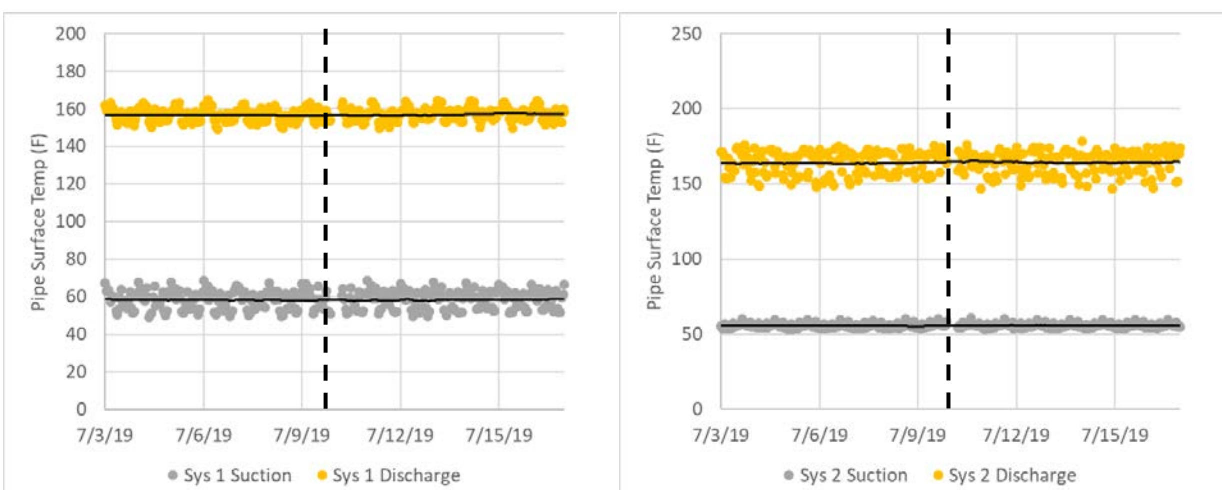


FIGURE 24. COMPRESSOR SUCTION AND DISCHARGE TEMPERATURES BEFORE AND AFTER RETROFIT (HB SITE)

These fan power savings without any negative compressor interaction are predicted by fan curves developed for the PMSM emerging technology and a sample of baseline fans from the host sites. Figure 25 shows fan curves for the PMSM emerging technology as well as six sample ECM fans that were obtained from the baseline cases. The solid lines represent the static pressure relationship to airflow while the dashed curves represent input fan power across airflow. Typically, display case evaporator fans operate between 0.10 and 0.20 inches of water. It is noteworthy that the pressure-airflow relationship for the PMSM fan is similar to the baseline fans within the expected operating range while the respective input power is lower. This indicates that the PMSM fan would move the same air across the evaporator coil with less input energy.

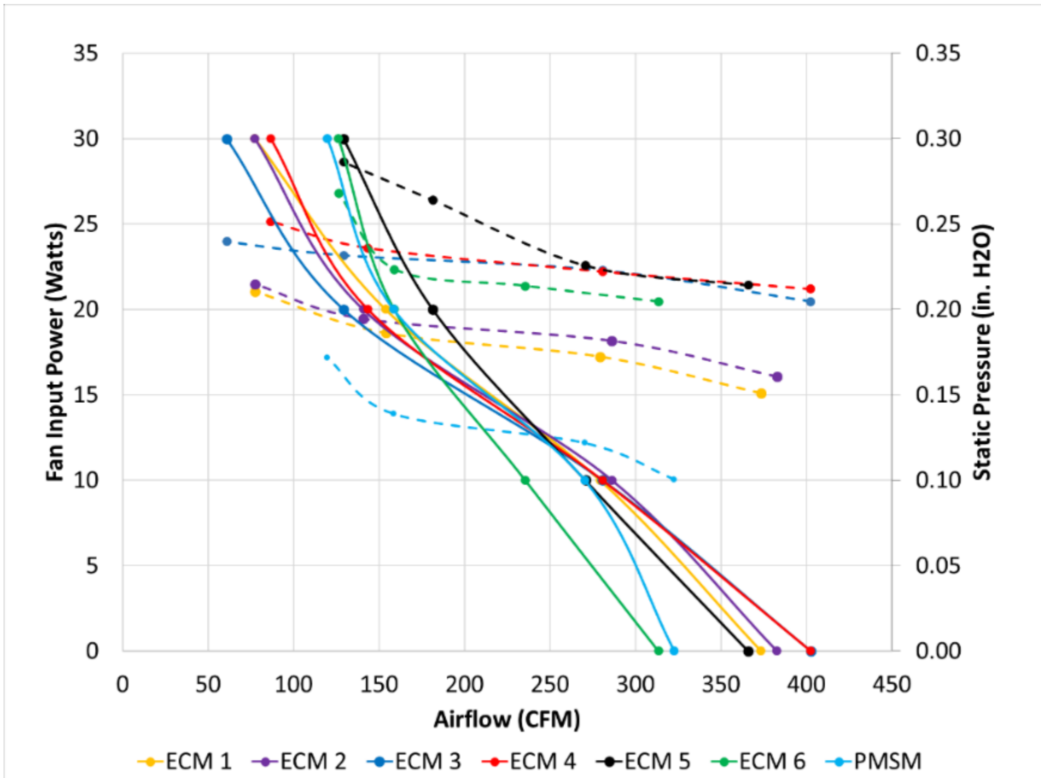


FIGURE 25. LABORATORY TEST FAN CURVES FOR PMSM AND SAMPLE ECM FANS[8] (SOLID = STATIC PRESSURE, DASHED = POWER)

Air conditions in nine cases at each site were monitored before and after retrofit to ensure that case performance was maintained, product was stored safely, and case temperature setpoints were not altered during the test. Two loggers in the cases failed, resulting in a dataset of 34 cases whose air T/RH was monitored.

[8] These fan curves were developed by the manufacturer in their test facility using industry standard test procedures, not by an independent third party. The tests showed results similar to those found by independent third party testing in 2016 by a member of the Air Movement and Control Association (AMCA) for a previous workpaper effort.

Figure 26 shows the monitored air conditions before and after retrofit at an example case at the HB site. Again, 3-day rolling averages show that the retrofit did not affect the system's ability to maintain conditions and ensure product safety.

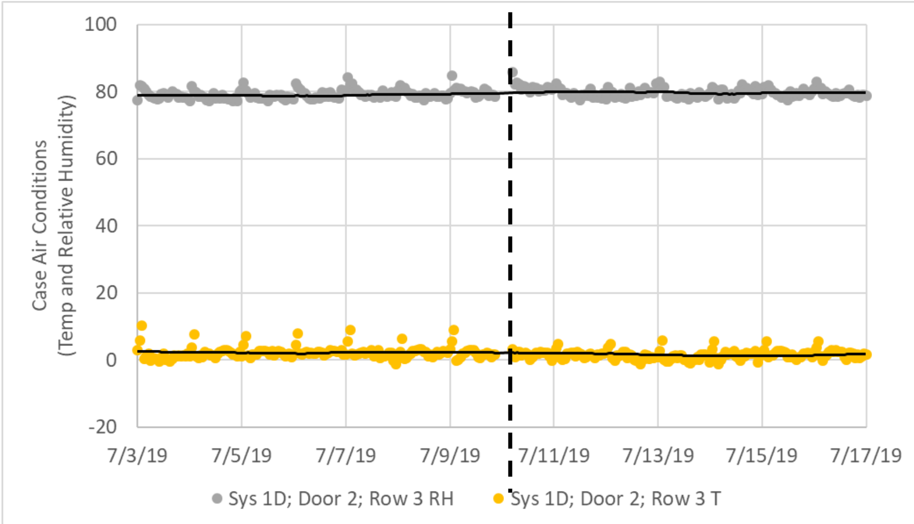


FIGURE 26. EXAMPLE CASE AIR MONITORING BEFORE AND AFTER RETROFIT (HB SITE)

This pattern of consistency was seen in all the sample cases that were monitored. Figure 27 shows the average temperatures and relative humidities for each monitored case across all four sites. Each point represents the average values for each individual case that was monitored, with the baseline value on the x-axis and post-retrofit value on the y-axis. The line with a slope of indicates where the pre and post values would be exactly the same. The close adherence to the slope of one indicates that the retrofit did not adversely affect case air conditions and that case setpoints were not altered during the test.

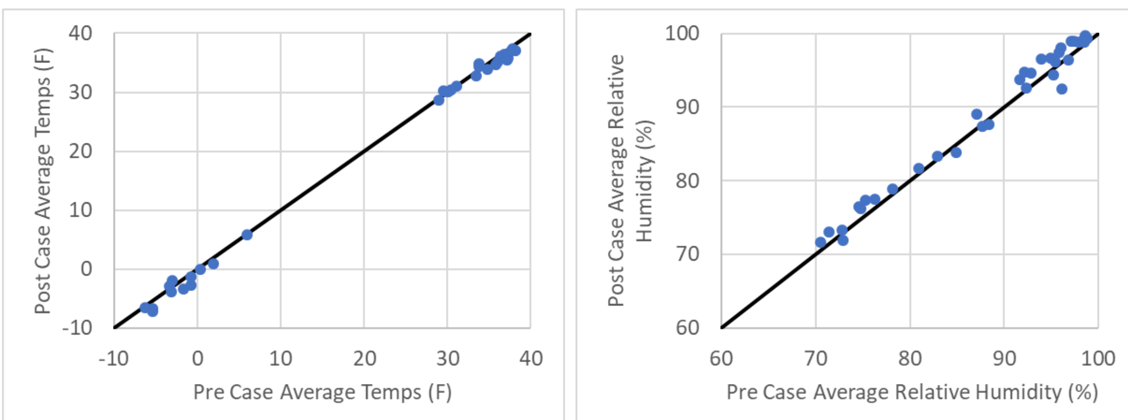


FIGURE 27. AVERAGE CASE AIR TEMPERATURES AND RELATIVE HUMIDITIES

The emerging technology will result in lower internal heat gains within the display cases roughly equivalent to the difference in input power. However, this decrease in load was a very small fraction of total system load at the field sites. As a result, it was not possible to directly measure the reduction in total refrigeration power. Despite this, the reduced fan input power will certainly result in a marginal reduced refrigeration load. To estimate this "interactive effect" of the fan retrofit, eQuest modeling of grocery store refrigeration was performed across all California climate zones as described in the Modeling Plan and Appendix D.

Table 12 lists the interactive effect (IE) factors calculated from refrigeration system modeling results using following equations. Note that demand here signifies DEER peak demand, which was calculated as the average of 2009 DEER peak periods for each CZ.

$$Demand\ IE\ factor\ \left(\frac{kW}{kW}\right) = \frac{Total\ system\ demand\ saving\ (kW)}{Fan\ demand\ saving\ (kW)}$$

$$Energy\ IE\ factor\ \left(\frac{kWh}{kWh}\right) = \frac{Total\ system\ energy\ saving\ (kWh)}{Fan\ energy\ saving\ (kWh)}$$

TABLE 12. REFRIGERATION SYSTEM INTERACTIVE EFFECT FACTORS

	CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
ECM BASELINE																
LT Demand DEER Peak IE Factor (kW/kW)	1.23	1.76	1.92	2.44	2.22	1.61	2.10	2.34	2.66	2.53	2.43	2.02	2.63	1.88	2.98	2.06
LT Energy IE Factor (kWh/kWh)	1.56	1.59	1.58	1.59	1.59	1.62	1.61	1.63	1.62	1.65	1.65	1.62	1.69	1.66	1.81	1.55
MT Demand DEER Peak IE Factor (kW/kW)	1.35	2.41	1.50	1.73	1.25	1.75	1.21	1.33	1.63	2.28	1.86	1.38	1.60	1.65	1.47	1.53
MT Energy IE Factor (kWh/kWh)	1.32	1.35	1.33	1.36	1.33	1.31	1.32	1.36	1.36	1.38	1.39	1.37	1.39	1.39	1.46	1.33
SP BASELINE																
LT Demand DEER Peak IE Factor (kW/kW)	1.76	2.28	1.86	2.16	1.83	1.91	1.89	2.05	2.50	2.56	2.51	2.44	2.50	2.27	2.90	1.95
LT Energy IE Factor (kWh/kWh)	1.56	1.61	1.59	1.62	1.59	1.63	1.63	1.65	1.66	1.68	1.69	1.65	1.70	1.69	1.85	1.58
MT Demand DEER Peak IE Factor (kW/kW)	1.40	1.66	1.39	1.67	1.34	1.44	1.39	1.45	1.77	1.87	1.76	1.77	1.80	1.64	1.97	1.47
MT Energy IE Factor (kWh/kWh)	1.32	1.35	1.34	1.36	1.33	1.33	1.33	1.36	1.37	1.38	1.39	1.37	1.39	1.39	1.47	1.35

Note that demand IE factors for LT system ranges greatly according to CZ, with hotter CZs having relatively large impact on the total demand savings. This is likely due to the stock compressor curve used for LT compressors in the modeling, whose efficiency deteriorates rather rapidly with increasing compressor discharge temperature. The details of the compressor performance curves, including the coefficients used in the eQuest modeling can be found in Appendix D.

Table 13 shows the total combined fan input power and refrigeration system savings for each baseline fan type and CZ. The savings in this table are based on field-verified per fan demand and energy saving values and the interactive effect factors from the preceding table.

TABLE 13. TOTAL PER FAN SAVINGS (COMBINED FAN AND REFRIGERATION SYSTEM SAVINGS)

ECM BASELINE	CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8	CZ9	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Total LT Demand Savings (kW)	0.008	0.011	0.012	0.015	0.014	0.010	0.013	0.015	0.017	0.016	0.015	0.013	0.017	0.012	0.019	0.013
Total LT Energy Savings (kWh)	86	87	87	87	87	88	88	89	89	90	90	89	93	91	99	85
Total MT Demand Savings (kW)	0.009	0.015	0.009	0.011	0.008	0.011	0.008	0.008	0.010	0.014	0.012	0.009	0.010	0.010	0.009	0.010
Total MT Energy Savings (kWh)	73	75	74	75	74	72	73	75	75	76	77	76	77	77	81	73
SP BASELINE																
Total LT Demand Savings (kW)	0.055	0.072	0.059	0.068	0.058	0.060	0.060	0.064	0.079	0.081	0.079	0.077	0.079	0.072	0.091	0.062
Total LT Energy Savings (kWh)	427	442	436	444	435	446	445	453	455	459	462	453	466	461	507	432
Total MT Demand Savings (kW)	0.044	0.052	0.044	0.053	0.042	0.045	0.044	0.046	0.056	0.059	0.056	0.056	0.057	0.052	0.062	0.046
Total MT Energy Savings (kWh)	365	374	369	375	367	368	367	374	377	380	384	379	385	384	404	374

Figure 28 and Figure 29 show the total system demand and energy savings per fan. The demand savings exhibit variability across CZs due to the large variations in IE factors. In comparison, the energy savings are highly consistent across CZs.

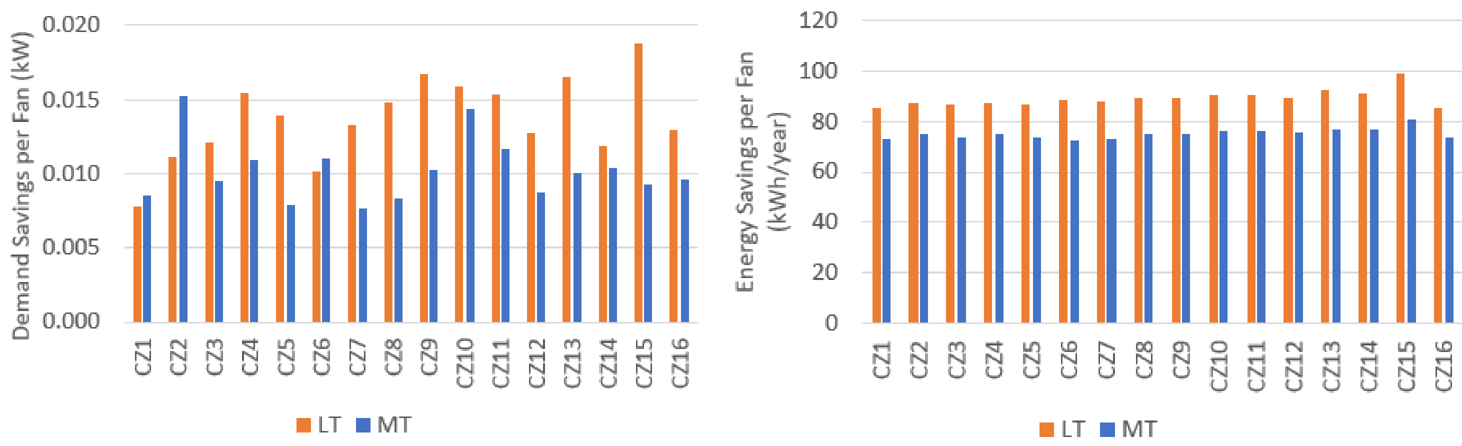


FIGURE 28. TOTAL DEMAND AND ENERGY SAVINGS PER FAN (ECM BASELINE)

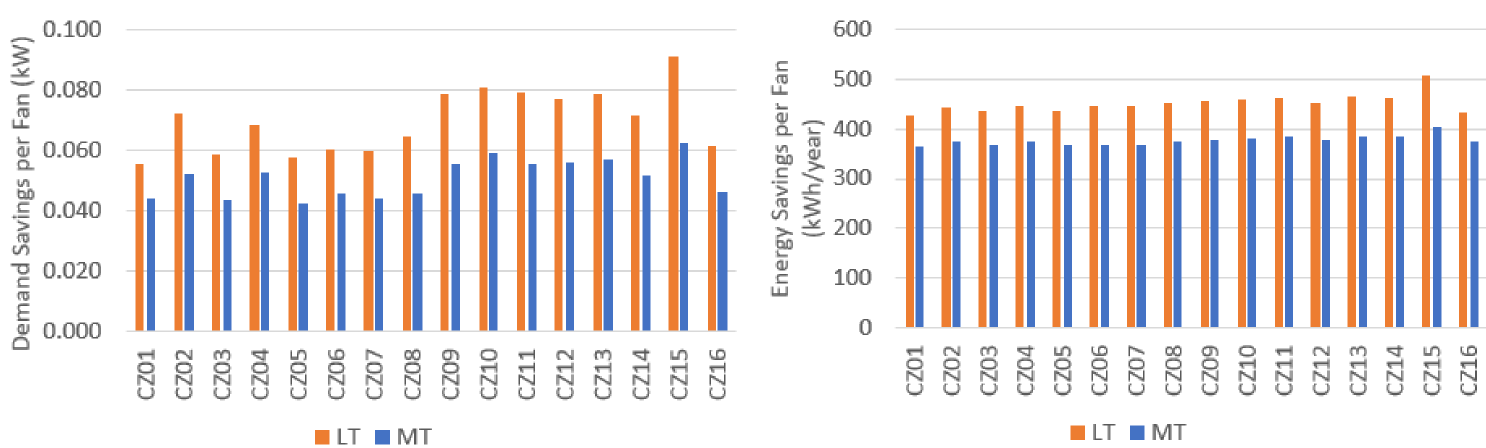


FIGURE 29. TOTAL DEMAND AND ENERGY SAVINGS PER FAN (SP BASELINE)

DISCUSSION & CONCLUSIONS

This effort assessed the energy benefits, market, and barriers of a new type of display case evaporator fan using permanent magnet synchronous motors. The field study showed reliable energy, demand, and power factor savings very similar to those published in previous efforts. These fans have a long measure life and the market awareness and uptake of alternatives to standard ECMs and SPs is negligible in both new installations and retrofits of exiting cases.

Average fan input power savings of 31% and 69% over ECM and SP baselines were calculated as shown in Table 14. While the baseline fan power will depend on the baseline technology, the post fan power for the PMSM retrofit was observed to be 13.9 watts regardless of baseline type. Since the fans operate at a constant speed and constant load profile the energy savings percentages are also 31% and 69% for the two baseline fan types. Fan energy savings are slightly lower for LT cases since fans have slightly reduced operating hours due to defrost cycles. With the exception of one poor application discussed below, every single retrofit fan showed energy, demand, and power factor savings.

TABLE 14. AVERAGE FAN POWER AND ENERGY RESULTS

Baseline Fan Type	Baseline Fan Power (W)	Post Fan Power (W)	Fan Power Reduction (W)	Low-Temp Fan Energy Savings (kWh/Yr)	Med-Temp Fan Energy Savings (kWh/Yr)
ECM	20.2	13.9	6.3 (31%)	54.7	55.2
SP	45.4		31.5 (69%)	273.6	275.9

Total refrigeration system savings were estimated through modeling of a representative supermarket system in each California CZ. Interactive effect factors for each CZ, case type (LT and MT), and baseline fan type (SP and ECM) were calculated to assess the total system savings including compressor savings resulting from reduced display case heat load.

TABLE 15. AVERAGE COMPRESSOR INTERACTIVE EFFECTS AND TOTAL SYSTEM SAVINGS

Baseline Fan Type	Avg Low-temp Compressor Interactive Effect Factor	Total System Energy Savings (kWh/Yr)	Avg Med-temp Compressor Interactive Effect Factor	Total System Energy Savings (kWh/Yr)
ECM	1.63	89.2	1.36	75.1
SP		446.0		375.2

Based on these total system savings, simple payback was calculated with the following formula:

$$Payback\ (years) = \frac{Measure\ Cost\ (\$)}{Energy\ Savings\ (kWh) * Blended\ Rate\ \left(\$/_{kWh}\right)}$$

Using the measure cost findings in Table 3, the full installed measure cost for a PMSM is about $107.03 when purchased direct from the manufacturer. The full measure cost would apply in an early retirement retrofit scenario typical to a direct install program or bulk replacement of existing fans with significant useful life remaining.

Assuming a blended rate of $0.15/kWh, the payback time for the unincentivized, full early retirement installed measure cost for each baseline motor type is listed in Table 16. However, given that the field observations and market survey showed an existing baseline blend of ECMs and SPs, the overall market average payback would likely be somewhere in between. Over the 15-year measure life at a 3% discount rate[9], this corresponds to net present values of about $551-$681 and $27-$51 per fan, for replacements of SP and ECM fans, respectively.

TABLE 16. ESTIMATED PAYBACK OF FULL MEASURE COST (E.G. EARLY RETIREMENT OF EXISTING FANS)

CASE TEMPERATURE	FULL MEASURE COST ($)	SP BASELINE PAYBACK (YRS)	SP BASELINE NET PRESENT VALUE ($)	ECM BASELINE PAYBACK (YRS)	ECM BASELINE NET PRESENT VALUE ($)
Med-Temp	$107.03	1.9	$551	9.5	$27
Low-Temp		1.6	$681	8.0	$51

Again referring to the measure costs in Table 3, the incremental costs for a PMSM replacement of a failed SP or ECM fan are about $30.01 and $4.25, respectively. The incremental cost over an ECM could potentially be disregarded since it is generally held that the cost of a PMSM fan is at parity with the market-average ECM. Regardless, the payback time and net present values are presented in Table 17 using the same assumptions listed above.

TABLE 17. ESTIMATED PAYBACK OF INCREMENTAL MEASURE COST DIRECT FROM MANUFACTURER (E.G. REPLACEMENT OF FAILED FANS)

CASE TEMPERATURE	PMSM INCREMENTAL COST OVER SP REPLACEMENT ($)	SP BASELINE PAYBACK (YRS)	SP BASELINE NET PRESENT VALUE ($)	PMSM INCREMENTAL COST OVER ECM REPLACEMENT ($)	ECM BASELINE PAYBACK (YRS)	ECM BASELINE NET PRESENT VALUE($)
Med-Temp	$30.01	0.5	$626	$4.25	0.4	$126
Low-Temp		0.4	$756		0.3	$151

Currently there is roughly cost parity between an average ECM replacement and the available PMSM model direct from the manufacturer. However, there could be a future scenario with wider distribution of the PMSM product which would incur a distributor markup. Assuming the distributor marked-up cost in Table 4, the resultant payback times are listed in Table 18.

TABLE 18. ESTIMATED PAYBACK OF INCREMENTAL MEASURE COST AFTER ASSUMED DISTRIBUTOR MARKUP (E.G. REPLACEMENT OF FAILED FANS)

CASE TEMPERATURE	PMSM INCREMENTAL MEASURE COST OVER SP REPLACEMENT ($)	SP BASELINE PAYBACK (YRS)	PMSM INCREMENTAL MEASURE COST OVER ECM REPLACEMENT ($)	ECM BASELINE PAYBACK (YRS)
Med-Temp	$72.01	1.3	$46.25	4.1
Low-Temp		1.1		3.5

Again, it should be noted that baseline equipment costs have a wide range and payback for any individual case retrofit will vary accordingly and with the aid of incentives, payback would

[9] California Title 24 code proposals use a 3% real discount rate (5% nominal) in their evaluations.

be greatly reduced in any given situation. For a deemed rebate measure program, average measure costs may suffice, but for a particular project and customer-facing proposals, payback may vary and site-specific calculations could be warranted. Regardless, it is apparent that return on investment and the net present value of PMSM replacements could be attractive, especially in bulk retrofit scenarios which would provide net present value benefits of thousands or tens of thousands of dollars per store. For example, the total retrofit of a store with 216 9-12W ECM fans would provide a net present value of about $10,000. For such a store with a 60/40 ECM to SP ratio, the net present value would be about $62,000.

In addition to the evaluation of energy and cost savings, the market survey data was analyzed and presented in the Market Survey section to identify market characteristics and barriers. This data suggested the following key takeaways:

- General opinion of market experts was that the PMSM fans are a reliable and robust product, but that market barriers exist.
- Generally, the market for ECM retrofits is decreasing but there are remaining hard-to-reach customers who are still using outdated technology.
- Reported existing case fans are 60% ECM and 40% SP. This differs somewhat from the observed 85% ECM and 15% SP at the host sites.
- Roughly 90% of repairs are performed by contracted service providers (as opposed to in-house refrigeration maintenance staff).
- Low product awareness amongst installing contractors and service providers in the field who will typically default to lowest-cost, stocked fans to achieve quick, cheap customer objectives.
- Efficiency program and consulting providers have been dissuaded from market because service providers will often undercut their opportunity by offering quick, cheap customer service at the expense of energy efficiency.
- Display case fans are viewed from a lens of reliability over energy costs by building owners since their products are dependent on cold case temperatures. Service providers and customers are most interested in keeping cases running in the high-pressure, low-margin food retail sector.
- Savings from fan retrofits are often perceived to be low and not worth proactive effort.

Two technical challenges with the PMSM product were observed in this study. First, the fans are designed to operate at 1,800 rpm instead of the standard 1,550 rpm of most baseline fans. This could be a concern if service providers ever elect to replace motors and not an entire fan assembly. However, it appears that it is generally standard practice to replace both the blades and motor simultaneously. One product catalog was found to offer an 1,800 rpm ECM motor specifically for use with the PMSM 1,800 rpm product fan blades.

Secondly, one targeted lineup of MT cases with doors at the DHS site was found to be a poor application of the available PMSM fan. The existing cases had low-pitch, low-power ECM fans which had input power of about 9W each. Due the unique, unusual baseline fan conditions and case design, the PMSM fans showed a slight increase in power. This highlights the variety of conditions and product variables in the evaporator fan market. Cases can operate at different static pressure points and fans can have a variety of fan blade and motor selection conditions. To satisfy these varying conditions, a fan catalog should ideally have a variety of options to suit any application. PMSM vendors should work to develop this catalog of options while programs and service providers should be cognizant of baseline conditions and whether the retrofit product is the right selection. Despite this complexity, the majority of reach-in display cases have very consistent conditions and such an occurrence is very unusual. This was the first instance of any such situation encountered by the vendor out of thousands of fan retrofits.

Based on the total California 9-12W case fan market size and emissions factors approved for use by the California Energy Commission in the 2022 Title 24 code cycle, the total market potential is shown in Table 19. Installed cases were assumed to have a 25% LT, 75% MT breakdown (ASHRAE, 2014) (PECI, 2014). If all California refrigerated case 9-12W fans were replaced with PMSM retrofits, roughly 252-411 GWh of site energy consumption would be avoided per year.

The estimated savings potential is similar to previously published estimates (Fricke & Becker, 2015). That paper estimated a total US potential of 4,900 GWh/yr which suggests a California potential savings of 735 GWh/yr when scaled by California GDP to total US GDP. This previously published value is higher due to a much higher assumed fraction of SP baseline fans than found in this study (65% SP and 35% ECM in supermarkets).

TABLE 19. TOTAL CALIFORNIA MARKET POTENTIAL FOR 9-12W FANS

BASELINE BLEND	ESTIMATED TOTAL FAN POPULATION IN CALIFORNIA	TOTAL SAVINGS POTENTIAL (GWH/YR)	SITE ENERGY EMISSIONS FACTOR (TONS/GWH)	TOTAL EMISSIONS SAVINGS POTENTIAL (TONS CO_2E/YR)
Market Survey (60% ECM, 40% SP)	2,000,000	411	240	98,535
Observed Field Sites (85% ECM, 15% SP)		252		60,522

RECOMMENDATIONS

Given the consistent, reliable energy and demand savings over baseline alternatives, PMSM fans should be included in deemed incentive programs. Several recommendations may help aid optimal program design:

- Early retirement classification is justified based on baseline fan EUL, industry standard repair practices, and measure cost. Direct install programs or scaled replacements would maximize savings by leveraging blended baselines of SP and ECM existing fans. However, the estimated incremental costs and savings over standard practice could enable other program delivery methods.
- Program support would help address the market barriers listed in the Discussion and Conclusions section and speed up market adoption.
- Bundled program offerings with other supermarket measures could help address the low-impact and low-priority perception of the measure. The measure could be bundled with others such as anti-sweat heaters and case doors to enhance customer benefits.
- The measure lends itself well to rebate and direct install programs due to its ease of implementation, consistent savings, and economies of scale. Installing large populations of fans after business hours is much more economical and feasible than targeting individual fans.
- Workpapers should determine the best blend of baseline fan types (ECM and SP) and case types (LT and MT). While fan savings are almost the same between LT and MT, refrigeration interactive effects will differ. A blended approach with a single deemed value could streamline the program process and documentation since accounting for baseline motor type and case type is a complication for service providers and program administrators. However, this could come at the expense of accuracy to a certain degree.

It is recommended that PMSM manufacturers continue to develop their product line in order to accommodate the variety of design conditions and refrigerated case applications. In addition to retrofits, the new display case market is an opportunity and giving refrigeration system designers the option to specify a PMSM fan in new cases would help aid market transformation.

Finally, the PMSM technology can be scaled and offered in other sizes relevant to the commercial refrigeration industry. For instance, the installed base of 38-50W food retail walk-in evaporator fans has roughly the same energy footprint as display case 9-12W fans. The emerging technology is currently available in this size and this market opportunity should be addressed by both manufacturers and incentive programs. In addition to refrigerated cases, PMSMs may also be applicable to fans in vending machines. Across the U.S. there are approximately 3,567,000 installed motors in vending machines (ASHRAE, 2014). Further market or energy savings assessments of other applications could inform program development beyond food retail refrigerated cases.

APPENDIX A: HOST SITE MONITORED DATA

Appendix A shows plots of monitored data from each host which were analyzed to generate the results and conclusions above. Not all data is shown here. For instance, only a sample of the 34 case air monitoring trends is included and some plots are limited to the days before and after retrofit to show impacts clearly.

Data was collected using logging instrumentation listed in Table 7 over a period of several months at all four sites. The logging period lasted four to six months for establishing a baseline and one to seven months for collecting data after the technology was implemented. The variables in the Table 20 were continuously monitored and logged on an interval basis at AC circuit breakers and inside cases throughout the host sites.

TABLE 20. MONITORED VARIABLES

HB	GG	DHS	LAH
Baseline Logging period 3/28/2019 - 7/9/2019	Baseline Logging period 3/28/2019 - 7/10/2019	Baseline Logging period 5/2/2018 - 11/30/2018	Baseline Logging period 5/2/2018 - 11/26/2018
Post Logging period 7/10/2019 - 8/22/2019	Post Logging period 7/11/2019 - 8/22/2019	Post Logging period 11/31/2018 - 7/12/2019	Post Logging period 11/29/2018 - 7/11/2019
System 1 & 2 Compressor Power	Rack A & B Compressor Power	System 9, 12 & 13 Compressor Power	Rack 1, 3 & 4 Compressor Power
System 1 & 2 Suction and Discharge Temperature	Rack A & B Suction and Discharge Temperature	System 9,12 & 13 Suction and Discharge Temperature	Rack 1, 3 & 4 Suction and Discharge Temperature
Condenser 1 & 2 Amps	Condenser 1 & 2 Amps	Condenser Power	Condenser 1, 3 & 4 Power
Outside Air Temperature /Relative Humidity (RH)	Outside Air Temperature /Relative Humidity (RH)	Outside Air Temperature /Relative Humidity (RH)	-
Indoor Air Temperature /Relative Humidity (RH)	Indoor Air Temperature /Relative Humidity (RH)	Indoor Air Temperature /Relative Humidity (RH)	-
System 1C, 1D, 2C, & 2D Power	System 29A, 30B, 32A & 4 Power	System 4, 12 & 13 Power	System 1A, 3B, 3D & 4E Power
System 1C, 1D, 2C, & 2D Inside Case Temperature/RH	System 29A, 30B, 32A & 4 Inside Case Temperature/RH	System 4, 9, 12 & 13 Inside Case Temperature/RH	System 1A, 3B, 3D & 4E Inside Case Temperature/RH

HUNTINGTON BEACH (CZ6)

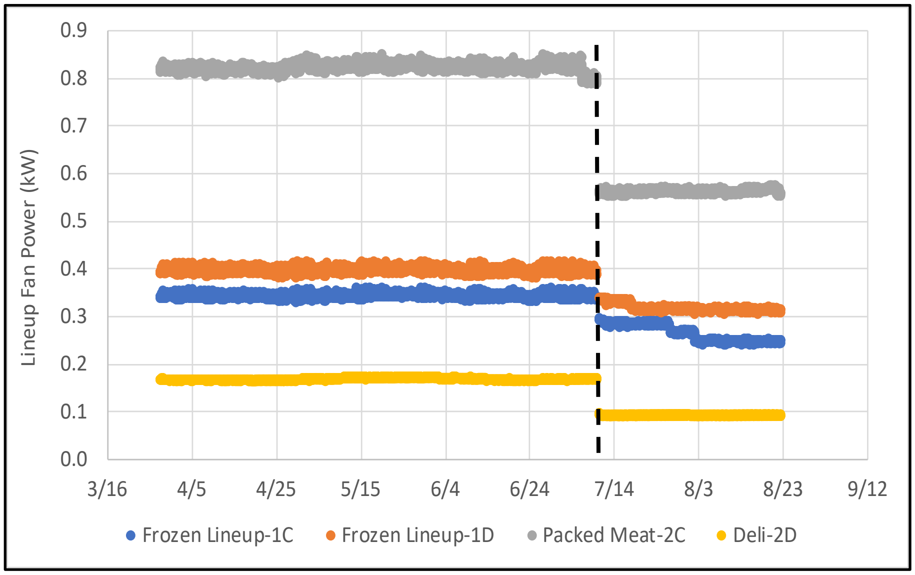


FIGURE 30. HB SYSTEM 1C, 1D, 2C AND 2D FAN POWER (VERTICAL DASHED LINE INDICATES RETROFIT)

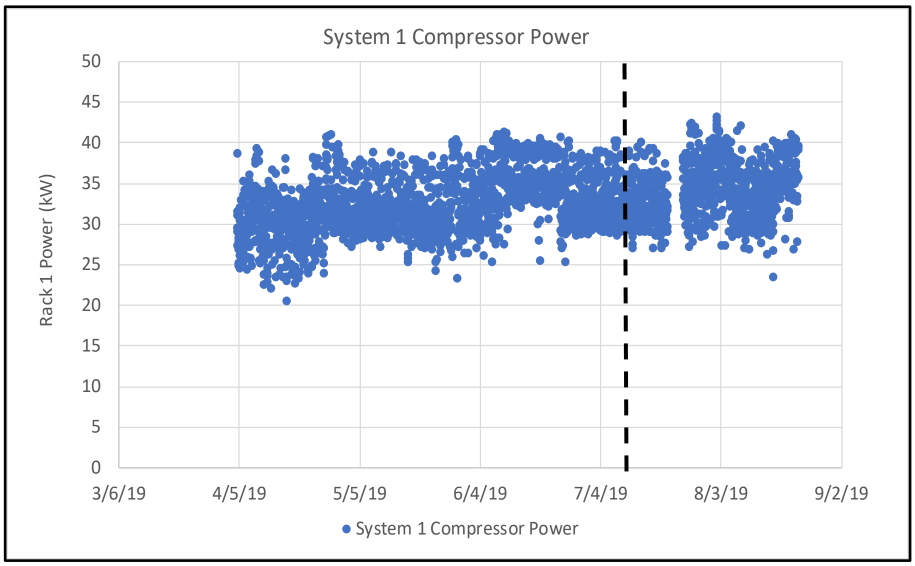


FIGURE 31. HB COMPRESSOR 1 POWER

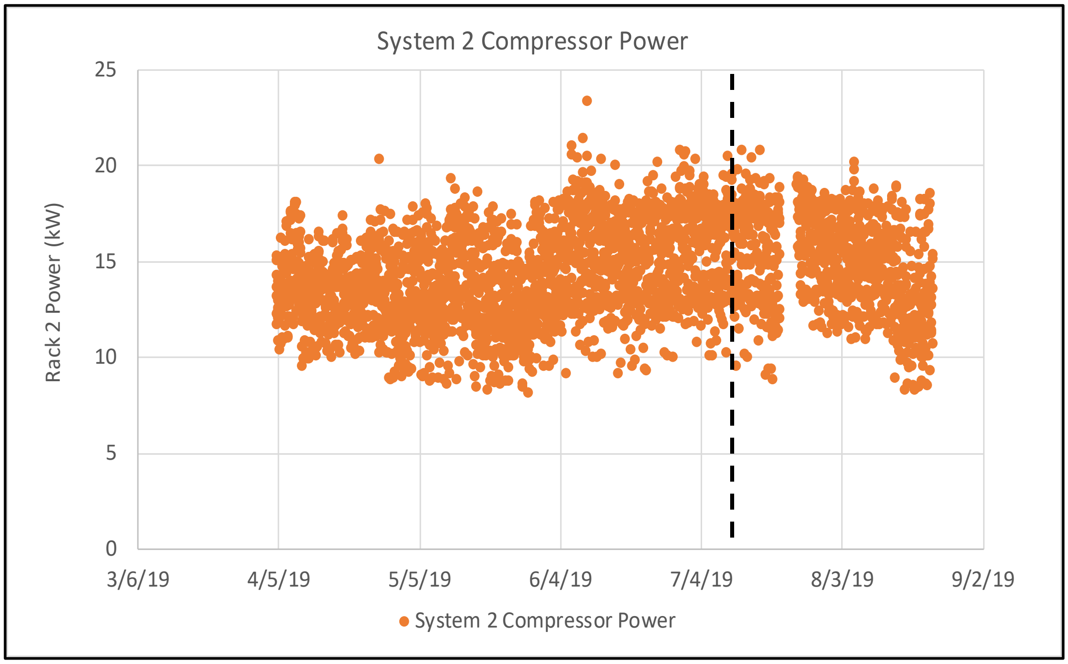


FIGURE 32. HB COMPRESSOR 2 POWER

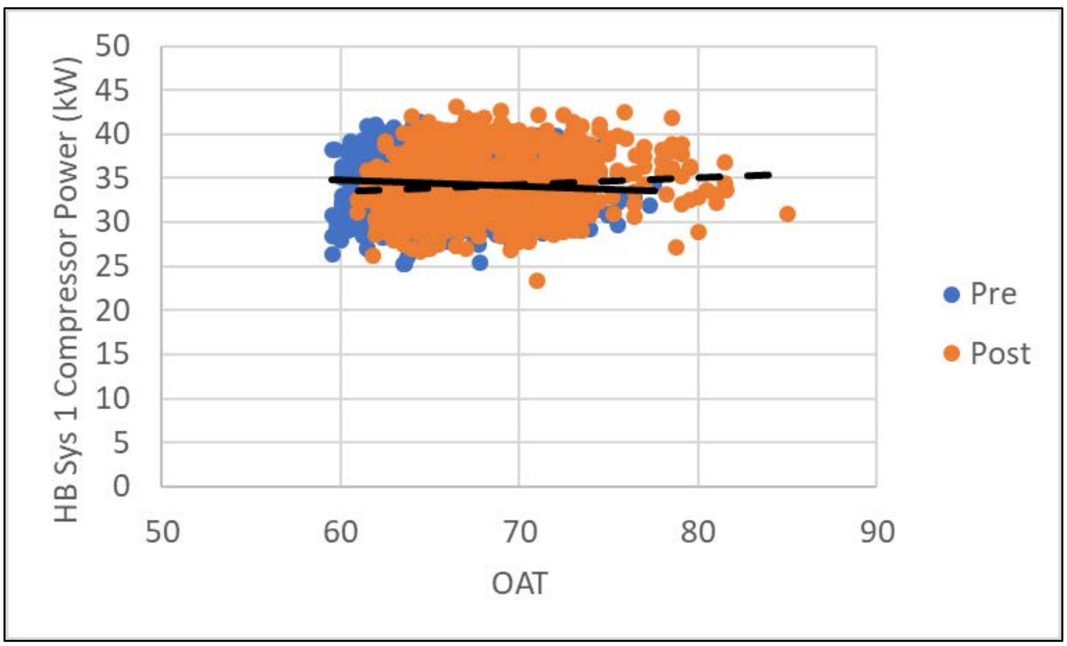


FIGURE 33. HB COMPRESSOR 1 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

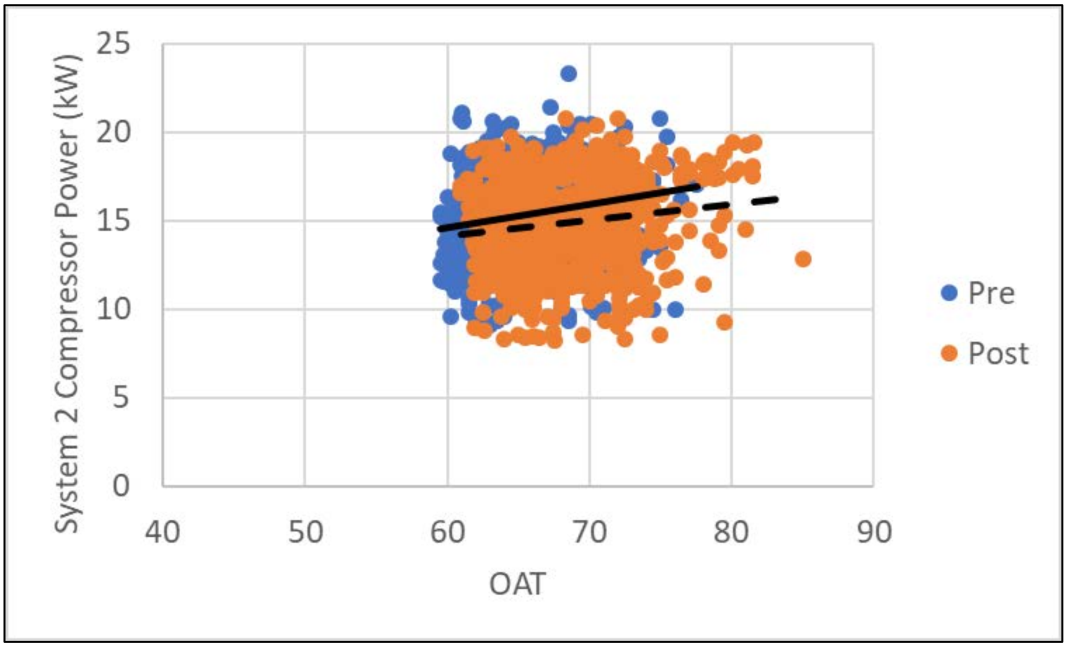


FIGURE 34. HB COMPRESSOR 2 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

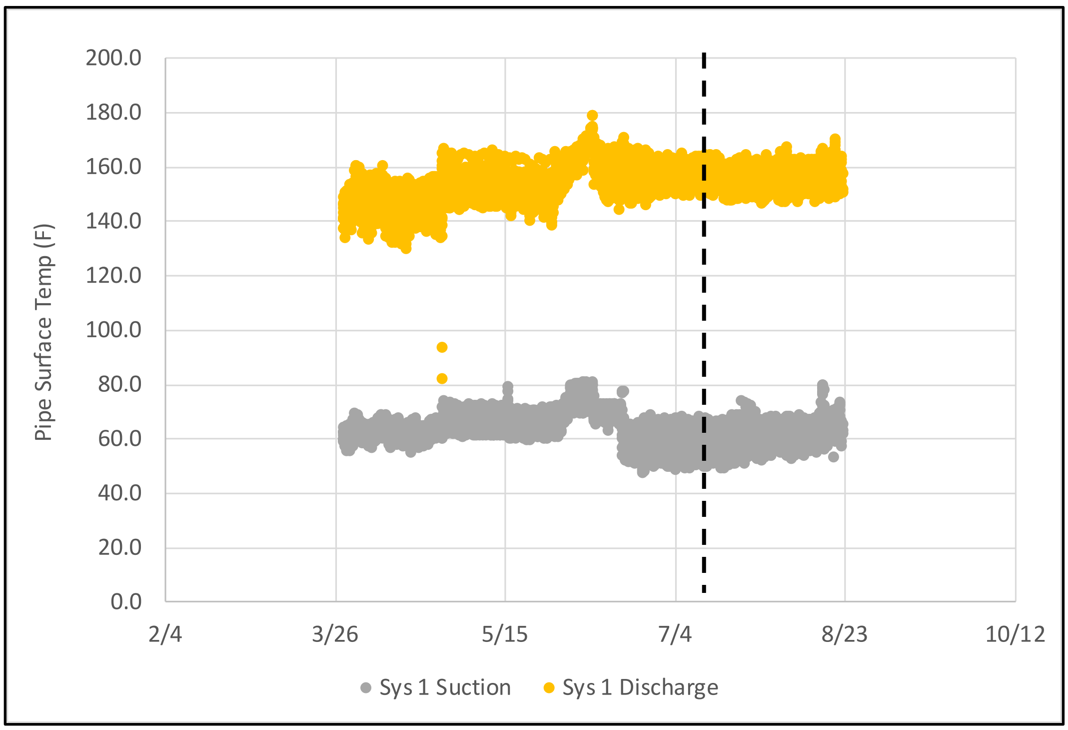


FIGURE 35. HB COMPRESSOR 1 SUCTION AND DISCHARGE TEMPERATURES

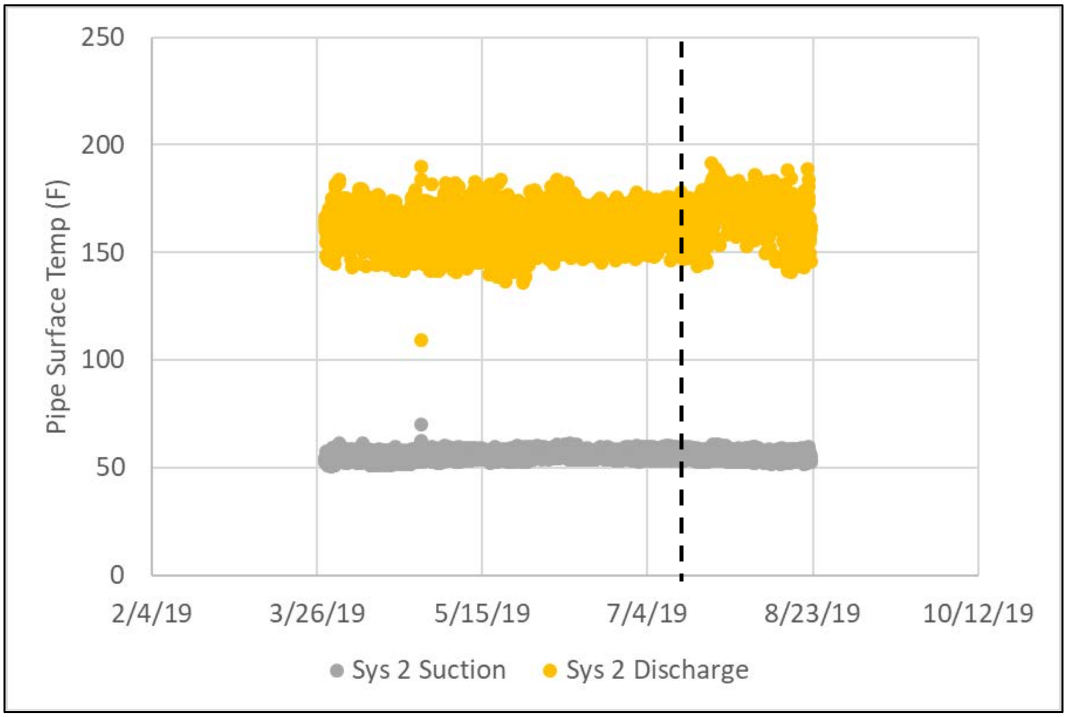


FIGURE 36. HB COMPRESSOR 2 SUCTION AND DISCHARGE TEMPERATURES

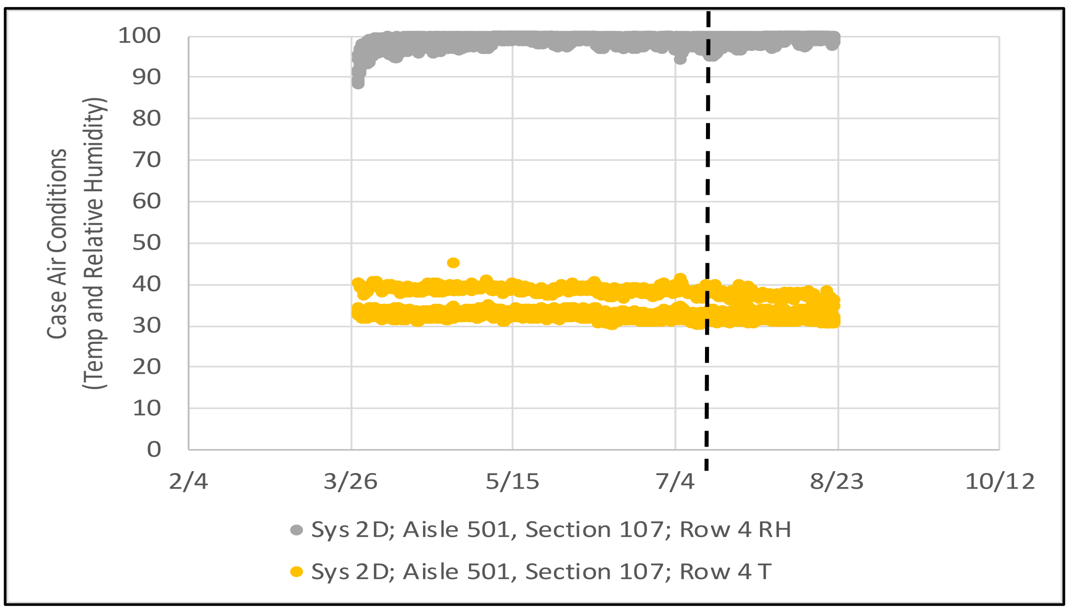


FIGURE 37. HB MT SYSTEM 2D AISLE 501 SECTION 107 ROW 4 TEMPERATURE AND RH (TYPICAL)

GARDEN GROVE (CZ8)

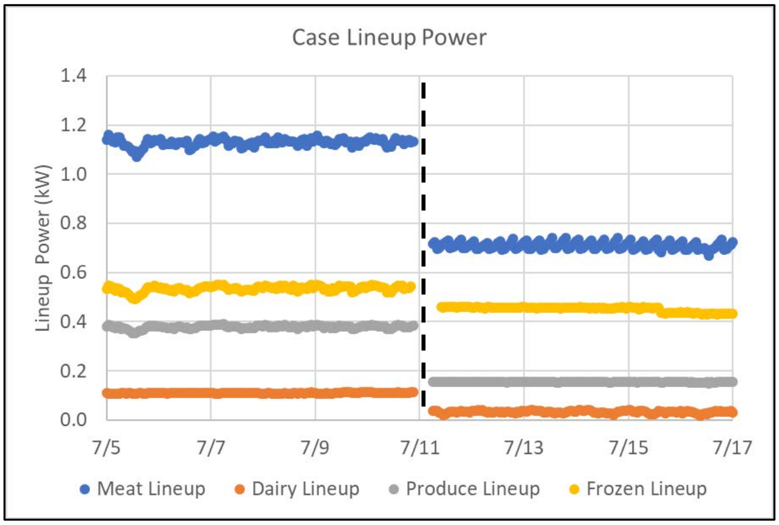


FIGURE 38. GG SYSTEM 29A, 30B, 32A AND 4 FAN POWER (VERTICAL DASHED LINE INDICATES RETROFIT)

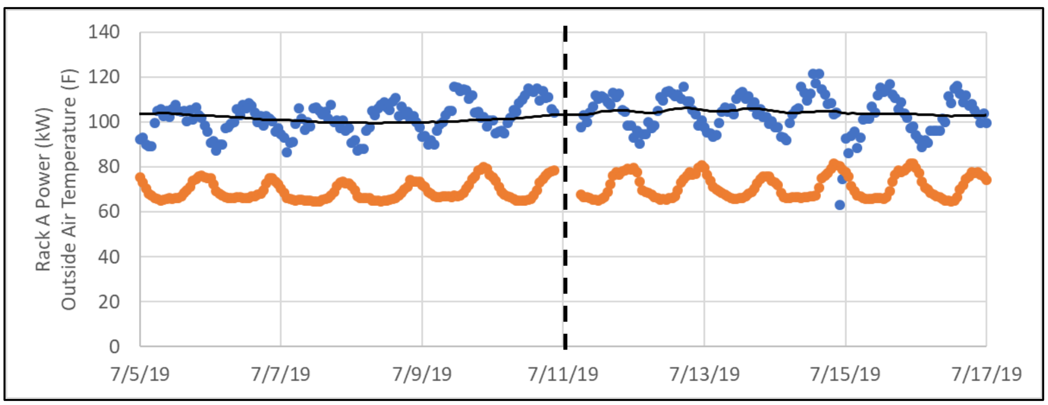


FIGURE 39. GG COMPRESSOR RACK A POWER WITH 72-HOUR MOVING AVERAGE

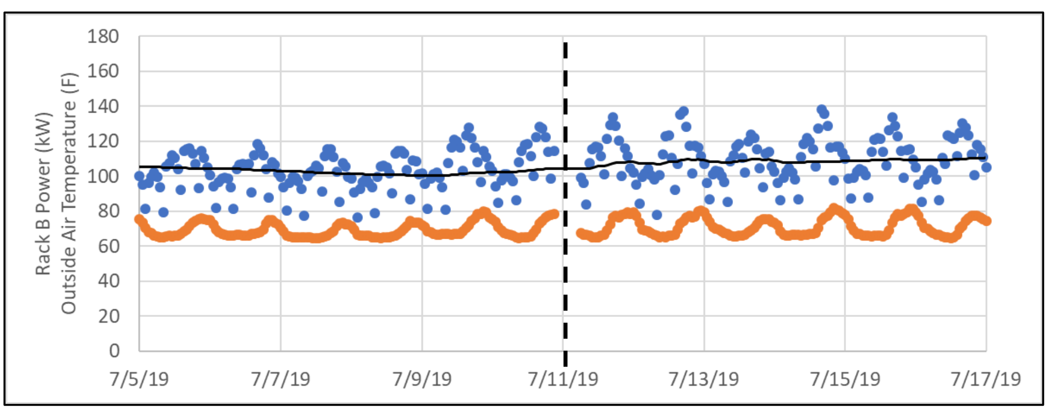


FIGURE 40. GG COMPRESSOR RACK B POWER WITH 72-HOUR MOVING AVERAGE

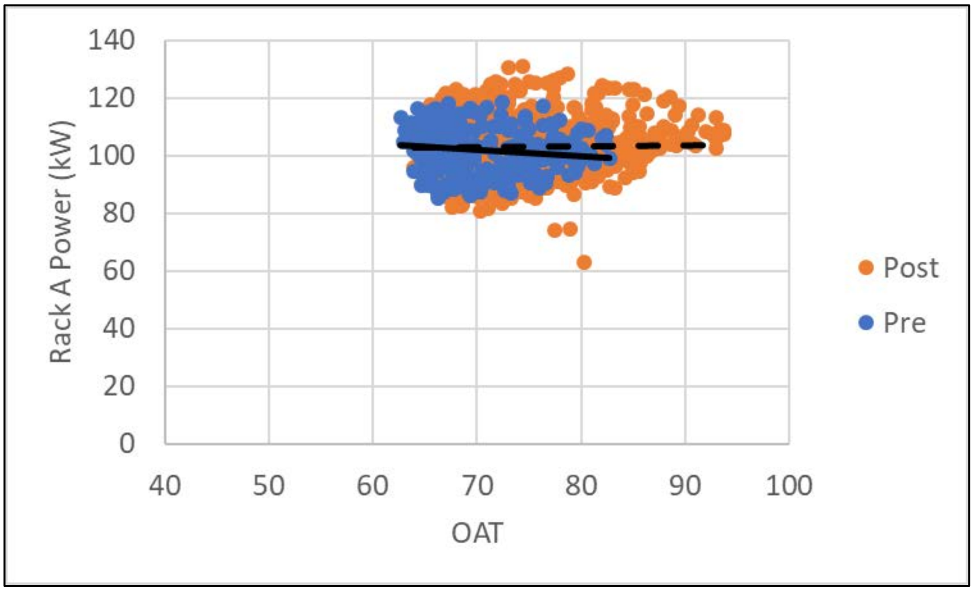


FIGURE 41. GG COMPRESSOR RACK A SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

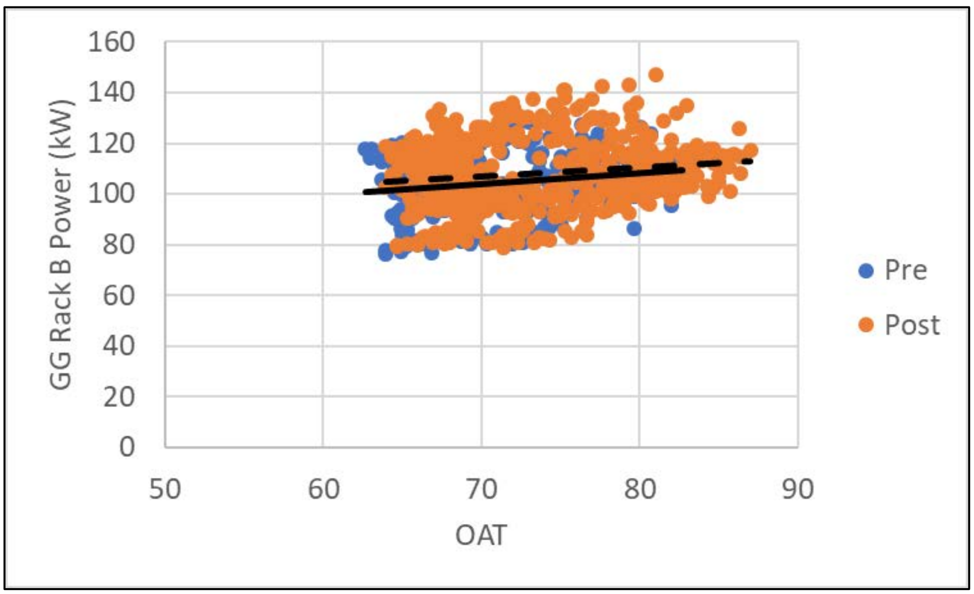


FIGURE 42. GG COMPRESSOR RACK B SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

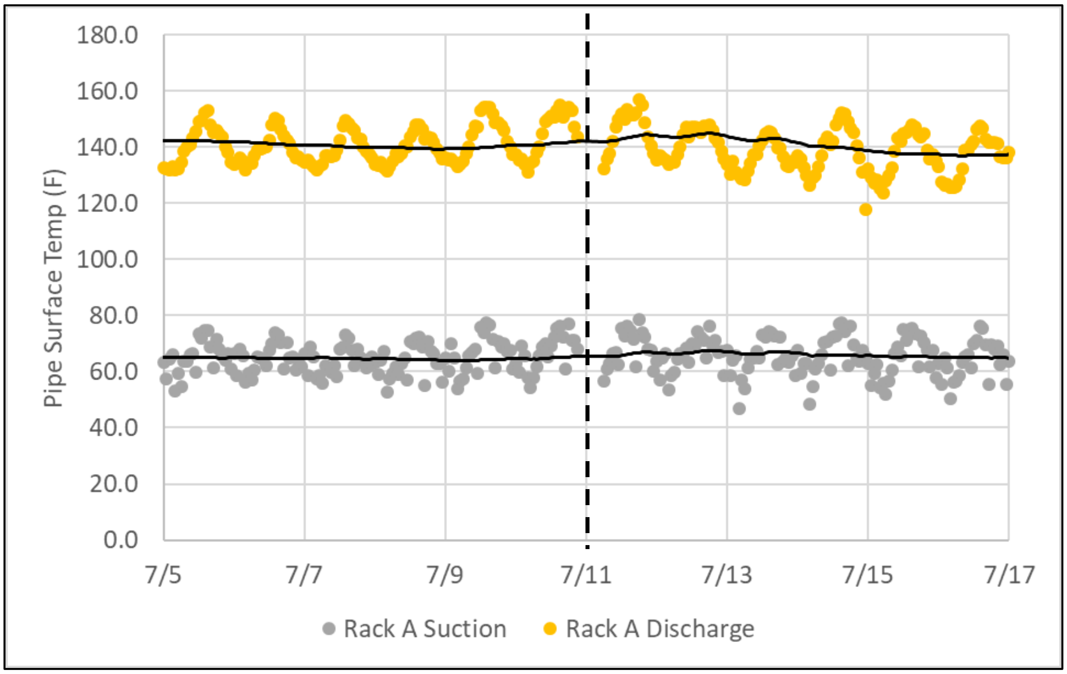


FIGURE 43. GG COMPRESSOR RACK A SUCTION AND DISCHARGE TEMPERATURES WITH 72-HOUR MOVING AVERAGES

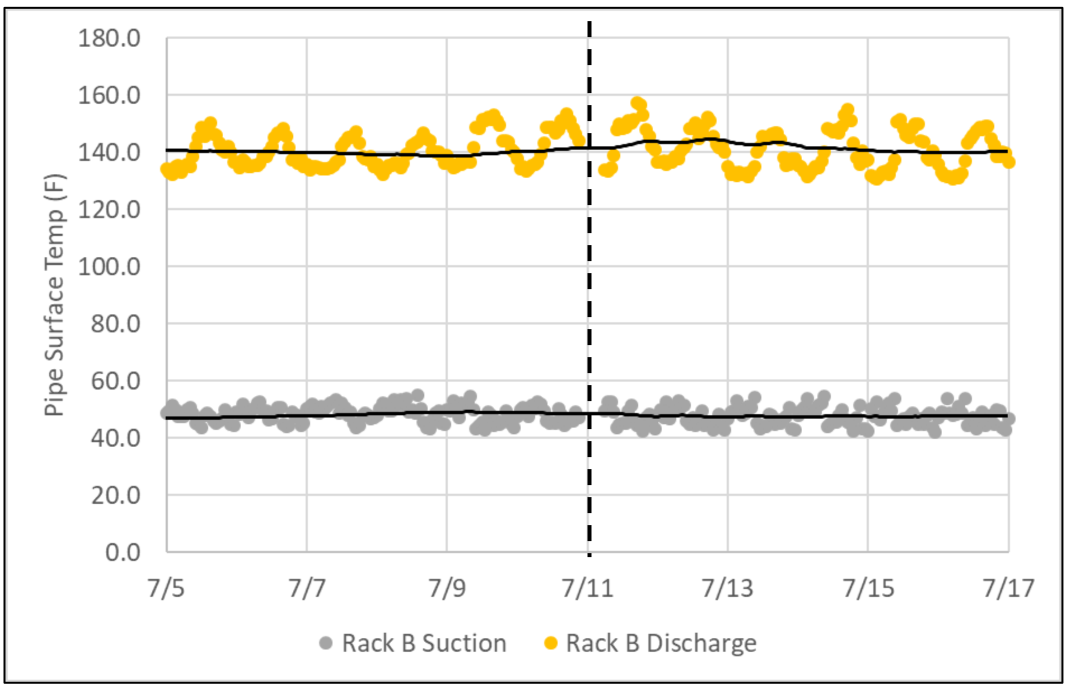


FIGURE 44. GG COMPRESSOR RACK B SUCTION AND DISCHARGE TEMPERATURES WITH 72-HOUR MOVING AVERAGES

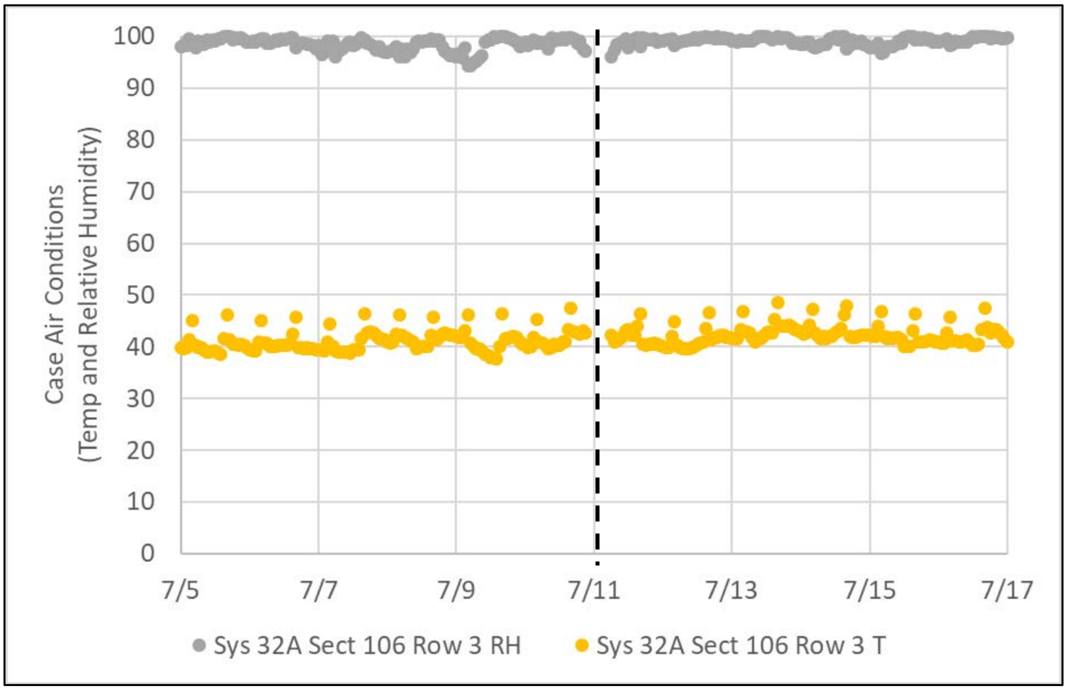


FIGURE 45. GG MT SYSTEM 32A SECTION 106 ROW 3 TEMPERATURE AND RH (TYPICAL)

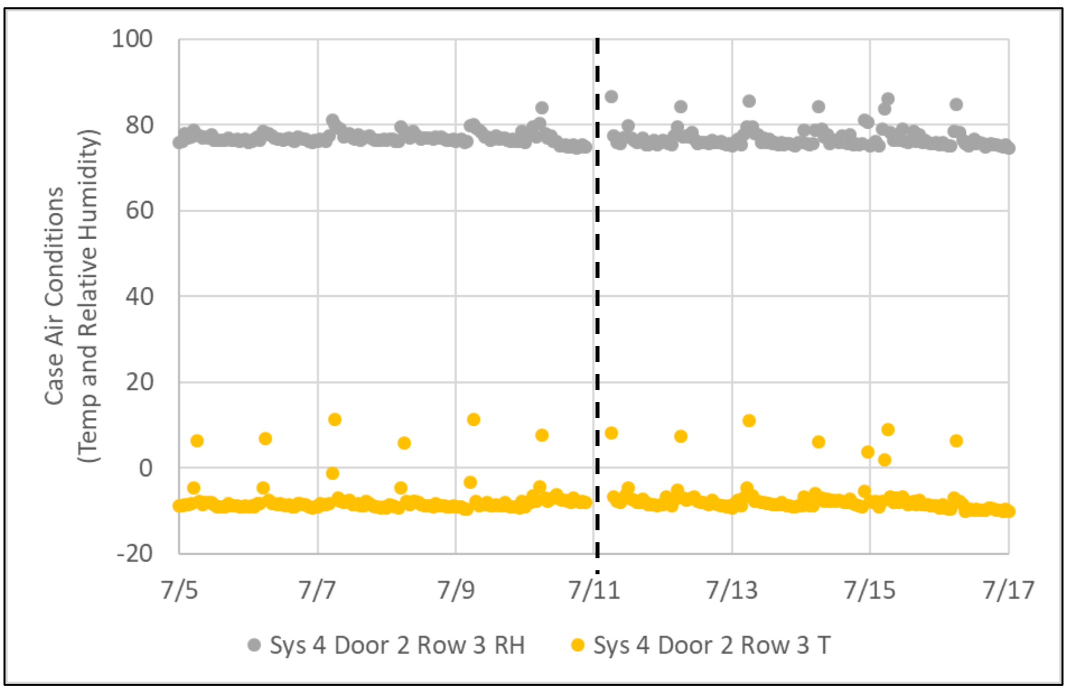


FIGURE 46. GG LT SYSTEM 4 ROW 3 DOOR 2 TEMPERATURE AND RH (TYPICAL)

DESERT HOT SPRINGS (CZ15)

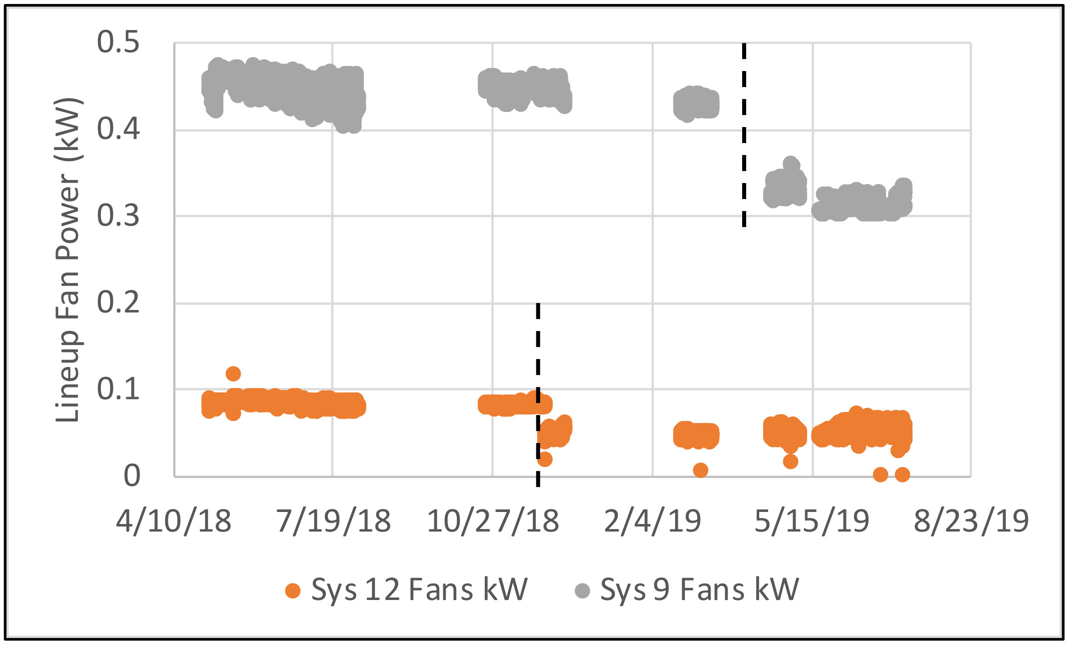


FIGURE 47. DHS SYSTEM 9 AND 12 FAN POWERS (TWO DIFFERENT RETROFIT DATES – VERTICAL DASHED LINES INDICATE RETROFITS)

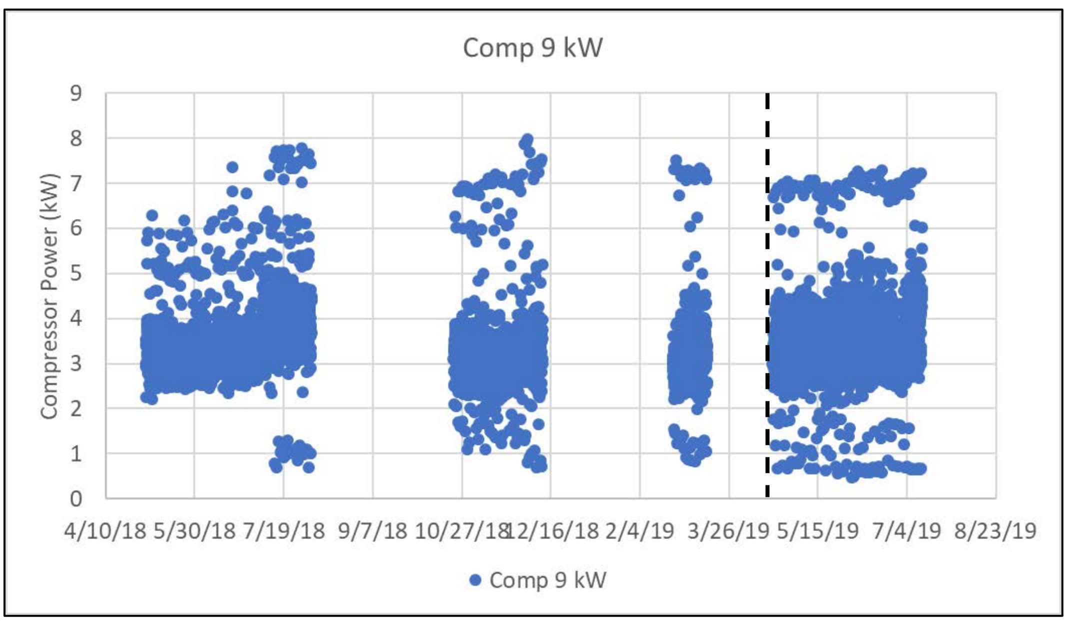


FIGURE 48. DHS COMPRESSOR 9 POWER

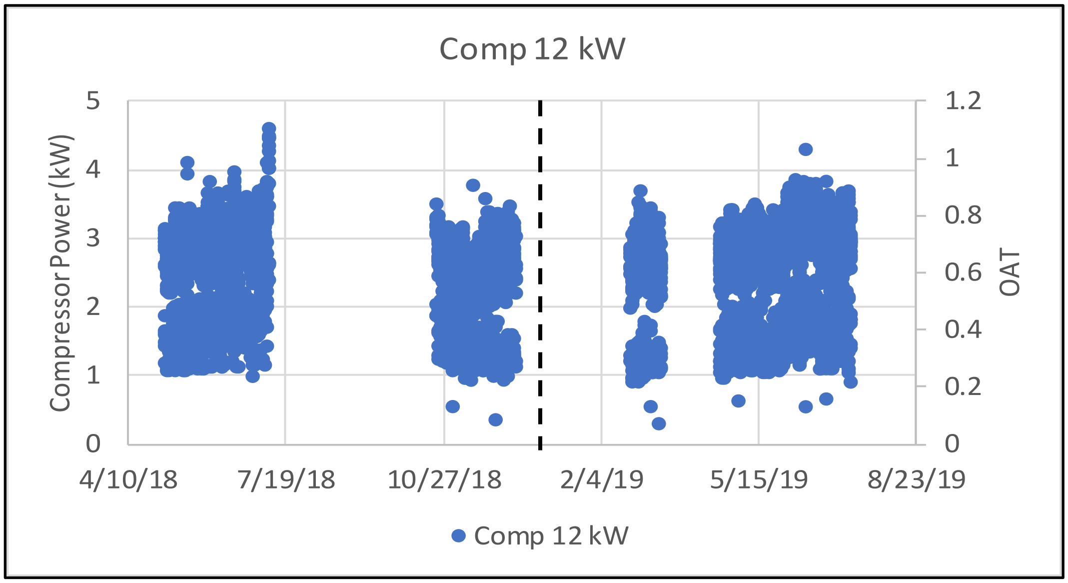


FIGURE 49. DHS COMPRESSOR 12 POWER

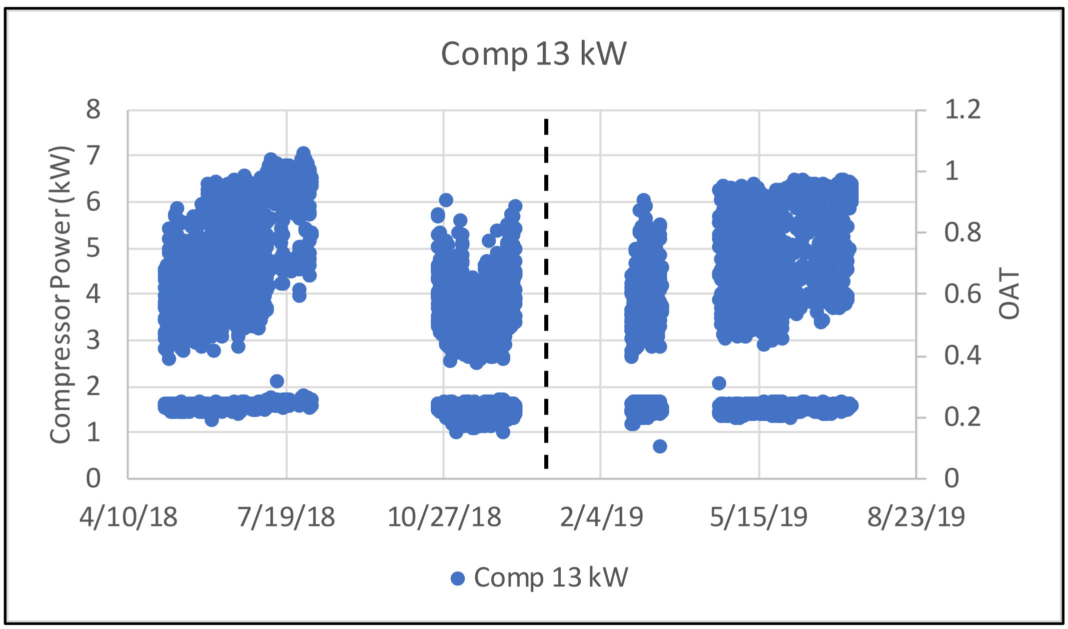


FIGURE 50. DHS COMPRESSOR 13 POWER

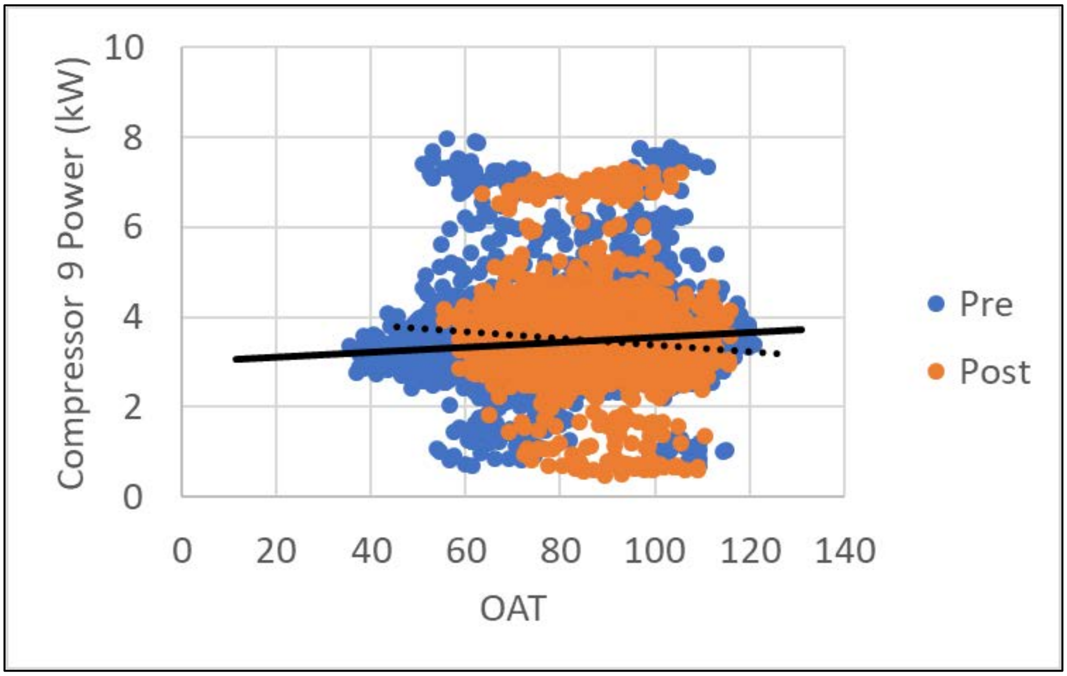


FIGURE 51. DHS COMPRESSOR 9 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

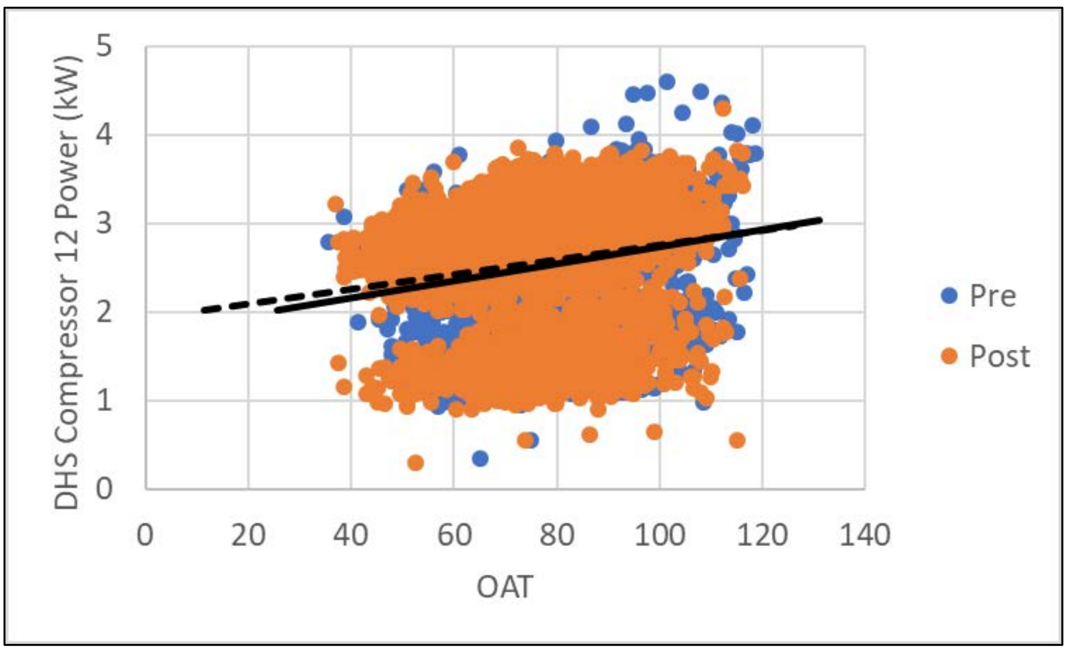


FIGURE 52. DHS COMPRESSOR 12 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

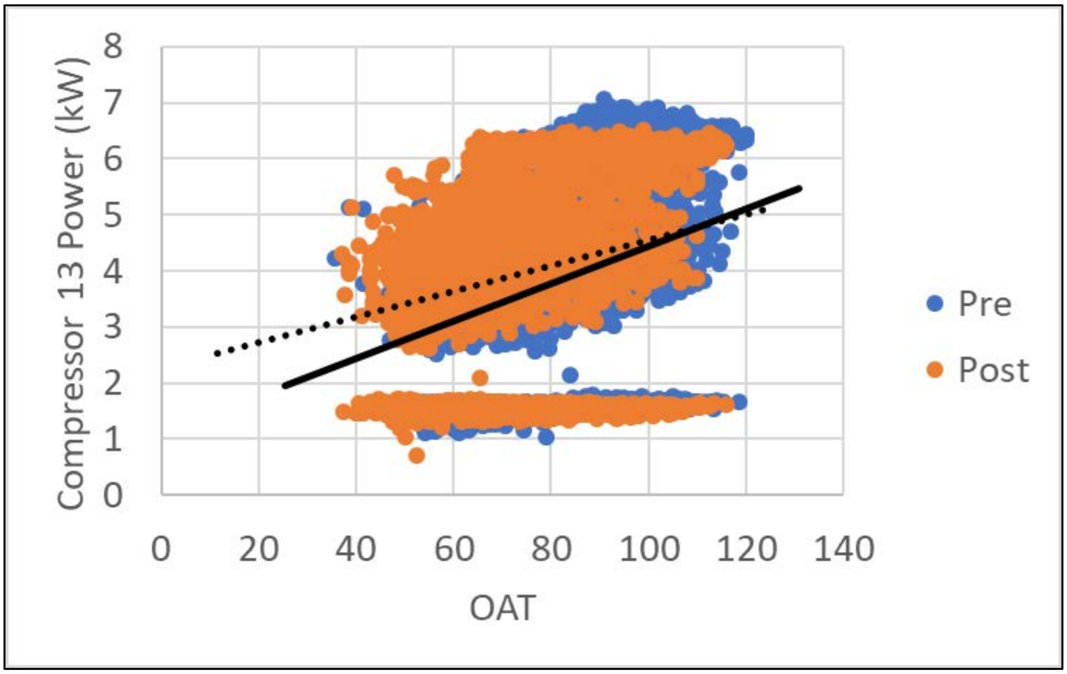


FIGURE 53. DHS COMPRESSOR 13 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

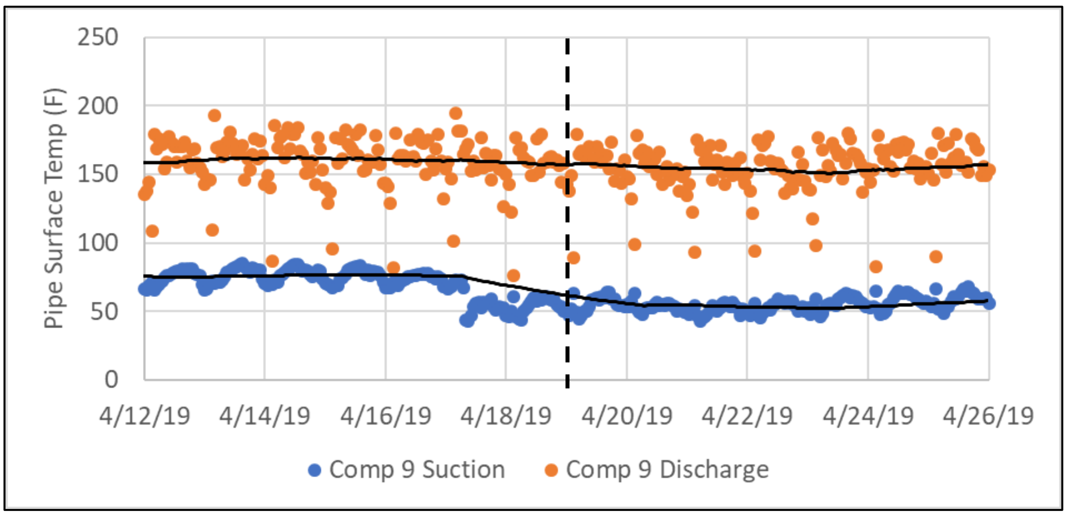


FIGURE 54. DHS COMPRESSOR 9 SUCTION AND DISCHARGE TEMPERATURES WITH 72-HOUR MOVING AVERAGES

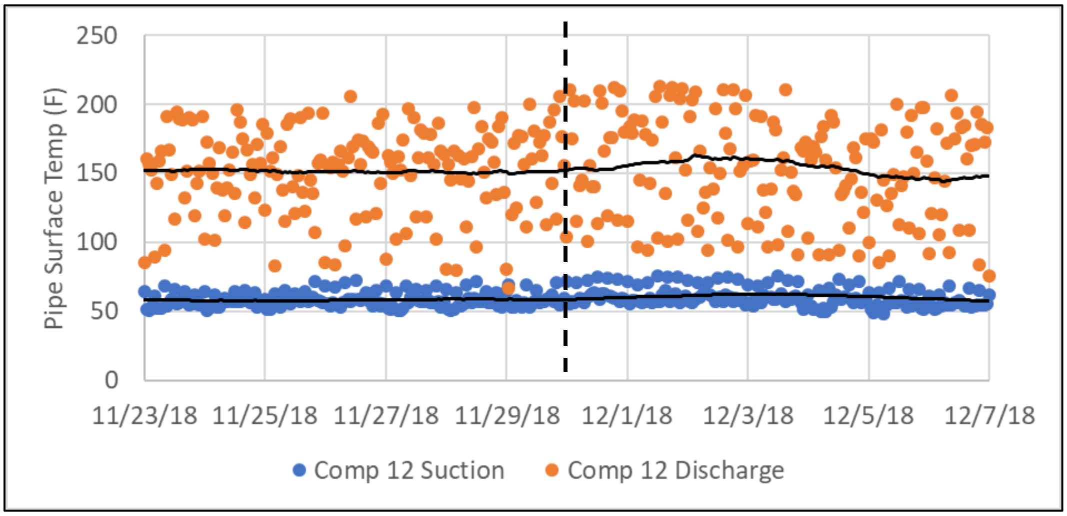


FIGURE 55. DHS COMPRESSOR 12 SUCTION AND DISCHARGE TEMPERATURES WITH 72-HOUR MOVING AVERAGES

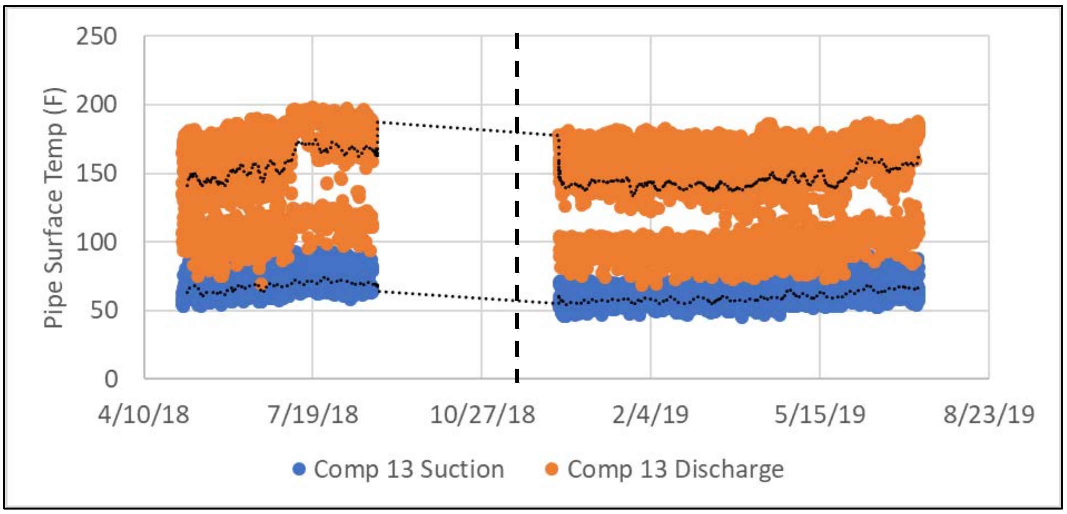


FIGURE 56. DHS COMPRESSOR 13 SUCTION AND DISCHARGE TEMPERATURES

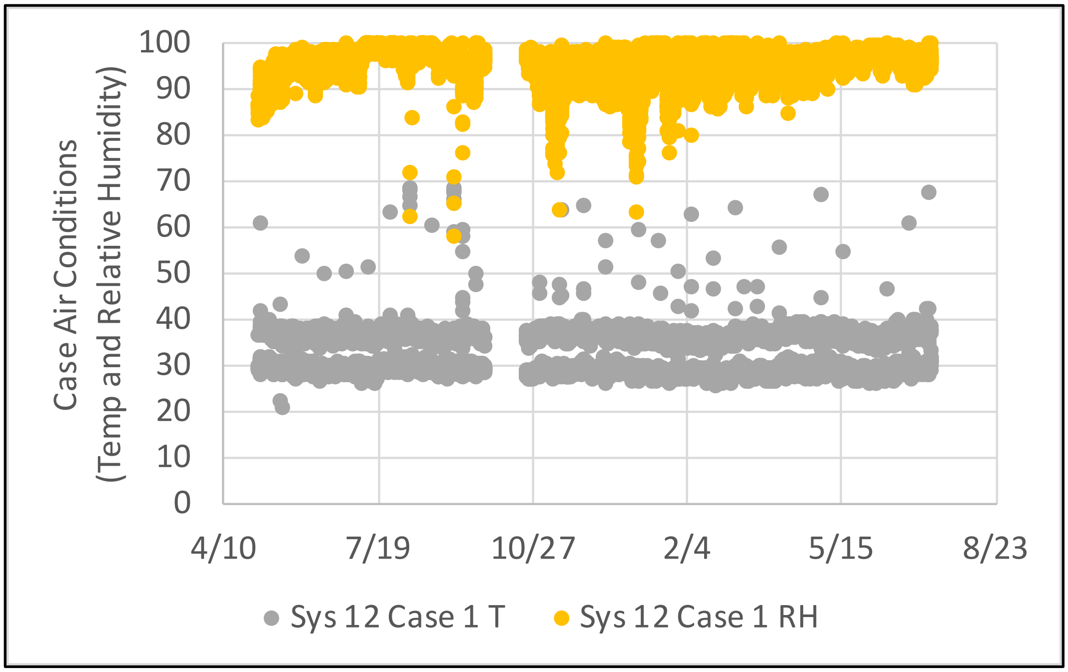


FIGURE 57. DHS MT SYSTEM 12 CASE 1 TEMPERATURE AND RH (TYPICAL)

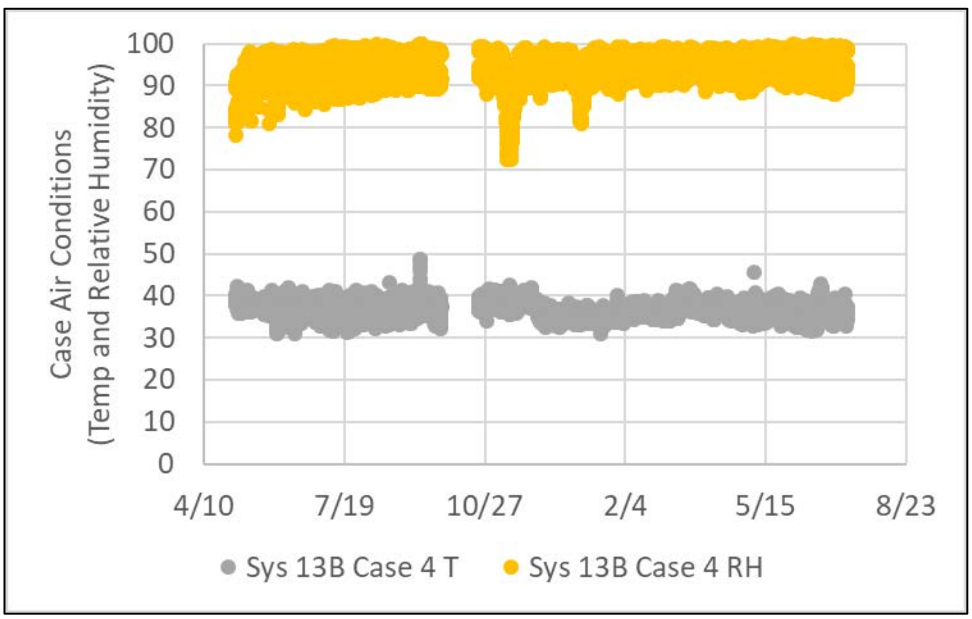


FIGURE 58. DHS MT SYSTEM 13 CASE 1 TEMPERATURE AND RH (TYPICAL)

LAKE ARROWHEAD (CZ16)

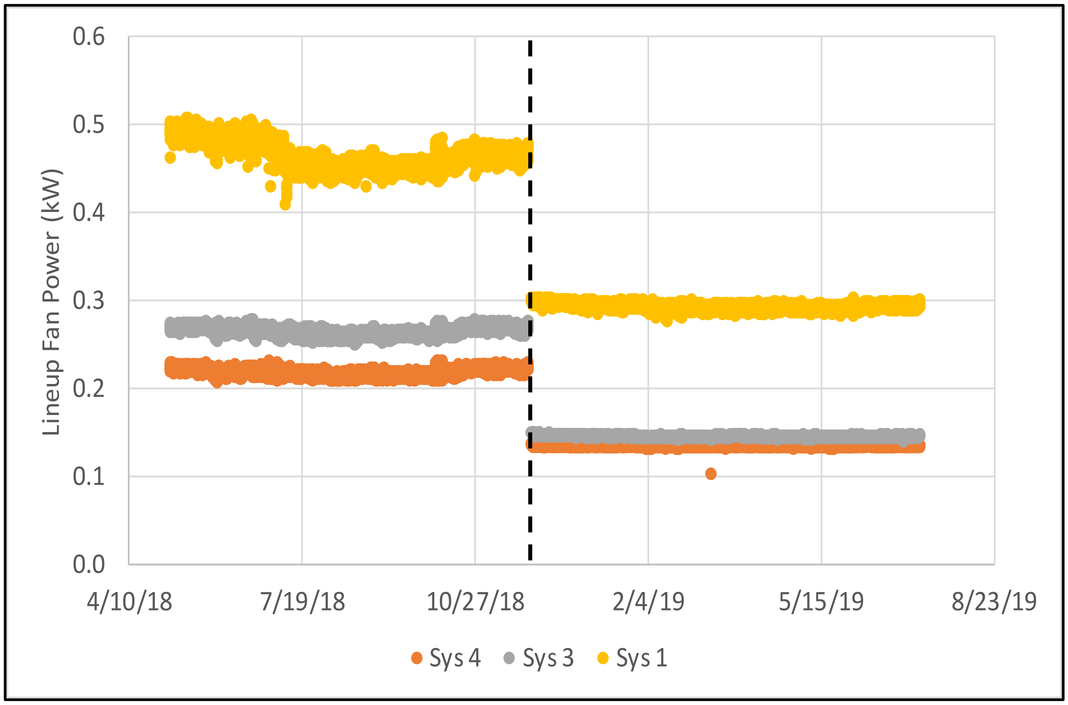


FIGURE 59. LAH SYSTEM 1, 3 AND 4 FAN POWERS

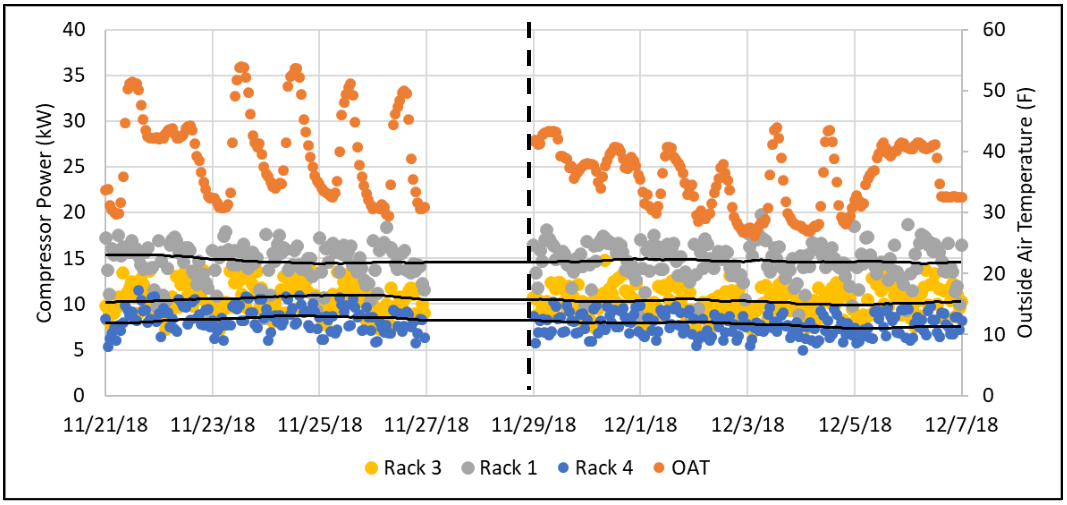


FIGURE 60. LAH COMPRESSOR RACK POWERS WITH 72-HOUR MOVING AVERAGES

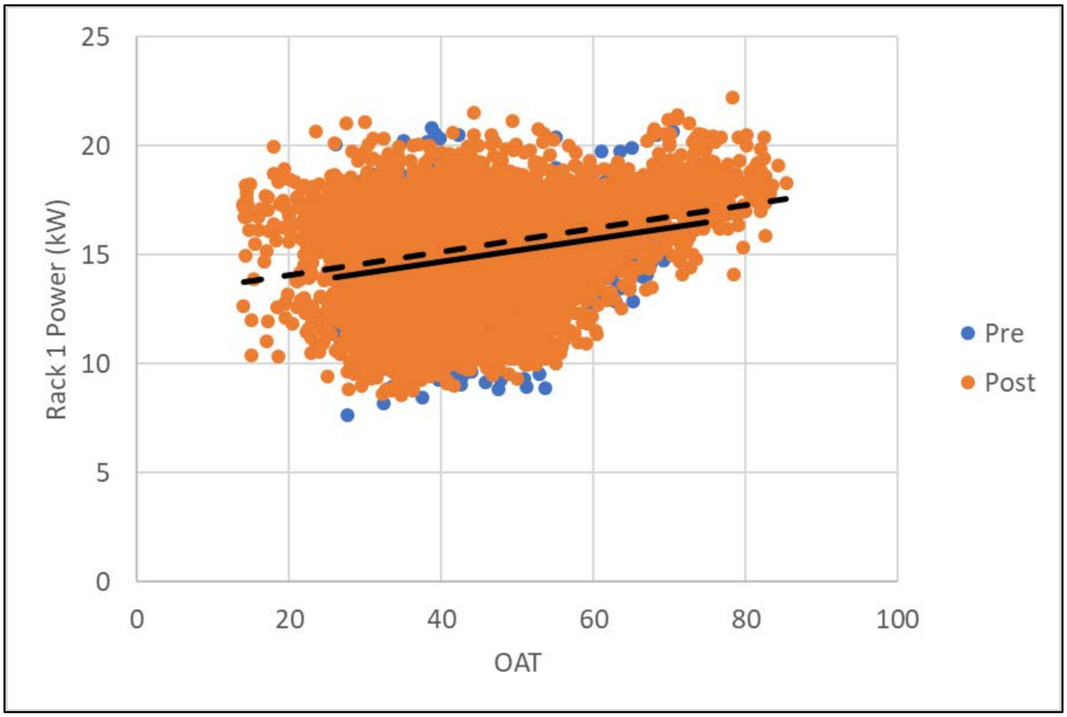


FIGURE 61. LAH RACK 1 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

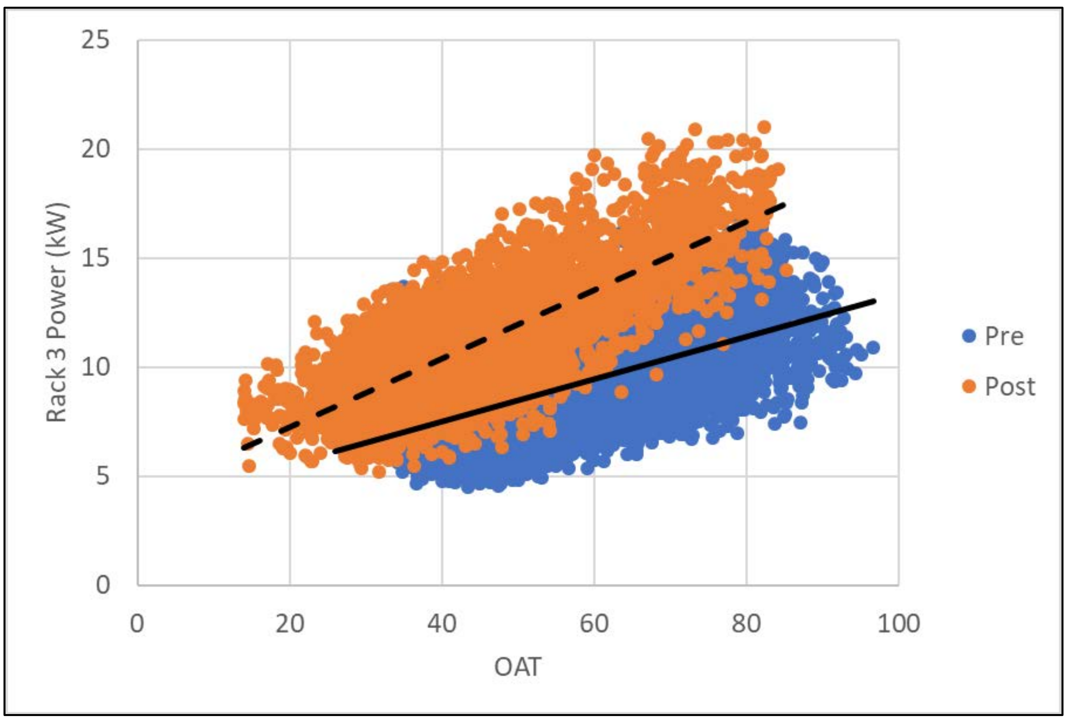


FIGURE 62. LAH RACK 3 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

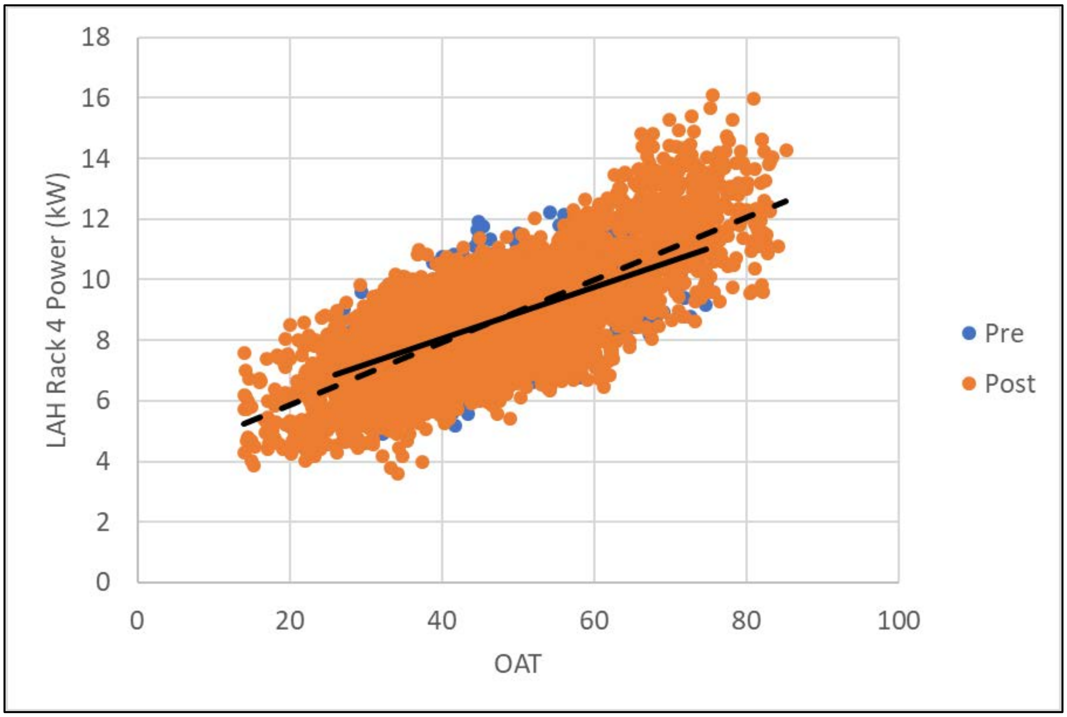


FIGURE 63. LAH RACK 4 SCATTER PLOT WITH OUTSIDE AIR TEMPERATURE

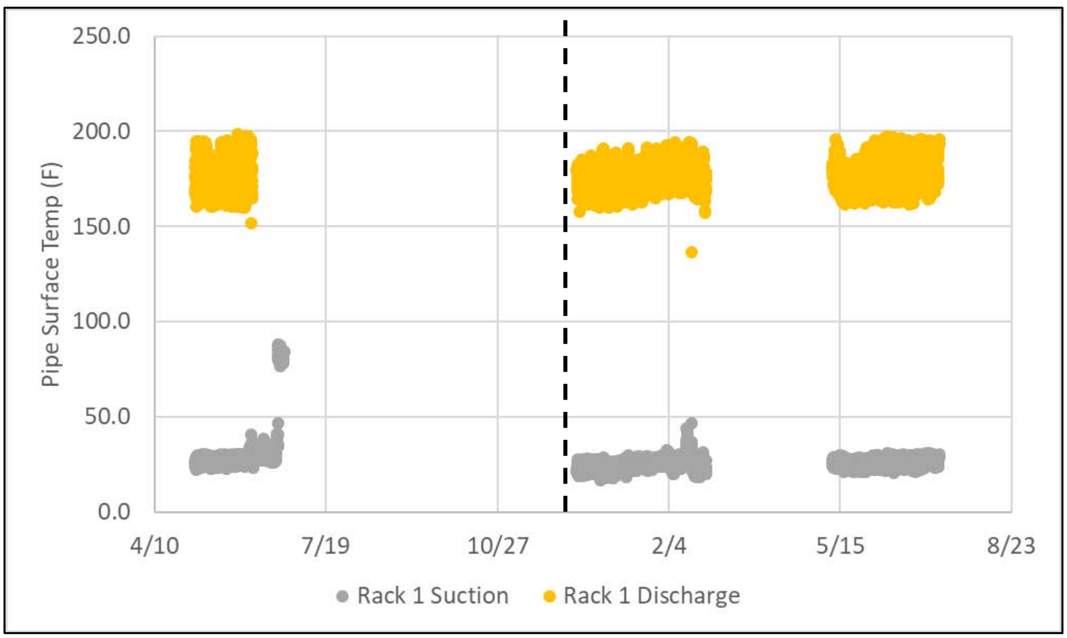


FIGURE 64. LAH RACK 1 SUCTION AND DISCHARGE TEMPERATURES

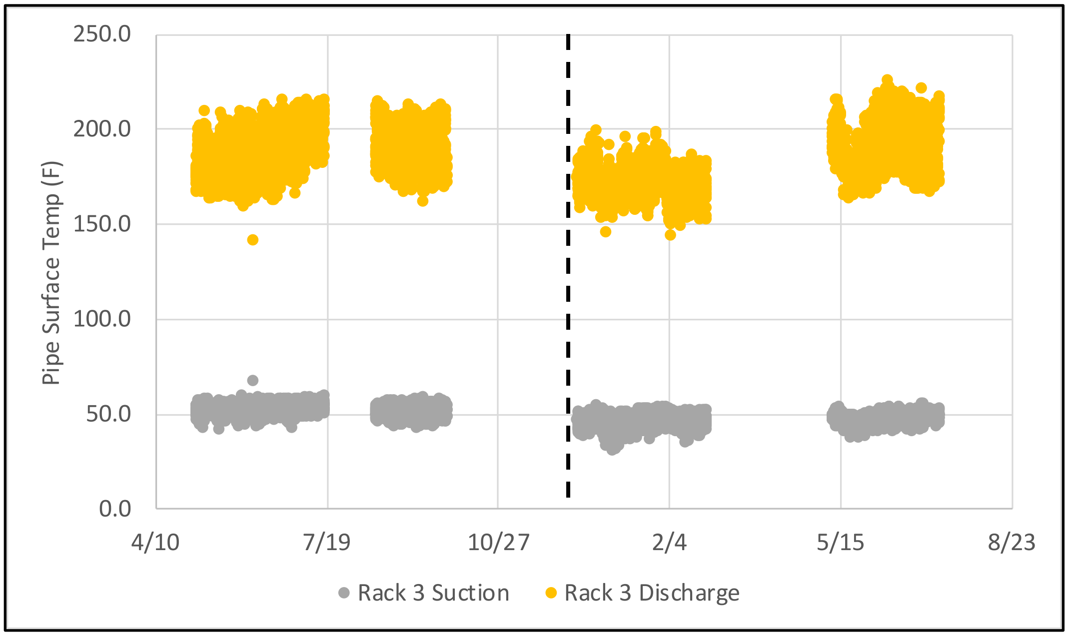


FIGURE 65. LAH RACK 3 SUCTION AND DISCHARGE TEMPERATURES

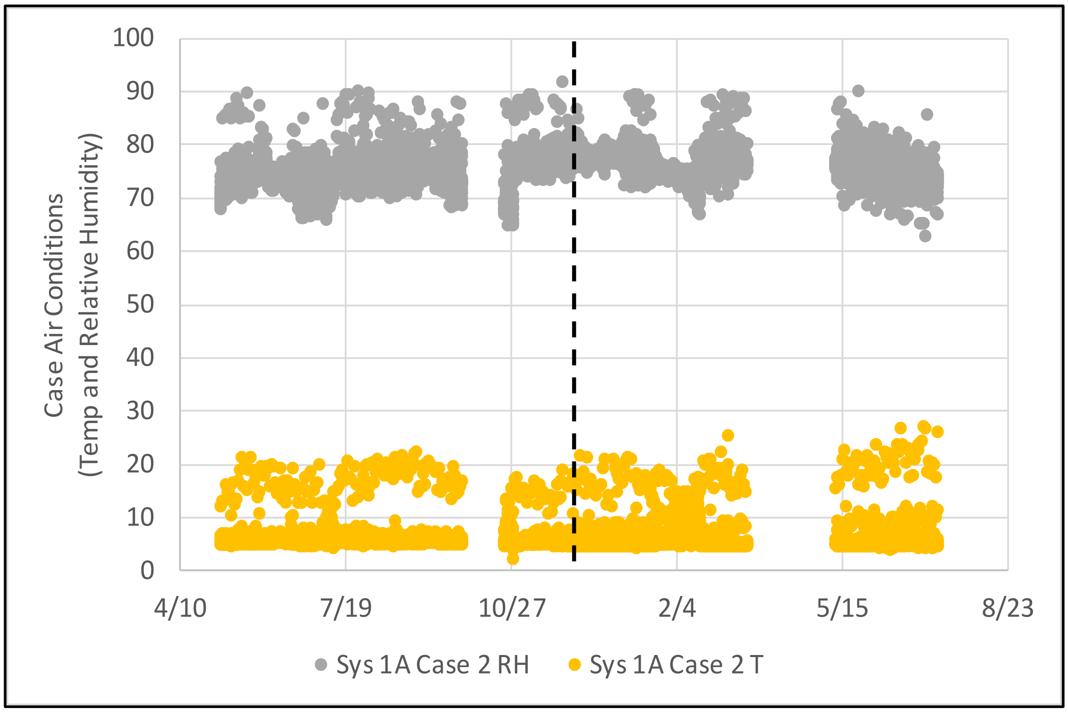


FIGURE 66. LAH LT SYSTEM 1A CASE 2 TEMPERATURE AND RH (TYPICAL)

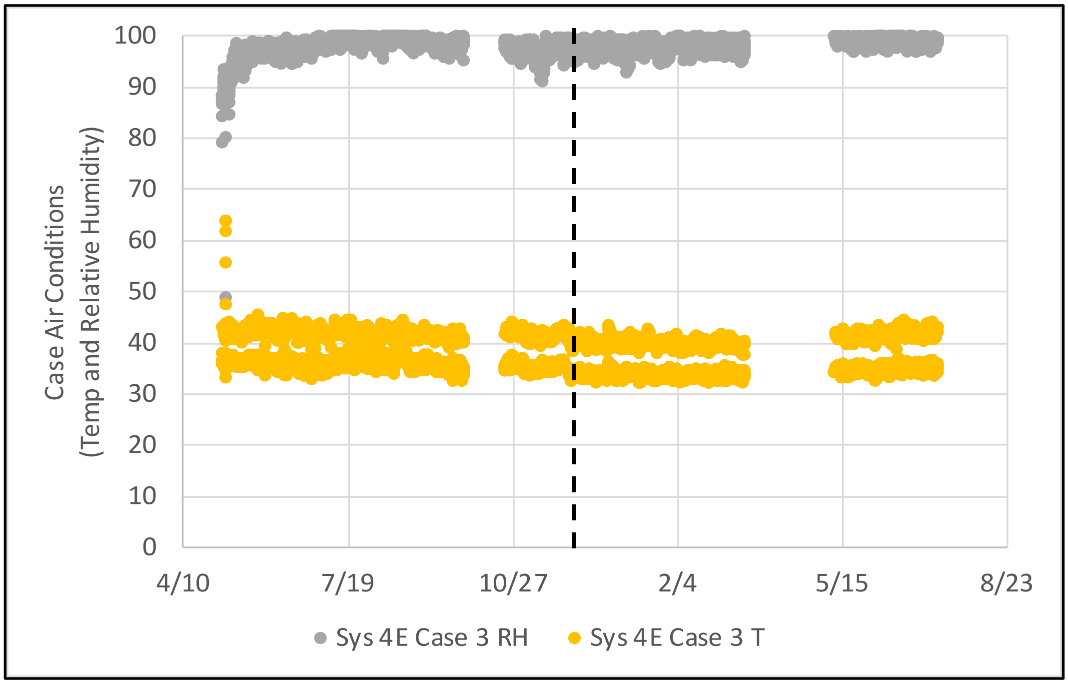


FIGURE 67. LAH MT SYSTEM 4E CASE 3 TEMPERATURE AND RH (TYPICAL)

APPENDIX B: RETROFIT SPOT MEASUREMENTS

TABLE 21. SPOT MEASUREMENTS AT HB AND GG SITE DURING RETROFIT INSTALLATION

Store	Fan ID	Temp	Pre-Power (W)	Pre-PF	Pre-Current (A)	Post Power (W)	Post PF	Post Current (A)	Savings W	Savings kWh	Motor Type	Notes
GG	4-1	Low	19.5	0.63	0.25	14	0.88	0.13	5.5	47.7	ECM	GE ECM 5SME44GG500SA
GG	4-2	Low	19.2	0.62	0.24	13.8	0.87	0.13	5.4	46.9	ECM	GE ECM 5SME44GG500SA
GG	4-3	Low	19.1	0.61	0.27	13.7	0.85	0.12	5.4	46.9	ECM	GE ECM 5SME44GG500SA
GG	4-4	Low	19.5	0.62	0.24	14.3	0.88	0.12	5.2	45.1	ECM	GE ECM 5SME44GG500SA
GG	4-5	Low	18.5	0.63	0.23	15.9	0.89	0.14	2.6	22.6	ECM	GE ECM 5SME44GG500SA
GG	4-6	Low	19.4	0.62	0.24	14.3	0.88	0.13	5.1	44.3	ECM	GE ECM 5SME44GG500SA
GG	4-7	Low	21.1	0.62	0.28	14.5	0.85	0.14	6.6	57.3	ECM	GE ECM 5SME44GG500SA
GG	4-8	Low	18	0.62	0.24	13.8	0.84	0.13	4.2	36.5	ECM	GE ECM 5SME44GG500SA
GG	4-9	Low	21	0.61	0.27	13.9	0.85	0.14	7.1	61.6	ECM	GE ECM 5SME44GG500SA
GG	4-10	Low	18.2	0.62	0.24	15.3	0.88	0.14	2.9	25.2	ECM	GE ECM 5SME44GG500SA
GG	4-11	Low	19.9	0.60	0.26	15.2	0.84	0.15	4.7	40.8	ECM	GE ECM 5SME44GG500SA
GG	4-12	Low	18.1	0.62	0.25	16.4	0.85	0.16	1.7	14.8	ECM	GE ECM 5SME44GG500SA
GG	4-14	Low	19.3	0.60	0.26	15.7	0.86	0.18	3.6	31.3	ECM	GE ECM 5SME44GG500SA
GG	4-15	Low	18.1	0.60	0.24	16.3	0.86	0.19	1.8	15.6	ECM	GE ECM 5SME44GG500SA
GG	4-16	Low	20.9	0.63	0.26	15.6	0.89	0.14	5.3	46.0	ECM	GE ECM 5SME44GG500SA
GG	4-17	Low	20.9	0.63	0.26	15.6	0.89	0.14	5.3	46.0	ECM	GE ECM 5SME44GG500SA
HB	1D-1	Low	17.4	0.57	0.25	15.6	0.85	0.15	1.8	15.6	ECM	GE 5SME44650058, end cap
HB	1D-2	Low	17.3	0.63	0.21	15.9	0.87	0.15	1.4	12.2	ECM	US Motor, end cap
HB	1D-3	Low	21	0.6	0.29	15.2	0.86	0.14	5.8	50.3	ECM	GE 5SME44650058
HB	1D-4	Low	19	0.6	0.27	14.4	0.88	0.14	4.6	39.9	ECM	GE 5SME44650058
HB	1D-5	Low	19	0.6	0.27	15.7	0.83	0.15	3.3	28.6	ECM	GE 5SME44650058
HB	1D-6	Low	20	0.6	0.27	14.8	0.86	0.14	5.2	45.1	ECM	GE 5SME44650058
HB	1D-7	Low	20	0.6	0.26	15.3	0.86	0.14	4.7	40.8	ECM	GE 5SME44650058
HB	1D-8	Low	21.5	0.6	0.3	14.7	0.86	0.14	6.8	59.0	ECM	GE 5SME44650058
HB	1D-9	Low	20	0.59	0.28	14.5	0.86	0.14	5.5	47.7	ECM	GE 5SME44650058

Store	Fan ID	Temp	Pre-Power (W)	Pre-PF	Pre-Current (A)	Post Power (W)	Post PF	Post Current (A)	Savings W	Savings kWh	Motor Type	Notes
HB	1D-10	Low	20.5	0.59	0.28	14.8	0.85	0.15	5.7	49.5	ECM	GE 5SME44650058
HB	1D-11	Low	19	0.59	0.27	15.5	0.84	0.16	3.5	30.4	ECM	GE 5SME44650058
HB	1D-12	Low	20	0.58	0.28	14.4	0.87	0.14	5.6	48.6	ECM	GE 5SME44650058
HB	1D-13	Low	21.5	0.6	0.29	13.6	0.87	0.12	7.9	68.6	ECM	GE 5SME44650058
HB	1D-14	Low	20.5	0.59	0.27	14.3	0.87	0.13	6.2	53.8	ECM	GE 5SME44650058
HB	1D-15	Low	21.5	0.59	0.29	13.8	0.87	0.12	7.7	66.8	ECM	GE 5SME44650058
HB	1D-16	Low	20.8	0.59	0.28	14.5	0.88	0.13	6.3	54.7	ECM	GE 5SME44650058
HB	1D-17	Low	20.6	0.6	0.26	15.8	0.87	0.14	4.8	41.7	ECM	GE 5SME44650058
HB	1D-18	Low	22.1	0.59	0.3	14.4	0.89	0.13	7.7	66.8	ECM	GE 5SME44650058
HB	1D-19	Low	20.9	0.58	0.28	13.4	0.87	0.12	7.5	65.1	ECM	GE 5SME44650058
HB	1D-20	Low	20.8	0.58	0.27	13.4	0.87	0.12	7.4	64.2	ECM	GE 5SME44650058 - (dead fan)
HB	1D-21	Low	20.2	-	-	13.6	0.87	0.13	6.57	57.0	ECM	GE 5SME44650058
HB	1D-22	Low	20.7	0.57	0.27	15.9	0.89	0.13	4.8	41.7	ECM	GE 5SME44650058
HB	1C-1	Low	20.4	0.6	0.26	13.5	0.84	0.3	6.9	59.9	ECM	GE 5SME44650058, end cap
HB	1C-2	Low	19	0.6	0.25	15.9	0.88	0.15	3.1	26.9	ECM	GE 5SME44650058, end cap
HB	1C-3	Low	21.8	0.3	0.59	14.9	0.87	0.15	6.9	60.2	ECM	GE 5SME44650058
HB	1C-4	Low	19.8	0.28	0.59	14.1	0.83	0.14	5.7	49.5	ECM	GE 5SME44650058
HB	1C-5	Low	20.4	0.28	0.58	13.7	0.86	0.13	6.7	58.2	ECM	GE 5SME44650058
HB	1C-6	Low	20.8	0.28	0.59	14.2	0.86	0.13	6.6	57.3	ECM	GE 5SME44650058
HB	1C-7	Low	20.8	0.29	0.6	16.5	0.87	0.15	4.3	37.3	ECM	GE 5SME44650058
HB	1C-8	Low	18.4	0.26	0.58	14.3	0.86	0.13	4.1	35.6	ECM	GE 5SME58AAF
HB	1C-9	Low	21.4	0.29	0.58	15	0.86	0.14	6.4	55.6	ECM	GE 5SME44650058
HB	1C-10	Low	21.2	0.28	0.57	14.5	0.88	0.13	6.7	58.2	ECM	GE 5SME44650058
HB	1C-11	Low	21.6	0.29	0.58	14.4	0.87	0.13	7.2	62.5	ECM	GE 5SME44650058
HB	1C-12	Low	20.7	0.28	0.58	16.2	0.89	0.14	4.5	39.1	ECM	GE 5SME44650058
HB	1C-13	Low	18.6	0.25	0.59	14.6	0.87	0.14	4	34.7	ECM	GE 5SME44650058
HB	1C-14	Low	18.6	0.25	0.59	15.2	0.88	0.14	3.4	29.5	ECM	GE 5SME44650058
HB	1C-15	Low	20.9	0.29	0.59	14.9	0.88	0.14	6	52.1	ECM	GE 5SME44650058

Store	Fan ID	Temp	Pre-Power (W)	Pre-PF	Pre-Current (A)	Post Power (W)	Post PF	Post Current (A)	Savings W	Savings kWh	Motor Type	Notes
HB	1C-16	Low	19.4	0.26	0.59	14.3	0.87	0.13	5.1	44.3	ECM	GE 5SME44650058
HB	1C-17	Low	17.2	0.23	0.59	15.5	0.89	0.14	1.7	14.8	ECM	GE 5SME44650058
GG	30B-1	Med	16.2	0.57	0.23	14.7	0.86	0.17	1.5	13.1	ECM	GE ECM 5SME446GG5000B
GG	30B-2	Med	18.1	0.56	0.25	14.8	0.89	0.13	3.3	28.9	ECM	GE ECM 5SME446GG5000B
GG	30B-3	Med	18.5	0.55	0.26	15	0.88	0.17	3.5	30.7	ECM	GE ECM 5SME446GG5000B
GG	30B-4	Med	18.3	0.56	0.26	15.5	0.86	0.15	2.8	24.5	ECM	GE ECM 5SME446GG5000B
GG	30B-5	Med	18.2	0.55	0.27	14.3	0.87	0.13	3.9	34.2	ECM	GE ECM 5SME446GG5000B
GG	30B-6	Med	18.0	0.56	0.26	14.9	0.89	0.13	3.1	27.2	ECM	GE ECM 5SME446GG5000B
GG	30B-8	Med	15.4	0.49	0.25	13.8	0.85	0.13	1.6	14.0	ECM	US motors (hidden model number)
GG	32A-4	Med	13.5	0.58	0.19	14.4	0.88	0.13	-0.9	-7.9	ECM	Morrill SSC2B12CSHEMA1
GG	29A-5	Med	26.7	0.58	0.38	13.9	0.87	0.12	12.8	112.1	ECM	Morrill SSC2B13CSHEMA1
GG	29A-7	Med	21.4	0.53	0.34	14.3	0.87	0.13	7.1	62.2	ECM	Morrill SSC2B13CSHEMA1
GG	29A-11	Med	12.8	0.48	0.22	13.7	0.84	0.13	-0.9	-7.9	ECM	US motors (hidden model number)
GG	29A-12	Med	16.8	0.52	0.2	15	0.85	0.14	1.8	15.8	ECM	US motors (hidden model number)
GG	29A-13	Med	13.61	0.48	0.21	14.8	0.85	0.14	-1.19	-10.4	ECM	US motors (hidden model number)
GG	29A-14	Med	20.4	0.54	0.31	16.3	0.85	0.16	4.1	35.9	ECM	GE 5SME44GG5000B
GG	29A-15	Med	14.7	-	-	14.1	0.82	0.15	0.5525	4.8	ECM	US motors (hidden model number)
GG	29A-16	Med	14.7	-	-	14.8	0.84	0.16	-0.1475	-1.3	ECM	US motors (hidden model number)
HB	2C-1	Med	21.1	0.55	0.32	12.8	0.86	0.12	8.3	72.7	ECM	GE 5SME44650058
HB	2C-2	Med	24.5	0.55	0.37	14	0.88	0.13	10.5	92.0	ECM	GE 5SME44650058
HB	2C-3	Med	25	0.55	0.38	13	0.86	0.12	12	105.1	ECM	GE 5SME44650058
HB	2C-4	Med	23.6	0.55	0.36	14.7	0.89	0.13	8.9	78.0	ECM	GE 5SME44650058
HB	2C-6	Med	35.7	0.54	0.56	15	0.89	0.13	20.7	181.3	ECM	
HB	2C-8	Med	23.9	0.53	0.37	14.8	0.88	0.13	9.1	79.7	ECM	GE 5SME44650058
HB	2C-10	Med	25	0.53	0.39	13.2	0.87	0.12	11.8	103.4	ECM	GE 5SME44650058
HB	2C-12	Med	28.5	0.56	0.42	13.1	0.85	0.12	15.4	134.9	ECM	Not working in baseline (dead fan)

Store	Fan ID	Temp	Pre-Power (W)	Pre-PF	Pre-Current (A)	Post Power (W)	Post PF	Post Current (A)	Savings W	Savings kWh	Motor Type	Notes
HB	2C-13	Med	26.8	0.55	0.4	15.5	0.87	0.14	11.3	99.0	ECM	GE 5SME44650058
HB	2C-14	Med	24	0.53	0.37	13.2	0.87	0.12	10.8	94.6	ECM	GE 5SME44650058
HB	2C-15	Med	26.4	0.54	0.4	14.7	0.88	0.14	11.7	102.5	ECM	GE 5SME44650058
HB	2C-16	Med	24.1	0.54	0.38	13	0.85	0.13	11.1	97.2	ECM	GE 5SME44650058
HB	2D-1	Med	25	0.53	0.38	13.5	0.85	0.13	11.5	100.7	ECM	GE 5SME44650058
HB	2D-2	Med	24	0.51	0.38	13.1	0.86	0.13	10.9	95.5	ECM	GE 5SME44650058
HB	2D-3	Med	27.4	0.52	0.43	13.2	0.87	0.12	14.2	124.4	ECM	GE 5SME44650058
HB	2D-4	Med	26	0.5	0.41	13	0.86	0.13	13	113.9	ECM	GE 5SME44650058
HB	2D-5	Med	25.3	0.57	0.37	13.1	0.87	0.12	12.2	106.9	ECM	GE 5SME44650058
HB	2D-6	Med	28.5	0.51	0.45	12.9	0.87	0.12	15.6	136.7	ECM	GE 5SME44650058
HB	2D-7	Med	26	0.5	0.42	13.4	0.87	0.13	12.6	110.4	ECM	GE 5SME44650058
GG	4-13	Low	44.4	0.67	0.55	14.6	0.82	0.15	29.8	258.7	SP	GE 5KSP51ECL551
GG	30B-7	Med	49.2	0.56	0.63	13.7	0.84	0.14	35.5	311.0	SP	Hussmann SVC MO 4410311
GG	32A-1	Med	48.8	0.68	0.55	13.7	0.87	0.14	35.1	307.5	SP	GE 5KGP51ECL55
GG	32A-2	Med	45.6	0.68	0.55	14.7	0.88	0.13	30.9	270.7	SP	GE 5KGP51ECL55
GG	32A-3	Med	45.8	0.67	0.55	13.8	0.87	0.12	32	280.3	SP	GE 5KGP51ECL55
GG	32A-5	Med	43.7	0.68	0.52	14.1	0.88	0.12	29.6	259.3	SP	Packard STK 61009
GG	32A-6	Med	43.0	0.67	0.52	14.4	0.88	0.13	28.6	250.5	SP	GE 5KSM81HFL1001
GG	32A-7	Med	41.8	0.68	0.50	13.4	0.87	0.13	28.4	248.8	SP	Packard STK 61009
GG	32A-8	Med	46.4	0.64	0.58	13.6	0.87	0.12	32.8	287.3	SP	Morill SPGE9HEV16
GG	32A-9	Med	39.2	0.67	0.58	14	0.86	0.13	25.2	220.8	SP	Mars 5KSM1HFL1111
GG	29A-1	Med	44.8	0.64	0.58	13.2	0.85	0.12	31.6	276.8	SP	Morrill SPGE9HEV16
GG	29A-2	Med	46.8	-	-	16.1	0.88	0.15	30.7	268.6	SP	Morrill SPGE9HEV16
GG	29A-3	Med	49.6	0.64	0.64	13.5	0.86	0.13	36.1	316.2	SP	Hussmann SVC MO 4410311
GG	29A-4	Med	50.6	0.64	0.65	15	0.87	0.14	35.6	311.9	SP	Hussmann SVC MO 4410311
GG	29A-6	Med	49.1	0.68	0.62	16.5	0.88	0.15	32.6	285.6	SP	Morrill SPGE9HEV16
GG	29A-8	Med	41.2	0.65	0.52	16.4	0.89	0.15	24.8	217.2	SP	GE 5KSP51ECL551
GG	29A-9	Med	40.7	0.66	0.5	14.1	0.86	0.13	26.6	233.0	SP	GE 5KSM81HFL1001
GG	29A-10	Med	41.3	0.65	0.51	15.7	0.85	0.15	25.6	224.3	SP	GE 5KSM81HFL1001

Store	Fan ID	Temp	Pre-Power (W)	Pre-PF	Pre-Current (A)	Post Power (W)	Post PF	Post Current (A)	Savings W	Savings kWh	Motor Type	Notes
GG	29A-17	Med	45.8	0.61	0.62	14.2	0.82	0.14	31.6	276.8	SP	Hussmann SVC MO 4410311
GG	29A-18	Med	45.9	0.59	0.63	15.5	0.84	0.15	30.4	266.3	SP	Hussmann SVC MO 4410311
GG	29A-19	Med	49.6	0.62	0.66	13.5	0.83	0.14	36.1	316.2	SP	Hussmann SVC MO 4410311
GG	29A-20	Med	39	0.65	0.5	15.2	0.84	0.15	23.8	208.5	SP	Packard STK 61009
GG	29A-21	Med	41.7	0.68	0.51	14.7	0.84	0.14	27	236.5	SP	Packard STK 65411
GG	29A-22	Med	43	0.67	0.52	16.2	0.85	0.16	26.8	234.8	SP	Packard STK 61009
GG	29A-23	Med	38.4	0.62	0.48	16.1	0.86	0.16	22.3	195.3	SP	Packard STK 61009
GG	29A-24	Med	39.4	0.66	0.49	16.3	0.86	0.16	23.1	202.4	SP	Packard STK 61009
HB	2C-5	Med	56.8	0.68	0.68	13	0.87	0.12	43.8	383.7	SP	
HB	2C-7	Med	45	0.73	0.5	13.8	0.87	0.12	31.2	273.3	SP	Packard STK 65411
HB	2C-9	Med	45.5	0.73	0.51	15.1	0.89	0.14	30.4	266.3	SP	Packard STK 65411
HB	2C-11	Med	59.6	0.73	0.66	14.4	0.89	0.13	45.2	396.0	SP	GE 5SME44650058

APPENDIX C: MARKET SURVEY QUESTIONS AND ANSWERS

Surveys were administered both over phone and via an online instrument. Questions were filtered based on respondent type (Question 1), thus not all questions were administered to each participant. Except for Question 1, answers were not required, allowing participants to skip questions they did not feel comfortable answering. Participants were asked to limit their responses within the context of the California marketplace as much as possible.

TABLE 22. MARKET SURVEY QUESTIONS AND ANSWERS

Respondent	Please select the title that best describes your job.		About how many low-temp (freezer) reach-in refrigerated cases do you have per store? Please specify unit (doors, linear feet, # cases).
#	Response	Job Title/Role	Open-Ended Response
1	Refrigeration Equipment Distributor or Manufacturer	EVP - Founder	
2	Refrigeration Equipment Distributor or Manufacturer		
3	Food Retail Employee	Director of Facilities	40
4	Food Retail Employee	Energy Manager	11
5	Food Retail Employee	Energy Management Director	
6	Food Retail Corporate	Energy Manager	10
7	Refrigeration Equipment Distributor or Manufacturer	Founder	
8	Food Retail Facilities Management	Construction/Facilities Manager	15
9	Food Retail Corporate	Energy Project Analyst	40
10	Food Retail Corporate	Assistant Purchasing	3
11	Food Retail Employee	Assistant General Manager	35
12	Refrigeration Service Provider	Technician	
13	Refrigeration Service Provider	Sales design consultant	
14	Food Retail Employee	Assistant Store Manager	0
15	Food Retail Employee	Procurement Manager	20
16	Refrigeration Service Provider	Owner	
17	Refrigeration Equipment Distributor or Manufacturer	VP Western Zone, Specialty Case Manufacturing	
18	Refrigeration Service Provider	President	
19	Refrigeration System Engineer, Designer, or Consultant	Director Business intelligence and analytics	
20	Refrigeration System Engineer, Designer, or Consultant	President	
21	Refrigeration Equipment Distributor or Manufacturer	Manager	
22	Refrigeration Equipment Distributor or Manufacturer	Energy Sales Specialist	
23	Refrigeration Service Provider	Sales	
24	Refrigeration System Engineer, Designer, or Consultant	Engineering Manager	
25	Refrigeration Service Provider	Officer of Company / Service Technician	
26	Refrigeration Equipment Distributor or Manufacturer	VP general manager	
27	Refrigeration Service Provider	Owner	
28	Refrigeration Equipment Distributor or Manufacturer	Manager	
29	Refrigeration Equipment Distributor or Manufacturer	Service Provider for West	
30	Refrigeration Equipment Distributor or Manufacturer	VP Western Zone, VP Specialty Case Mfg	
31	Refrigeration Equipment Distributor or Manufacturer	Energy Specialist	

Respondent	About how many med-temp (cooler) reach-in refrigerated cases do you have per store? Please specify unit (doors, linear feet, # cases).	About what percentage of display cases are low-temp freezer cases?	About what percentage of existing refrigerated display cases in the market were purchased prior to 2017?	About what percentage of the med-temp cases are open (do not have doors)?	What is the expected useful lifespan of a refrigerated case (in years)?
#	Open-Ended Response	Open-Ended F	Open-Ended Response	Open-Ended F	Open-Ended R
1		40	90	65	25
2		38	93	80	15
3	80				
4	50		85	75	
5					
6	40		80	100	
7		25		80	18
8	70		90	80	
9	47		95	90	
10	3				
11	40			20	
12					
13				100	
14	12				
15	40		85	70	
16		50	91	50	
17		36	92	85	8
18		33	95	70	
19		50	81	45	
20		39	92	72	
21		40	90	38	10
22		51	91	50	10
23		50	90	30	
24		20	98	25	
25		80		20	
26		40	90		17.5
27		60	30	40	
28					
29		30	95	50	12.5
30		36	92	15	8
31		30	90	75	20

Respondent	Do you maintain or replace your case fans regularly while they are still functional or do you wait until there is a failure?		Who makes decisions on what type of replacement case fans are installed in existing cases?	
#	Response	Other (please specify)	Response	Other (please specify)
1			Refrigeration service provider	A combination of refrigeration company & company policy
2			Refrigeration service provider	
3	Regularly maintained and sometimes replaced before they fail		Other (please specify)	operations
4	Only when a failure is noticed		Company policy	
5	Only when a failure is noticed		Refrigeration service provider	
6	Only when a failure is noticed		Company policy	
7			Refrigeration service provider	
8	Other (please specify)	Only when a failure is noticed, however we are retrofitting some of our cases in advance through SCE support	Refrigeration service provider	
9	Only when a failure is noticed		Refrigeration service provider	
10	Other (please specify)	Up to the warehouse	Don't know	
11	Regularly maintained and sometimes replaced before they fail		Company policy	
12	Other (please specify)	ususally when they fail, otherwise when they make noise	Other (please specify)	the customer
13	Other (please specify)	Majority is when they fail	Refrigeration service provider	brand that the wholesale stocks
14	Regularly maintained and sometimes replaced before they fail		Refrigeration service provider	
15	Only when a failure is noticed		Refrigeration service provider	
16	Only when a failure is noticed		Other	Availability/Cost
17				
18	Typically only when they fail			
19				
20				
21				
22				
23	Other (please specify)	recommends to customer, but only when called out		
24				
25	Typically only when they fail			
26				
27	Typically only when they fail			
28				
29				
30				
31				

Respondent	Who selects the type of case fans for new stores or new refrigerated case installations?		About what percentage of existing refrigerated cases use electrically commutated motor (ECM) fans?	About what percentage of new case installations use electrically commutated motor (ECM) fans?	Of replacement evaporator fans sold to the California market, what percentage use electrically commutated motors (ECMs)?
#	Response	Other (please specify)	Open-Ended Resp	Open-Ended Response	Open-Ended Respo
1	Other (please specify)	A combination of refrigeration company & company policy	10	15	20
2	Other (please specify)	All ECM now	80	100	100
3	Other (please specify)	Construction			
4	Company policy		65	98	
5	Refrigeration service provider		55	100	
6	Company policy		100	100	
7	Other (please specify)	As specified for cases from manufacturer	70	100	50
8	Company managers		70	100	
9	Company policy				
10	Other (please specify)	There are standard company specs			
11	Company policy		100	100	
12	Don't know		70	100	
13	Other (please specify)	factory	50	90	
14	Refrigeration service provider				
15			70	100	
16			25	50	
17			50	75	50
18	Other (please specify)	Engineering and Design	60	90	
19	Other (please specify)	Sourcing on new stores	61	75	70
20	Company policy		90	95	95
21					20
22			70	70	50
23	Company policy		50	100	
24			60	80	90
25	Other (please specify)	service provider - offers	30		
26			10	65	17
27	Other (please specify)	Manufacturers	90	100	
28			25	100	25
29			20	95	30
30			50	75	50
31			75	100	75

Respondent #	What might prevent you from specifying a new, more efficient type of fan motor type in your refrigerated cases? Unfamiliar with options	Cost premiums	Reliability concerns	Company policy	Other (please specify)
1					Nothing would prevent us from specifying that we would always specify that.
2					impact is minimal and not worth the trouble to do discretely
3		Cost premiums			
4		Cost premiums	Reliability concerns		
5		Cost premiums			
6	Unfamiliar with options	Cost premiums	Reliability concerns		
7					
8	Unfamiliar with options	Cost premiums	Reliability concerns		
9			Reliability concerns		
10					Ease of replacement
11		Cost premiums		Company policy	
12		Cost premiums			
13		Cost premiums	Reliability concerns		
14		Cost premiums	Reliability concerns		
15		Cost premiums			
16		Cost premiums			Availability
17		Cost premiums			
18					
19					Initially cost but techs grab whatever they have on their truck
20					small change in speed thus airflow can increase energy usage
21					
22			Reliability concerns		Service providers won't carry them on their trucks until they r
23					always recommends high efficiency, but ultimately up to cust
24			Reliability concerns		
25					leaves it up to customer
26					
27					
28					Contractor only going to sell if customer requires it (cheaper f
29			Reliability concerns		Availability
30					
31			Reliability concerns		

Respondent	When replacing fans in existing cases, how often do you use electrically commutated motor (ECM) models?		What is the typical cost for a replacement ECM fan assembly (6-12 watt size typical to refrigerated cases)?		About what percentage of case fan ECMs in use are high-efficiency, low-power ECMs?
#	Response	Other (please specify	Open-Ended Response		Open-Ended Re
1			$130.00	130	10
2			150	150	32
3					
4					
5					50
6					
7			$100 for whole assembly, $70 retail for motor; $30 motor at cost	100	50
8					
9					
10					
11					
12	Always		depends - over $100	100	
13	Other (please specify)	Many manufacturers use as standard - so quite a bit	Under $200 ($180)	180	50
14					
15					
16	Never		149	149	
17					
18	Rarely		$90	90	10
19			Don't know		11
20			no idea		91
21			80	80	
22			150	150	1
23	Always		under $200	200	
24			$75	75	2
25	Rarely		no - vary		
26			$60 for whole assemb	60	
27	Usually		$200?	200	20
28			$50 (shaded pole $30	50	
29			$84	84	20
30					
31			55 parts	55	

Respondent	refrigerated case options, what are the most important criteria in selection? (rank from most important at top to least important at bottom). Please skip if you are not involved in refrigerated case decision making process.						
#	Cost	Energy efficiency	Reliability	Manufacturer	ROI	Functional features	Familiarity
1	4	7	5	2	6	3	1
2	2	4	1	5	3	6	7
3							
4	3	5	6	4	7	1	2
5							
6	5	4	1	6	2	3	7
7							
8	2	4	1	5	6	3	7
9							
10		1			2		
11					3		
12	1		2				
13			1				2
14	3	5	1	4	2	6	7
15	1	3	2	7	4	5	6
16	1						
17	3	1	2	5	4	6	7
18	1	4	2	7	5	6	3
19	3	1	2	6	4	5	7
20	6	2	1	7	4	3	5
21	1	7	4	3	6	2	5
22							
23		2		1			
24	4	5	2	7	6	1	3
25	1			2			
26							
27	2	3	7	6	4	1	5
28							
29							
30	3	1	2	5	4	6	7
31	5	6	4	3	2	1	7

Respondent	How often do you discuss the energy efficiency options for fan motors with the customer?	Have you ever heard of case fan options using permanent magnet synchronous motors (like QM Power Q-Sync motors)?	Have you ever heard of case fan options using low-power, high-efficiency ECMs (higher efficiency than standard ECMs)?	Would you allow your refrigeration service provider to replace many fans in the whole store or in sections of cases with a more efficient option if the return-on-investment was attractive? (as opposed to just replacing fans as they fail)	Food product at the bottom of refrigerated cases must be removed before installing or replacing case fans. Replacing the fans in a row of cases or throughout an entire store would require removing, and replacing a lot of product at once, but would save more energy and reduce effort to one night of work. Replacing fans one-at-a-time as they fail or get old would require moving less product at a time, but would save less energy, have lower return-on-investment, and be reoccuring over time. Given the choice, would you rather have many fans replaced all at once or individually as needed?
#	Response	Response	Response	Response	Response
1	Always	Yes	Yes		
2	Usually	Yes	Yes		
3					
4		Yes	No	Yes	All at once
5		Yes		Yes	All at once
6		No		Yes	All at once
7					
8		No		Yes	All at once
9		Yes		Yes	All at once
10		No		Not sure yet	Not sure
11		No		Not sure yet	Not sure
12	Rarely	No			
13	Always	No			
14		No		Yes	All at once
15		No	Yes		
16					
17		Yes	Yes		
18		Yes	Yes		
19	Always	Yes	Yes		
20	Other (please specify)	Yes	No		
21		No	Yes		
22		Yes	No		
23		Yes	Yes		
24	Always	Yes	Yes		
25		No	No		
26		No	No		
27		Yes	Yes		
28		Yes	Yes		
29		No	No		
30		Yes	Yes		
31		Yes	No		

Additional findings:

- There are different ECM efficiency tiers primarily based on brand and vintage (domestic brands with tight tolerances and newer ECMs will be higher efficiency than foreign or older ECMs). This may explain the category of "low-power, high-eff ECMs." One SME estimates that roughly 32% of existing cases use higher-eff ECMs.
- One SME suggested that programs may want to consider focusing existing rebates on refined ECM specifications. In fact, he decided to avoid CA market years ago in part because service providers would default to the cheapest, lowest quality equipment to win the bid and save costs while still getting and pocketing rebates.
- When replacing failed motors, refrigeration tech or service provider will typically just install whatever is at hand under current practices. This suggests that retrofits and replacements are likely not assured to be "low-power, high-eff ECMs" or ECMs at all. Repairs are driven by urgent need to get up and running again. Thus, early retirement is the primary opportunity until PMSM motors are kept in stock by providers. Roughly 90% of these repairs are done by service providers (instead of in-house).
- Three of these SMEs suggested that the 1800 rpm spec of PMSMs is a technical barrier since standard motors and fans are designed for 1550 rpm, generally. However, one SME called this a false premise since he has typically seen entire assemblies replaced as a whole unit. Another SME has seen retrofits of both whole assemblies and individual components.
- One program barrier is the small incremental savings that is not particularly motivational without large wholesale retrofit projects or when packaged with other measures (such as anti-sweat heaters, doors, curtains, lighting). A 10 to 25-watt improvement on a $5,000 case just doesn't carry much weight to a store owner unless done across whole store. This is a barrier for both ECMs and PMSMs which can be addressed by program support.
- General opinion is that PMSM technology is sound and reliable, but market and economic barriers pose challenges.
- PMSM could qualify for ECM rebate but, could be competing with low-cost, low-eff eligible ECMs unless the program rules specify qualifying characteristics of ECMs or yield tiered rebates.
- Freezer cases are a shrinking market category as consumers shift towards fresh foods.
- Doors on cases are becoming standard practice (horizon of roughly 5 years to 75% adoption).
- The market for ECM retrofits has dropped off and the remaining opportunities are increasingly hard-to-reach customers. One SME suggested these hard-to-reach customers may be dragging their feet since they assume that utility program support will always be there (a sunset date for the rebate could be motivational).

APPENDIX D: REFRIGERATION MODELING

The refrigeration module of eQuest modeling software version 3-65-7175 was used to estimate the energy saving potential of PMSM fan assemblies at whole-building level, including the refrigeration system compressor and condenser energy consumption. The software calculates hourly plug loads, HVAC, and refrigeration system energy consumption for the entire year. The CZ2010 weather files published by California Energy Commission were used for the simulations. The baseline model was built upon DEER grocery store model, a prototypical grocery store model provided by the eQuest refrigeration software. This model had been used in previous workpapers. The following table summarizes the major parameters of the DEER grocery store model used.

TABLE 23. EQUEST MODEL CHARACTERISTICS

FIELD	VALUE
Prototype Name	DEER Grocery
Area	50,000 sq. ft.
Occupied Hours	6AM to 10PM, 7 days a week
Lighting Power Density	2.0 W/SF
HVAC System Type	Packaged AC
Refrigerant	R-507
Refrigeration System Type	Multiplex
Number of Suction Groups	2 (LT & MT)
Number of LT Cases	5
Number of LT Case Motors	169
Number of MT Cases	10
Number of MT Case Motors	156

A few modifications were made as necessary to comply with the California Title 24 requirements. Additionally, the baseline case fan energy values for LT and MT cases were modified so that they matched with the field observations.

Since the baseline site had a mix of ECM and SP motors, energy savings were estimated for two baseline scenarios for each CZ. The first iteration is based on a baseline consisting of all ECM motors replaced with PMSMs. The second iteration uses a baseline consisting of all SP motors replaced with PMSMs. The baseline and post-implementation models for each CZ are identical with the exception of the changes detailed below in Table 24.

TABLE 24. EQUEST MODEL INPUT PARAMETERS

Component	Baseline: ECM	Measure: PMSM	Baseline: SP	Measure: PMSM
LT Fan Power	0.02 (kW/dr)	0.014 (kW/dr)	0.045 (kW/dr)	0.014 (kW/dr)
LT Fan Power	0.0076 (kW/ft)	0.0052 (kW/ft)	0.0171 (kW/ft)	0.0052 (kW/ft)
MT Fan Power	0.0076(kW/ft)	0.0052 (kW/ft)	0.0171 (kW/ft)	0.0052 (kW/ft)

Compressor Performance Curves

The refrigeration system in the model consists of eight MT reciprocating compressors and nine LT compressors. The compressor performance is dependent on saturated suction temperature (SST), saturated discharge/condensing temperature (SDT), and refrigerant flow in the system. The compressor power is calculated using the following formula:

$$\begin{aligned}&\boldsymbol{Compressor\ power}\ (\boldsymbol{kW})\\&\quad = \boldsymbol{a} + \boldsymbol{b}\cdot \boldsymbol{SST} + \boldsymbol{d}\cdot \boldsymbol{SST}^2 + \boldsymbol{g}\cdot \boldsymbol{SST}^3 + (\boldsymbol{c} + \boldsymbol{d}\cdot \boldsymbol{SST} + \boldsymbol{h}\cdot \boldsymbol{SST}^2)\boldsymbol{SDT} + (\boldsymbol{f} + \boldsymbol{i}\cdot \boldsymbol{SST})\\&\quad + \boldsymbol{j}\cdot \boldsymbol{SDT}^3\end{aligned}$$

The coefficients in above equation varies with different type of compressor. The prototype model uses two types of compressors for LT and three for MT. The coefficients used in the model are summarized in below table.

TABLE 25. COMPRESSOR PERFORMANCE CURVES AND COEFFICIENTS USED IN THE MODEL

COEFFICIENT	LT COMPRESSOR TYPE 1	LT COMPRESSOR TYPE 2	MT COMPRESSOR TYPE 1	MT COMPRESSOR TYPE 2	MT COMPRESSOR TYPE 3
Performance Curve Name	Reed-3db3-0750-R507A_pwr	Reed-4dt3-2200-R507A_pwr	Reed-2da3-075e-R507A_pwr	Reed-3db3-100e-R507A_pwr	Reed-3ds3-100e-R507A_pwr
a	0.09634791	23.56579781	-1.60891008	3.44485998	5.02124977
b	-0.04650830	0.48198798	-0.04476720	-0.03424740	0.08126411
c	0.12794299	-0.28534099	0.14761999	0.04994890	0.06899331
d	0.00020739	0.00475229	-0.00106144	-0.00103907	0.00009632
e	0.00154147	-0.00661736	0.00118962	0.00111387	-0.00043673
f	-0.00053736	0.00357310	-0.00088545	0.00017822	0.00015533
g	0.00000666	0.00002581	-0.00000312	-0.00000394	-0.00000563
h	0.00000110	-0.00003973	0.00000799	0.00000560	-0.00000683
i	-0.00000210	0.00003792	-0.00000150	0.00000078	0.00000794
j	0.00000099	-0.00001096	0.00000197	-0.00000120	-0.00000113

Since the suction temperature is relatively constant over the course of simulation year, hourly system efficiency (calculated as total compressor energy divided by system load) was plotted against saturated condensing temperature to better understand the simulated performance of compressors. As expected, the compressor efficiency declined as the discharge temperature increased. However, there is a changepoint at around 90F for both systems where the incremental change in efficiency becomes large. The implication of this is that for CZs that have outside air temperatures in excess of this changepoint during peak hours, energy and demand reductions due the reduced case load from the fan retrofit are more pronounced.

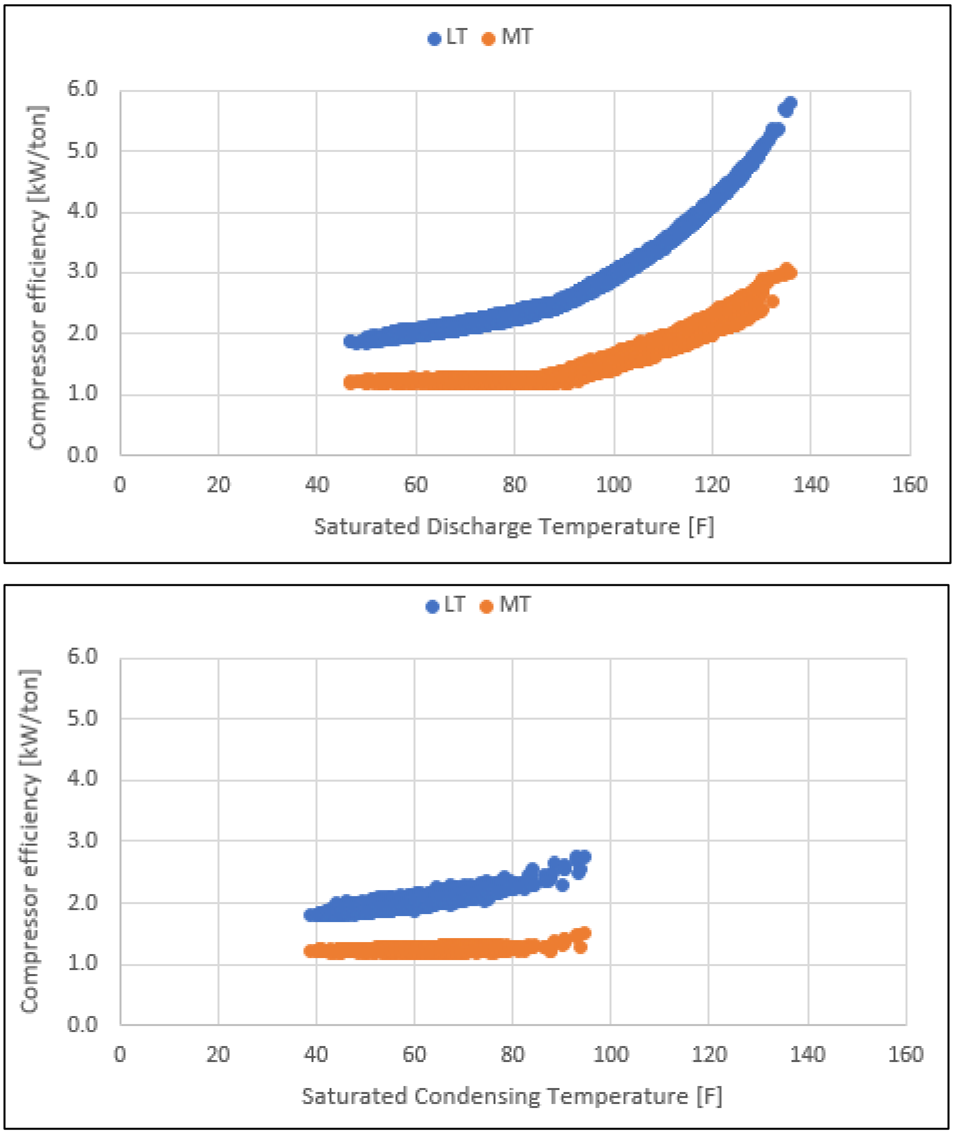


FIGURE 68. SIMULATED COMPRESSOR PERFORMANCE OVER SATURATED CONDENSING TEMPERATURES FOR CZ15 (TOP) AND CZ1 (BOTTOM)

Savings Calculations

Once simulations were completed, the annual whole building energy consumption and LT and MT compressor's energy consumption were tabulated. Since eQuest didn't report refrigerated case fan energy consumption separately, the evaporator fan energy consumption was approximated as the difference between the annual whole building energy consumption and the compressor (LT and MT) energy consumption. The evaporator fan energy savings were then calculated using the values in the baseline and the post-implementation models. The difference was divided by the total number of evaporator fans that were modeled.

$$Electric\ Savings\ \left[\frac{kWh}{Unit}\right] = \frac{Base\ Case\ Usage - Measure\ Case\ Usage}{Total\ Count\ of\ Evaporator\ Fans}$$

The demand savings were derived from the same models and by using the same approach that was used to estimate the electric energy savings. They were calculated as the difference between the peak power demand in the baseline and the post-implementation model during the CPUC defined peak demand period (year 2009) for each CZ. The difference was then divided by the total number of evaporator fans that were modeled.

$$Demand\ Reduction\ \left[\frac{kW}{Unit}\right] = \frac{Base\ Case\ Peak\ kW - Measure\ Case\ Peak\ kW}{Total\ Count\ of\ Evaporator\ Fans}$$

Table 26 shows a sample of calculated total savings and demand reduction for the CZ1.

TABLE 26. ANNUAL ENERGY SAVINGS AND DEMAND REDUCTION (FOR CZ1)

	ECM Baseline	SP Baseline
Total # of Motors	325	325
Low Temp Motor	169	169
Medium Temp Motor	156	156
Baseline Fan kW (DEER Peak)	0.540	0.566
Post Fan kW (DEER Peak)	0.534	0.534
Fan kW Savings (DEER Peak)	**0.0063**	**0.0316**
Baseline Fan kWh	3,761	3,986
Post Fan kWh	3,705	3,705
Fan kWh Savings	**56.4**	**281**
LT comp kW savings (DEER Peak)	0.0014	0.0239
LT comp kWh savings	31.7	158
MT comp kW savings (DEER Peak)	0.0022	0.0127
MT comp kWh savings	18.2	91.0
Baseline Annual Total kWh	1,875,044	1,980,787
Post Annual Total kWh	1,848,526	1,848,526
Total kWh Savings	26,518	132,262
Baseline Total kW (DEER Peak)	273	287
Post Total kW (DEER Peak)	270	270
Total kW Savings	2.64	16.3

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