Work Paper Abstract
PMSM Fan Motor Assembly for Refrigerated Case Evaporators
Revision # 1.1

California Technical Forum

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Permanent Magnet Synchronous Fan Motor Assembly for Refrigerated Case Evaporators

Abstract

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Table 1 Work Paper Abstract Snapshot

Work Paper Abstract Snapshot		
Item	**Details**	**Notes**
Measure name	Permanent magnet synchronous fan motor assembly for refrigerated case cvaporators	
Measure description	Evaporator fan/motor assembly retrofits for refrigerated cases that reduce demand and refrigeration load.	
Sector (Res/Non-Res)	Non-residential	
Subsector (e.g. Ag)	Food retail	Supermarkets, grocery stores, convenience stores, gas stations, delis
Delivery Channel (e.g. Upstream)	Downstream prescriptive rebate Direct install (DI)	DI limited by large customer peak demand
Measure Application Type (e.g. ROB)	Replace on burnout Early retirement	

1. Measure Description & Key Terms

This abstract is the next natural step to a successful emerging technology study sponsored by the SDG&E ET group in which 173 fan motor assemblies for refrigerated case evaporators have been tested and showed high savings potential. It follows that the abstract goal is to seek suggestion to include this technology in the energy efficiency programs.

Primary References:

Energy Savings of Permanent Magnet Synchronous Fan Motors Assembly for Refrigerated Case evaporators, ET15SDG1061, SDG&E Emerging Technologies, March 2016.

Refrigerated cases in supermarkets, convenience stores, pharmacies, and other commercial customers with food retail operations rely on small fans that circulate air past evaporator coils to maintain case temperature setpoints. These fans operate 24/7 with the exception of brief, daily defrost periods in most freezer cases. Evaporator fans are powered by small motors, which are typically ECMs or shaded pole (SP) based on industry standard practice (although incumbent motors will occasionally be split capacitor type). The units are purchased and replaced as preassembled units of fan, coupling, electronics, and motor. These assemblies come in varying fractional horsepower sizes and can be categorized as 4-8W, 9-12W, or 38-50W. These sizes are typically used in small refrigerated cases, medium-temp or low-temp reach-in cases, and walk-ins respectively. This workpaper focuses only on the mid-size 9-12W motors that are the most common and are employed in the majority of reach-in refrigeration or freezer cases.

The proposed measure is a new type of permanent magnet synchronous motor (PMSM) fan assembly that uses new technology to provide an affordable energy efficiency solution to ECM losses. The measure improves efficiency and power factor by by-passing supply power

rectification during the vast majority of motor operation at synchronous speed. The AC to DC rectification, which is necessary for ECM control on a continuous basis, is turned off for the proposed technology when the motor speed is synchronous with the grid. When that happens the motor is directly connected to the grid without the electronics "in between." The technology uses a Hall effect sensor to verify that the motor is turning at synchronous speed. The electronics are controlling the motor only during start up and when operating at lower then synchronous speed.

The high efficiency PMSM fan assemblies are easily installed as long as the right size fan is selected for the case frame. Retrofit installation can be performed easily by a refrigeration contractor in less than 10 minutes once the bottom shelf of the case has been emptied of product.

These motors are expected to have the same effective useful lifespan of 15 years as the existing ECM (PG&E FSTC Report 5011.05.13 and DEER 2014 EUL ID GrocDisp-FEvapFanMtr).

There are no HVAC interactive effects with the store envelope as all the heat load of the motors is contained within the refrigeration system and rejected through the condensing units, which are outside.

Key Terms:

- High efficiency permanent magnet synchronous motors (PMSM): measure that improves upon existing PMSM technology which allows for implementation in refrigerated cases
- Electrically commutated and shaded pole motors: baseline technology
- Refrigerated case: reach-in low and med temperature food cases

2. **Program Implementation Method**

The proposed program is a downstream deemed rebate and a direct install program for replace on burnout and early retirement of existing food retailer case fan assemblies. The measure may be eligible as either replace on burnout (ROB) or as earlier retirement (RET) if the baseline units are functional and have significant remaining useful life.

The program goal would be to achieve early retirement of existing fan populations, make sure that replace on burnout do not re-install SPs or ECMs, and to incent stores to replace the entire fan base. Without an early retirement or replace on burnout utility program, the refrigeration technician would only replace the fan assembly when a motor fails and probably with the standard ECM or SP technology rather than the unknown, emerging PMSM technology. For this reason, it is proposed that even if the proposed technology has a very small incremental cost compared to ECMs, an external incentive is needed to move the market.

Although the measure should be applicable at any refrigerated case with standard fan sizes, supermarkets and grocery stores account for about 80% of the baseline fan energy consumption in California and could be specifically targeted for improved program success and market transformation. The rebate should be made available to any application, but supermarkets and grocery stores should be specifically targeted for greatest program effectiveness.

Since there are no HVAC interactive effects the associated refrigeration systems do not significantly vary across all statewide conditions, the program and measure implementation should consistent across all climate zones and building types. The variation across climate zones, case types, and baseline motor types is discussed in the calculation methodology explanation in

Section 8. The deemed value is a weighted blend of savings values for med-temp and low-temp cases and for baseline motors of SP and ECM type. A more rigorous program design that provides separate deemed values and rebates for each type of baseline motor or case temperature would be overly complex without providing much added benefit to total program savings estimates.

Aside from program evaluation reasons, no measurement of pre or post conditions would be required. The measure provides a nearly constant, dependable load reduction that lends itself well to a deemed, rebate program. The only unaccounted variables include differences in savings for the refrigeration COP among different systems that are minimal compared to the whole measure, as described in Section 8.

One possibility to improve program design and understanding would be to collect data on the ratios of low and mid temp cases and existing motor types during implementation. Although a single, blended savings value is recommended, these data could be collected to improve savings estimates and validate the workpaper assumptions. If the collected data suggest that the mid and low temp ratios or baseline type need adjustment after 1 year, the workpaper and deemed values can be revised.

3. **Mixed Baseline**

There is no California code standard or documented industry standard practice for refrigerated case evaporator motors. The closest relevant code is Title 24 Section 120.6(b) that requires a certain level of motor efficiency or ECMs to be used in refrigerated warehouses.

The emerging technology study, recently performed at a San Diego grocery store evaluated the replacement of 173 fan motor assemblies and 92% of the replaced fans were driven by ECM motors, while the remaining 8% by SP motors. However, this location was selected specifically because it was a high proportion ECM site. Citing industry partners, a September 2015 report by Oak Ridge National Labs claimed that supermarkets have about 65% SP and 35% ECMs at the national level. Interviews with California refrigeration professionals suggested that although there is a large variation in baseline motor mix from site to site, it was estimated that about 80% of installed motors are ECMs. This is the mix that the workpaper will utilize until further information becomes available. It should be noted that ECM retrofits are still be incentivized and are thus still considered to be more efficient that industry standard practice.

However, if information collected for each supported project during the first year of program implementation shows a different baseline technology mix, the savings should be recalculated to reflect that updated understanding.

Based on audit and implementation findings from the EnergySmart Grocer program and according to the ASHRAE Refrigeration Handbook, food retail buildings have a mix of roughly 75% low-temp cases and 25% med-temp cases.

If large corporations with many sites selectively implement the technology on a trial basis, there should be no conflict with program support. However, if it becomes company policy or a company-wide initiative, it may be then fall under industry standard practice for that customer; therefore, bringing this product to customers before the industry as a whole realizes the benefit is in utilities' and ratepayers' best interests. It is expected that due to the relatively small impact on corporate balance sheets, large chains are unlikely to adopt companywide retrofits for several years at the earliest.

4. **Measure Summary**

Table 2 Measure Summary

Characteristic	Measure
Baseline Technology or Mix	75% ECM and 25% shaded pole fan assemblies
Measure Technology	PMSM fan assembly
Measure Application Type	ROB and ER
Delivery Mechanism	Downstream rebate and direct install
Impacted Markets	Commercial – food retail
Relevant Codes and Standards	No code for 9-12 watt refrigerated case motors

5. **Estimated Size of Offer (Number of Participants)**

Since this is a new technology and only one company is currently offering the product, the market penetration and adoption rate are essentially 0%. Based on US Census data and estimates of installed fans per customer type, the following table lists the approximate baseline fan population in California. This includes about 8,800 supermarkets and grocery stores which will comprise the majority of the market.

Table 3 California market size (from United States Census Bureau and ORNL study)

Facility Type	# of CA Establishments	9-12 W motors per site	Total number of fans
Supermarkets and other grocery stores	8,805	216	1,748,323
Convenience stores	2,373	7	16,611
Specialty food stores	2,896	50	144,800
Liquor stores	3,815	2	7,630
Drug stores	4,435	8	35,480
Gas stations with convenience stores	6,089	2	12,178

Based on the assumed baseline mix described above, the total potential energy savings in California is about 272 GWh/year if all the 9-12 watt fan assemblies were replaced. The associated total demand reduction potential is about 31.3 MW. After program support, market adoption rate will improve, the market will transform, and when the technology becomes industry standard practice or free ridership is too great, the program will not provide any additional benefit. This will be the limiting factor on the number of participants.

The emerging technology study evaluated 173 9-12W fan motors and the above market estimates do not include savings from the smaller and larger fan categories (4-8W and 38-50W) which will soon become a potential application when the manufacturer releases their forthcoming smaller and bigger models. These could potentially be included in future program or workpaper updates.

6. Estimated Impact of the Measure on Statewide Energy Efficiency Savings.

Based on the emerging technology study and blending of case and baseline motor types:

Energy savings per fan assembly: 138.6 kWh/year
Demand reduction per fan assembly: 15.9 watts
Estimated 9-12 W fan market size in CA: 1,965,000
Total estimated energy savings potential (100% market penetration): 272 GWh/year
Total estimated demand reduction potential (100% market penetration): 31.3 MW

This savings potential is for the entire available California market. If reasonable, a cutoff point of market penetration when the technology becomes ISP could improve the estimated impact of the measure on statewide energy efficiency savings. For instance, assuming that the technology becomes ISP at 50% market uptake could provide a point that program support could end and thus reduce the estimated EE program savings potential.

These savings are based on results of the Emerging Technologies field case study and follow-up research. The savings potential would increase by 2-3 times if the smaller and larger fan sizes are included once the products become available.

7. Applicable DEER & CPUC Guidance

The relevant DEER parameters are as follows:

EUL: 15 year EUL and 5 year RUL (DEER2014 GrocDisp-FEvapFanMtr)

NTG: 0.85 (DEER2014 ET-Default ET approved by ED through workpaper review)
0.70 (DEER2014 All other EEMs with no evaluated NTGR; new tech in program <2 years)

There is no DEER measure evaporator fan motor retrofits. However, the DEER operating hours of equipment for refrigerated storage includes the 24/7/365 type operation that justify the 8,760 hours.

Title 24 2013 (Section120.6(b)) states that for refrigerated warehouses “single phase fan motors less than 1 hp and less than 460 Volts in newly installed evaporators shall be electronically commutated motors”. With this assumption and knowing the fact that in the real world there is still a percentage of shaded poles and permanent split capacitor motors, the energy savings will be slightly greater than used in program claims.

8. Proposed Measure Parameter Values, Methodology, and Data Sources

All energy savings, demand reduction, market potential, and measure cost figures were developed based on a recent emerging technologies study and follow-up research. The energy savings and demand reduction were established by performing an M&V study at a supermarket that included baseline and post-implementation monitoring at 173 evaporator fan motor assemblies which were distributed roughly evenly between closed freezer cases and open med-temp refrigerated cases. Due to the large number of fans and consistent savings across every instance, the confidence level for the energy metrics is high. The variance in savings across the fans was very low, resulting in high accuracy and reliability of savings estimates. This high level of confidence in a single average savings per fan suggests that a deemed rebate measure is appropriate. Additionally, these savings were validated by previous lab testing as reported by Oak Ridge National Labs in a separate study (September 2015), internal manufacturer testing, and a follow-up lab test performed at AMCA using standardized fan test protocols.

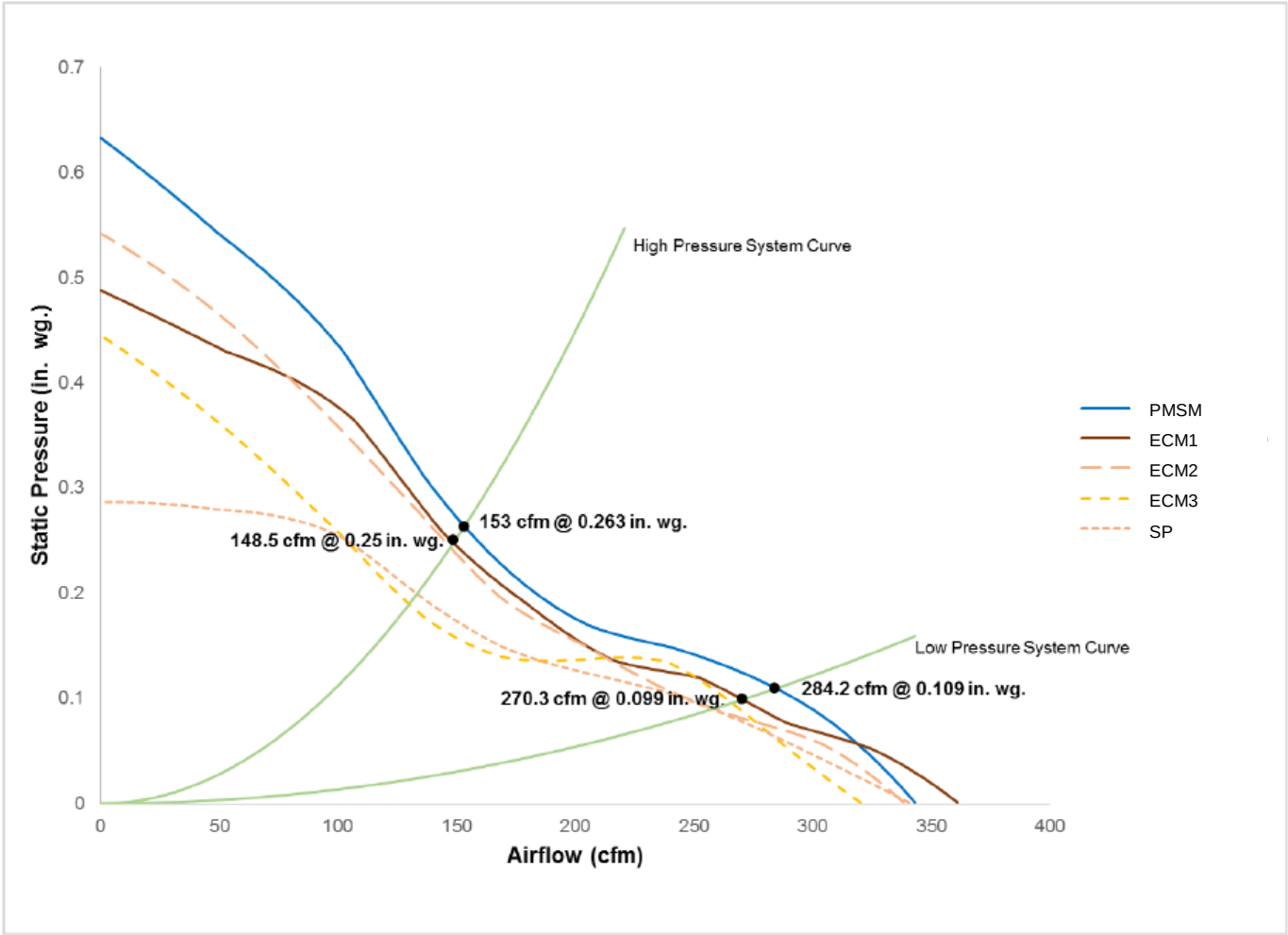
The field test involved 1 month of baseline monitoring and 1 month of post-implementation monitoring of fan circuit demand at subpanels, a sample of case bulk air temperature and humidity, and spot measurements of airflow and power characteristics. Energy and demand savings were determined using real power measurements at the circuit breaker and supplemented by spot measurements of each fan. Demand was consistent across all conditions with only slight diurnal, periodic variation that depended on grid supply voltage. Thus, energy and demand savings were easily calculated by a simple comparison between pre and post data. Annualized values were calculated by extrapolating to 8,760 hours for the mid-temp cases and 8,575 hours for the freezers to account for daily 30 minute defrost cycles. The direct energy savings per fan assembly are shown in the following table.

Table 4 – ET study empirical per unit findings (direct fan assembly savings)

	Med-temp		Low-temp	
	Shaded Pole Baseline	**ECM Baseline**	**Shaded Pole Baseline**	**ECM Baseline**
Baseline on-peak power [W]	41.6	20.7	41.6	20.7
Post on-peak power [W]	14.1	14.1	14.1	14.1
On-peak demand reduction [W]	27.5	6.6	27.5	6.6
Baseline energy [kWh/yr]	364.3	181.5	356.7	177.7
Post energy [kWh/yr]	123.8	123.8	121.2	121.2
Energy savings [kWh/yr]	240.5	57.7	235.5	56.5

In addition to these findings, follow up testing performed at AMCA under standardized laboratory testing conditions showed similar savings and that airflow was not decreased due to retrofit. This is particularly important in order to verify that measured direct savings are not a result of decreased airflow rather than efficiency. Figure 1 shows the fan curves for the PMSM model and baseline motor types. The blue PMSM curve to the right of the others indicates airflow is not decreased by retrofit and savings can thus be attributed to improved fan and motor efficiency.

Figure 1 – Fan curve results from AMCA testing of relevant fan assemblies (Test Standard 210:07)



Energy savings and demand reduction are also realized at the refrigeration system due to reduced heat input from the fans in the refrigerated cases. Using site specific efficiency system kW/ton values, savings associated with the reduced fan heat load were also included. Using COPs of 2.5 for med-temp cases and 1.4 for low-temp cases, the energy and demand of the refrigeration system can be calculated using the following equations. These COPs correspond to 1.4 and 2.5 kW/ton, respectively, in order to represent typical, average conditions. This approach is similar to that taken by workpaper PGECOLTG174 for refrigerated case LED lighting.

$$Energy_{refrig} = \frac{Fan\ Energy * 3{,}412 * kW/ton}{12{,}000}$$

$$Demand_{refrig} = \frac{Fan\ Demand * 3{,}412 * kW/ton}{12{,}000}$$

where *Fan Energy* and *Fan Demand* are the empirically measured per unit values for the baseline or post fan assemblies and the constants are unit conversion factors. Using these equations, the refrigeration system energy, demand, and savings are listed in the following table.

Table 5 – Refrigeration system savings

	Med-temp		Low-temp	
	Shaded Pole Baseline	**ECM Baseline**	**Shaded Pole Baseline**	**ECM Baseline**
Baseline on-peak power [W]	16.6	8.3	29.7	14.8
Post on-peak power [W]	5.6	5.7	10.1	10.1
On-peak demand reduction [W]	11.0	2.6	19.6	4.7
Baseline energy [kWh/yr]	145.7	72.6	254.8	127.0
Post energy [kWh/yr]	49.5	49.5	86.6	86.6
Energy savings [kWh/yr]	96.2	23.1	168.2	40.4

Using a refrigeration system bin modeling analysis of California's most extreme climate zones, it was shown that there was about an 18% variation in refrigeration system savings across California's conditions. Since the refrigeration system savings accounts for about 29-42% of the total savings, an 18% variation results in less than 10% overall variation. Based on this small variability due to climate zone effects, it is recommended that an average COP and refrigeration system savings as described above be used.

The total per unit savings are a sum of those shown in Tables 4 and 5.

For programmatic simplicity, cost-effectiveness, and to avoid freeridership on a low-temp specific option, a blended single deemed value approach will be used. This is similar to the approach taken by similar workpapers PGECOLTG174 and PGE3PREF124 for case

lighting and ECM fans, respectively. Based on the ASHRAE Refrigeration Handbook and EnergySmart Grocer program, the existing refrigerated case population is about 75% med-temp and 25% low-temp. Based on surveying of California refrigeration industry professionals, the existing fan motor assembly population is an estimated 80% ECM and 20% SP. These values are the blending weights used in calculating averaged deemed values from the data in Tables 4 and 5.

Table 6 – Blended value weights

Weighting Factor	Value
Med-temp %	75%
Low-temp %	25%
Shaded Pole Baseline %	20%
ECM Baseline %	80%

$$Deemed\ Savings = \omega_{med-temp}(\omega_{SP} * Energy\ Savings_{SP-med} + \omega_{ECM} * Energy\ Savings_{ECM-med}) + \omega_{low-temp}(\omega_{SP} * Energy\ Savings_{SP-low} + \omega_{ECM} * Energy\ Savings_{ECM-low})$$

where ω are the weights listed in Table 6 and *Energy Savings* are the combined savings for each type of motor and case type in Tables 4 and 5. A similar weighting applies to the demand reduction.

Table 7 – Deemed energy savings and demand reduction

Metric	Deemed Value
Baseline on-peak power [W]	36.8
Post on-peak power [W]	20.9
On-peak demand reduction [W]	15.9
Baseline energy [kWh/yr]	320.5
Post energy [kWh/yr]	181.9
Energy savings [kWh/yr]	138.6

Installed cost per unit was taken from the project experience, vendor quotes, and refrigeration service provider rates. However, a range of unit costs was provided by the manufacturer and thus the respective confidence is low. However, the range is relatively small and is not expected to reach levels that make the technology unviable and is roughly the same as baseline technology costs. Market size was determined using US Census data for food retail businesses in California. The number of fans at each type of business was defined by estimates in the reference Oak Ridge National Labs paper. Combining the ET study findings and this estimated market size allowed for total market potential energy savings and demand reduction.

Table 8 Proposed Measure Parameter Methods, Data, Assumptions and Sources

Measure Parameter	Proposed Value	Methodology Description	Key Assumptions	Data Source Name and Description	Input Requested from TF	Confidence Level (High, Med Low)
Baseline Energy kWh/yr	320.5	Emerging technologies field study and weighted blending	Field case study and weighting derived from research are representative of California market	ET15SDG1061 Report		High
Measure Energy kWh/yr	181.9					High
Savings – kWh/yr	138.6					High
Baseline Demand - kW	.0368					High
Measure Demand - kW	.0209					High
Savings – kW	.0159					High
Baseline Energy Therms/yr	0					High
Measure Energy Therms/Yr	0					High
Savings – therms/yr	0					High
EUL	15 Years	DEER		DEER2014 GrocDisp-FEvapFanMtr		High
MC	$95/unit	Supplier surveying		Manufacturer quotes and contractor info		Low
NTG	0.85			DEER2014 ET-Default ET approved by ED through workpaper review		Medium

9. Proposed Level of Complexity

Since this is a straightforward deemed rebate, drop-in retrofit with constant savings, a high level of confidence, and similar findings from AESC, Oak Ridge National Labs, AMCA, and the manufacturer, the level of complexity and risk are low.

10. Preliminary TRC Estimates

Table 9 Preliminary TRC Estimates and Parameters

TRC Parameter	Parameter Estimate or Required Parameter Value Threshold (specify if estimate or threshold)	Confidence Level (High, Medium, Low)	Comments
UES			
IMC	$96	Med	
EUL	15	High	
NTG	0.85	Med	
Incentive/unit	$20-60	Low	
Number of units	Thousands	High	
Installation Rate	0.8	Med	
Gross Realization Rate	0.9	Med	
TRC Value:	**Estimated 1.1 – 2.0 (will be updated in workpaper)**		

11. Literature Review

Small motors comprise a significant portion of grid demand and will not decrease in the foreseeable future without measures such as the one proposed here. This type of motor and low cost VFDs are the only expected technologies in the pipeline that could address this end-use. As far as the authors know, the technology has not yet been granted program support in other jurisdictions due to its being a brand new available product.

References:

Fricke, B., & Becker, B. (2015). Q-Sync Motors in Commercial Refrigeration: Preliminary Test Results and Projected Benefits, ORNL/TM-2015/466. Oak Ridge National Laboratory.

- EM&V results, market size estimations, numbers of motors per establishment, proposed measure technology description

Karas, A. (2006). GE ECM Evaporator Fan Motor Energy Monitoring. Fisher-Nickel, Inc. and Pacific Gas & Electric.

- Evidence that motors run 24/7 in most establishments

NCI and PNNL. (2011). Preliminary Technical Support Document: Energy Conservation Program for Certain Commercial and Industrial Equipment: Commercial Refrigeration Equipment. Washington, D.C.: Building Technologies Program, Office of Energy Efficiency and Renewable Energy, US Department of Energy.

- Baseline motor efficiency

US Census Bureau. (2013). County Business Patterns (NAICS).

- Market size estimations

Valmiki, M M and Corradini, Antonio. (2016). Energy Savings of Permanent Magnet Synchronous Fan Motor Assembly in Refrigerated Case Evaporators. SDG&E Emerging Technologies, ET15SDG1061.

- Energy savings calculations, EM&V field study

Personal correspondence with refrigeration service providers

- Baseline technology mix of 70% ECM and 30% SP

Smith, Wade and Sheard, Anthony. (2016). Report on Fan Performance Tests.

- Report on fan curves developed for all relevant technology types using standard AMCA testing protocols in an accredited laboratory environment.
- Showed that PMSM measure does not have an impact on evaporator air flow while maintaining previously measured energy savings.

PG&E and PECI. (2016). Work Paper PGE3PREF124 Display Case ECM Motor Retrofit Revision 3.

PG&E. (2016). Work Paper PGECOLTG174 LED Refrigeration Case Lighting Revision 2.

12. Additional Research Needed

ORNL and ET reports are in good agreement with very consistent results. No additional information is needed for the workpaper at this time. As suggested above, data collected during program implementation for the first year could help revise case type blend or baseline motor types, if needed.

13. Questions for CPUC Staff on Applicability of DEER Values, Methods, Tools, Data, Etc.

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14. Cal TF Comments on Proposed Measure Parameter Values, Methodology, and Data Sources

Cal TF comments on proposed data and sources. Do data represent best available data? If not, what are alternate data/sources that should be considered?

Table 10 Cal TF Comments on Measure Parameter Methods, Data, Assumptions, and Sources

Measure Parameter	Cal TF Comments / Recommendations
Baseline Energy kWh/yr	
Measure Energy kWh/yr	
Savings – kWh/yr	
Baseline Demand kW/yr	
Measure Demand kW/yr	
Savings – kW/yr	
Baseline Energy Therms/yr	
Measure Energy Therms/Yr	
Savings – therms/yr	
EUL or RUL	
MC or IMC	
NTG	

15. Cal TF Comments on Proposed Level of Complexity

Cal TF comments on proposed level of complexity based on input from abstract developer and Cal TF discussion.

16. Other Cal TF Comments

This page to be completed by Cal TF Staff

17. Commission Staff Review and Feedback

Commission staff should provide feedback on proposed data and sources within 10 days of request.

Table 11 Commission Staff Feedback on Proposed Data and Sources

Measure Parameter	Commission Staff Comments / Recommendations
Baseline Energy kWh/yr	
Measure Energy kWh/yr	
Savings – kWh/yr	
Baseline Demand kW/yr	
Measure Demand kW/yr	
Savings – kW/yr	
Baseline Energy Therms/yr	
Measure Energy Therms/Yr	
Savings – therms/yr	
EUL or RUL	
MC or IMC	
NTG	

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Appendix A – Sources

Primary Source: ETCC Report (Calculations and M&V analysis can be provided on request)

Secondary Source: ONRL Report