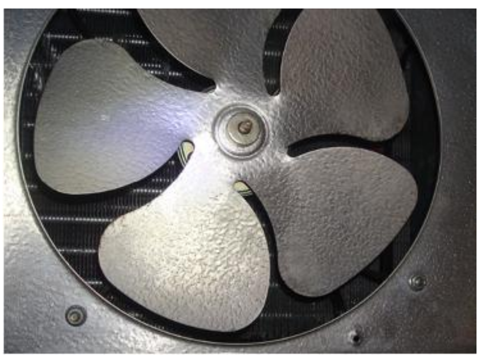
Northeast Energy Efficiency Partnerships



Commercial Refrigeration Loadshape Project

October 2015

About NEEP & the Regional EM&V Forum

REGIONAL EVALUATION, MEASUREMENT & VERIFICATION FORUM

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency in the building sector through public policy, program strategies and education. Our vision is that the region will fully embrace energy efficiency as a cornerstone of sustainable energy policy to help achieve a cleaner environment and a more reliable and affordable energy system.

The Regional Evaluation, Measurement and Verification Forum (EM&V Forum or Forum) is a project facilitated by Northeast Energy Efficiency Partnerships, Inc. (NEEP). The Forum's purpose is to provide a framework for the development and use of common and/or consistent protocols to measure, verify, track, and report energy efficiency and other demand resource savings, costs, and emission impacts to support the role and credibility of these resources in current and emerging energy and environmental policies and markets in the Northeast, New York, and the Mid-Atlantic region.

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Commercial Refrigeration Loadshape Project

FINAL REPORT

October 9, 2015

Northeast Energy Efficiency Partnerships
Regional Evaluation, Measurement, and Verification Forum
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Acronym Glossary

Acronym	Definition
ASDH	Anti-sweat door heater
CRL	Commercial refrigeration loadshape (i.e., this study)
DMI	Demand Management Institute – provides expertise on energy-related technical assistance, ranging from cost-benefit analysis of a single energy efficiency opportunity, to comprehensive strategies for reduced energy consumption in a campus of facilities
ECM	Electronically-commutated motor
EF	Evaporator fan
EM&V	Evaluation, measurement, and verification
GEE	Global Energy Efficiency – a large volume, full-service energy management company in New York
ISO-NE	Independent System Operator, New England, Inc. – is an independent, non-profit regional transmission organization (RTO), serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont
NEEP	Northeast Energy Efficiency Partnerships – a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency in the building sector through public policy, program strategies and education.
NRM	National Resource Management, Inc. – a large volume refrigeration retrofit contractor in the northeast.
PA	Program administrator
PJM	Pennsylvania-New Jersey-Maryland Interconnection – a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia
PSC	Permanent split capacitor
SP	Shaded pole
TRM	Technical Reference Manual

1 Executive Summary

The Northeast Energy Efficiency Partnerships (NEEP) Regional Evaluation, Measurement, and Verification Forum (EM&V Forum) conducts research studies to support energy efficiency programs and policy in the Northeast and Mid-Atlantic states. In 2014, the EM&V Forum and its sponsors commissioned this commercial refrigeration loadshape (CRL) study to determine the hourly energy and demand impacts of three common commercial refrigeration retrofit measures commonly installed through energy efficiency programs in the Northeast and Mid-Atlantic states:

- Electronically commutated motors (ECMs) installed on evaporator fans in coolers and freezers
- Evaporator fan (EF) controls
- Anti-sweat door heater (ASDH) controls

The EM&V Forum and its sponsors chose to study these three measures because they reliably produce commercial energy and demand savings, yet little or no evaluations using empirical evidence exist. This study employed pre- and post-installation metering to evaluate the savings. Due to the regional nature of the study, the findings provide insights on a variety of manufacturers, products, and types of technologies.

Cadmus and the Demand Management Institute (DMI), the evaluation team, worked with the EM&V Forum's Technical Committee to complete this study. This report describes the study objectives, methods, and results and the evaluation team's recommendations for future implementation and evaluation of energy-efficient measures on commercial refrigeration equipment.

1.1 Objectives

The EM&V Forum commissioned this study to assess the annual, peak, and hourly demand impacts from the three commercial refrigeration retrofit measures most commonly installed through energy efficiency programs in the Northeast and Mid-Atlantic states.[1] Through primary and secondary data collection and analysis, the evaluation team developed hourly demand savings estimates—savings loadshapes—for ECM retrofits, evaporator fan controls, and ASDH controls installed on commercial refrigeration equipment. The evaluation team used these loadshapes to calculate key savings metrics, including annual energy savings and demand savings during peak periods. The evaluation team also created a loadshape calculation tool, which enables users to select whether to include interactive refrigeration savings, determine if the refrigerated case is a cooler or freezer, and compute the savings for any specific period of interest throughout the year.

The EM&V Forum provides these study results and primary data to its members to support activities including regulatory filings for energy efficiency programs, developing or updating technical reference

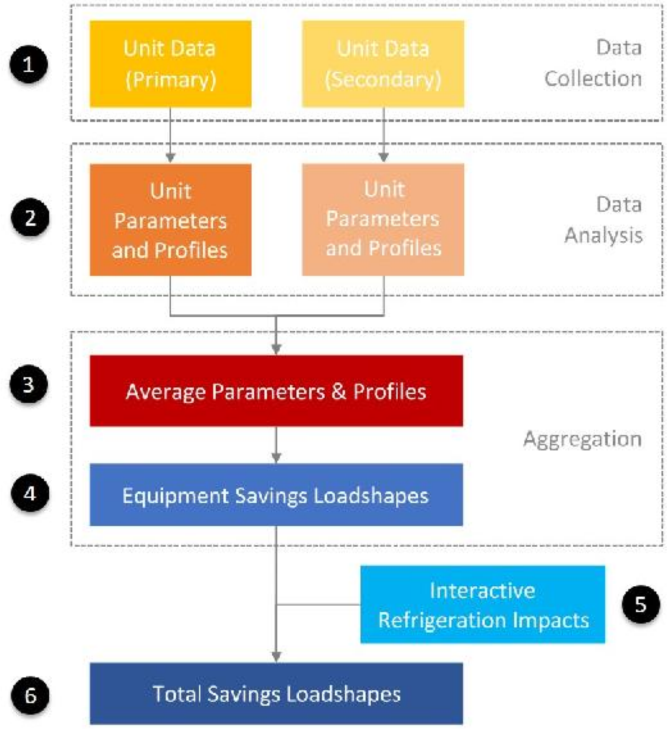
[1] The study was sponsored by eleven states—Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont—and Washington, D.C.

manuals (TRMs), supporting demand resource values submitted to forward-capacity markets, and air emission impacts.

1.2 Methods

The evaluation team used six steps to develop the total savings loadshapes, including data collection, data analysis, and data aggregation, and calculation of interactive effects (as shown in Figure 1).

Figure 1. Sequence of Steps to Estimate Total Savings Loadshapes



Step 1 involved primary and secondary data collection. We performed pre- and post-installation metering at customer locations in four states and collected secondary data from previous evaluation activities.[2] In **Step 2**, we analyzed meter data to develop key parameters (e.g., average motor operating power) and profiles (e.g., hourly run time with controls) for each measured unit.

In **Step 3**, we combined the unit-level parameters and profiles to estimate population average parameters and profiles. In **Step 4**, we used engineering algorithms to combine population average parameters and profiles and calculate average equipment savings loadshapes for each measure. We used these equipment savings loadshapes to calculate savings metrics such as annual energy savings and average demand savings during peak hours.

2 We collected primary data from Maryland, Massachusetts, New York and Rhode Island. We collected secondary data from Connecticut and Massachusetts.

In **Step 5**, we estimated the interactive effects of the retrofit measures on refrigeration system loads and power. Finally, in **Step 6**, we combined the refrigeration interactive effects with the equipment savings loadshapes to estimate the total savings loadshapes.

Final Sample

Table 1 is a summary of the final sample from on-site metering and secondary data collection tasks.

Table 1. Final Measurement Sample (Primary and Secondary Data)

Measure	Number of Sites	Number of Unique Measurements
ECM Retrofits	48	92
EF Motor Controls	35	57
ASDH Controls	22	29

We collected primary data at 40 unique sites in Maryland, Massachusetts, New York, and Rhode Island and secondary data from an additional 19 unique sites in Massachusetts and Connecticut. Since many refrigeration projects include a combination of the three retrofit measures, we collected data on all three measures at many sites. At some sites, we collected only pre-retrofit data, at some sites we collected only post-retrofit data, and at some sites we collected both pre- and post-retrofit data. Section 3.3 provides additional details on the final sample.

We found some instances of unusual circumstances that required stakeholder discussion to determine appropriate treatment of the site data. For example, we found one pre-retrofit evaporator fan SP motor that already operated with controls. We used the full load motor operating power in our calculation for average SP motor power. However, since the control was older and made by a different manufacturer than the other controls observed in our sample, we did not include the run-time measurement in our post-installation data analysis for evaporator fan controls. For a full list of special cases, see Section 3.5.2.3.

The majority of sites were small retail facilities, such as liquor stores, convenience stores, delis, and pharmacies. There were several small chain restaurants, one nursing home, and one large retail facility. Table 2 shows the final sample by building type for the 40 primary data collection sites visits for this study.

Table 2. Final Sample by Building Type (Primary Data)

Building Type	Count of Sites
Small Retail	35
Restaurant	3
Other*	1
Large Retail	1
Total	**40**

*Nursing home

Site visits took place in BGE territory in Maryland where measures were installed by National Resource Management, Inc. (NRM), Anthony International, and Johnson Controls; National Grid territory in Massachusetts and Rhode Island with measures installed by NRM; and Con Edison territory in New York with measures installed by Global Energy Efficiency (GEE) and Willdan. Measurements for the 19 secondary sites took place in National Grid territory in MA and Eversource territory in Connecticut.[3][4]

The majority of cases we measured were walk-in coolers. Table 3 shows the makeup of our final sample by temperature (cooler vs. freezer) and case style (walk-in vs. reach-in).

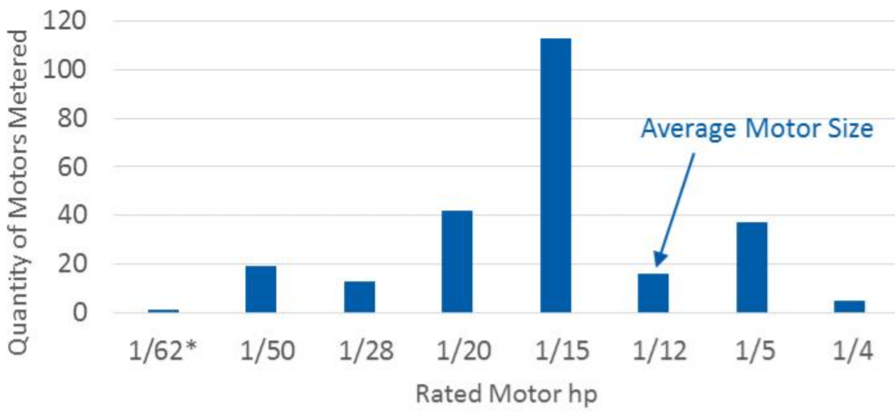
Table 3. Percent of Final Measurement Sample by Case Type

Characteristic	ECM Retrofit	EF Motor Controls	ASDH Controls
Case Temperature			
Cooler	80%*	93%	55%
Freezer	10%*	7%	17%
Unknown**	11%*	0%	28%
Case Style			
Walk-in	53%	79%	72%
Reach-in	11%	21%	14%
Unknown**	36%	0%	14%

*These numbers do not sum to 100% due to rounding error.
**Certain characteristics of some cases included in our sample are unknown because they were not recorded in the secondary data.

Figure 2 shows the quantity of post-retrofit ECMs metered by rated horsepower.

Figure 2. Quantity of Motors Metered by Rated Horsepower



[3] There was one site in Maryland where the installer is unknown.

[4] The Connecticut data was from a secondary source and the installer is unknown.

*Motors rated below 1/50 hp are typically reported in watts; value presented is equivalent horsepower.

The majority of installed motors are rated at 1/15 horsepower, but we observed motors ranging from 12 Watts (equivalent to 1/62 hp) to 1/4 hp. The average rated horsepower from our sample was 1/12 hp. If the program administrator cannot track the installed motor horsepower, we recommend using 1/15 hp as the standard value to evaluate savings.

Unit Parameters and Profiles

To estimate savings for evaporator fan motors and ASDHs, the evaluation team used primary and secondary data to assess key parameters (single values) and profiles (hourly values based on time of day and day of week). The average full load operating power is a key parameter to determine the power draw of motors and door heaters. The effective hourly run-time profiles provide hourly estimates of the operating status of equipment with or without controls. The evaluation team examined the unit parameters and profiles shown in Figure 3.

Figure 3. Unit Parameters and Profiles

EF Motor ECM Retrofits and Controls	ASDH Controls

• Pre/Post EF Motor Operating Power
• Operating Power for SP Motors (per HP)
• Operating Power for ECMs (per HP)
• EF Motor Run Time without Controls
• ECM Run Time with Controls
	• ADSH Operating Power
	• ASDH Run Time without Controls
	• ASDH Run Time with Controls
	  • *ON/OFF controls*
	  • *Micropulse controls*
	  • *Unknown controls*

* Shaded pole (SP) motors represent the baseline case for evaporator fans.

1.3 Results

The evaluation team created a loadshape calculation tool to estimate hourly energy and demand savings for each retrofit measure. The tool enables the user to select whether to include interactive refrigeration savings, estimate savings separately for coolers or freezers, and compute the savings for any specific period of interest throughout the year.

This report presents annual energy and peak demand savings for three peak periods—ISO-NE summer, ISO-NE winter, and PJM summer—for each measure type, and refrigerator space type (cooler or freezer).[5]

[5] ISO-NE summer comprises 1:00 PM to 5:00 PM on non-holiday weekdays in June through August, ISO-NE winter comprises 5:00 PM to 7:00 PM on non-holiday weekdays in December and January, and PJM summer comprises 2:00 PM to 6:00 PM on non-holiday weekdays in June through September.

1.3.1 Key Findings

This study developed key parameters for estimating savings from ECM Retrofits, EF Controls, and ASDH controls including the refrigeration interactive effects. PAs may use these values to update parameters in their TRMs and to estimate savings values for the three retrofit measures.

1.3.1.1 Key Parameters for ECM Retrofits and EF Controls

Table 4 shows the average parameters calculated for the baseline and installed case.

Table 4. Average Parameters – EF Motors

Parameter	Description	Source	Meter Sample (# Circuits)	Value
$\left(\frac{W_{SP}-W_{ECM}}{W_{ECM}}\right)\times 100$	Percentage change in power relative to post wattage	Pre/post metering only*	9 primary 0 secondary	157%
$\left(\frac{W}{hp}\right)_{ECM}$ ECM hors	ECM power normalized by horsepower (see Figure 42)	All ECM measurements	42 primary 24 secondary	758 W/hp
$\left(\frac{W}{hp}\right)_{SP}$ SP by 45)	SP motor power normalized by horsepower (see Figure 45)	All SP motor measurements	13 primary 5 secondary	2,088 W/hp
$\%_{ON_{NONE}}$ Effective run time o uncontrolled motor	Effective run time of uncontrolled motors	All uncontrolled metering (ECM and SP)	32 primary 0 secondary	97.8%**
$\%_{ON_{ALL}}$	Effective run time of all control styles	All control style metering (ON/OFF and multi-speed)	25 primary 0 secondary	66.5%**
$\%_{ON_{ON/OFF}}$ Effective run time of ON/OFF style control	Effective run time of ON/OFF style control	ON/OFF style control metering	12 primary 0 secondary	63.6%**
$\%_{ON_{MS}}$ Effective speed sty	Effective run time of multi-speed style controls	Multi-speed style control metering	13 primary 0 secondary	69.2%**

* We calculated this parameter by first computing $\frac{W_{SP}-W_{ECM}}{W_{ECM}}$ for each unit for which we collected both pre and post measurements and then averaging these nine values.

** This is an annual run-time value defined as the sum of the hourly run-time values from the population average run-time profile.

The EF motor power parameters are calculated as W/hp so the program administrator (PA) can multiply the parameter by the installed motor horsepower to calculate the W/motor for the baseline case and installed case. PAs that do not track rated horsepower information should use a default motor size of 1/15 hp based on the most common motor size observed in this study (see Figure 2). The baseline case for evaporator fan motors is assumed to be shaded pole (SP) motors because more than 90% of observed baseline motors were SP.

1.3.1.2 Key Parameters for ASDH Controls

Table 5 shows the average parameters calculated for the baseline and installed case.

Table 5. Average Parameters - ASDH

Parameter	Description	Source	Meter Sample (# Circuits)	Value
$\left(\frac{W}{door}\right)_{ASDH}$	Operating power per door	All door heater measurements	21 primary 6 secondary	130 W/door
$\%ON_{NONE}$	Effective run time of uncontrolled heaters	All uncontrolled metering	10 primary 0 secondary	90.7%*
$\%ON_{ALL}$	Effective run time of all control styles	All control style metering (ON/OFF and micropulse)	11 primary 8 secondary**	45.6%*
$\%ON_{ONOFF}$	Effective run time of ON/OFF control	ON/OFF style metering	6 primary 0 secondary	58.9%*
$\%ON_{MP}$	Effective run time of micropulse controls	Micropulse style control metering	5 primary 1 secondary	42.8%*

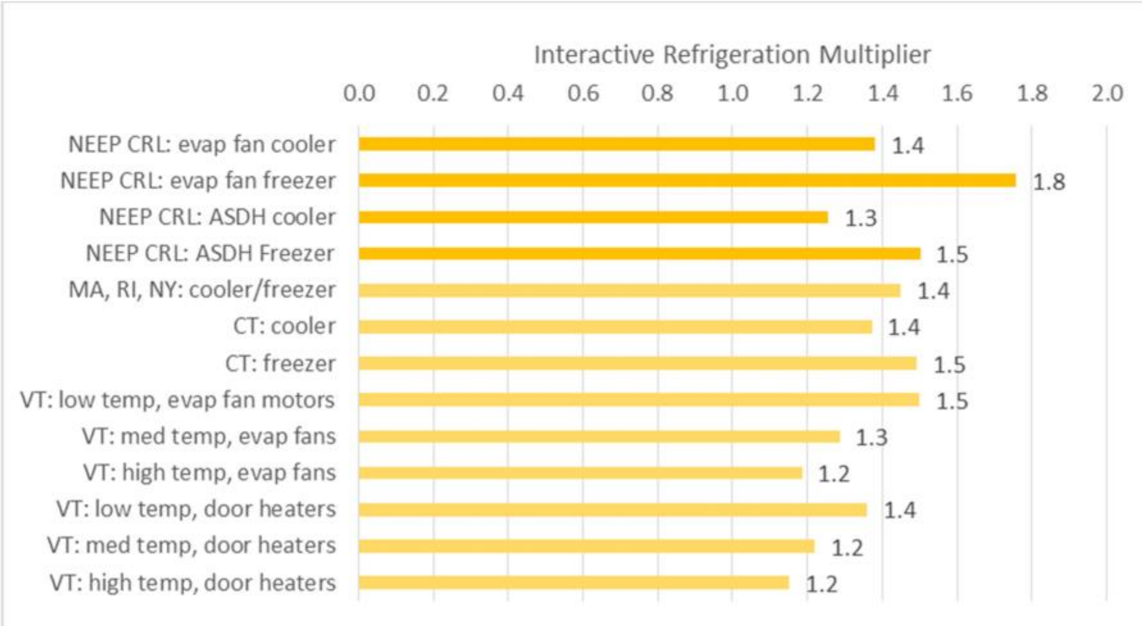
*This is an annual run-time value, defined as the sum of the hourly run-time values from the population average run-time profile.
**The style of seven of the eight controls of the secondary data was unknown; therefore, they are included only in the all-control-style loadshape, not ON/OFF nor micropulse.

The ASDH power parameter is calculated as W/door so the PA can multiply the parameter by the number of doors the ASHD controls were installed on to get the power per circuit. PAs that do not track the number of doors should use an average number of eight doors per circuit. PAs should note that the number of ASDH control per circuit varies by manufacturer. Some manufactures have one control per door, one per circuit, or one for multiple circuits.

1.3.1.3 Refrigeration Interactive Effects

The evaluation team estimated savings factoring in refrigeration interactive effects. Figure 4 compares the average interactive refrigeration savings multiplier applied in this report to TRMs from the Northeast.

Figure 4. TRM Comparison – Interactive Refrigeration Multiplier



The NEEP CRL interactive refrigerator multiplier value for evaporator fans in coolers is consistent with the CT TRM, but slightly higher than the VT TRM. The multiplier is higher than the MA, RI, NY TRMs, which use a blended rate of 1.4 to represent both coolers and freezers. The NEEP CRL interactive refrigerator multiplier for evaporator fans in freezers is much higher than all the TRMs.

The disparity between the NEEP CRL multiplier value and current TRMs might be attributable to the refrigeration equipment characteristics of our sample. The evaluation team based the refrigeration system performance assumptions on the systems in the sample, which is comprised primarily of small commercial businesses. These businesses are less likely to have high efficiency systems than the overall commercial and industrial population, and thus greater refrigeration interactive effects.

For ASDH, the NEEP CRL interactive refrigerator multiplier value for coolers is lower than the CT TRM, but higher than the VT TRM and consistent with the MA, RI, NY TRMs, which uses a blended rate for coolers and freezers. The value for ASDH in freezers is consistent with the CT TRM, but higher than the VT TRM, and presumably consistent with the MA, RI, NY TRMs.

1.3.2 Summary of Annual Energy Savings and Peak Demand Savings

The evaluation team computed cooling savings with interactive refrigeration effects independently for seven weather regions throughout the Northeast and Mid-Atlantic and found that the savings varied by less than 1%. Because the differences are so small, we present weather-independent interactive savings values that we calculated as the average of the seven weather regions.

Table 6 (page 10) summarizes the annual energy savings in kWh/hp and peak demand savings in W/hp with and without interactive refrigeration savings for all evaporator fan motor measures. Program administrators should track the horsepower of installed motors and use the reported savings in as a multiplier. Annual and peak demand savings from the SP to ECM retrofit and ECM controls are additive if the measures are done together.

Table 7 shows the annual energy savings in kWh/door and peak demand savings in W/door with and without interactive cooling savings for both types of ASDH controls as well as a single overall average. Program administrators should track the number of doors per ASDH control installed and use the reported savings in Table 7 as a multiplier. PAs should note that the number of doors per ASDH control varies by manufacturer and application. Some manufactures have one control per door, one control per circuit, or one control for multiple circuits.

Table 6. Key Savings Metrics for Evaporator Fan Motor Retrofits

Equipment Type	Savings Category			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
Annual Energy Savings (kWh/hp)					
SP to ECM Retrofit	10,198	14,122	17,944	5%	4%
EF Controls on SP Motor (All)	5,712	7,908	10,048	3%	2%
EF Controls on SP Motor (OnOff)	6,248	8,650	10,991	3%	3%
EF Controls on SP Motor (MS)	5,217	7,224	9,178	5%	4%
EF Controls on ECM (All)	2,074	2,872	3,650	2%	2%
EF Controls on ECM (OnOff)	2,269	3,142	3,992	2%	2%
EF Controls on ECM (MS)	1,895	2,624	3,334	3%	3%
ISO-NE Summer Peak Savings (W/hp)					
SP to ECM Retrofit	1,155	1,609	2,053	5%	4%
EF Controls on SP Motor (All)	544	758	967	3%	3%
EF Controls on SP Motor (OnOff)	557	776	990	4%	3%
EF Controls on SP Motor (MS)	532	741	945	5%	4%
EF Controls on ECM (All)	198	275	351	2%	2%
EF Controls on ECM (OnOff)	202	282	360	3%	2%
EF Controls on ECM (MS)	193	269	343	4%	3%
ISO-NE Winter Peak Savings (W/hp)					
SP to ECM Retrofit	1,162	1,608	2,042	5%	4%
EF Controls on SP Motor (All)	551	762	968	3%	3%
EF Controls on SP Motor (OnOff)	559	773	981	5%	5%
EF Controls on SP Motor (MS)	544	753	956	5%	5%
EF Controls on ECM (All)	200	277	352	2%	2%
EF Controls on ECM (OnOff)	203	281	356	3%	3%
EF Controls on ECM (MS)	198	273	347	4%	4%
PJM Summer Peak Savings (W/door)					
SP to ECM Retrofit	1,156	1,607	2,048	5%	4%
EF Controls on SP Motor (All)	536	746	950	3%	3%
EF Controls on SP Motor (OnOff)	544	756	963	4%	4%
EF Controls on SP Motor (MS)	529	736	938	5%	5%
EF Controls on ECM (All)	195	271	345	2%	2%
EF Controls on ECM (OnOff)	197	275	350	3%	3%
EF Controls on ECM (MS)	192	267	341	4%	4%

*Interactive savings are averaged over the weather regions shown in the section 0 because the variation among regions was less than 1%.

Table 7. Key Savings Metrics for ASDH Controls

Equipment Type	Savings Category			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
Annual Energy Savings (kWh/door)					
All Controls	515	646	773	5%	4%
On/Off Controls	364	456	546	11%	9%
Micropulse Controls	547	686	821	7%	5%
ISO-NE Summer Peak Savings (W/door)					
All Controls	58	72	87	6%	4%
On/Off Controls	41	52	63	12%	9%
Micropulse Controls	60	76	91	8%	6%
ISO-NE Winter Peak Savings (W/door)					
All Controls	55	69	83	6%	5%
On/Off Controls	39	49	59	13%	10%
Micropulse Controls	56	70	84	9%	7%
PJM Summer Peak Savings (W/door)					
All Controls	57	72	86	6%	5%
On/Off Controls	41	52	62	12%	9%
Micropulse Controls	58	73	88	8%	6%

*Interactive savings are averaged over the weather regions shown in the section 0 because the variation among regions was less than 1%.

1.3.2.1 How to Use Savings Metrics Tables (Table 6 and Table 7)

To use Table 6 and Table 7 to calculate annual and peak period savings for a program, PAs will need to know three pieces of information: the period of interest, the equipment type (measure) of interest, and whether or not they want to consider savings from refrigeration interactive effects. PAs should follow the steps below to calculate savings.

1. **Identify Savings Period of Interest in Column 1**

   In Table 6 or Table 7, identify the sub-heading that corresponds to the desired energy savings period (Annual Energy Savings, ISO-NE Summer Peak Savings, ISO-NE Winter Peak Savings, or PJM Summer Peak Savings).

2. **Identify Equipment Type of Interest in Column 1**

   Underneath the column sub-heading identified in step 1, identify the equipment type (measure) of interest. For example, if a PA wants to know savings for ECM retrofits in the ISO-NE summer peak period, identify the “SP to ECM Retrofit” row underneath the “ISO-NE Summer Peak Savings” column sub-heading.

3. **Look Up Value Corresponding to Savings Category of Interest (Column 2, 3, or 4)**

Depending on whether the PA is interested in calculating savings with or without refrigeration interactive effects, look up the row corresponding to the savings category of interest (column 2, 3, or 4). For instance, if the PA wants to know the ISO-NE summer peak savings for ECM retrofits in cooler cases including refrigeration interactive effects, look up the value in the third column ("Equipment and Interactive (Cooler)"). In this example, the value is 1,609 W/hp.

4. **Multiply Value by Horsepower Per Motor or Quantity of Doors Per Control**
    a. **Evaporator Fans (Table 6):** If the ECM motor horsepower for the program is known, multiply the value found in step 3 by the rated horsepower. If the ECM motor horsepower is unknown, multiply the value found in step 3 by 1/15 hp (the most often installed ECM motor size observed in this evaluation). Table 8 shows example results as savings per measure for equipment in a cooler case and using the ISO-NE summer peak period.
    b. **ASDH Controls (Table 7).** If the quantity of doors per ASDH control is known, multiply the value found in step 3 by the quantity of doors per ASDH control. If the quantity of doors per ASDH control is unknown, multiply the value found in step 3 by eight doors (the average number of doors per ASDH control observed in this evaluation). Table 8 shows example results as savings per measure for equipment in a cooler case and using the ISO-NE summer peak period.
5. **Multiply Result by Quantity of Measures in Program**

    Multiply the results calculated in step 4 by the quantity of units installed in the program to calculate program savings for that measure.

Table 8 shows example results as savings per measure for equipment in a cooler case and using the ISO-NE summer peak period.

Table 8. Example Measure Savings Results

Measure	EF Motor Retrofit	EF Motor Controls	Door Heater Controls
Assumptions	1/15 hp motor	1/15 hp ECM; all controls average	8 doors/control; all controls average
No interactive effects			
Annual Energy Savings	680 kWh/motor	138 kWh/motor	4,120 kWh/control
Peak Demand Savings*	77 W/motor	13 W/motor	464 W/control
With interactive effects (cooler case)			
Annual Energy Savings	941 kWh/motor	191 kWh/motor	5,168 kWh/control
Peak Demand Savings*	107 W/motor	18 W/motor	576 W/control
With interactive effects (freezer case)			
Annual Energy Savings	1,196 kWh/motor	243 kWh/motor	6,184 kWh/control
Peak Demand Savings*	137 W/motor	23 W/motor	696 W/control

* ISO-NE Summer

1.4 Findings and Recommendations

The evaluation team offers the following findings and recommendations for program administrators, implementers, and evaluators of these commercial refrigeration measures to improve the energy savings of installations and the effectiveness of programs.

1.4.1 Key Findings

- All three measure provide both energy and peak demand savings.
- The evaluated operating parameters and savings results for all measures are similar to the values currently estimated in the PAs TRMs.
- All three measures are unobtrusive and provide reliable savings. There is minimal opportunity for interference from the customer that could impact performance.
- The measures have a wide range of commercial applications. The evaluation team observed measure installations in coolers and freezers, walk-in spaces, and reach-in cases. The team also observed measure installations across variety of commercial building types, including small businesses and large commercial facilities.
- The evaluation team observed negligible differences (<1%) in measure performance based on weather. There is therefore no reason for different performance expectation based on geographic region.

1.4.2 ECM Retrofits

- ECM retrofits reduce operating power by 59% on average compared to baseline SP motors.

- Uncontrolled evaporator fan motors operate continuously and therefore adding controls is a good measure for both annual energy and peak demand savings.
- Only two of the observed baseline motors were PSC. Implementation contractors confirmed they are less likely to replace baseline PSC motors because the replacement is less cost-effective compared to SP replacements. Program administrators that use a blended SP/permanent split capacitor (PSC) baseline should consider using a SP only baseline.[6]
- The majority of installed motors are rated at 1/15 horsepower, but we observed motors ranging from 12 Watts (equivalent to 1/62 hp) to 1/4 hp. The average rated horsepower from our sample was 1/12 hp.
- Operating power varies for both baseline SP motors and uncontrolled ECMs. This variation is caused by multiple factors, including differences in rated motor horsepower and efficiency, diameter and pitch of attached fans, and airflow restrictions. Cadmus tested the impact of airflow restrictions on motor power. Refer for Appendix B. Airflow Restriction Testing for the results of the testing. See Section 3.5.2.1 for more detail on the observed variation in operating power.
- The rated horsepower of pre-installation and post-installation motors do not always match. For example, a 1/15-hp SP motor might be replaced with a 1/20-hp ECM, or vice versa. This is due to geometrical constraints and equipment availability.
- One pre-retrofit small grocery site (Site 27. EF-A: Small Grocery) had uncontrolled SP motors that exhibited an average run time of 51%. We confirmed that the motors did not have controls but noted that the power consumption fluctuated rapidly and turned off frequently. This indicated the motor was malfunctioning, which is expected for a small percentage of baseline condition motors.

1.4.3 Evaporator Fan Controls

- Evaporator fan controls reduce run time by 32% compared to fans without controls.
- Controlled evaporator fan motors operate more frequently during peak periods than periods of inactivity, but continue to turn on and off throughout the day and are therefore still a good measure for peak demand savings.
- The average run time for controlled motors varies. This variation is caused by multiple factors, including the control type (ON/OFF style controls which vary the runtime of the motor, versus multi-speed controls which vary the speed and runtime of the motor), space temperature settings, and condition of refrigeration equipment. See Section 3.5.2.1 for more detail on the observed variation in operating power.
- The two types of EF controls (ON/OFF and multi-speed) perform differently. ON/OFF controls resulted in slightly greater energy and peak demand savings than multi-speed controls.

[6] Contractors confirmed SP motors are the predominant equipment used on evaporator fan motors for commercial refrigeration applications. Since they are less efficient than PSC motors, they are also more likely to be targeted for upgrades.

- At two of the sites we included in our analysis, controls were disconnected by the customer. Future metering studies of controls such as these should include investigations of customer behavior to understand whether controls are routinely disconnected by the customer, and if so, the reasons why.

1.4.4 Anti-Sweat Door Heater Controls

- ASDH controls reduce run time by 45% compared to door heaters without controls.
- Controlled ASDHs operate more frequently during peak periods than periods of inactivity, but continue to turn on and off throughout the day and are therefore still a good measure for peak demand savings.

- The two types of door heater controls (micropulse and ON/OFF) perform differently. Micropulse controls resulted in greater energy and peak demand savings than ON/OFF controls.
- There is variation in the run time of uncontrolled ASDH due to manual operation. At one site (2. DH-A: Liquor Store), site personnel manually turned the heaters off every night. Through discussions with contractors, we confirmed this is fairly common operating condition (Section 3.5.2.2).
- The average run time of controlled ASDH varies. This is caused by a variety of factors including type of control and type of sensor.
- ASDH operating power varies depending on the make, model, and condition of the heater.
- Three sites with the same control manufacturer and implementation contractor exhibited no savings despite installed controls.

1.4.5 Recommendations

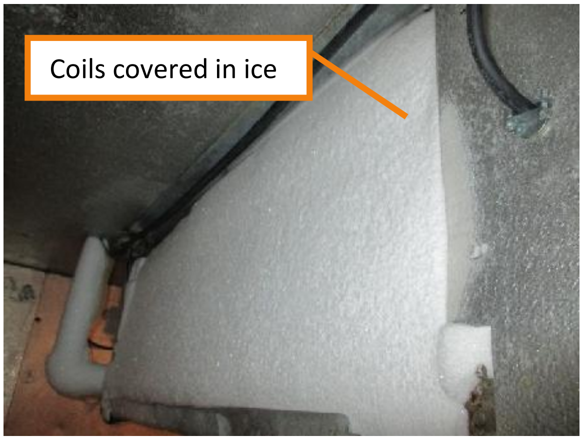
- We recommend the PAs adopt the savings estimates from this study as TRM estimates for the average population or use some of the individual savings parameters developed. Based on our review of PA tracking data, our estimates are representative of the case types (coolers vs. freezers and walk-ins vs. reach-ins) in which measures are installed. We recommend PAs continue to track these differentiators and recommend additional evaluation research to grow the sample and develop case-specific results.

- Current PA estimates of savings are inconsistent in the region due to a variety of sources of assumptions. However, and the evaluation team recommends all PAs adopt the savings results from this study, which represent the current, measured equipment performance in the region. Estimates between PAs should only vary by controller style, if applicable. Controls produced by different manufacturers operate using different strategies, which we observed to impact performance. We recommend sampling different control types during any future evaluations and that implementers record manufacturer and model information on all metered units.

- Cadmus' literature review found few to no studies with pre- and post-installation data, making this the first study with empirical evidence for these three measures. We recommend that any future studies be designed to supplement the data from this study, to increase sample sizes, given the range of performance observed in this study.

- To facilitate future evaluations and updates to savings evaluations, we recommend that implementers record baseline motor type, horsepower, manufacturer, model, and customer behavior as part of an ongoing data collection protocol.
- The power consumed by evaporator fan motors varied significantly between cases due to a variety of factors likely including rated hp, fan size, and airflow restrictions. Measurements of pre- and post-installation operation on single units gave the most reliable data on the impact of ECM retrofits. We recommend that in future studies, PAs work with implementation contractors to facilitate targeting measurements of pre- and post-installation data for each unit.
- Because the evaporator fan motors and ASDHs are located entirely within air-conditioned spaces, we do not expect the measure performance to vary significantly throughout the year. However, we only collected data during the summer and fall; to confirm this hypothesis we would require additional metering data from the winter and spring on the same units.
- The evaluation team observed many iced-up or dirty evaporator coils during the study (Figure 5). These conditions restrict air flow across the evaporator, causing evaporator fan motors to operate at higher powers and the refrigeration system to be less efficient. To enhance the impact of ECM retrofits and installing controls on evaporator fan motors, we recommend incentivizing refrigeration maintenance, such as coil cleaning, by possibly including a one-time coil maintenance with the installation of controls as part of the program delivery, as well as providing general customer education on this issue.

Figure 5. Examples of Poor Evaporator Coil Conditions



2 Introduction

The commercial refrigeration loadshape (CRL) study is the fourth in a series of savings loadshape studies sponsored by NEEP. These studies evaluate the loadshapes of efficient technologies implemented through energy efficiency programs in the Northeast and Mid-Atlantic states. This CRL study examines the annual, peak, and hourly electricity savings achieved by three commercial refrigeration measures commonly installed in commercial buildings throughout the Northeast and Mid-Atlantic states, including Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont, and Washington D.C. The three measures are electrically commutated motor (ECM) evaporator fan retrofits, evaporator fan (EF) motor controls, and anti-sweat door heater (ASDH) controls.

2.1 NEEP EM&V Forum

The Northeast Energy Efficiency Partnerships (NEEP) is a nonprofit organization established to promote energy efficiency throughout the Northeast and Mid-Atlantic states.[7] NEEP created the Regional Evaluation, Measurement, and Verification Forum (EM&V Forum) in 2008 "to support the development and use of consistent protocols to evaluate, measure, verify, and report the savings, costs, and emission impacts of energy efficiency and other demand-side resources."

In particular, the EM&V Forum facilitates joint research and evaluation by pooling funds from multiple sponsors to conduct large-scale research studies such as the loadshape series.[8] These studies provide estimates of the hourly energy and demand savings achieved by energy efficiency measures in the Northeast and Mid-Atlantic states.

Figure 6 shows the EM&V Forum sponsors and indicates the states participating in this commercial refrigeration loadshape project.

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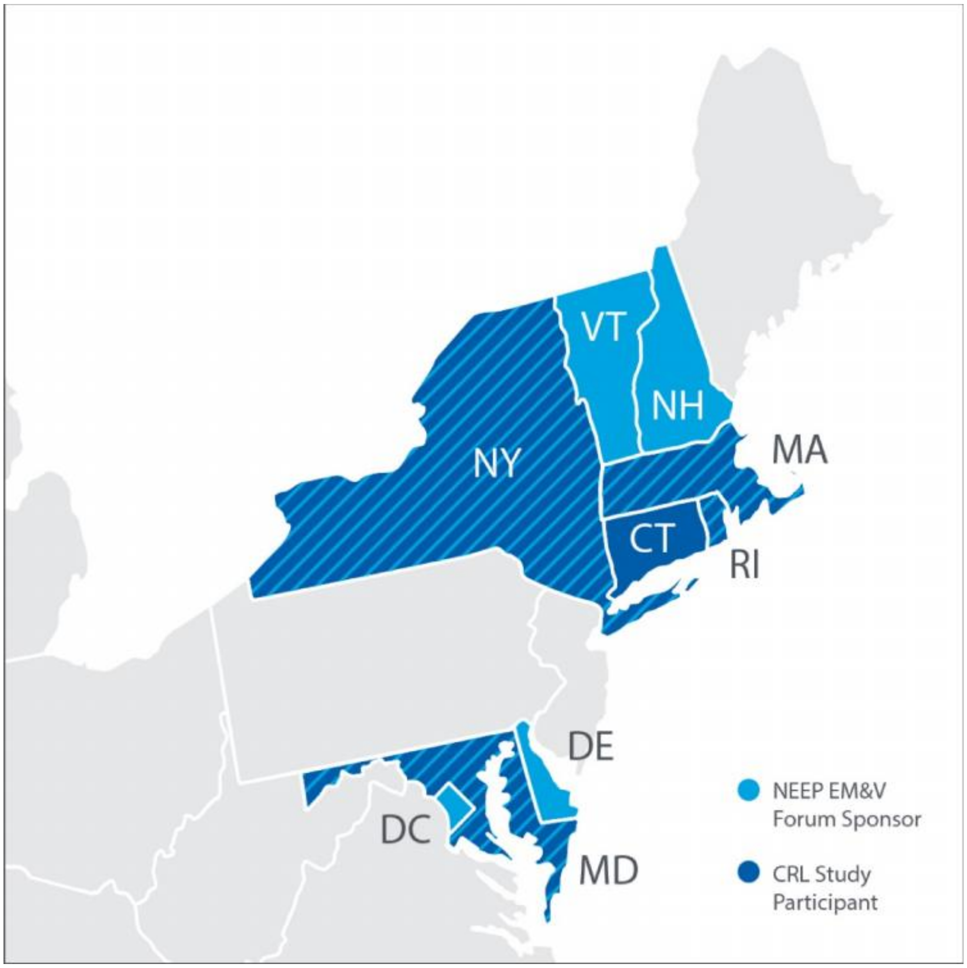
7 More information about the Northeast Energy Efficiency Partnership can be found at www.neep.org.

8 The NEEP EM&V forum has completed three loadshape studies to date: The Commercial Lighting Loadshape Study (completed in 2011), the Unitary AC Loadshape Study (completed in 2012), and the VSD Loadshape Study (completed in 2014).

Figure 6. EM&V Forum Sponsors and CRL Study Sponsors and Participants*



*CT provided secondary data, but is not a sponsor.

2.2 Project Objectives and Scope

This CRL study examines three commercial refrigeration efficiency measures delivered throughout the Northeast and Mid-Atlantic states:

- ECM retrofits on evaporators fans
- EF motor controls
- ASDH controls

For each measure, the study's goals are to:

- Produce annual (8,760) hourly savings loadshapes
- Determine peak demand and annual energy savings

- Provide recommendations to improve prescriptive savings estimates, such as those described in technical reference manuals (TRM)

The study uses both primary data—direct power metering and data collection for a sample of measure installations across the sponsors' programs—and secondary data from existing studies to establish the hourly savings loadshapes for each of these selected measures.

2.3 Technology Review

For each measure, the sections below describe the typical baseline and installed conditions and how the measure saves energy.

2.3.1 ECM Retrofits

Evaporator fans circulate cool air in refrigerated spaces by drawing air across the evaporator coil and into the space. Fans are found in both reach-in and walk-in space types. Figure 7 shows an evaporator fan box with two evaporator fans located in a walk-in cooler used to store produce.

Figure 7. Example of Two Evaporator Fans in a Walk-in Cooler

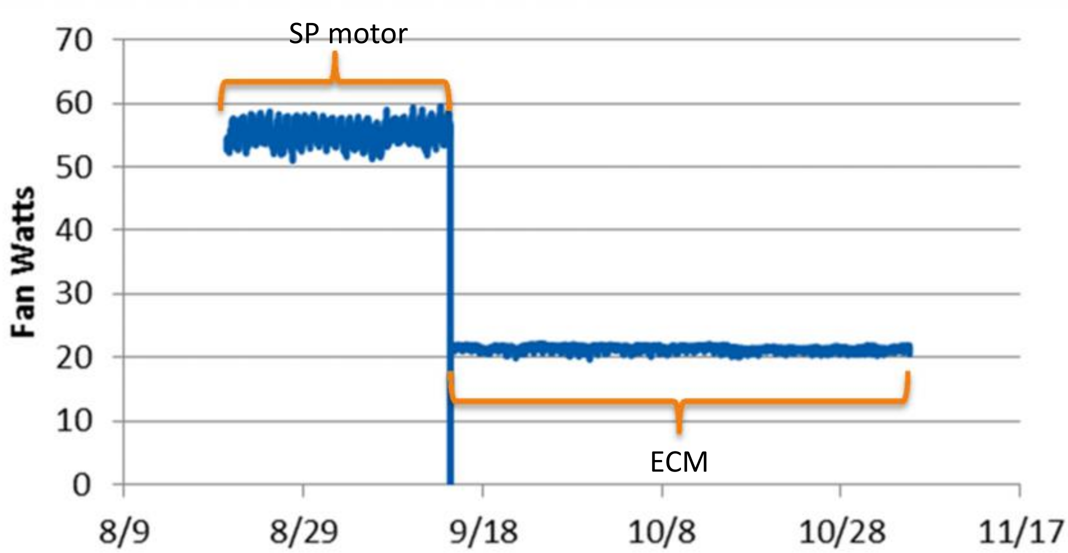
Figure 8 shows a single evaporator fan located in a reach-in cooler used to store dairy products.

Figure 8. Example of Evaporator Fan in a Reach-in Cooler

Evaporator fans are typically powered by SP motors (which held true for 23 of the 25 cases we observed in this study). In two cases, the baseline motor was a permanent split capacitor (PSC) motor. Because it accounted for more than 90% of the baseline cases, we considered SP as the baseline case for our evaluation. In the baseline case, the motors typically run 24 hours a day, seven days per week (24/7).

The installed case for this measure is an ECM. Without controls installed, ECMs also run 24/7, but save energy compared to baseline motors because they have a lower operating power than SP and PSC motors. Figure 9 shows an example of impacts on operating power when a SP motor is replaced with an ECM.

Figure 9. Example of Operating Power for ECM Retrofit (SP replaced with ECM)



This figure shows the one-minute interval power data collected by the evaluation team before and after the ECM retrofit. Before the ECM retrofit, the SP motor operated 24/7 at approximately 55 watts. After the ECM was installed on September 14, the motor still operated 24/7 but with a reduced power of 21 watts.

Energy and demand savings for this measure are achieved by the reduction in motor operating power. Additional savings come from refrigeration interactive effects. Because ECMs are more efficient and use less power, they introduce less heat into the refrigerated space compared to the baseline motors and result in a reduction in cooling load on the refrigeration system.

2.3.2 Evaporator Fan Controls

As demonstrated in the previous section, baseline uncontrolled evaporator fan motors usually operate continuously at constant speed. Evaporator fans controls reduce fan run time or speed depending on the call for cooling, thus saving energy and reducing demand. Figure 10 and Figure 11 show evaporator fan motor controls installed on evaporator fan boxes.

Figure 10. Example of EF Motor Controls in Walk-In Cooler

Figure 11. Example of EF Controller for ECM

The evaluation team observed two types of evaporator fan controls:

- Multispeed controls change the speed of the motors in response to the call for cooling.
- ON/OFF controls turn the motors on and off in response to the call for cooling.

Figure 12 and Figure 13 shows examples of these two control methods. Both figures show one-minute interval power data over a one-hour period.

Figure 12 shows an example of a fan power when operating with multispeed controls. The operating power of a multispeed control fluctuates from high to low power at seven- to eight-minute intervals.

Figure 12. Example of Operating Power for EF Motor with Multispeed Controls

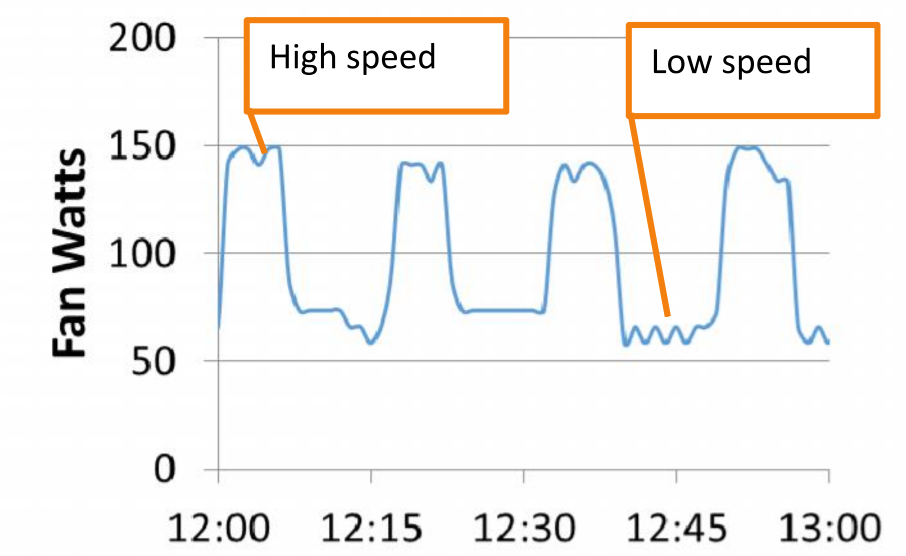
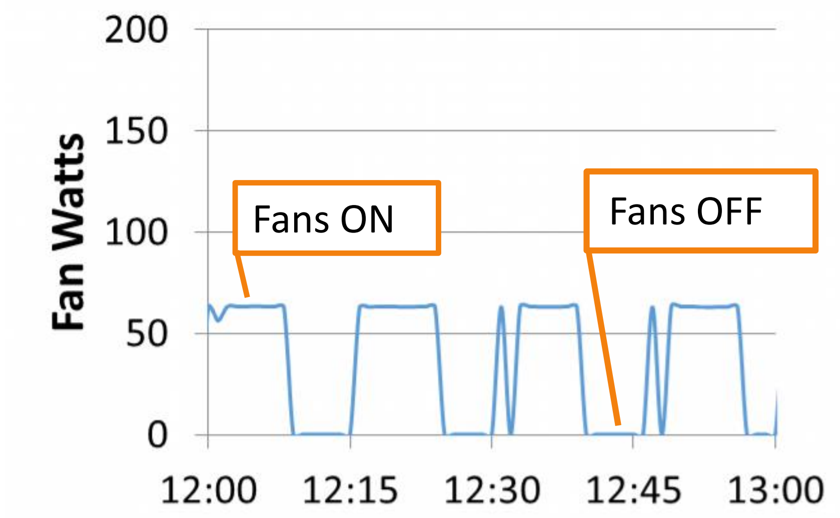


Figure 13 shows and example of ON/OFF controls. The power of an ON/OFF style control fluctuates between ON and OFF in seven- to eight-minute intervals.

Figure 13. Example of Operating Power for EF Motor with ON/OFF Controls



For the multispeed controls, energy and demand savings come from a reduction in operating power and run time (multispeed motors can also turn OFF). For the ON/OFF controls, savings come from a reduction in run time. Because evaporator fan controls reduce motor operating power and/or run time, they introduce less heat into the refrigeration and produce additional savings from reducing cooling load.

2.3.3 Anti-Sweat Door Heater Controls

Anti-sweat door heaters, also known as anti-condensate door heaters, prevent condensation from forming on cooler and freezer doors. In the baseline case, the heaters run 24/7. The heaters can be set to run at intervals (or pulsed)—micropulse controls pulse at small intervals and ON/OFF controls turn on or off for longer periods, in response to the call for heating, which is typically determined using either a door moisture sensor or an indoor air temperature and humidity sensor to calculate dew point. Figure 14 shows an ASDH control and Figure 15 shows a door moisture sensor.

Figure 14. Example of ASDH Control Installed on Reach-in Case

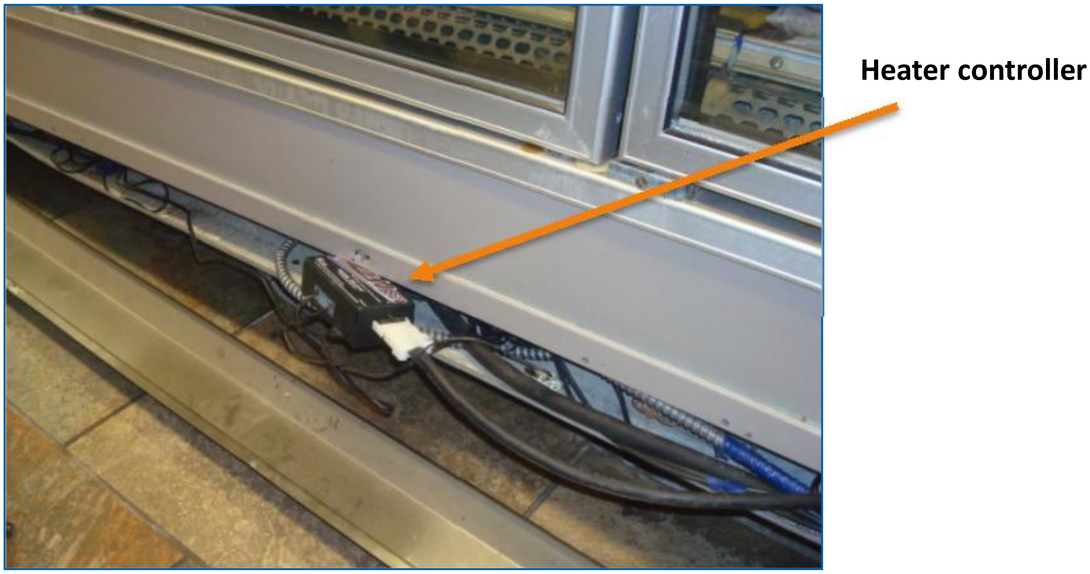


Figure 15. Example of Moisture Sensor for ASDH Control

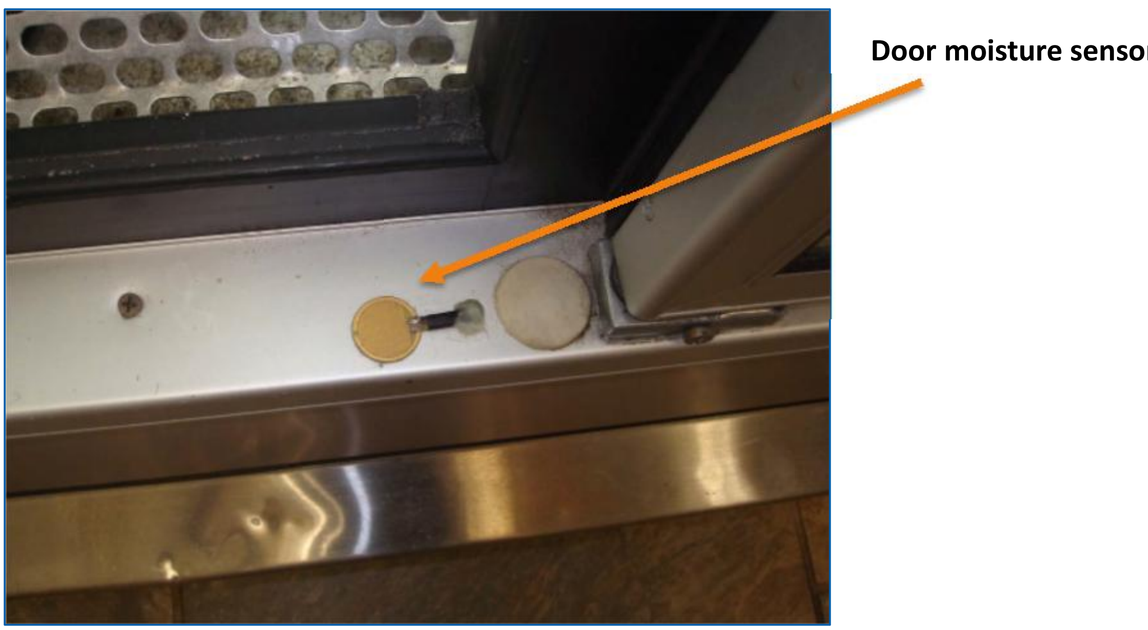


Figure 16 and Figure 17 show examples of the impact on power of the micropulse and ON/OFF ASDH controls, respectively.

Figure 16. Example of Operating Power for ASDH with Micropulse Controls

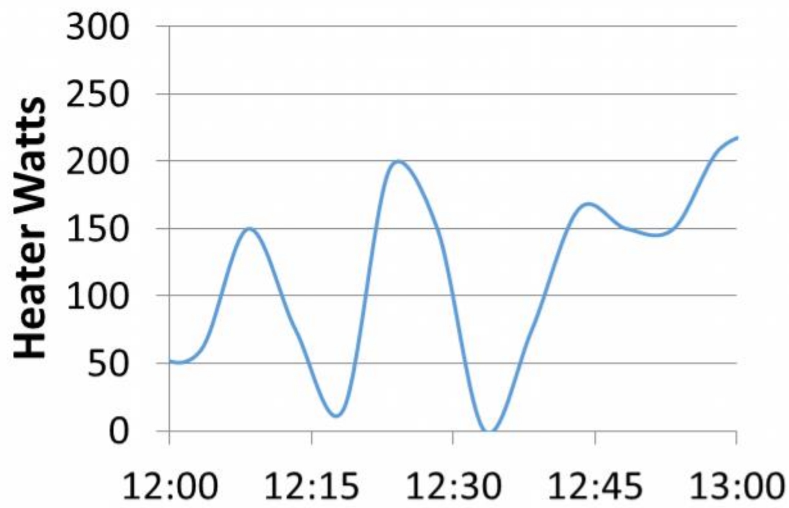


Figure 17. Example of Operating Power for ASDH with ON/OFF Controls

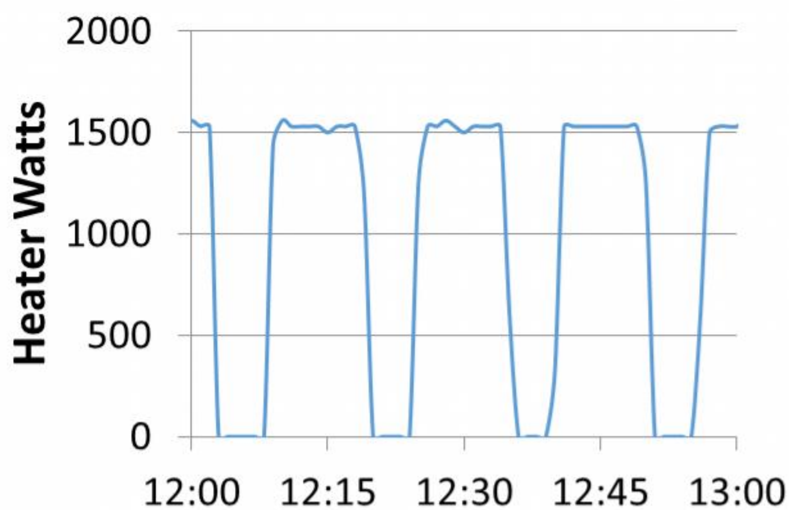
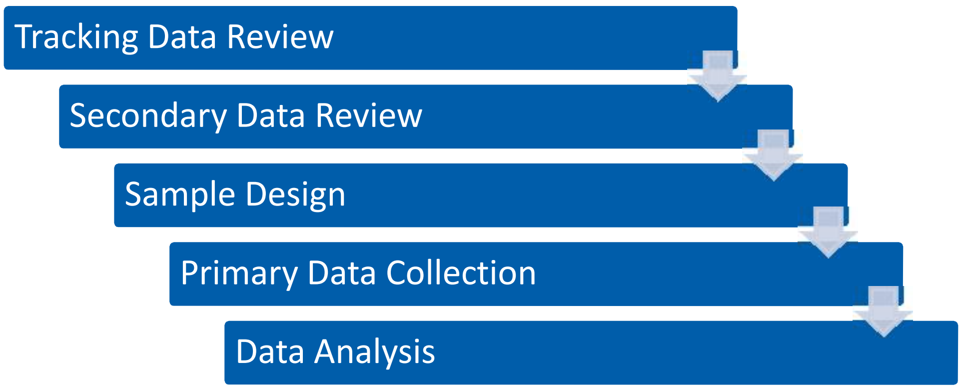


Figure 16 and Figure 17 show one-minute interval power data for ASDH controls over a one-hour period. Micropulse controls pulse the door heaters for fractions of a second, in response to the call for heating. Because Figure 16 shows the operating power at a one-minute interval resolution, the micro-reductions in run time appear as a reduction in operating power. The ON/OFF controls turn the heaters on and off for minutes at time, resulting in a reduction in run time. Both of these reductions result in energy and demand savings. Additional savings come from refrigeration interactive effects. When the heaters run less, they introduce less heat into the refrigeration system and reduce the cooling load.

3 Methods

The evaluation team completed five key tasks, as listed in Figure 18. The progression of tasks for this CRL study is similar to the previous loadshape studies and other EM&V research commissioned by NEEP. In this section and the appendices, we describe the methods for each analysis task and our observations and assumptions.

Figure 18. Key Tasks for Commercial Refrigeration Loadshape Analysis



3.1 Tracking Data Review

The evaluation team asked participating program administrators (PAs) for the past two years of program tracking data on prescriptive refrigeration equipment installations. These data showed the distribution of projects across the program administrators' service territories, the distribution of measures across projects, and the tracked energy savings for each measure and each program administrator.

In this section, we summarize the project and measure level information contained in the data and describe some of the key population characteristics that informed sample design and site visit planning.

3.1.1 Tracking Data Received

Table 9 lists the data received for each program administrator.[9] These data were for ECM retrofits, evaporator fan controls, and ASDH controls measures.

[9] The evaluation team received program tracking data from Baltimore Gas and Electric, Con Edison, National Grid, and Unitil. NYSEG indicated that few projects had installed the measures of interest, sothey were not included in the sample.

Table 9. Program Administrator Data Received

Program Administrator	Program Tracking Data
Baltimore Gas and Electric (BGE)	Measure level project data including measure quantity and total reported energy and demand savings for 108 unique projects; 2012, 2013
Consolidated Edison	Measure level project data including measure quantity and total reported energy savings for 387 unique projects; 2012, 2013, 2014 (to date)
National Grid	Measure level project data including measure quantity and total reported energy and demand savings for 605 unique projects; 2012, 2013
Unitil	Measure level project data including measure quantity and total reported energy savings for three unique projects; 2012, 2013

3.1.2 Tracking Data Summary

The energy savings estimates provided in the tracking data were calculated differently for each program administrator:

- BGE used DEER 2005 to estimate energy savings for evaporator fan measures, and the Connecticut 2008 Savings Documentation for ASDH controls.
- Con Edison and Unitil used TRM equations to estimate savings.[10]
- National Grid's savings estimates were calculated by National Resource Management, Inc. (NRM).

For each program administrator that provided data, we calculated the total tracked savings and number of measures recorded in each program administrator's dataset. We also calculated the average number of measures per site and determined the number of sites at which all three measures had been installed.

In Table 10, we summarize the total tracked savings (kWh) associated with each measure type and program year. Con Edison recorded the highest kWh savings across years and measure types with a total of 10.2 MWh from the three key refrigeration retrofit measures. Overall, ASDH control measures account for the largest portion of total savings.

[10] Con Edison used the equations in the New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs. Unitil used the equations in Massachusetts Technical Reference Manual.

Table 10. Total Tracked Savings (kWh) by Measure and PA

Year	Program Administrator				
	Measure	BGE	Con Edison	National Grid	Unitil
2012	ECMs*	354,796	307,613	1,026,423	21,105
	EF Controls	3,314	0	1,572,159	0
	ASDH Controls	1,129,915	252,684	914,362	0
2013	ECMs*	35,356	2,314,800	971,952	11,793
	EF Controls	0	1,389,484	1,767,443	0
	ASDH Controls	239,417	5,896,582	1,005,357	0
Total	ECMs*	390,152	2,622,413	1,998,375	32,898
	EF Controls	3,314	1,389,484	3,339,602	0
	ASDH Controls	1,369,332	6,149,266	1,919,719	0
	ALL	**1,762,798**	**10,161,162**	**7,257,696**	**32,898**

*ECM retrofits were specified for display cases and walk-in coolers in the Con Edison and National Grid datasets but not in the BGE dataset.

In Table 11, we summarize the total number of measures recorded within measure type. ECM retrofits are the most common measure, appearing with the highest frequency across the program administrators.

Table 11. Total Tracked Measures by Measure and PA

Year	Measure	Program Administrator			
		BGE	Con Edison	National Grid	Unitil
2012	ECMs*	5,932	658	2,025	1
	EF Controls	7	0	441	0
	ASDH Controls	1,043	55	301	0
2013	ECMs*	628	4,282	1,904	2
	EF Controls	0	809	515	0
	ASDH Controls	221	1,983	344	0
Total	ECMs*	6,560	4,940	3,929	3
	EF Controls	7	809	956	0
	ASDH Controls	1,264	2,038	645	0
	ALL	**7,831**	**7,787**	**5,530**	**3**

*ECM installations were specified distinctly for display cases and walk-in coolers in the Con Edison and National Grid datasets but not in the BGE dataset.

Table 12 provides the average per-unit kWh savings by program administrator.

Table 12. Average Tracked Unit Savings (kWh)

Measure	Program Administrator*		
	BGE	Con Edison	National Grid
ECM Retrofit (Refrigerated Case)	59	330	249
ECM Retrofit (Walk-In Cooler/Freezer)		964	550
EF Controls	473	1,881	3,320
ASDH Controls	1,083	2,829	2,866

*Unit averages not reported for Unitil due to small total number of measures (3)

Note: Average per-unit savings data calculated as the total reported savings in the PA tracking database divided by the total quantity of units in the PA tracking database.

BGE's per-unit reported savings are lower than both Con Edison and National Grid for all measures. National Grid reports the largest savings per unit for evaporator fan controls, but Con Edison claims the highest savings for ECM retrofits. National Grid and Con Edison have nearly the same average savings from ASDH control installations.

Table 13 lists the number of sites within each program administrator that contain one or more of the measure types (combined across years). This gave us information on the number of measures we could expect to meter at each sampled location and helped us plan our site visits. For example, at the 47 Con Edison project sites, we could expect to meter units of all three types, whereas at all BGE sites, we could expect to measure at most two types of measures. Note that although Con Edison has the highest number of measures (as shown in Table 11), National Grid has the highest number of sites (605) overall (as shown in Table 13). National Grid also has the highest number of sites that include all three measure types (ECMs, evaporator fan controls, and ASDH controls).

Table 13. Number of Unique Measures Installed Per Site

Number of Unique Measures Installed	Program Administrator			
	BGE	Con Edison	National Grid	Unitil
1	65	108	101	3
2	43	232	229	0
3	0	47	275	0
Total Number of Sites	**108**	**387**	**605**	**3**

Table 14 lists the average number of measures per site by measure type. Note that the average number of measures per National Grid site was quite a bit lower than at either the BGE or Con Edison sites. BGE had the highest number of ECMs and evaporator fan controls installed per site (67 on average) and Con Edison had the highest number of ASDH controls installed per site.

Table 14. Average Number of Measures per Site

Measure	Program Administrator*		
	BGE	Con Edison	National Grid
ECM Retrofit (Refrigerated Case)	64	32	20
ECM Retrofit (Walk-In Cooler/Freezer)		11	6
EF Controls	7	5	2
ASDH Controls	27	29	2

*Averages not reported for Unitil due to small total number of measures (3).

To understand the variation in savings within each program administrator, we calculated the coefficient of variation for each measure type and program administrator. As shown in Table 15, for example, there is greater variability in savings from National Grid's ASDH controls than in National Grid's savings from ECM measures.

Table 15. CV of Unit Tracked Savings (kWh)

Measure	Program Administrator**		
	BGE	Con Edison	National Grid
ECM Retrofit (Refrigerated Case)	0.436	1.599	0.208
ECM Retrofit (Walk-In Cooler/Freezer)		0.621	0.297
EF Controls	N/A*	0.496	0.489
ASDH Controls	0.000	0.596	0.744

*Sample size too small to calculate standard deviation.
**Unit-level savings not reported for Unitil due to small total number of measures (3)

In addition to energy savings, BGE and National Grid datasets also recorded demand savings. Table 16 shows the average per-unit kW savings each reported. As with the recorded per-unit energy savings, BGE's reported per-unit demand savings were much lower than those reported by National Grid.

Table 16. Average Unit-Level Tracked Savings (kW)

Measure	Program Administrator***		
	BGE	Con Edison*	National Grid**
ECM Retrofit (Refrigerated Case)	0.01	N/A	0.03
ECM Retrofit (Walk-In Cooler/Freezer)			0.10
EF Controls	0.06	N/A	0.32
ASDH Controls	0.02	N/A	0.16

*Savings in kW not reported
**Values are based on Peak Diversified kW Reduction dataset values.
***Average unit-level savings not reported for Unitil due to small total number of measures (3)

Table 17 shows the coefficient of variation (CV) of the average per-unit demand savings recorded by BGE and National Grid.

Table 17. CV of Average Unit Tracked kW Savings

Measure	Program Administrator****		
	BGE	Con Edison*	National Grid**
ECM Retrofit (Refrigerated Case)	0.077	N/A	0.003
ECM Retrofit (Walk-In Cooler/Freezer)		N/A	0.099
EF Controls	N/A***	N/A	0.667
ASDH Controls	0.001	N/A	0.750

*Not reported
**Used Reported Peak Diversified kW Reduction
***Sample size too small to calculate standard deviation
****Average unit-level savings not reported for Unitil due to small total number of measures (3)

3.1.3 Summary of Findings from Tracking Data Review

From our review of the tracking data, we determined that:

- The 2012 and 2013 participation populations in BGE, Con Edison, and National Grid territories provide a sufficient number of sites for post-installation metering. Other program administrators may also have had sites available for sampling, but they did not have significant participation levels.
- Given the expectation of a small number of sample sites for metering, the project sampling plan attempts to meter customer types that would be typically served by the sponsors.
- The average tracked savings for each measure vary by program administrator. BGE reported the lowest average savings by measure across all measures, National Grid reported the highest average savings for evaporator fan control installations, and Con Edison reported the highest savings for ECM installations. Con Edison and National Grid reported nearly identical average savings for ASDH control installations.

Our review of the tracking data demonstrates that sponsors are reporting different savings for nearly identical measure installations. The study therefore does not attempt to create a sample representing the populations based on reported energy savings.

3.2 Secondary Data Review

The team collected secondary data—including reports and raw metering data from previous evaluation studies—to design the sampling plan and supplement the primary data collection. This section discusses the secondary data records collected and how they were useful in shaping project analysis and overall approach.

We used secondary data in two ways. First, to establish the sampling approach and metering protocols for the overall analysis plan, we collected and analyzed available secondary data from completed evaluations, technology assessments, and TRMs from the Northeast and Mid-Atlantic. Our review confirmed or determined the following operating parameters and the variability in performance across measure installations (to inform the sampling plan):

- Evaporator fan motors and door heaters without controls operate nearly continuously (24/7).
- Door heater control operation does not vary with outside temperatures, so data collection can be short and at any time of year.
- Although technology performance may not vary by location, implementers use different equipment models in each region, so it is important to capture data in several regions.
- There are limited baseline power measurements available, which suggests the existing TRM savings estimates are based on assumptions and not baseline equipment measurements.

Second, to create a more robust sample, we added any secondary metered data that met the minimum data collection requirements (e.g., metering duration) to the primary dataset. This secondary data research contributed to preparing a more effective evaluation plan, reducing the required evaluation sample, shortening the expected data collection period, and reducing evaluation costs.

We worked with the NEEP project coordinator to request metering data from four commercial refrigeration utility program evaluators. Table 18 shows these vendors and the states in which the secondary data were recorded.

Table 18. Metering Data Received

Vendors	State
Michaels/EMI	CT
KEMA/DNV-GL	CT, MA
DMI	MA

See Appendix A. Secondary Data Review for complete descriptions of the secondary data including sources, type, and value to the study.

3.3 Sample Design

The team designed the evaluation sample for primary data collection to include sites that offer pre-retrofit baseline case (projects that are in the pipeline but had not yet been installed) and installed case (projects that had been installed) metering. Site visits took place in BGE territory in Maryland where measures were installed by NRM, Anthony International, and Johnson Controls; National Grid territory in Massachusetts and Rhode Island with measures installed by NRM; and Con Edison territory in New York with measures installed by Global Energy Efficiency (GEE) and Willdan.[11] [12] The team worked with

[11] There was one site in Maryland where the installer is unknown.

[12] Data collection is limited to the territories of the program administrators that provided tracking data and has significantly large populations from which to sample.

program vendors to identify customers eligible for baseline metering. The team used a random sample, stratified by PA, to identify customers for post-installation metering.

Table 19 and Table 20 show the overall final sample for primary data collection (in number of unique sites) by subcontractor and building type, respectively.

Table 19. Final Site Sample by Implementer (Primary Data)

Implementer	Unique Sites	MD (BGE)	MA / RI (National Grid)	NY (Con Edison)
NRM	18	3	15	0
GEE	11	0	0	11
Anthony International	2	2	0	0
Johnson Controls	6	6	0	0
Unknown	1	1	0	0
Willdan	2	0	0	2
Total	**40**	**12**	**15**	**13**

The majority of sampled projects (29 of 40) were completed by NRM and GEE. NRM is the exclusive large volume implementer for the small business projects in Massachusetts and Rhode Island and also operates in Maryland. GEE installs most refrigeration projects for Con Edison in New York, as a subcontractor to Willdan (which also installs some projects).

Table 20 shows the final sample by building type.

Table 20. Final Sample by Building Type

Building Type	Count of Sites
Small Retail	35
Restaurant	3
Other	1
Large Retail	1
Total	**40**

The majority of installations were in small retail facilities, such as liquor stores, convenience stores, delis, and pharmacies. There were several small chain restaurants, one nursing home (categorized as "Other"), and one large retail facility.

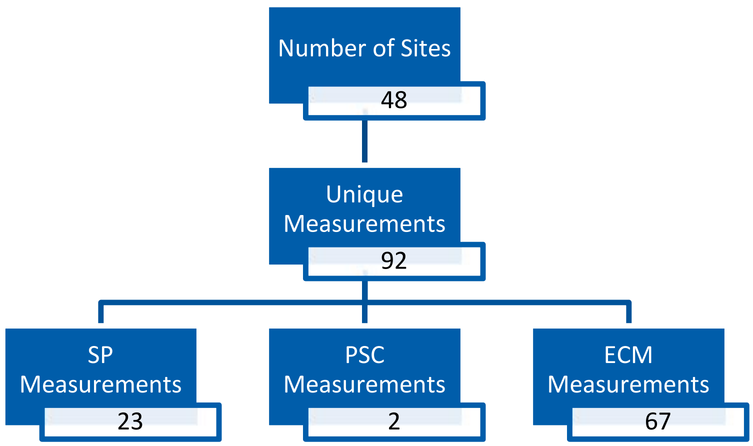
In addition to the 40 total unique sites for primary data, we collected secondary data from an additional 19 unique sites. Since many refrigeration projects include a combination of the three retrofit measures, we collected data on all three measures at many sites.

From the 59 unique primary and secondary sites, we collected a total of 178 unique measurements. The following sections describe the number of sites visited and unique measurements collected for each of the three measures.

3.3.1 ECM Retrofits

Between primary and secondary data collection, the evaluation team collected 92 unique measurements at 48 sites, as shown in Figure 19.

Figure 19. ECM Retrofit Measurements (Primary and Secondary)



There are more unique measurements than sites because the evaluation team often metered multiple cases at a single site. Frequently, one case (i.e., circuit) had multiple motors. Our 92 unique measurements correspond to 317 evaporator fan motors.

We collected measurements before and after installation on nine circuits, before installation only on 16 circuits, and after installation only on 58 circuits. The majority of our measurements were in coolers (80% coolers, 10% freezers, 9% unknown) and walk-in spaces (53% walk-in, 11% reach-in, and 36% unknown).[13]

Table 21 shows the final sample of circuits metered by motor type and state. Nearly three-quarters of our measurements were on ECMs.

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[13] Certain characteristics of some cases included in our sample are unknown because they were not recorded in the secondary data.

Table 21. ECM Retrofit Measurements by Motor Type and State (Primary and Secondary Data)

Motor Type	MD	NY	RI	MA	Total	% of Total
SP	3	9	1	10	23	25%
PSC	0	1	0	1	2	2%
ECM	16	18	3	30	67	73%
Total	**19**	**28**	**4**	**41**	**92**	**100%**
% of Total	21%	30%	4%	45%	100%	

Table 22 shows the final sample of circuits metered by building type. The majority of sites were small grocery stores (38%) and pharmacies (19%).

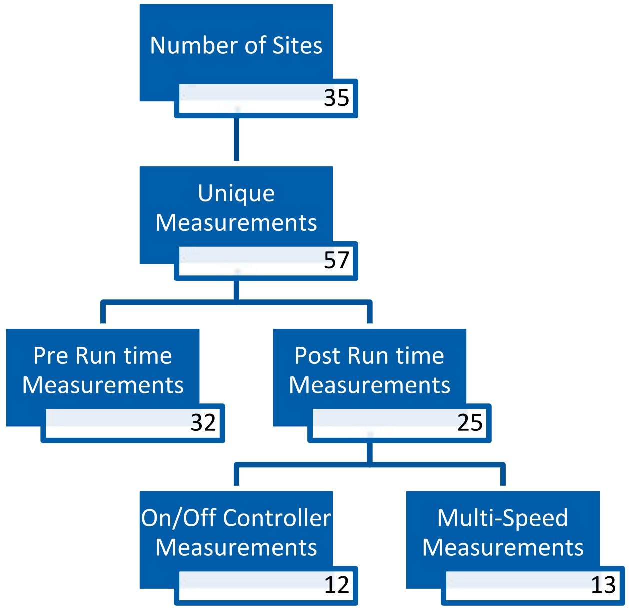
Table 22. ECM Retrofit Measurements by Building Type (Primary and Secondary Data)

Building Types	Percent of Sample
Gas Station	8%
Liquor Store	9%
Nursing Home	2%
Pharmacy	19%
Restaurant	6%
Small Grocery	38%
Small Grocery/Butcher Shop	2%
Small Grocery/Deli	8%
Small Grocery/Take-out	4%
Supermarket	6%

3.3.2 Evaporator Fan Motor Controls

The evaluation team collected 57 unique measurements at 35 sites, as shown in Figure 20.

Figure 20. EF Control Measurements (Primary and Secondary Data)



There are more unique measurements than sites because the evaluation team often metered multiple circuits at a single site. Frequently, one circuit had multiple motors. Our 57 unique measurements correspond to 175 evaporator fan motors.

We collected measurements before and after installation on nine circuits, before installation only on 23 circuits, and after installation only on 16 circuits. The majority of measurements were in coolers (93% coolers and 7% freezers) and walk-in spaces (79% walk-in and 21% reach-in).

Table 23 shows the final sample of metered circuits by control type and state. In some states, implementers may only install certain controls for PA programs. For Con Edison in New York, the implemented only installs multispeed controls. For National Grid in Massachusetts and Rhode Island, the implementer only installed ON/OFF controls in the sampled sites. In Maryland, implementers install a mix of multispeed and ON/OFF controls.

Table 23. EF Control Measurements by Control Type and State (Primary and Secondary Data)

Control Type	MD	NY	RI	MA	Total	% of Total
None*	14	14	0	4	32	56%
ON/OFF Controls	2	0	4	6	12	21%
Multispeed Controls	2	11	0	0	13	23%
Total	**18**	**25**	**4**	**10**	**57**	**100%**
% of Total	32%	44%	7%	18%	100%	

* None indicates operation without controls. This is the baseline for the fan motor controls measure.

Table 24 shows the final sample of circuits metered by building type for evaporator fan controls. The majority of sites were small grocery stores (39%) and pharmacies (18%).

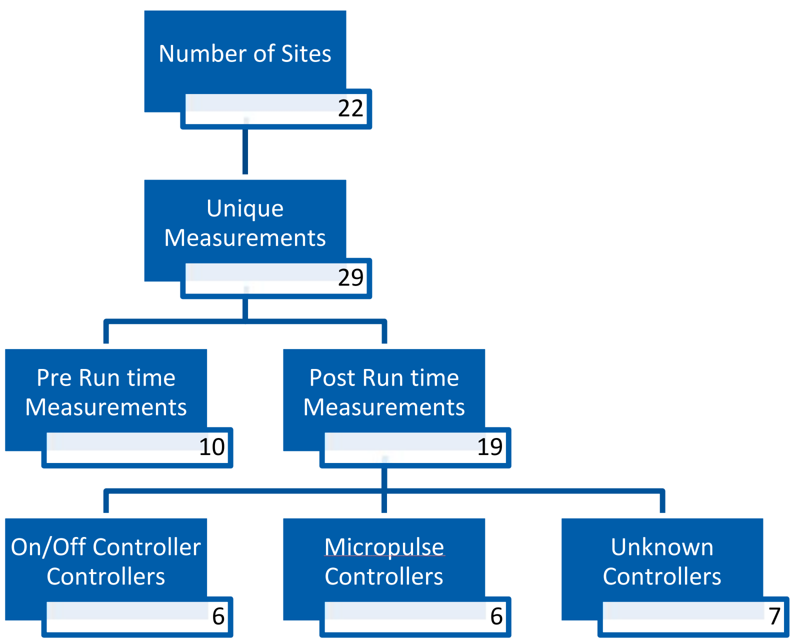
Table 24. EF Control Measurements by Building Type (Primary and Secondary Data)

Building Types	Percent of Sample
Gas Station	11%
Liquor Store	9%
Nursing Home	2%
Pharmacy	18%
Restaurant	5%
Small Grocery	39%
Small Grocery/Butcher Shop	2%
Small Grocery/Deli	5%
Small Grocery/Take-out	5%
Supermarket	5%

3.3.3 Anti-Sweat Door Heater Controls

We collected 29 unique ASDH measurements at 22 sites, as shown in Figure 21.

Figure 21. ASDH Measurements (Primary and Secondary Data)



There are more unique ASDH measurements than sites because the evaluation team often metered multiple case circuits at a single site. Our 29 measurements, which each correspond to a single controller that control a group of doors, correspond to 240 doors.

We collected measurements before and after installation on three circuits, before installation only on 7 circuits, and after installation only on 16 circuits. The majority of our measurements were in coolers (55% coolers, 17% freezers, and 28% unknown) and walk-in spaces (72% walk-in, 14% reach-in, and 14% unknown).

Table 25 shows the final sample of circuits metered by ASDH control type and state. In some states, implementers may only install certain controls for PA programs. For Con Edison in New York, the implementer only installs ON/OFF controls. For National Grid in Massachusetts and Rhode Island, the implementer only installed micropulse controls at the sampled sites. For BGE in Maryland, implementers installed a mix of ON/OFF and micropulse controls.

Table 25. ASDH Measurements by Control Type and State (Primary and Secondary Data)

Control Type	MA	NY	RI	MA	CT	Total	% of Total
None*	7			3		10	21%
All Control Types**	6	2	1	5	8	19	40%
ON/OFF	4	2				6	13%
Micropulse	2		1	2	1	6	13%
Unknown***					7	7	15%
Total	**19**	**4**	**2**	**10**	**16**	**48**	**100%**
Percentage of Total	40%	8%	4%	15%	33%	100%	

*None indicates operation without controls. This is the baseline for the ASDH control measure.
**All is the sum of all control types (ON/OFF + Micropulse + Unknown)
***All unknown control type data are from a secondary source that did not record this information

Table 26 shows the final sample of circuits metered by building type. The most common building type with ASDH installations was pharmacies (28%) and liquor stores (21%). The building type for 28% of the sites is unknown because the data are from previous studies that did not record the building type.

Table 26. ASDH Measurements by Building Type (Primary and Secondary Data)

Building Types	Percent of Sample
Gas Station	7%
Liquor Store	21%
Pharmacy	28%
Small Grocery	10%
Small Grocery/Deli	3%
Supermarket	3%
Unknown*	28%

3.3.4 Sample Recruitment for Baseline Data

For baseline metering, the evaluation team worked with program implementation contractors (implementers) to recruit participants:

- For Massachusetts and Rhode Island, we worked with National Resource Management, Inc. (NRM) to identify and schedule seven baseline sites.
- In New York, we worked with Willdan Energy Services to identify and schedule five baseline sites.
- In Maryland, NRM scheduled three baseline sites. We contacted five additional BGE program contractors to identify more baseline sites. Two contractors reported they had no upcoming retrofits, and we did not receive responses from the other three.

To maximize participation rates and minimize participation bias, we offered gift cards totaling $100 to baseline participants ($50 gift card at the time of meter installation and $50 gift card at the time of meter removal).

3.3.4.1 Selection Bias

Collecting baseline data requires that the evaluator access the equipment before the customer implements the energy-efficient measure. However, because the implementer is responsible for most implementation activities, it could select customers, sites, or projects that are likely to have the best measure performance, for example, poor baseline performance (to demonstrate large improvement), higher load or operating hours (to maximize savings potential), or customers most likely to optimize or sustain measure performance.

Programs with measures that vary across customer sites (e.g., custom programs) or that perform differently depending on the customer (e.g., lighting controls) are more vulnerable to this selection bias. To minimize this risk of this bias, the evaluation team coordinated with the implementer and the program administrator.

The evaluation team coordinated directly with the implementer in each state to identify any eligible customer sites that could delay having the measure installed by at least two weeks to allow for sufficient baseline metering. For convenience and to minimize customer burden, the implementer recruited the sites for inspection and metering and scheduled all baseline visits. We understood this exposed the sample to selection bias but made this choice because we anticipated little variation in measure performance across customer sites (based on our secondary data review) and, therefore, low risk of selection bias on the study results.

3.3.4.2 Performance Bias

Any pre-installation evaluation activities may introduce performance bias in the overall program and measure performance; however, performance bias is not a concern in this study, due to the nature of the measures. When evaluating measures that depend heavily on the customer interaction, performance bias is of concern because the implementer may be more diligent with installation or the customer may be more attentive to proper operation of the measure. However, the simplicity of measure installation and the limited opportunity of the customer to influence measure performance reduced the concerns for these sources of bias. For all three refrigeration measures, installation is relatively simple—it either works or it does not—so the implementer or customer has little influence on the measure performance. The ECM retrofit measure is a straightforward equipment replacement with little variation in the selected make/model of the new equipment. For motor and door heater controls, the implementer installs and connects a control box on the existing equipment, typically using the same make and model of control equipment on all installations; controls typically require a one-time setup with no future interaction by the contractor or customer.

3.3.5 Sample Recruitment for Post-Installation Data

For post-installation metering, the evaluation team randomly sampled participants from PA tracking data showing customers who installed the three commercial refrigeration measures. Although we designed the sample to not require collecting post-installation data only from baseline sites, we worked with implementers in each state to maximize the amount of post-installation data we could collect at sites where we also collected baseline data. Our final sample includes nine sites where we were able to collect both baseline and post-installation data.

Similar to the baseline metering, to maximize participation rates and minimize participation bias, we offered gift cards totaling $100 to baseline participants ($50 gift card at the time of meter installation and $50 gift card at the time of meter removal).

3.4 Primary Data Collection

The evaluation team collected primary data at 40 sites through on-site inspection and metering of key equipment. We completed all on-site metering over a 3-4 month period from August 12 to December 17, 2014.

Figure 22 shows the duration of pre- and post-installation metering for each site. The pink bars indicate baseline metering and the light green bars indicate post-installation metering. For sites in the baseline sample, we collected a minimum of one week of data. For sites in the post-installation sample, we collected a minimum of two weeks of post-installation data. On average, we collected five weeks of pre- and seven weeks of post-installation data.

Figure 22. Metering Period (Primary Data)

We installed data loggers at the majority of sites in August 2014, to capture performance data during the summer season. We installed all loggers at Massachusetts and Rhode Island sites between August 13 and September 11, at Maryland sites during the week ending August 15, and at New York sites during the week ending August 22.

3.4.1 Metering Protocol

We completed on-site data collection and meter installations according to our data collection protocols. In general, we collected key nameplate data and installed power meters on the existing evaporator fan motors and ASDHs to collect the key parameters for the savings loadshapes:

- EF motor power (for baseline and high-efficiency motors)[14]

[14] Some control technologies may vary the power of the motor during operation.

- EF motor run time with and without controls
- ASDH power and run time with controls
- ASDH power and run time without controls[15]

We used program contractor documentation to identify which motors and ASDHs would be (for baseline sites) or were (for post-installation sites) retrofitted. To determine where to install metering equipment at a site, we looked for circuits with isolated measures and clear labeling. The evaluation team used the metering equipment in Table 27 to measure power.

Table 27. Power Logging Equipment

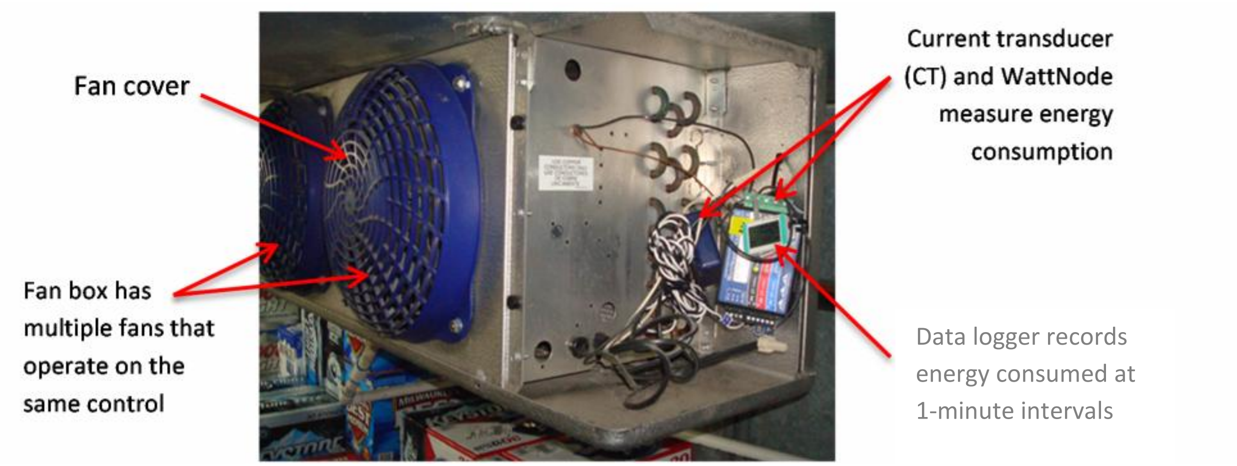
Parameter	Logging Equipment	Logging Frequency
Watts	HOBO UX120-018 Plug Load	1 minute
Watts	HOBO UX190-001M State/Pulse/Event/Run Time	1 minute

In addition to power metering, the evaluation team also installed loggers in the refrigerated spaces to log indoor air temperature and relative humidity data at 1-minute intervals.

3.4.1.1 Evaporator Fan Motors

The evaluation team metered evaporator fan motors in both walk-in and reach-in cases. Figure 23 is an example of our meters installed on an evaporator fan box in a walk-in cooler.

Figure 23. Example of Meter Installation on Evaporator Fans



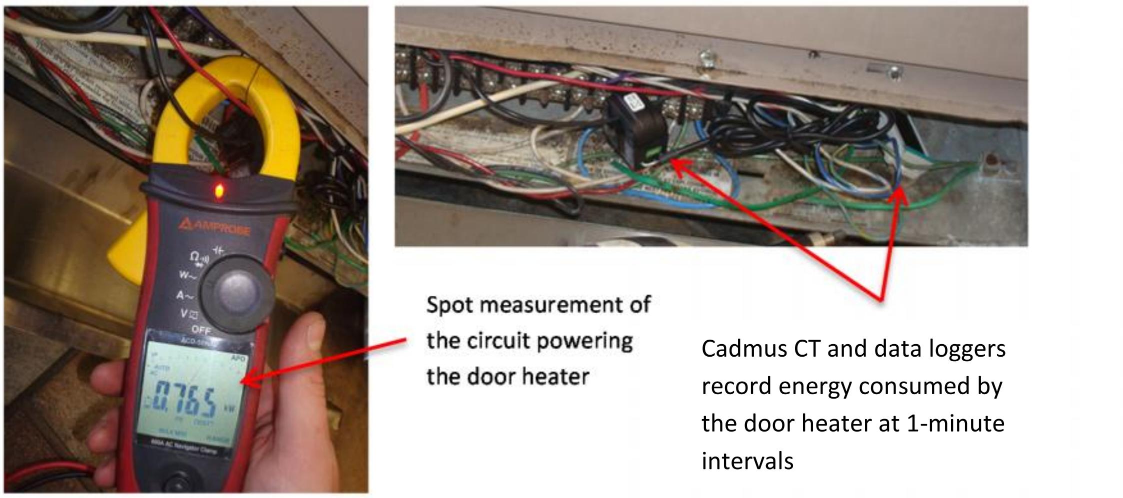
This example shows our data logger recording 1-minute power data on an evaporator fan box with two motors. In the example, the fans do not operate with controls, but we use a similar metering setup for fans or fan boxes with controls.

15 For some ASH control technologies, the run-time control appears as a reduction in average W (rather than standard on/off controls).

3.4.1.2 Anti-Sweat Door Heaters

We metered ASDHs in both coolers and freezers. Figure 24 is an example of our meters installed on an ASDH.

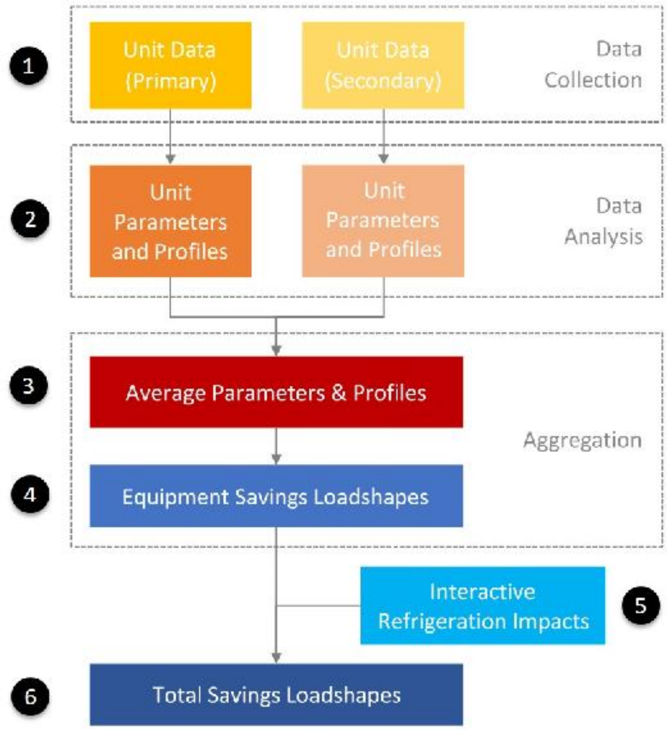
Figure 24. Example of Meter Installation on Door Heaters



3.5 Data Analysis

The evaluation team used six major steps to develop the total savings loadshapes, including data collection, data analysis, and aggregation methods (as shown in Figure 25).

Figure 25. Summary of Methods



Step 1 involved primary and secondary data collection. All data used in the CRL study were based on field verification and metering. We performed pre- and post-installation metering at customer locations in Maryland, New York, Massachusetts, and Rhode Island. We collected secondary data from previous evaluation activities at sites in Massachusetts and Connecticut. In **Step 2**, we analyzed power meter data recorded over a period of weeks or months to develop parameters (e.g., average motor operating power) and profiles (e.g., hourly run time with controls) for each measured unit. We normalized results by number of motors or doors per circuit and rated horsepower per installed motor.

In **Step 3**, we combined the unit-level pre- and post-installation parameters and profiles to estimate population average parameters and profiles. Due to the sampling methods, we calculated these population values as straight averages of the unit values.[16] In **Step 4**, we applied the population average pre- and post-installation parameters and profiles to calculate hourly savings estimates for each measure. We used these equipment savings loadshapes to calculate metrics such as annual energy savings and average demand savings during peak hours.

[16] We developed the baseline sample through collaboration with implementers and developed the post-installation sample through simple random sampling methods (through which each site had an equal opportunity for selection).

In **Step 5**, we developed the model to estimate the refrigeration interactive effects of the equipment retrofit on refrigeration system loads and power. These effects result in additional savings due to the reduced heat rejection requirements on the refrigeration system.

Finally, in **Step 6**, we applied the refrigeration interactive effects model to the equipment savings loadshapes to calculate the total savings loadshapes. The total savings loadshapes represent the combined impacts of the equipment retrofit and reduced refrigeration load. We separated Step 5 and Step 6 from Step 4 to distinguish between savings from the equipment retrofit and saving due to interactive load reduction on the refrigeration systems. Most TRMs use a similar approach to apply these interactive effects as a multiplier on the equipment savings.

3.5.1 Unit Parameters and Profiles

To estimate savings for evaporator fan motors and ASDHs, the evaluation team used primary and secondary data to assess key parameters (single values) and profiles (hourly values based on time of day and day of week). The average full load operating power is a key parameter to determine the power draw of motors and doors. The effective hourly run-time profiles provide hourly estimates of the operating status of equipment with or without controls.

The next sections describe our approach to estimating these parameters and profiles.

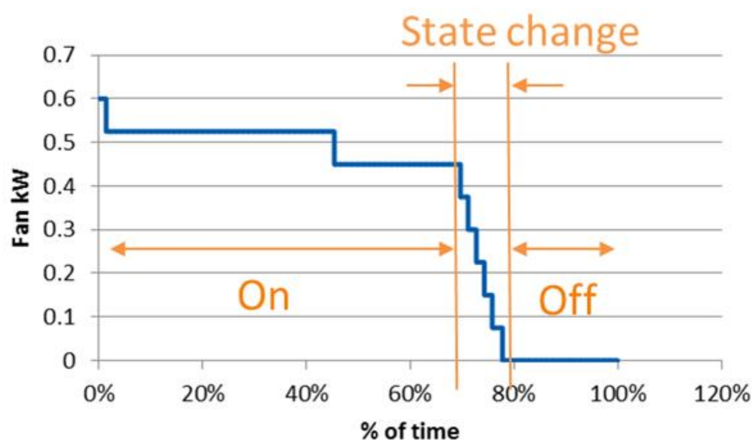
3.5.1.1 Average Full Load Operating Power

We evaluated average hourly pre- and post-installation operating power for evaporator fan motors and ASDHs by collecting one-minute interval power readings from each sampled unit. The meter data showed three modes of operation:

- ON, during which the motor/heater is running at full power for the entire minute interval
- OFF, during which the motor/heater is off
- State change, during which the motor/heater is either running at partial power or is turned ON or OFF within the one-minute interval

Figure 26 shows power data from one evaporator fan motor with controls and identifies the three modes of operation.

Figure 26. Example Load Duration Curve for EF Motor (Post-installation)



To calculate average full load operating power, we averaged the power data during the ON mode only. During the ON mode, it appears the motor is operating at three distinct power levels; however, this is not the result of controls. The changes in observed power during the ON mode are due to factors including the resolution of the sensor and minor changes in power consumption that could result from changes to airflow restrictions, source voltage fluctuations, and air density.[17]

3.5.1.2 Effective Hourly Run Time

The effective hourly run time indicates the equivalent time that the equipment (motor or ASDH) would operate at full power to use the same energy that is consumed in that hour.

The evaluation team evaluated the effective hourly run time for evaporator fan motors or ASDHs by dividing the average measured energy of each hour by the average full load operating power. We use the effective hourly run time to differentiate the impacts of total power reduction (a change in the full load operating power) and controls (a change in run time or a reduction to partial power during the ON state).

3.5.1.3 Evaporator Fans ECM Retrofit

Figure 27 through Figure 30 show the pre- and post-installation average hourly operating power and run time of an example evaporator fan motor retrofitted from a SP motor to an ECM. This unit, located in a reach-in cooler at a small grocery store in New York, did not have any installed controls.

Figure 31 through Figure 34 show the pre- and post-installation average hourly operating power and run time of an example evaporator fan motor retrofitted with 1/20 horsepower (hp) ECM and ON/OFF style fan controls. The baseline motor type was a 1/15 hp SP motor. The unit was a walk-in cooler located at a liquor store in Maryland.

[17] Cadmus tested the impact of airflow restrictions on motor power. Refer for Appendix B. Airflow Restriction Testing for the results of the testing.

Figure 27. Average Hourly Baseline Motor Power[18] (Site 10 EF-B)

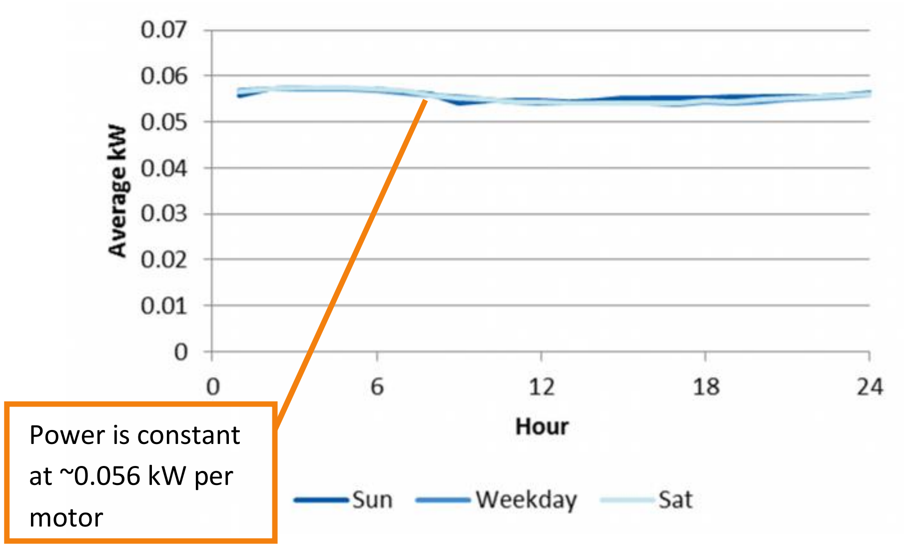


Figure 28. Average Hourly Post-installation Motor Power[18] (Site 10 EF-B)

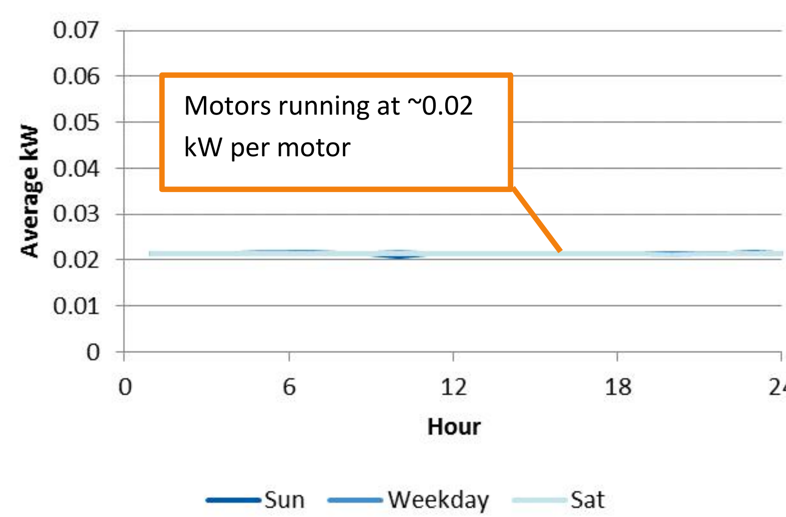


Figure 29. Average Pre/Post Motor Run Time[18] (Site 10 EF-B)

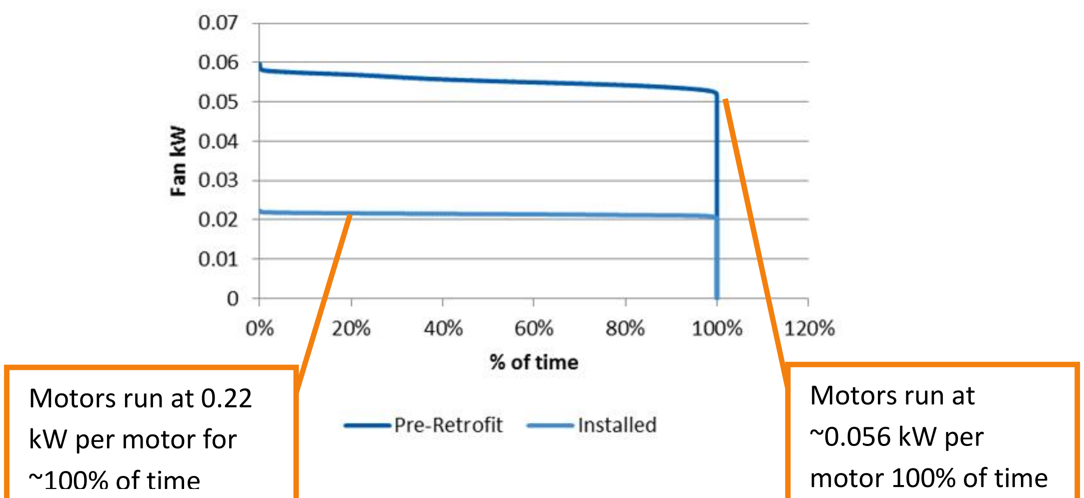
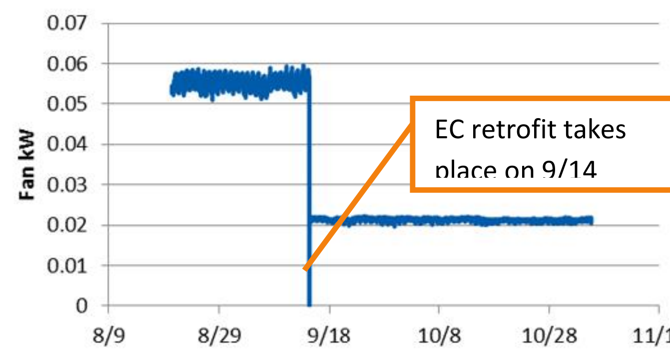


Figure 30. Time series of Metered Motor Power (Site 10 EF-B)



[18] The changes in observed power are due to the resolution of the sensor and minor changes in power consumption that could result from changes to airflow restrictions, source voltage fluctuations, and air density.

Figure 31. Average Hourly Baseline Motor Power[19] (Site 3 EF-A)

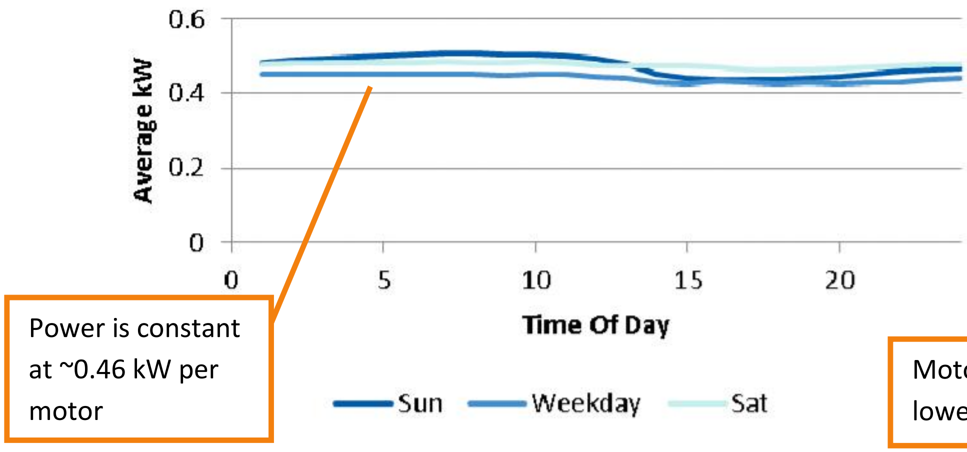


Figure 32. Average Hourly Post-installation Motor Power[19] (Site 3 EF-A)

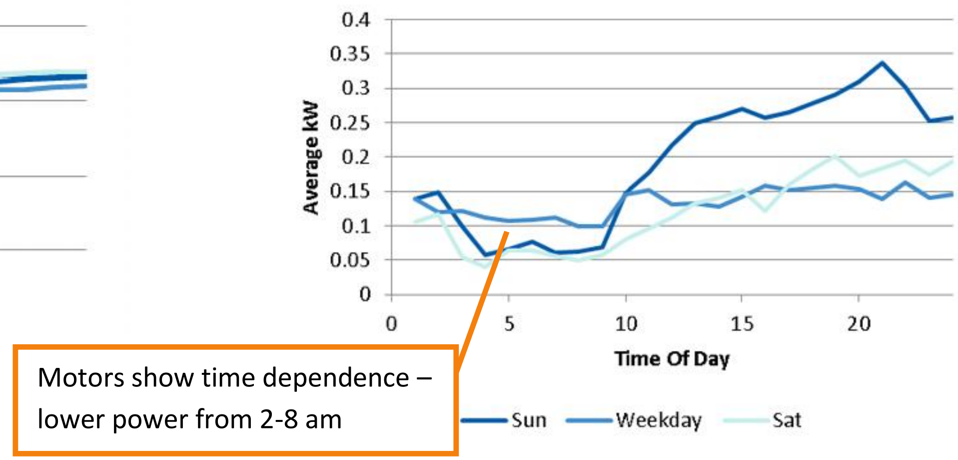


Figure 33. Average Pre/Post Motor Run Time[19] (Site 3 EF-A)

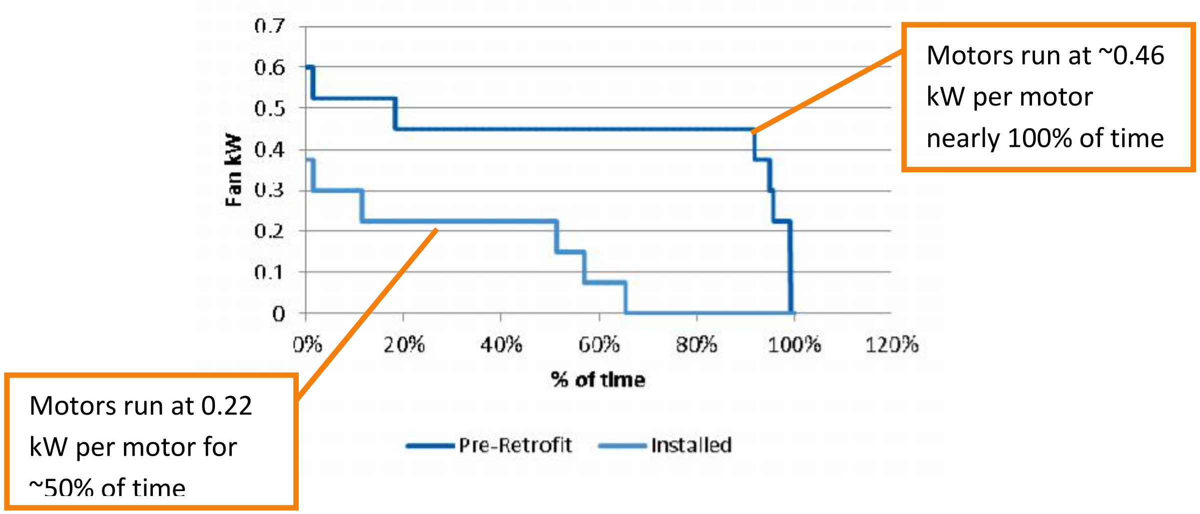
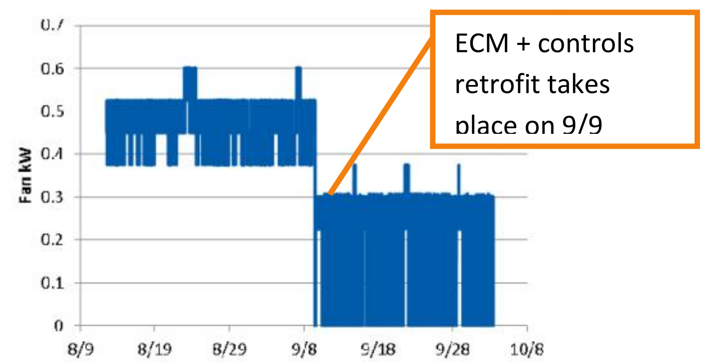


Figure 34. Timeseries of Metered Motor (Site 3 EF-A)



[19] The changes in observed power are due to the resolution of the sensor and minor changes in power consumption that could result from changes to airflow restrictions, source voltage fluctuations, and air density.

3.5.1.4 Anti-Sweat Door Heater Controls

Figure 35 through Figure 38 show the pre- and post-installation average hourly operating power of an example ASDH retrofitted with micropulse style controls. This control operates by automatically calculating the dew point in the store and applying just enough heat to doors to prevent sweating. The unit was located in a walk-in cooler at a gas station in Massachusetts.

Figure 35. Average Hourly Baseline ASDH Power[20] (Site 6 DH-A)

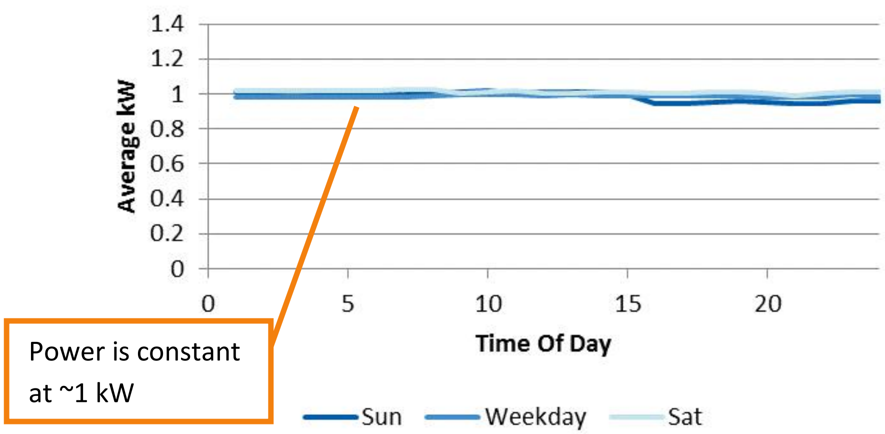


Figure 36. Average Hourly Post-installation ASDH Power[20] (Site 6 DH-A)

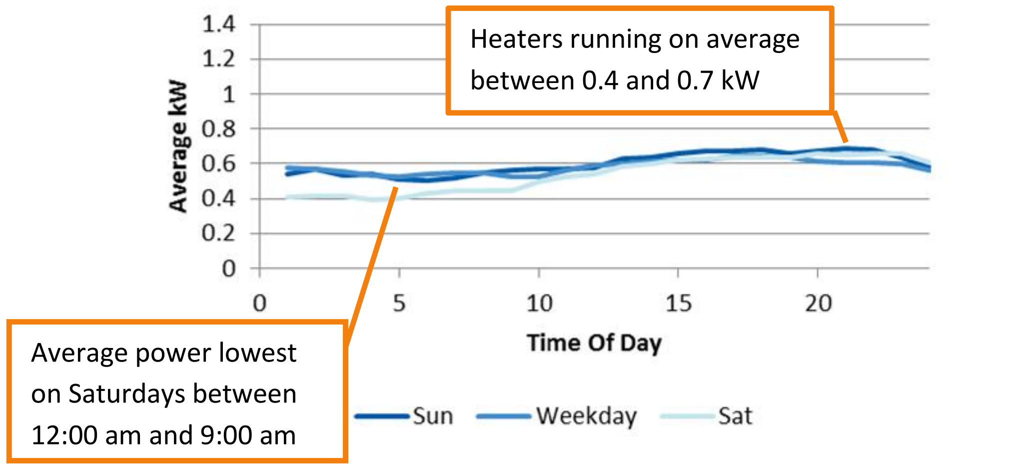


Figure 37. Average Pre/post ASDH Run Time[20] (Site 6 DH-A)

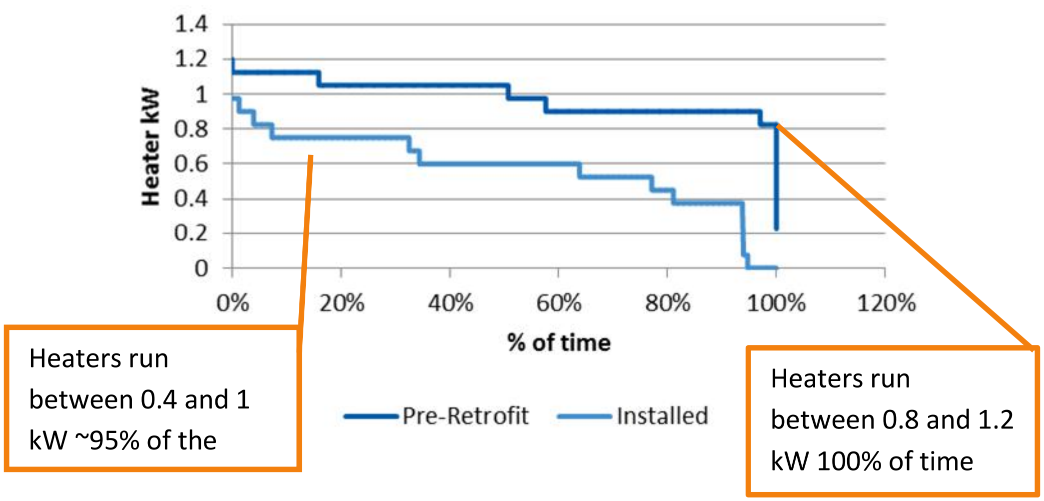
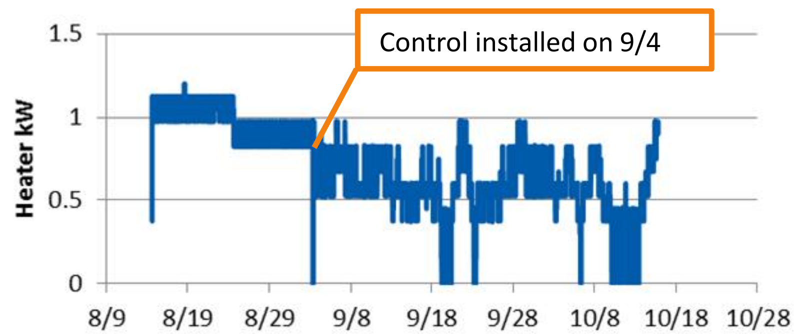


Figure 38. Timeseries of Metered ASDH Power[20] (Site 6 DH-A)



[20] The changes in observed power are due to the resolution of the sensor and minor changes in power consumption that could result from source voltage fluctuations.

3.5.2 Comparison of Unit Data

The evaluation team compared the unit results for key parameters and profiles to assess the variation across units and determine population average results. The figures in the next sections illustrate these comparisons.

3.5.2.1 Evaporator Fan ECM Retrofits and Controls

To examine the performance of evaporator fan ECM retrofits and controls, the evaluation examined the following unit parameters and profiles:

- Pre/Post Evaporator Fan Motor Operating Power
- SP Motors Operating Power (per Horsepower)
- ECM Operating Power (per Horsepower)
- Evaporator Fan Motor Run Time without Controls
- ECM Run Time with Controls

Pre/Post Evaporator Fan Motor Operating Power

Figure 39 compares the pre- and post-installation full load operating power at nine sites where we collected both data both before and after the measure installation. At all nine sites, the new ECM motors replaced existing SP motors. For each site in the figure, the darker bar on the left represents the average baseline power of the SP motor, the lighter bar on the right shows the average power of the new ECMs, and the dot indicates the percentage reduction in motor power.

Figure 39. Unit Comparison – Average Pre/Post EF Motor Operating Power

Note: In all cases, the new ECM replaced a SP baseline motor. The hp shown is of the installed ECM, which was in some cases different than the pre-existing SP motor due to geometrical constraints and availability.

Key Findings: The reduction from pre- to post- retrofit ranged from 36 to 73 percent, with an average reduction of 59 percent. The evaluation team used these percent reduction data to estimate the savings from a motor retrofit measure (see Section 4.1).

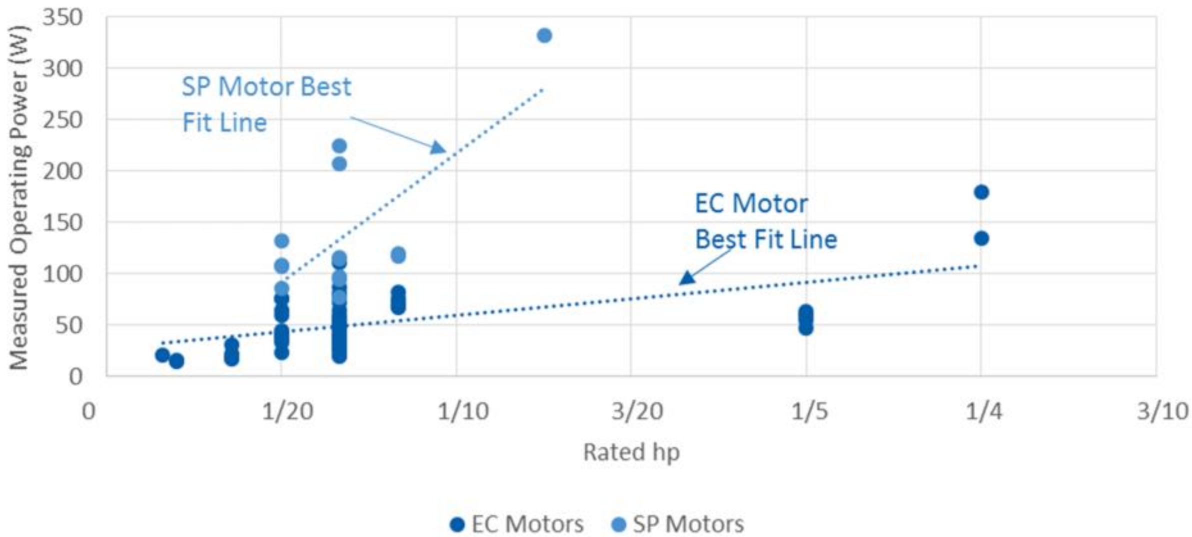
Unexpected Findings: The average motor operating power varies across the sites, even when normalized for motor size (hp). This variation is likely caused by multiple factors, including differences in rated motor horsepower and efficiency, diameter and pitch of attached fans, and airflow restrictions.[21]

Estimating Average Motor Operating Power

For evaporator fan motors, we computed the full load operating power normalized by rated horsepower for each motor. Figure 40 compares measured average operating power to rated horsepower for SP and ECMs.

[21] Cadmus tested the impact of airflow restrictions on motor power. Refer for Appendix B. Airflow Restriction Testing for the results of the testing.

Figure 40. Evaporator Fan Motor Measured Full Load Operating Power vs. Rated Horsepower



Key Findings: As expected, the observed power is proportional to rated horsepower, and for every rated horsepower, the EC motors consume less energy than the SP motors.

Unexpected Findings: There is a natural variation in the average operating power at a given rated horsepower due to factors such as motor efficiency, airflow conditions, and size of the connected fan.

SP Motor Operating Power

Figure 41 compares the full load operating power (normalized by horsepower) for 18 SP motors. The SP motors are from the nine pre/post sites and nine pre-only sites.

Figure 41. Unit Comparison – Average Baseline EF Motor Operating Power (W/hp)*

Note: In all cases, the baseline motor was SP.
*The site numbers beginning with an "S" are from secondary data sources.

Key Findings: The SP motor full load operating power ranged from 1,150 to 3,350 Watts per horsepower, with an average of 2,088 Watts per horsepower. This is the full load power used to calculate savings for controls installed on a SP motor.

Unexpected Findings: The variation in SP motor operating power per horsepower is greater than expected. This is due to a number of factors including the range in efficiencies of motors metered, diameter and pitch of attached fans, and airflow restrictions.[21]

ECM Operating Power

Figure 42 compares the full load operating power (normalized by horsepower) for 66 ECMs. The ECMs are from the 9 pre/post sites and 57 post-only sites.

Figure 42. Unit Comparison – Average ECM Operating Power (W/hp)*

*The site numbers beginning with an "S" are from secondary data sources.

Key Findings: The average ECM full load operating power ranged from 250 to 1,650 Watts per horsepower, with an average of 758.5 Watts per horsepower. We used this result to estimate motor power for ECM retrofits and for controls installed on an ECM (see Section 4.1.1).

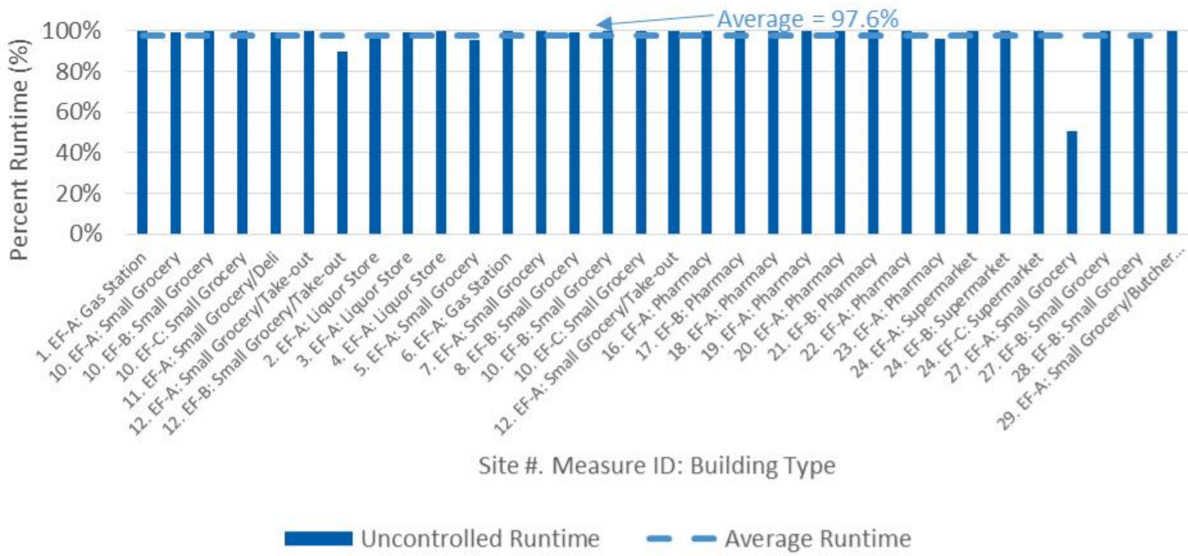
Unexpected Findings: The variation ECM operating power per horsepower is greater than expected. This is due to a number of factors including the range in efficiencies of motors metered, diameter and pitch of attached fans, and airflow restrictions.[22]

[22] Cadmus tested the impact of airflow restrictions on motor power. Refer to Appendix B. Airflow Restriction Testing for the results of the testing.

Evaporator Fan Motor Run Time without Controls

Figure 43 compares average effective run time for 32 uncontrolled evaporator fan motors, including both SP and ECMs. These uncontrolled fan data are from nine pre/post sites and five pre-only sites (uncontrolled SP motors) and 18 post-only sites (uncontrolled ECMs).

Figure 43. Unit Comparison – Average Baseline EF Motor Run Time (%)*



*All data from primary measurements

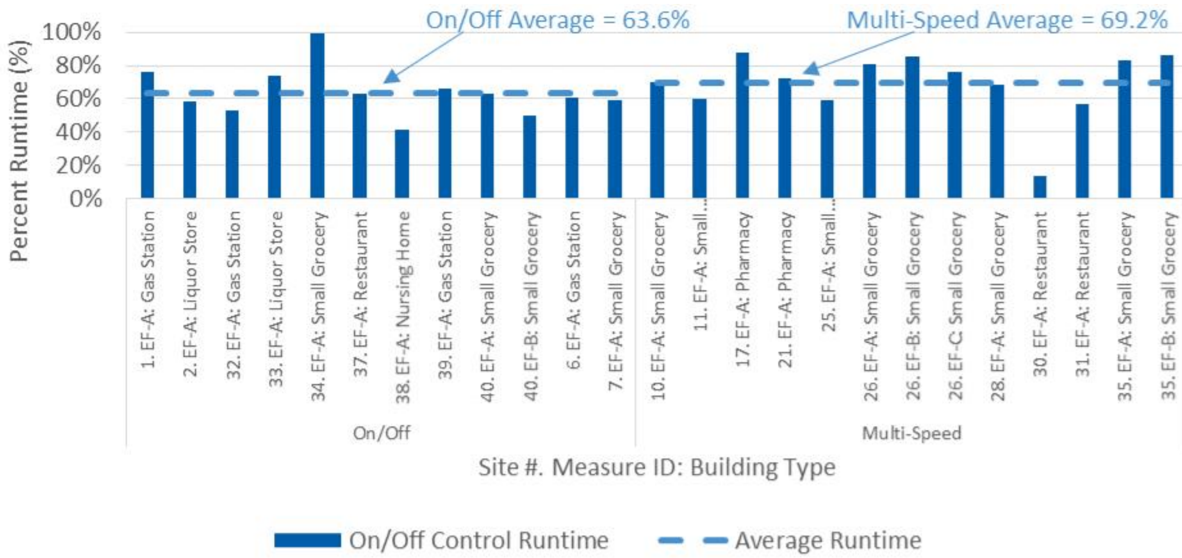
Key Findings: Without controls, almost all evaporator fans operated nearly 100%. The run time is not exactly 100% for most of the motors because some of the evaporator fan motors are off during defrost cycles. The evaluation team used the average hourly run-time profiles as the pre- and post-installation run-time condition for ECM retrofits and the baseline run-time condition for motor controls (see Section 4.1.2).

Unexpected Findings: One unit at a small grocery (Site 27. EF-A: Small Grocery) exhibited an average run time of 51%. We confirmed that the motors did not have controls but noted that the power consumption fluctuated rapidly and turned off frequently. This indicated the motor was malfunctioning, which is expected for a small percentage of baseline condition motors. We included the result in our analysis because it is a real world observation, though it had minimal impact on the overall average run-time value.

ECM Run Time with Controls

Figure 44 compares the run time of 12 ECMs with ON/OFF controls and 13 ECMs with multispeed controls. The ECMs are from the nine pre/post sites, 15 post-only sites, and one pre-only site (controlled SP motor).

Figure 44. Unit Comparison – Average ECM Run Time with Controls (%)*



*All data from primary measurements

Key Findings: Both styles of controls result in reduced evaporator fan motor run time. ON/OFF style controls (run time = 63.6%) slightly outperform multispeed controls (run time = 69.2%). As a result, ON/OFF controls produce slightly greater energy and peak demand savings than multi-speed controls.

Unexpected Findings: We observed a range of operation for both control types: run time ranged from 41.6% to 99.6% for ON/OFF controls, and from 13.6% to 73.8% for multispeed controls. Due to the varied characteristics of these installations (e.g., size, location, and temperature setpoint), the amount that evaporator fans need to operate will vary from case to case.

The evaluation team observed one site where the evaporator fan operated 100% of the time after controls were installed. The technician noted that the case had a performance problem with maintaining the temperature. The technician still installed the controls because the customer expressed intent to fix the problem.

3.5.2.2 Anti-Sweat Door Heaters

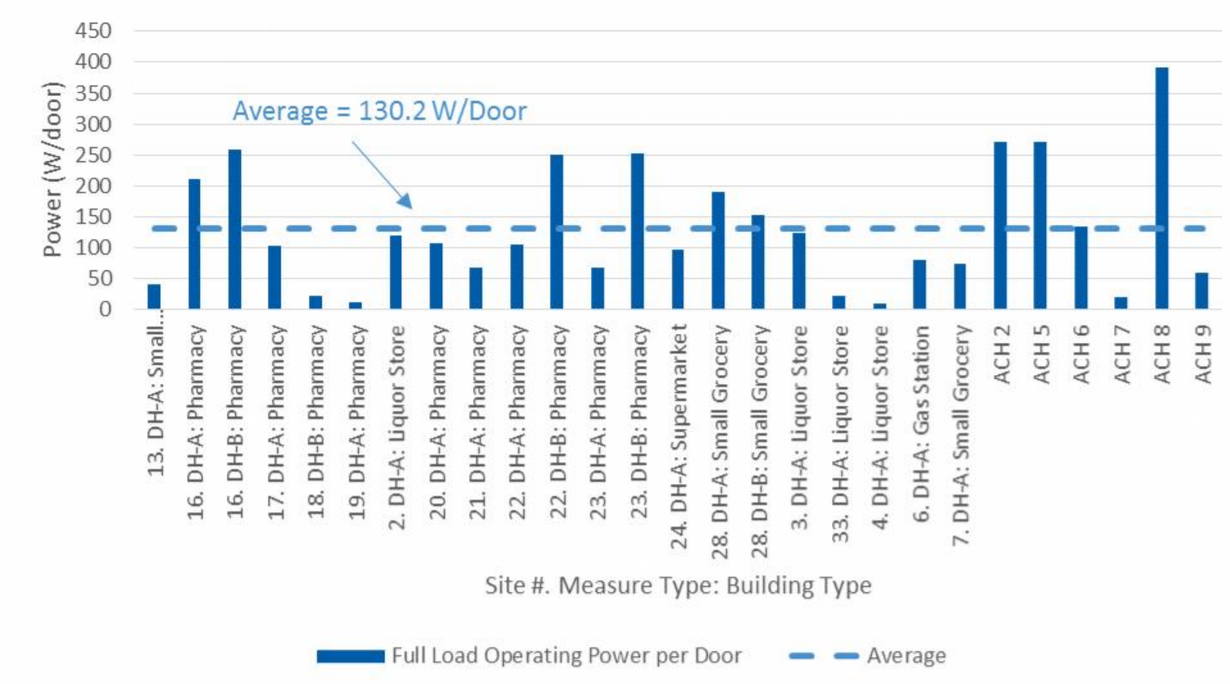
To examine the performance of ASDH controls, the evaluation team compared the following unit parameters and profiles:

- ASDH Operating Power
- ASDH Run Time without Controls
- ASDH Run Time with Controls
    - ON/OFF controls
    - Micropulse controls
    - Unknown controls

ASDH Operating Power

Figure 45 compares the full load operating power of ASDHs normalized by the number of doors from measurements at 27 sites.

Figure 45. Unit Comparison – Average Baseline ASDH Operating Power (W/door)*



*Site numbers that begin with "ACH" are from secondary data collection.

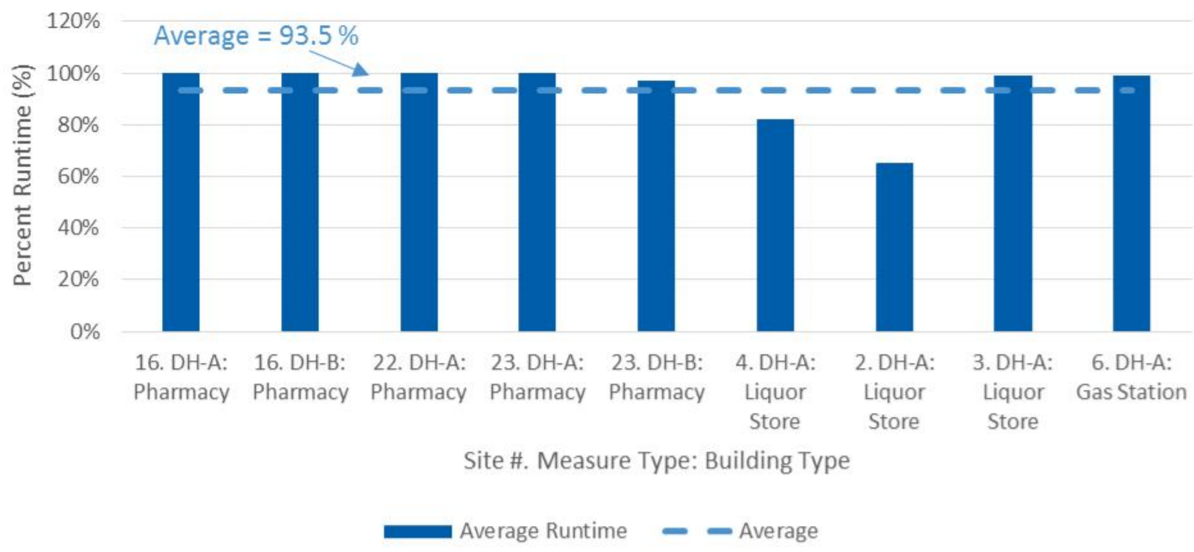
Key Findings: The average door heater full load operating power ranged from 10 to 400 Watts per door, with an average of 130.2 Watts per door. The evaluation team used this result to estimate the full load operating power for door heaters (see Section 4.1.1).

Unexpected Findings: The variation in door power is greater than expected. This parameter depends on factors including the temperature or humidity setpoint, rated door power, and door size.

ASDH Run Time without Controls

Figure 46 compares the effective run time of nine ASDHs operating without controls.

Figure 46. Unit Comparison – Average Baseline ASDH Run Time (%)*



*All data from primary measurements

Key Findings: The average uncontrolled run time for ASDHs was near 100% (overall average = 93.5%). The evaluation team used this result as the baseline run-time condition for ASDH controls.

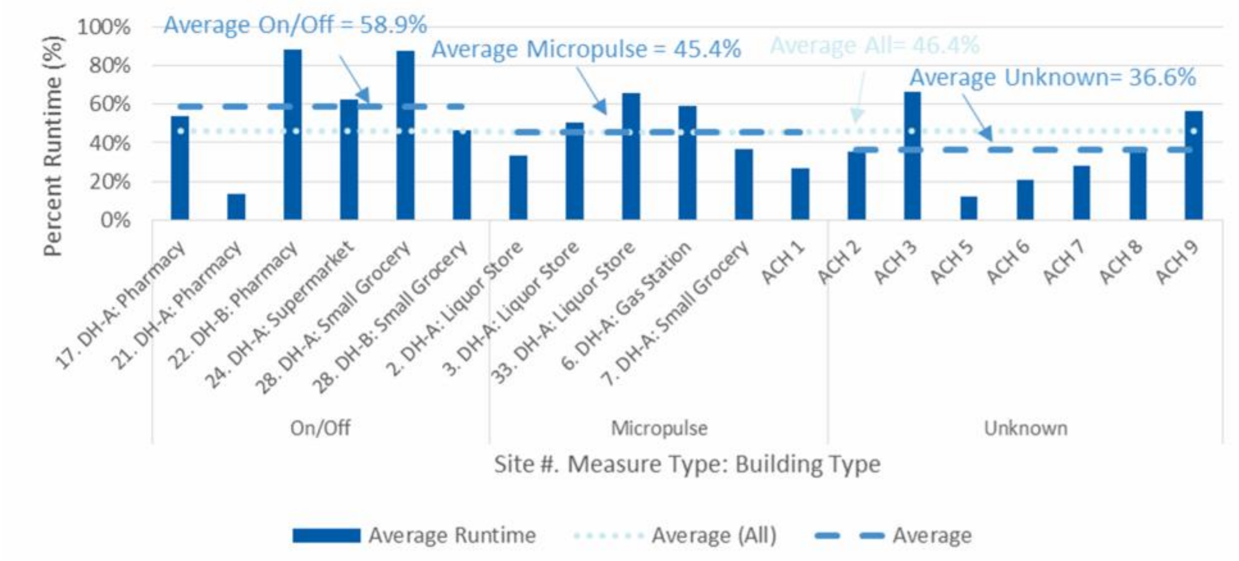
Unexpected Findings: Two of the ASDHs had lower run-time values. At one site (2. DH-A: Liquor Store), site personnel manually turned the heaters on and off every night. Through discussions with contractors, we confirmed this is fairly common operating condition. We collected pre- and post-installation data on this case, so we kept these results because it could be accurately included in both loadshapes. At another site (4. DH-A: Liquor Store), the heater was manually turned off intermittently throughout the metering period for as long as two days at a time. We also included this site in our analysis.

ASDH Run Time with Controls

Figure 47 compares the effective run time of 19 ASDHs with controls (ON/OFF, micropulse, and unknown).[23]

[23] The unknown control type data came from a secondary source that did not track the type of control that was measured.

Figure 47. Unit Comparison – Average ASDH Run Time with Controls*



*Site numbers that begin with "ACH" are from secondary data collection.

Key Findings: The average run time for all ASDHs with controls was 46.4%. The micropulse controls (45.4%) outperformed the ON/OFF controls (58.9%). The evaluation team used these results to estimate performance of ASDH controls (see Section 4.1.2).

Unexpected Findings: The effective controlled run time ranged from 11.9% to 88.3%. This parameter is dependent on many factors, including control strategy temperature setpoint and rated power of the heater.

3.5.2.3 Treatment of Special Cases

Our primary data collection uncovered several atypical scenarios for both baseline and post-installation conditions. This section summarizes these scenarios and our treatment of the data.

Evaporator Fan Motors and Controls

- A SP-to-ECM retrofit that was not provided an incentive through the program.
  - Because the baseline and installed conditions were consistent with our other observations from program-sponsored measures, we included this unit in our analysis.
- Two ECM retrofit measures replaced PSC motors instead of SP motors.
  - Because PSC motors were not prevalent in the sample, we removed them from our analysis. Thus, our results are based on a SP motor baseline.
- One evaporator fan SP motor already had controls installed.
  - Since the control was older and a different make than the other controls observed in our sample, we did not include the measured run time in our analysis. However, we did use the full load motor power in our calculation for average SP motor power.

- Controls installed on a SP motor (rather than an ECM) as part of the program.
    - We included the run-time profile from this controller in our analysis because (1) the control type matched other controllers observed in our sample, and (2) contractors confirmed this was not unusual.
- Two evaporator fan controls units were disconnected, resulting in no savings from controls.
    - Because contractors confirmed that such removal is not unusual, we included these cases in our analysis.
- At one site, a planned controls installation was cancelled after the implementer advised against installing controls.
    - We used this unit as a baseline condition only to estimate full load operating power and motor run time without controls.

ASDH Controls

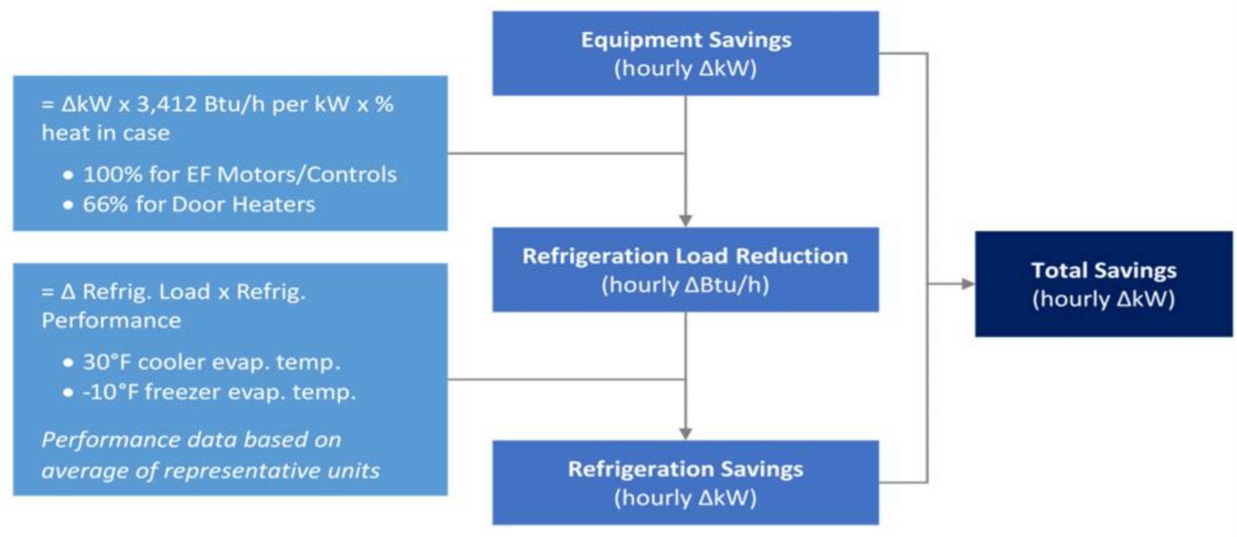
- One ASDH unit was not connected (i.e., consumed no power) in the baseline condition. The implementer re-connected the unit after installing new controls.
    - We used only the post-installation data from this site to estimate run time with controls.
- At one site, the store manager manually turned off the ASDHs each night.
    - We included both the pre- and post-installation condition in our analysis because we could capture data about the behavior of pre- and post-control installation and because we confirmed with contractors that it was not unusual.
- Three ASDH units exhibited zero savings.
    - We were unable to determine what caused these controls to be ineffective but speculated there could be an issue with the control model, a faulty installation, or user error. Since we could not determine the cause and because the addition of these three sites would drastically affect the results due to the small sample size, we excluded these units from our analysis.

3.5.3 Refrigeration Interactive Effects

As noted in Step 5 (Refrigeration Interactive Effects) and Step 6 (Total Savings Loadshapes)—described at the beginning of this section, Data Analysis, Figure 25—the *total* savings from the refrigeration retrofit measures includes savings resulting from the reduced heat that must be rejected by the refrigeration equipment. For example, for an ECM retrofit inside a refrigerated space, total savings includes both the direct power reduction of the more efficient fan motor and the reduced load due to less waste heat produced by the motors.

The evaluation team developed an Excel-based calculator to estimate these refrigeration interactive effects for each hour of the year, based on the hourly equipment savings loadshape and ambient weather data. Figure 48 shows our process for calculating the additional savings from the reduced refrigeration load.

Figure 48. Analysis Steps for Estimating Refrigeration Interactive Effects



Starting with the hourly estimates of equipment savings, we used a simple unit conversion to convert the reduced equipment power requirements to reduced refrigeration load. The model also estimates scaling factors to account for the fraction of the reduced motor use that would have stayed inside the cooler and resulted in a reduced refrigeration load. We assumed that 100% of the fan motor power must be removed by the system because the equipment is fully enclosed in the refrigerated space and that 66% of the door heater power must be removed because some of the heat is rejected through the case door into the ambient space.

The next step was to estimate the reduction in refrigeration system energy due to the reduction in refrigeration load. We developed a multi-variable regression model to estimate this refrigeration performance (in kW/ton) based on performance curves for the typical packaged refrigeration systems observed in our study, typical cooler and freezer evaporator temperatures (30°F for coolers and -10°F for freezers), and typical hourly outdoor temperatures (from National Oceanic and Atmospheric Administration typical meteorological year 3 weather data records) from these cities:

- Portland, Maine
- Rochester, New York
- Concord, Massachusetts
- Boston, Massachusetts
- Providence, Rhode Island
- New York City, New York
- Baltimore, Maryland

The evaluation team developed a representative performance profile for both 30°F and -10°F evaporator temperatures that is an average for three differently-sized units at each evaporator temperature. It is assumed that all coolers operate at 30°F evaporator temperature and all freezers operate at -10°F evaporator temperature. The performance of both the cooler and freezer units improves down to 80°F ambient dry bulb temperature and is assumed to be constant below that point.

The profiles are then used to lookup the performance of either a freezer or cooler unit (kW/ton) at varying ambient dry bub temperatures.

We assumed the load reduction to be constant for every hour in a typical year and calculated refrigeration savings using the following equation:

$$\text{Savings (kW)} = \text{Load reduction (kW)} \times 3{,}412\ \text{BTU/kW} \div 12{,}000\ \text{BTU/ton} \times \text{Performance (kW/ton)}$$

Finally, we calculated the total savings by adding refrigeration savings to equipment savings for each hour of the year. We examined the impacts of these savings by calculating the ratio of total savings to equipment savings. We refer to this ratio as the bonus factor because it represents the additional or bonus savings achieved at the refrigeration system when multiplied by the equipment savings. We found that the savings calculated for each city differed by less than 1%, and therefore determined it is best to use average values to represent all seven weather regions.

4 Results

This study combined primary and secondary data to examine key equipment performance parameters and develop savings loadshapes for ECM retrofits, evaporator fan motor controls, and ASDH controls. In this section, we describe the aggregation of the unit-level results to estimate population average parameters and savings for each measure.

4.1 Population Average Parameters

For each result, we compare the average parameters estimated in this study to existing parameters used in TRMs across the Northeast and Mid-Atlantic, including TRMs in Connecticut, Maine, Massachusetts, New York, and Vermont.[24] We recommend the PAs adopt the population average estimates from this study as TRM estimates. Based on our review of PA tracking data, our estimates are representative of the case types (coolers vs. freezers and walk-ins vs. reach-ins) in which measures are installed. We recommend PAs continue to track these differentiators and recommend additional evaluation research to grow the metered data sample and develop case-specific results.

4.1.1 Full Load Operating Power for Evaporator Fan Motors

Table 28 shows the average operating power, in units of Watts per horsepower, for evaporator fan motors and the average percentage change in power observed for ECM retrofit measures. The population average values are straight averages of the sampled units.

Table 28. Average Parameters – Full Load Operating Power for EF Motors

Parameter	Description	Source	Meter Sample (# Circuits)	Value**
$\left(\frac{W_{SP} - W_{ECM}}{W_{ECM}}\right) \times 100$	Percentage change in power relative to post wattage	Pre/post metering only*	9 primary 0 secondary	157%
$\left(\frac{W}{hp}\right)_{ECM}$	ECM power normalized by horsepower (see Figure 42)	All ECM measurements	42 primary 24 secondary	758 W/hp
$\left(\frac{W}{hp}\right)_{SP}$	SP motor power normalized by horsepower (see Figure 45)	All SP motor measurements	13 primary 5 secondary	2,088 W/hp

* We calculated this parameter using only data from units where we collected both pre and post measurements.
**Values calculated as straight averages of available primary and secondary data.

Program Administrators can use these Watts per horsepower relationships to estimate motor operating power given rated horsepower data for the existing or installed motors. If the PA does not have the rated horsepower information, it should use 1/15 hp based on the size of motor most installed, of the 256 motors observed in this study (see Figure 55).

[24] Note that others TRMs – NEEP Mid-Atlantic, etc. do not have this measure listed in the TRM.

TRM Comparison

Table 29 compares the average ECM operating power to existing TRM values.

Table 29. TRM Comparison – ECM Operating Power (W/motor)

Source	Case Type	Temp	Motor Power (Watts/motor)
NEEP CRL	**all***	**all**	**51**
VT	walk-in	all	40
VT	reach-in	all	11

*Based on measurement of 34 reach-ins and 8 walk-ins.

Note: Only the VT TRM provides W/motor values. Other TRMs direct PAs to estimate motor power based on rated Volts, Amps, PF, and other values.

The average NEEP CRL values (based on measurements of 34 reach-ins and 8 walk-ins and an ECM horsepower of 1/15) is higher than the VT TRM value for ECMs installed in walk-in spaces and much higher than the VT TRM value for reach-in cases. For PAs not tracking case type (walk-in vs. reach-in) or motor size we recommend using the NEEP CRL value.

Table 30 compares the average baseline motor power to existing TRM values.

Table 30. TRM Comparison – Baseline Motor Operating Power (W/motor)

Source	Motor Type	Case Type	Motor Power (Watts/motor)
NEEP CRL	**SP***	**Walk-in*****	**130**
NEEP CRL	**SP****	**Walk-in*****	**139**
VT	SP	all	132
VT	SP	walk-in	132
VT	SP	reach-in	41
VT	PSC	all	88
VT	SP + PSC	all	123
ME	SP + PSC	all	123

*Based on nine measurements at pre/post sites only

**Based on measurements at 18 pre-only and pre/post sites

***All measurements on walk-in cases

The average NEEP CRL value is based on SP motors only and assumes a motor size of 1/15 hp. The value is similar to TRM estimates with two exceptions: the NEEP CRL value is much higher than the VT value for SP motors in reach-in cases and the value for PSC motors. We recommend PAs update their TRMs with the W/motor parameter for SP motors in walk-ins that was calculated using both the pre/post and pre-only sites only (139 W/motor).

Table 31 compares the average motor load reduction factor to existing TRM values. We calculated this value as the average percent reduction in operating power from pre- (SP motor) to post-retrofit (ECM) condition of the nine instances where we collected pre- and post-retrofit measurements on the same exact cases in the same locations.

Table 31. TRM Comparison – Load Reduction Factor for ECM Retrofits (%)

Source	Baseline	Case Type	Load Reduction Factor (%)
NEEP CRL	**SP**	**all***	**59%**
CT	SP	all	65%
MA, RI, NY	all	walk-in	65%
VT	SP	walk-in	70%
MA, RI, NY	SP	reach-in	53%
VT	SP	reach-in	73%
CT	PSC	all	40%
MA, RI, NY	PSC	reach-in	29%

*Based on pre- and post-installation measurement of 6 walk-ins and 3 reach-ins

The average NEEP CRL value is based on SP motors only and within the range of TRM estimates for replacing SP motors with ECMs.[25] As expected, the NEEP CRL value is higher than TRM estimates for replacing PSC motors with ECMs (since PSC motors are more efficient than SP motors). For PAs who do no tracking case type (walk-in vs. reach-in), we recommend using the NEEP CRL value based on SP motors only.

4.1.2 Full Load Operating Power for ASDH

Table 32 shows the average operating power, in units of Watts per door, for anti-sweat door heaters. The population average values are straight averages of the sampled units.

Table 32. Average Parameters – Full Load Operating Power for ASDH

Parameter	Description	Source	Meter Sample (# Circuits)	Value
$\left(\frac{W}{door}\right)_{ASDH}$	Operating power per door	All door heater measurements	21 primary 6 secondary	130 W/door

Program administrators can use this average Watts per door value to estimate the full load operating power for ASDH units. The average number of doors we metered on each circuit was eight. If the PA does not have information about the number of connected doors per controller or circuit, this is the number that should be used, i.e., the default savings per controller should be 1,040 W ($= 130\frac{W}{door} \times 8\ doors$).

TRM Comparison

Table 33 compares the average ASDH power per door to existing TRM values.

[25] We observed very few PSC motors in the field so we removed them from our baseline condition.

Table 33. TRM Comparison – ASDH Operating Power (Watts/door)

Source	Case Type	Case Temp	ASDH Power (W/door)
NEEP CRL	**all**	**all***	**130**
VT	all	cooler	131
VT	all	freezer	245

*Based on 14 coolers, 5 freezers, 2 combined cooler/freezers (8 cooler doors + 4 freezer doors), and 6 unknown temperature cases (from secondary data)
Note: Only the VT TRM provides W/door values. Other TRMs direct PAs to estimate door power based on rated Volts, Amps, PF, and other values.

The average NEEP CRL value is based on 27 measurements in 223 cooler/freezer doors. The result is almost identical to the VT TRM estimate for door heaters in coolers, but is much lower than the VT estimate for door heaters in freezers. For PAs who do not track case type (cooler vs. freezer) we recommend using the NEEP CRL value.

4.1.3 Effective Run Time for Evaporator Fan Motors

Table 34 shows the average annual run-time results, in units of % of annual hours, for controlled evaporator fan motors. The population average values are straight averages of the sampled units.

Table 34. Average Parameters – Effective Run Time for EF Motors

Parameter	Description	Source	Meter Sample (# Circuits)	Annual Value*
$\%ON_{UNCONTROLLED}$	Effective run time of uncontrolled motors	All uncontrolled metering (ECM and SP)	32 primary 0 secondary	97.8%
$\%ON_{ALL}$	Effective run time of all control styles	All control style metering (ON/OFF and multi-speed)	25 primary 0 secondary	66.5%
$\%ON_{ON/OFF}$	Effective run time of ON/OFF style control	ON/OFF style control metering	12 primary 0 secondary	63.6%
$\%ON_{MS}$	Effective run time of multi-speed style controls	Multi-speed style control metering	13 primary 0 secondary	69.2%

*The annual run-time values are the averages of the individual 8760 run-time loadshape profiles for each control type (or uncontrolled ASDHs).

Program Administrators can use these results to estimate the reduction in motor run time cause by installing evaporator fan controls. This study estimated hourly run-time profiles for the parameters described in Table 34, for which the PAs can use to estimate run time for specific hours or periods. The run-time profiles for each day type (weekday, Saturday, and Sunday) are available in Table 35. We generated the annual loadshapes by assigning each day of the year into one of these categories (treating holidays as Sundays).

Table 35. EF Motor Run-time Profiles by Control Type for a Weekday (WD), Saturday (Sat), and Sunday (Sun)

Hour	Uncontrolled Run Time (%)			All Controls Run Time (%)			ON/OFF Controls Run Time (%)			Multi-speed Controls Run Time (%)		
	WD	Sat	Sun	WD	Sat	Sun	WD	Sat	Sun	WD	Sat	Sun
0	98%	98%	98%	65%	64%	64%	58%	57%	57%	71%	70%	69%
1	98%	99%	99%	62%	64%	61%	58%	57%	55%	66%	70%	66%
2	99%	99%	99%	60%	62%	58%	56%	57%	54%	64%	66%	62%
3	98%	99%	99%	60%	59%	58%	55%	52%	52%	65%	66%	65%
4	98%	99%	99%	60%	60%	60%	56%	53%	52%	64%	66%	67%
5	98%	99%	99%	59%	56%	58%	55%	51%	51%	63%	61%	64%
6	98%	99%	99%	61%	58%	56%	54%	49%	48%	67%	67%	65%
7	98%	99%	99%	61%	60%	58%	54%	50%	49%	67%	68%	66%
8	97%	98%	98%	64%	61%	62%	62%	57%	58%	65%	65%	65%
9	97%	98%	97%	64%	61%	63%	64%	58%	60%	64%	64%	65%
10	98%	98%	97%	67%	64%	66%	68%	62%	65%	65%	65%	67%
11	97%	98%	98%	71%	69%	68%	71%	65%	65%	71%	72%	71%
12	97%	98%	97%	72%	70%	71%	70%	66%	69%	73%	73%	73%
13	97%	98%	98%	70%	70%	70%	70%	67%	70%	71%	72%	71%
14	97%	98%	97%	70%	69%	70%	70%	67%	72%	71%	71%	68%
15	97%	98%	97%	72%	70%	73%	71%	68%	73%	72%	72%	73%
16	97%	98%	97%	72%	71%	73%	71%	71%	70%	72%	72%	75%
17	97%	98%	97%	72%	70%	73%	72%	70%	72%	71%	70%	73%
18	98%	98%	97%	71%	69%	70%	69%	69%	71%	72%	69%	70%
19	98%	99%	98%	72%	70%	71%	71%	70%	70%	73%	70%	71%
20	98%	98%	97%	72%	70%	71%	71%	69%	68%	73%	71%	75%
21	97%	96%	96%	70%	70%	70%	67%	67%	68%	73%	74%	72%
22	98%	98%	98%	70%	72%	69%	67%	68%	67%	74%	77%	71%
23	98%	99%	97%	67%	69%	68%	62%	61%	62%	73%	77%	73%

TRM Comparison

Table 36 compares the load reduction factor, equal to the percent reduction in effective runtime (see 3.5.1.2 Effective Hourly Run Time for definition), for a fan with controls to existing TRM values. A higher load reduction factor indicates lower total energy consumption by the controlled fan and, therefore, results in higher energy savings.

Table 36. TRM Comparison – Load Reduction Factor for EF Motor with Controls (%)

Source	Case Type	Case Temp	Control	Load Reduction Factor (%)
NEEP CRL	**all***	**all***	average	**32%**
NEEP CRL	**all****	**all****	ON/OFF	**35%**
NEEP CRL	**all*****	**all*****	multi-speed	**29%**
MA, RI	walk-in	all	ON/OFF****	**54%**
NY	walk-in	all	multi-speed*****	**36%**
CT	all	all	all	**35%**
CT	all	all	ON/OFF	**34%**
CT	all	all	2-speed	**43%**
VT	all	cooler	all	**50%**
VT	all	freezer	all	**50%**

*Based on measurement of 45 walk-ins and 12 reach-ins; 53 coolers and 4 freezers.
**Based on measurement of 31 walk-ins and 11 reach-ins; 41 coolers and 1 freezer
***Based on measurement of 29 walk-ins and 11 reach-ins; 36 coolers and 4 freezers
****Primary implementer in MA and RI uses ON/OFF controls
*****Primary implementer in NY uses multi-speed controls

The average NEEP CRL load reduction value is similar to the values used in NY and CT, but lower than values used in MA, RI, and VT. We recommend PAs use the NEEP CRL values in their TRMs.

4.1.4 Effective Run Time for ASDH

Table 37 shows the average annual run-time results, in units of % of annual hours on, for anti-sweat door heaters. The population average values are straight averages of the sampled units.

Table 37. Average Parameters – Effective Run Time for ASDH

Parameter	Description	Source	Meter Sample (# Circuits)	Annual Value*
$\%ON_{UNCONTROLLED}$	Effective run time of uncontrolled heaters	All uncontrolled metering	10 primary 0 secondary	90.7%*
$\%ON_{ALL}$	Effective run time of all control styles	All control style metering (ON/OFF and micropulse)	11 primary 8 secondary**	45.6%*
$\%ON_{ON/OFF}$	Effective run time of ON/OFF control	ON/OFF style metering	6 primary 0 secondary	58.9%*
$\%ON_{MP}$	Effective run time of micropulse controls	Micropulse style control metering	5 primary 1 secondary	42.8%*

*The annual run-time values are the averages of the individual 8760 run-time loadshape profiles for each control type (or uncontrolled ASDHs).
**The style of seven of the eight controls of the secondary data was unknown; therefore, they are included only in the all-control-style loadshape, not ON/OFF nor micropulse.

Program Administrators can use these results to estimate the reduction in heater run time caused by installing ASDH controls. This study estimated hourly run-time profiles the parameters described in Table 37, for which the PAs can use to estimate run time for specific hours or periods. The run-time profiles for each day type (weekday, Saturday, and Sunday) are available in Table 38. We generated the annual loadshapes by assigning each day of the year into one of these categories (treating holidays as Sundays).

Table 38. ASDH Run-time Profiles by Control Type for a Weekday (WD), Saturday (Sat), and Sunday (Sun)

Hour	Uncontrolled Run Time (%)			All Controls Run Time (%)			ON/OFF Controls Run Time (%)			Micropulse Controls Run Time (%)		
	WD	Sat	Sun	WD	Sat	Sun	WD	Sat	Sun	WD	Sat	Sun
0	90%	92%	88%	47%	48%	41%	63%	59%	56%	47%	47%	36%
1	90%	92%	92%	47%	46%	47%	60%	64%	63%	46%	44%	44%
2	91%	92%	94%	44%	46%	45%	60%	58%	61%	45%	42%	43%
3	92%	94%	94%	43%	45%	45%	59%	58%	58%	42%	36%	41%
4	92%	94%	94%	44%	44%	46%	58%	60%	59%	41%	34%	40%
5	92%	94%	94%	43%	44%	45%	59%	58%	59%	39%	34%	38%
6	92%	94%	94%	45%	45%	45%	60%	60%	59%	39%	38%	37%
7	92%	94%	94%	46%	45%	45%	58%	63%	57%	42%	40%	41%
8	92%	94%	94%	44%	44%	44%	60%	60%	57%	41%	40%	39%
9	92%	93%	94%	45%	46%	43%	59%	60%	54%	40%	37%	36%
10	91%	93%	93%	51%	49%	45%	59%	64%	55%	44%	43%	37%
11	91%	93%	91%	47%	48%	44%	59%	62%	56%	42%	42%	37%
12	91%	93%	91%	44%	48%	43%	61%	60%	54%	42%	40%	38%
13	91%	93%	90%	46%	47%	44%	59%	63%	54%	43%	43%	41%
14	90%	93%	88%	46%	46%	42%	58%	60%	54%	44%	43%	38%
15	90%	91%	90%	47%	46%	42%	59%	59%	52%	46%	47%	42%
16	90%	91%	90%	48%	45%	42%	58%	63%	50%	44%	46%	40%
17	89%	91%	90%	48%	46%	44%	58%	60%	53%	47%	48%	46%
18	88%	91%	90%	47%	47%	42%	59%	58%	53%	46%	47%	45%
19	88%	91%	90%	48%	46%	39%	59%	60%	51%	43%	44%	39%
20	88%	91%	90%	49%	47%	41%	58%	60%	55%	44%	47%	40%
21	88%	91%	88%	48%	45%	41%	60%	58%	51%	42%	44%	39%
22	88%	91%	88%	46%	46%	39%	60%	61%	50%	49%	49%	39%
23	90%	91%	88%	46%	46%	41%	60%	61%	54%	47%	47%	38%

TRM Comparison

Table 39 compares the average ASDH annual load reduction factors with controls, which is calculated as one minus the percent reduction in run time, to existing TRM values. A higher load reduction factor indicates higher energy savings.

Table 39. TRM Comparison – Load Reduction Factor with ASDH Controls (%)

Source	Case Type	Case Temp	Control Type	Load Reduction Factor (%)
NEEP CRL	**all**	**all***	**all**	**45%**
NEEP CRL	**all**	**all****	**ON/OFF**	**32%**
NEEP CRL	**all**	**all*****	**Micropulse**	**48%**
MA, NY, CT	all	freezer	all	**46%**
MA, NY, CT	all	cooler	all	**74%**
VT	all	all	Humidity	**55%**
VT	all	all	Conductivity	**70%**

*Based on 15 coolers, 5 freezers, 1 combined cooler freezer (8 cooler doors and 4 freezer doors), and 8 unknown temperature cases (from secondary data)
**Based on 10 coolers, 5 freezers, and 1 combined cooler/freezer (8 cooler doors and 4 freezer doors)
***Based on 13 coolers, 2 freezers, and 1 unknown temperature case (from secondary data)

The average NEEP CRL value for all control types is similar to the MA, NY, and CT values for ASDH controls on freezers but is lower than the TRM values for ASDH controls in coolers and is lower than both VT TRM values. We recommend PAs use the NEEP CRL values.

4.2 Savings Calculations

The evaluation team used the population average parameters and profiles described in the previous section to calculate hourly equipment savings loadshapes for each measure. Program administrators can use these equipment savings loadshapes to estimate key savings metrics such as annual energy savings (the sum of hourly savings estimates over a full year), peak demand savings (the average hourly savings during peak hours), and the percentage of savings in each energy period.

In the following sections for each measure, we describe the algorithms and inputs we used for each calculation and present a representative week from the resulting equipment savings loadshapes.

4.2.1 Evaporator Fan ECM Retrofit

We calculated the hourly savings for evaporator fan ECM motor retrofit in units of Watts per horsepower of the installed ECM. As described in Equation 1, the hourly savings is the product of the ECM power normalized by horsepower, the percentage change in power relative to ECM power, and the hourly percentage run time of an uncontrolled motor.

Equation 1

$$\left(\frac{\Delta W}{hp_{ECM}}\right)_{h} = \left(\frac{W}{hp}\right)_{ECM} \times \left(\frac{W_{SP} - W_{ECM}}{W_{ECM}}\right) \times \%ON_{UNCONTROLLED,h}$$

Table 40 describes the input parameters for Equation 1.

Table 40. Calculation Parameters for ECM Retrofit

Parameter	Description	Value	Source
$\left(\frac{\Delta W}{hp}_{ECM}\right)_h$	Wattage reduction for ECM motor replacing SP motor in hour *h*	Calculated	Equation 1
$\left(\frac{W}{hp}\right)_{ECM}$	Average ECM wattage per rated horsepower	758 W/hp	Table 28
$\left(\frac{W_{SP}-W_{ECM}}{W_{ECM}}\right)$	Percentage change in power relative to ECM wattage	157%	Table 28
$\%ON_{UNCONTROLLED,h}$	Effective run time of uncontrolled motors in hour *h*	See hourly profile	Table 34*

*The annual $\%ON_{UNCONTROLLED}$ value is 97.8% (see Table 34).

Required Tracking Data

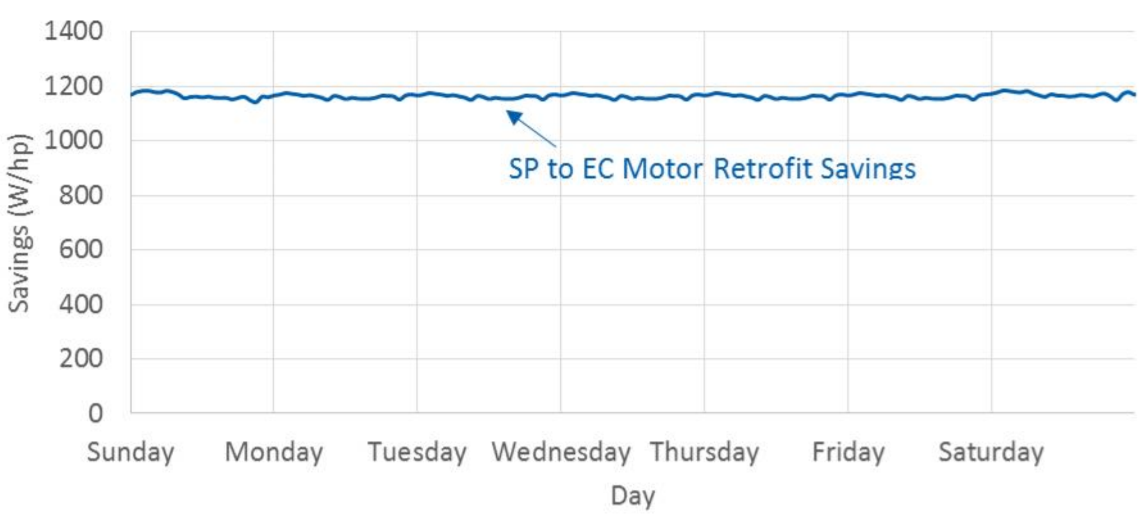
Program administrators should collect the rated horsepower of the installed ECM. PAs can calculate the hourly power savings for the ECM retrofit by multiplying the result from Equation 1 (W/hp) by the rated horsepower of the new ECM (hp).

If the PA does not have horsepower information for the installed motors, it can use 1/15, based on the most installed motor size (1/15 hp) observed in this study.

Savings Loadshape

Figure 49 shows a typical week from the equipment savings loadshape for an ECM replacing a SP motor.

Figure 49. Equipment Savings Loadshape for ECM Retrofit (1 week)



Note: Baseline motor is SP.

The loadshape shows a continuous average savings value just under 1,200 W/hp with minimal variation with time of day or day type.

4.2.2 Evaporator Fan Motor Controls

We calculated the hourly savings for evaporator fan motor controls installed on ECMs or SP motors in units of Watts per horsepower of the installed motor. As described in Equation 2 and Equation 3, the hourly savings is the product of the motor wattage normalized by horsepower and the difference in hourly run time between an uncontrolled and controlled motor.

Equation 2
(EF motor controls on ECM)

$$\left(\frac{\Delta W}{hp_{ECM}}\right)_h = \left(\frac{W}{hp}\right)_{ECM} \times \left(\%ON_{UNCONTROLLED} - \%ON_{X}\right)_h$$

Equation 3
(EF motor controls on SP motor)

$$\left(\frac{\Delta W}{hp_{SP}}\right)_h = \left(\frac{W}{hp}\right)_{SP} \times \left(\%ON_{UNCONTROLLED} - \%ON_{X}\right)_h$$

Table 40 describes the input parameters for Equation 2 and Equation 3.

Table 41. Calculation Parameters for EF Motor Controls

Parameter	Description	Value	Source
$\left(\frac{\Delta W}{hp_{ECM}}\right)_h$	Wattage reduction for EF controls on an ECM in hour *h*	Calculated	Equation 2
$\left(\frac{W}{hp}\right)_{ECM}$	Average ECM wattage per rated horsepower	758 W/hp	Table 28
$\left(\frac{\Delta W}{hp_{SP}}\right)_h$	Wattage reduction for EF controls on a SP motor in hour *h*	Calculated	Equation 3
$\left(\frac{W}{hp}\right)_{SP}$	Average SP wattage per rated horsepower	2,088 W/hp	Table 28
$\%ON_{UNCONTROLLED,h}$	Effective run time of uncontrolled motor in hour *h*	Hourly profile	Table 34*
$\%ON_{X,h}$	Effective run time of motor with control type *X* in hour *h*	Hourly profile	Table 34*

*The annual $\%ON_{UNCONTROLLED}$ value is 97.8% (see Table 34).

Required Tracking Data

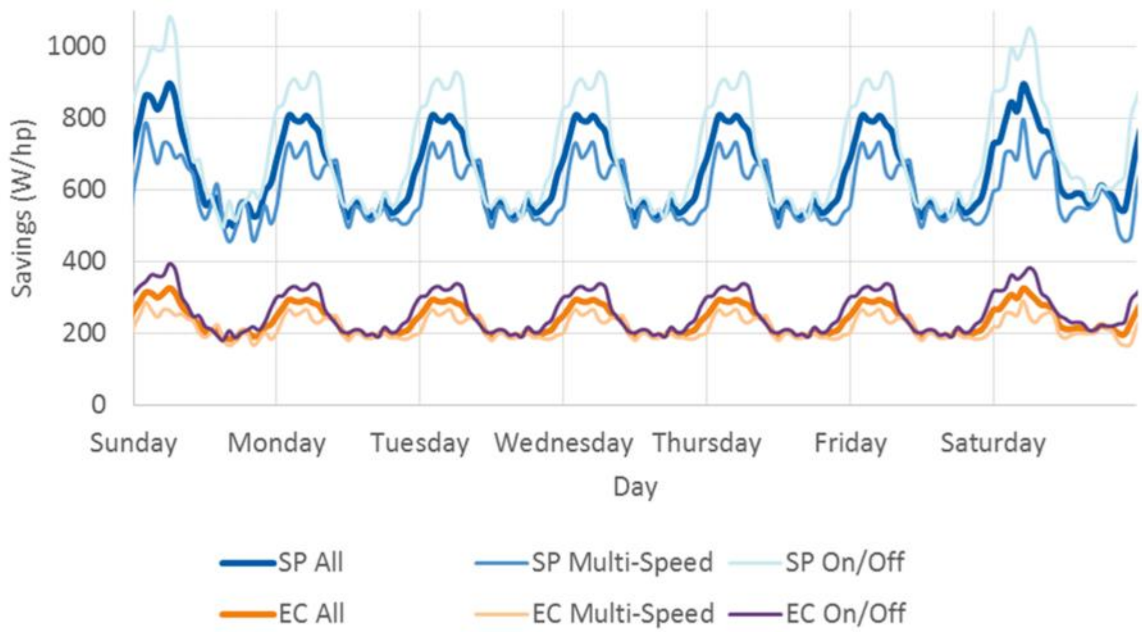
Program administrators should collect the rated horsepower of the motor on which the controls are installed. PAs can calculate the hourly power savings for the EF motor controls by multiplying the result from Equation 2 (for ECMs) or Equation 3 (for SP motors) (W/hp) by the rated horsepower of the installed motor (hp).

If the PA does not have horsepower information for the installed motors, it can use 1/15 for ECMs or SP motors.

Savings Loadshape

Figure 50 shows a representative week from the equipment savings loadshape for evaporator fan motor controls. The figure shows results for multiple control types installed on SP motors and ECMs.

Figure 50. Equipment Savings Loadshape for EF Motor Controls (1 week)



All loadshapes show a similar pattern, with higher savings values in the morning hours and lower savings values in the afternoon and evenings, consistent with the expected activity in the store. For example, when refrigerator doors are opened and closed frequently, the cooling system fans have to work harder to maintain the setpoint in the space. Therefore, the evaporator fan controls must operate the motors more frequently, thereby reducing the amount of savings.

Savings for controls on SP motors are higher than for ECM due to the higher demand of the less efficient SP motor. However, if an SP motor is replaced with an ECM and controls are added, the savings of the two measures are additive and the total savings is greater than simply installing controls on a SP motor alone.

Also, although sample sizes are small, we observed that savings for ON/OFF controls tend to be slightly higher than savings for multispeed controls.

4.2.3 Anti-Sweat Door Heater Controls

The hourly savings value, in units of Watts per door, is estimated as the product of the estimated Watts per door value (Table 28) and the difference in hourly run time between an uncontrolled and controlled motor (Table 34).

Equation 4 is the formula we used to calculate average hourly power savings for ASDH controls per door.

Equation 4

$$\left(\frac{\Delta W}{door}\right)_h = \left(\frac{W}{door}\right)_{ASDH} \times \left(\%_{ON\ NON} - \%_{ON\ X}\right)_h$$

Table 42 describes the input parameters for Equation 4.

Table 42. Calculation Parameters for ASDH Controls

Parameter	Description	Value	Source
$\left(\frac{\Delta W}{door}\right)_h$	Wattage reduction per connected door for ASDH controls in hour *h*	Calculated	Equation 4
$\left(\frac{W}{door}\right)_{ASDH}$	Average wattage of ASDH per connected door	130 W/door	Table 32
$\%ON_{UNCONTROLLED,h}$	Effective run time of uncontrolled ASDH in hour *h*	Hourly profile	Table 37*
$\%ON_{X,h}$	Effective run time of ASDH with control type *X* in hour *h*	Hourly profile	Table 37**

*The annual $\%ON_{UNCONTROLLED}$ value is 90.7% (see Table 37).

**The annual $\%ON_X$ value is 45.6% for all controls, 58.9% for ON/OFF controls, and 42.8% for micropulse controls (see Table 37).

Required Tracking Data

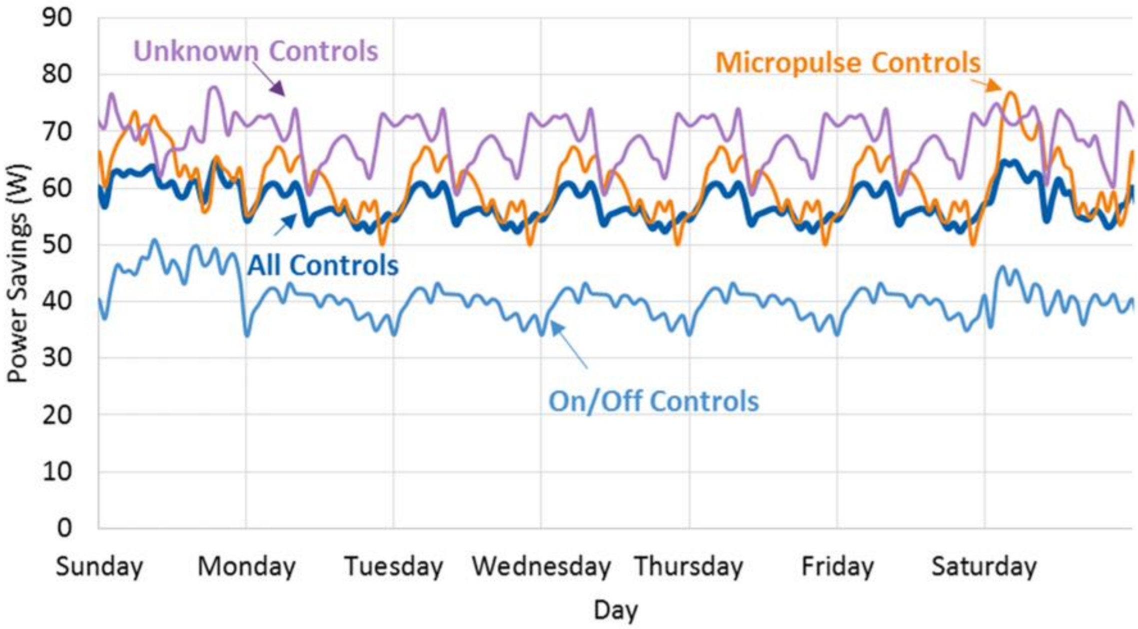
Program administrators should collect the number of doors connected to the ASDH controller installed. PAs can calculate the hourly power savings for ASDH controls by multiplying the result from Equation 4 (W/door) by the number of doors connected to the ASDH control or controls.

The average number of doors we metered on each circuit was 8. If the PA does not have information about the number of connected doors per controller or circuit, this is the number that should be used.

Savings Loadshape

Figure 51 shows a typical week from the equipment savings loadshapes for ASDH controls. The figure shows multiple control types as well as an average loadshape for all control types.

Figure 51. Equipment Savings Loadshape for ASDH Controls (1 week)



Similar to the fan motor controls, the door heater control savings loadshapes demonstrate a time dependence, with higher savings values in the early mornings and lower savings value in the afternoons and into the evening, similarly explained by store activity. Although sample sizes were small, the micropulse and unknown control types tended to save more than the ON/OFF door heater controls.[26]

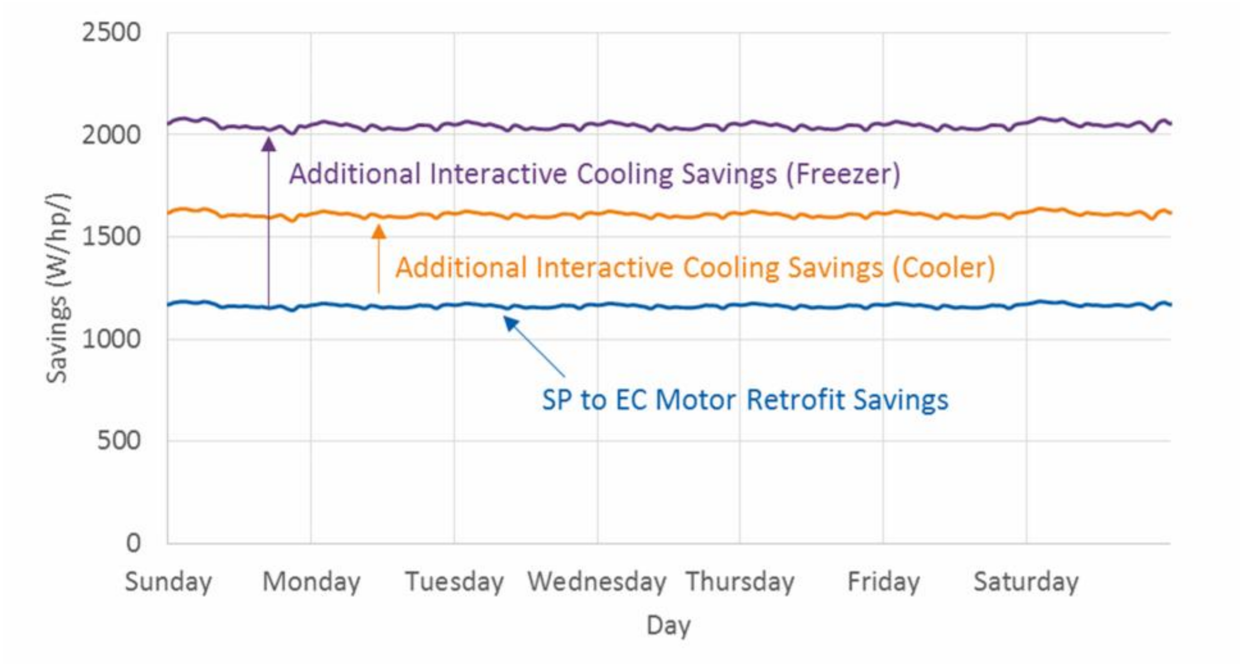
4.3 Refrigeration Interactive Effects

Using the process outlined in the Refrigeration Interactive Effects section (Section 3.5.3), we estimated the total savings factoring in refrigeration interactive effects. Figure 52 and Figure 53 show savings loadshape including interactive refrigeration savings for a SP to ECM retrofit (one week and one year, respectively). These results are averaged over all weather regions described in 3.5.3.[27]

[26] Because the unknown controls types are from the secondary dataset, we could not verify the type of controller. However, based on the measure performance, we suspect they are micropulse controls.

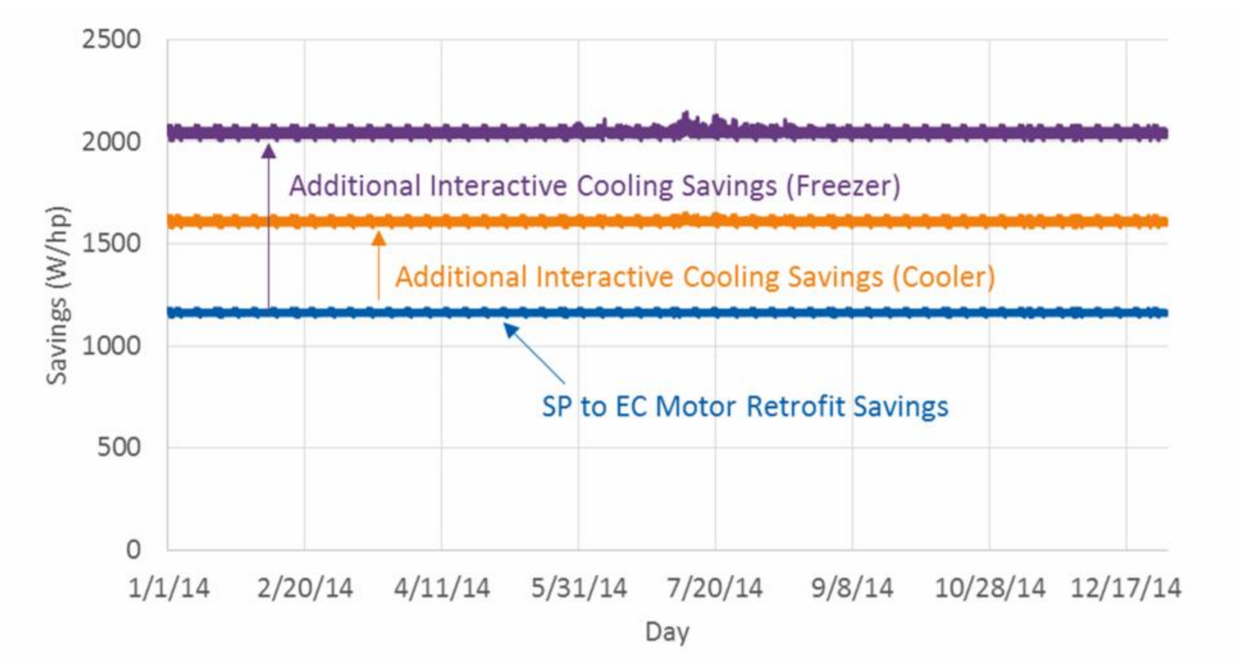
[27] The evaluation team calculated interactive savings for each weather region separately and found that the results across regions varied by less than 1%. Therefore, we averaged the results for all weather regions to present a single average result for the NEEP region.

Figure 52. Total Savings Loadshape for ECM Retrofit (1 week)



Note: Baseline motor is SP.

Figure 53. Total Savings Loadshape for ECM Retrofit (8760)

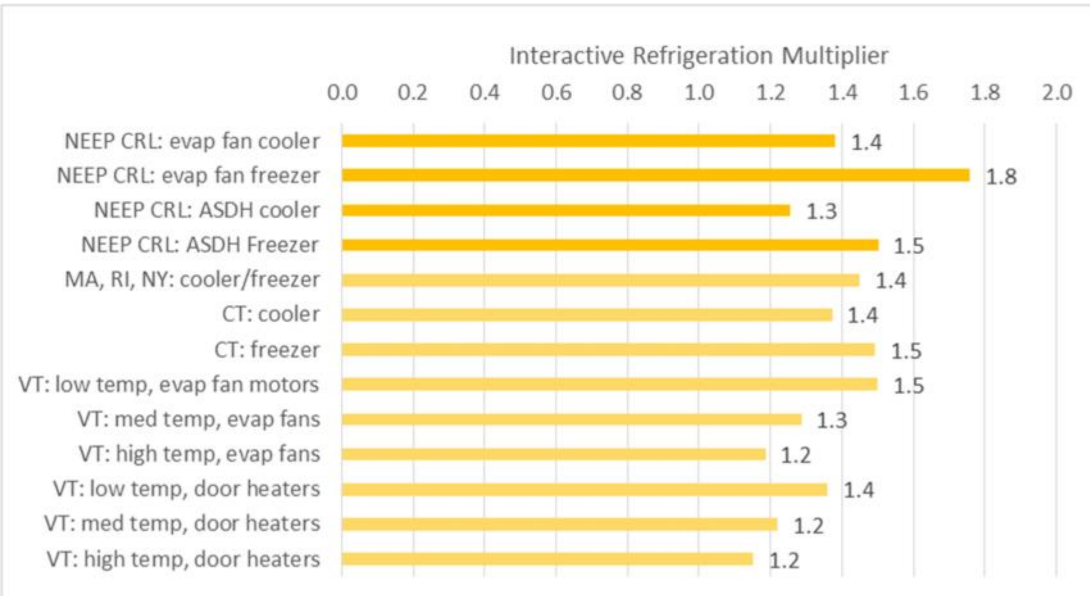


Note: Baseline motor is SP.

The interactive refrigeration savings increase total savings by a nearly constant factor. The savings are slightly greater during the summer (when the outside air temperature is high), because the refrigeration system operates less efficiently and therefore the reduction of waste heat from the motor has a more significant impact on the cooling power. Similarly, refrigeration systems serving freezers require a lower suction pressure, operate less efficiently, and require more power to reject an equal amount of heat.

Figure 54 compares the average interactive refrigeration savings multiplier applied in this report to TRMs from the Northeast.

Figure 54. TRM Comparison – Interactive Refrigeration Multiplier



The NEEP CRL interactive refrigerator multiplier value for evaporator fans in coolers is consistent with the CT TRM, but slightly higher than the VT TRM. The multiplier is presumably higher than the MA, RI, NY TRMs, which use 1.4 to represent both coolers and freezers. The NEEP CRL interactive refrigerator multiplier for evaporator fans in freezers is much higher than all the TRMs.

The disparity between the NEEP CRL multiplier value and current TRMs might be attributable to the refrigeration equipment characteristics of our sample. The evaluation team based the refrigeration system performance assumptions on the systems in the sample, which is comprised primarily of small commercial businesses. These businesses are less likely to have high efficiency systems than the overall commercial and industrial population, and thus greater refrigeration interactive effects.

For ASDH, the NEEP CRL interactive refrigerator multiplier value for coolers is lower than the CT TRM, but higher than the VT TRM and presumably consistent with the MA, RI, NY TRMs, which combines coolers and freezers. The value for ASDH in freezers is consistent with the CT TRM, but higher than the VT TRM, and presumably consistent with the MA, RI, NY TRMs.

4.4 Key Savings Metrics

We used the equipment and total savings loadshapes to estimate the following key savings metrics with and without interactive refrigeration savings:

- Annual energy savings (the sum of the hourly power savings for the entire year)
- Percentage annual savings by energy period (the sum of the loadshape energy savings during each period divided by the total annual energy savings)
- Peak demand savings (the average watt savings during the hours that comprise the peak period of interest)

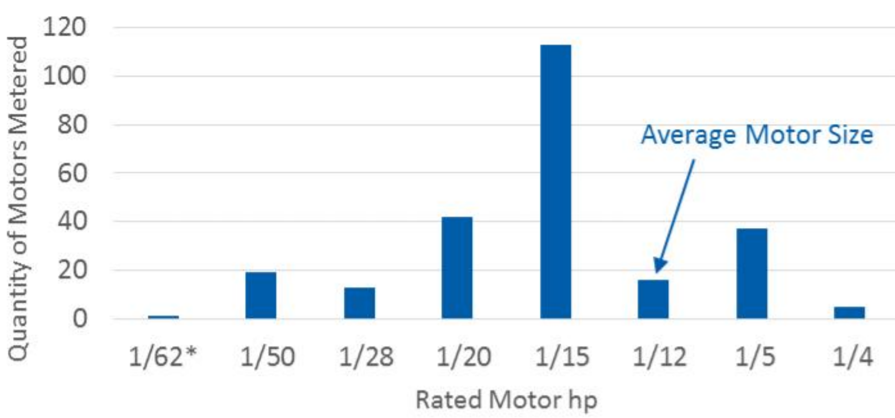
For evaporator fan motors and controls, we present the energy and demand savings metrics as savings per horsepower of the installed motor. For ASDH controls, we present the energy and demand savings metrics as savings per door.

4.4.1 Evaporator Fan Motors and Controls

For evaporator fan ECM retrofits and controls, we present savings in terms of Watts per horsepower. PAs should track the horsepower of installed motors and use the reported savings below as a multiplier. If they cannot track these implementation data, program administrators should use a motor size of 1/15 hp.

Figure 55 shows the quantity of motors metered by rated horsepower. Although the evaluation team observed the average rated horsepower from our sample to be 1/12 hp, motors rated at 1/15 hp are the most often installed. If the program administrator cannot track the installed motor horsepower, we recommend using 1/15 hp as the standard value to evaluate savings.

Figure 55. Quantity of Motors Metered by Rated Horsepower



*Motors rated below 1/50 hp are typically reported in watts; value presented is equivalent horsepower.

4.4.1.1 Annual Energy Savings

Table 43 summarizes the annual energy savings in kWh/hp for all evaporator fan motor measures. We presented the results in terms of the horsepower of the post-installation measure, i.e., the ECM for a SP to ECM retrofit or whatever unit the motor controls are installed on.

Table 43. Annual Energy Savings for EF Motors and Controls

Equipment Type	Annual Energy Savings (kWh/hp)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
SP to ECM Retrofit	10,198	14,122	17,944	5%	4%
EF Controls on SP Motor (All)	5,712	7,908	10,048	3%	2%
EF Controls on SP Motor (OnOff)	6,248	8,650	10,991	3%	3%
EF Controls on SP Motor (MS)	5,217	7,224	9,178	5%	4%
EF Controls on ECM (All)	2,074	2,872	3,650	2%	2%
EF Controls on ECM (OnOff)	2,269	3,142	3,992	2%	2%
EF Controls on ECM (MS)	1,895	2,624	3,334	3%	3%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

The savings from adding controls to an SP motor are greater than an ECM; however, the savings for adding controls to an ECM are incremental to the SP to ECM retrofit if both measures are performed together. For example, using the average of all control types, the savings for installing controls on an SP motor are 5,712 kWh/hp, but the savings from replacing the SP motor with an ECM and adding controls is 10,198 + 2,074 = 12,272 kWh/hp. Thus, replacing a SP motor and adding controls results in significantly more savings than just adding controls.

Table 44 shows the distribution of annual energy savings from evaporator fan measures in each energy period.[28]

[28] Summer on peak comprises 7:00 AM to 11:00 PM on non-holiday weekdays in June through September; summer off peak comprises 11:00 pm – 7:AM on non-holiday weekdays and all hours on weekends and holidays in June through September; winter on peak comprises 7:00 AM to 11:00 PM on non-holiday weekdays in October through May; and winter off peak comprises 11:00 PM to 7:00 AM on non-holiday weekdays and all hours on weekends and holidays in October through May.

Table 44. Energy Period Allocations for EF Motors and Controls

Equipment Type	Summer On Peak			Summer Off Peak			Winter On Peak			Winter Off Peak		
	%	RP@ 90%	RP@ 80%	%	RP@ 90%	RP@ 80%	%	RP@ 90%	RP@ 80%	%	RP@ 90%	RP@ 80%
Equipment Only												
SP to ECM Retrofit	15%	7%	5%	18%	18%	18%	30%	30%	30%	37%	37%	37%
EF Controls on SP Motor (All)	14%	5%	4%	19%	19%	19%	27%	27%	27%	40%	40%	40%
EF Controls on SP Motor (OnOff)	13%	6%	4%	20%	20%	20%	26%	25%	25%	41%	41%	41%
EF Controls on SP Motor (MS)	15%	8%	6%	19%	19%	19%	28%	28%	28%	39%	39%	39%
EF Controls on ECM (All)	14%	5%	4%	19%	19%	19%	27%	27%	27%	40%	40%	40%
EF Controls on ECM (OnOff)	13%	5%	4%	20%	20%	20%	26%	25%	25%	41%	41%	41%
EF Controls on ECM (MS)	15%	8%	6%	19%	19%	19%	28%	28%	28%	39%	39%	39%
Equipment and Interactive (Cooler)*												
SP to ECM Retrofit	15%	7%	5%	18%	18%	18%	30%	30%	30%	37%	37%	37%
EF Controls on SP Motor (All)	14%	5%	4%	19%	19%	19%	27%	27%	27%	40%	40%	40%
EF Controls on SP Motor (OnOff)	13%	6%	4%	20%	20%	20%	25%	25%	25%	41%	41%	41%
EF Controls on SP Motor (MS)	15%	8%	6%	19%	19%	19%	28%	28%	28%	39%	39%	39%
EF Controls on ECM (All)	14%	5%	4%	19%	19%	19%	27%	27%	27%	40%	40%	40%
EF Controls on ECM (OnOff)	13%	5%	4%	20%	20%	20%	25%	25%	25%	41%	41%	41%
EF Controls on ECM (MS)	15%	8%	6%	19%	19%	19%	28%	28%	28%	39%	39%	39%
Equipment and Interactive (Freezer)*												
SP to ECM Retrofit	16%	7%	5%	18%	18%	18%	30%	30%	30%	37%	37%	37%
EF Controls on SP Motor (All)	14%	5%	4%	19%	19%	19%	27%	27%	27%	40%	40%	40%
EF Controls on SP Motor (OnOff)	13%	6%	4%	20%	20%	20%	25%	25%	25%	41%	41%	41%
EF Controls on SP Motor (MS)	15%	8%	6%	19%	19%	19%	28%	28%	28%	39%	39%	39%
EF Controls on ECM (All)	14%	5%	4%	19%	19%	19%	27%	27%	27%	40%	40%	40%
EF Controls on ECM (OnOff)	13%	5%	4%	20%	20%	20%	25%	25%	25%	41%	41%	41%
EF Controls on ECM (MS)	15%	8%	6%	19%	19%	19%	28%	28%	28%	39%	39%	39%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

4.4.1.2 Peak Demand Savings

Table 45 (ISO-NE summer peak), Table 46 (ISO-NE winter peak), and Table 47 (PJM summer peak) show peak demand savings in Watts per horsepower for evaporator fan ECM retrofits and controls. As for annual kWh savings, peak demand savings from the SP to ECM retrofit and ECM controls are additive if the measures are done together.

Table 45. ISO-NE Summer Peak Savings for EF Motors and Controls

Equipment Type	ISO-NE Summer Peak Savings (W/hp)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
SP to ECM Retrofit	1,155	1,609	2,053	5%	4%
EF Controls on SP Motor (All)	544	758	967	3%	3%
EF Controls on SP Motor (OnOff)	557	776	990	4%	3%
EF Controls on SP Motor (MS)	532	741	945	5%	4%
EF Controls on ECM (All)	198	275	351	2%	2%
EF Controls on ECM (OnOff)	202	282	360	3%	2%
EF Controls on ECM (MS)	193	269	343	4%	3%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

Table 46. ISO-NE Winter Peak Savings for EF Motors and Controls

Equipment Type	ISO-NE Winter Peak Savings (W/hp)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
SP to ECM Retrofit	1,162	1,608	2,042	5%	4%
EF Controls on SP Motor (All)	551	762	968	3%	3%
EF Controls on SP Motor (OnOff)	559	773	981	5%	5%
EF Controls on SP Motor (MS)	544	753	956	5%	5%
EF Controls on ECM (All)	200	277	352	2%	2%
EF Controls on ECM (OnOff)	203	281	356	3%	3%
EF Controls on ECM (MS)	198	273	347	4%	4%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

Table 47. PJM Peak Savings for EF Motors and Controls

Equipment Type	PJM Peak Savings (W/hp)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
SP to ECM Retrofit	1,156	1,607	2,048	5%	4%
EF Controls on SP Motor (All)	536	746	950	3%	3%
EF Controls on SP Motor (OnOff)	544	756	963	4%	4%
EF Controls on SP Motor (MS)	529	736	938	5%	5%
EF Controls on ECM (All)	195	271	345	2%	2%
EF Controls on ECM (OnOff)	197	275	350	3%	3%
EF Controls on ECM (MS)	192	267	341	4%	4%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

4.4.2 Anti-Sweat Door Heater Controls

In this section, we present the key savings metrics for ASDH controls in three categories:

- all controls, an overall average of all control styles (including the unknown controls from the secondary dataset);
- ON/OFF controls, an average of only ON/OFF-style controls; and
- Micropulse controls, an average of micropulse-style controls only.

4.4.2.1 Annual Energy Savings

Table 48 show the annual energy savings in kWh/door for each combination of ASDH controls.

Table 48. Annual Energy Savings for ASDH Controls

Equipment Type	Annual Energy Savings (kWh/door)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
All Controls	515	646	773	5%	4%
On/Off Controls	364	456	546	11%	9%
Micropulse Controls	547	686	821	7%	5%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

Table 49 shows the distribution of annual energy savings from ASDH controls for each energy period.

Table 49. Energy Period Savings Allocations for ASDH Controls

Equipment Type	Summer On Peak			Summer Off Peak			Winter On Peak			Winter Off Peak		
	%	RP@ 90%	RP@ 80%	%	RP@ 90%	RP@ 80%	%	RP@ 90%	RP@ 80%	%	RP@ 90%	RP@ 80%
Equipment Only												
All Controls	15%	10%	7%	18%	12%	9%	29%	19%	14%	38%	24%	18%
On/Off Controls	15%	25%	16%	18%	29%	18%	29%	46%	30%	38%	60%	37%
Micropulse Controls	15%	12%	9%	18%	14%	10%	29%	23%	17%	38%	29%	20%
Equipment and Interactive (Cooler)*												
All Controls	15%	10%	7%	18%	12%	9%	29%	19%	14%	38%	24%	18%
On/Off Controls	15%	25%	16%	18%	29%	18%	29%	46%	30%	38%	60%	37%
Micropulse Controls	15%	12%	9%	18%	14%	10%	29%	23%	17%	38%	29%	20%
Equipment and Interactive (Freezer)*												
All Controls	15%	10%	7%	18%	12%	9%	29%	19%	14%	38%	24%	18%
On/Off Controls	15%	25%	16%	18%	29%	18%	29%	46%	30%	37%	60%	37%
Micropulse Controls	15%	12%	9%	18%	14%	10%	29%	23%	17%	38%	29%	20%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

4.4.2.2 Peak Savings

Table 50 (ISO-NE summer peak), Table 51 (ISO-NE winter peak), and Table 52 (PJM summer peak) show peak savings in Watts per door for both types of ASDH controls as well as a single overall average.

Table 50. ISO-NE Summer Peak Savings for ASDH Controls

Equipment Type	ISO-NE Summer Peak Savings (W/door)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
All Controls	58	72	87	6%	4%
On/Off Controls	41	52	63	12%	9%
Micropulse Controls	60	76	91	8%	6%

*Interactive savings are averaged over the weather regions shown in section 4.4because the variation among regions was less than 1%.

Table 51. ISO-NE Winter Peak Savings for ASDH Controls

Equipment Type	ISO-NE Winter Peak Savings (W/door)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
All Controls	55	69	83	6%	5%
On/Off Controls	39	49	59	13%	10%
Micropulse Controls	56	70	84	9%	7%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

Table 52. PJM Summer Peak Savings for ASDH Controls

Equipment Type	PJM Peak Savings (W/door)			Relative Precision (%)	
	Equipment Only	Equipment and Interactive (Cooler)*	Equipment and Interactive (Freezer)*	90% Confidence	80% Confidence
All Controls	57	72	86	6%	5%
On/Off Controls	41	52	62	12%	9%
Micropulse Controls	58	73	88	8%	6%

*Interactive savings are averaged over the weather regions shown in section 3.5.3 because the variation among regions was less than 1%.

5 Findings and Recommendations

The evaluation team offers the following findings and recommendations for program administrators, implementers, and evaluators of these commercial refrigeration measures to improve the energy savings of installations and the effectiveness of programs.

5.1.1 Key Findings

- All three measure provide both energy and peak demand savings.
- The evaluated operating parameters and savings results for all measures are similar to the values currently estimated in the PAs TRMs.
- All three measures are unobtrusive and provide reliable savings. There is minimal opportunity for interference from the customer that could impact performance.
- The measures have a wide range of commercial applications. The evaluation team observed measure installations in coolers and freezers, walk-in spaces, and reach-in cases. The team also observed measure installations across variety of commercial building types, including small businesses and large commercial facilities.
- The evaluation team observed negligible differences (<1%) in measure performance based on weather. There is therefore no reason for different performance expectation based on geographic region.

5.1.2 ECM Retrofits

- ECM retrofits reduce operating power by 59% on average compared to baseline SP motors.
- Uncontrolled evaporator fan motors operate continuously and therefore adding controls is a good measure for both annual energy and peak demand savings.
- Only two of the observed baseline motors were SP. Implementation contractors confirmed they are less likely to replace baseline PSC motors because the replacement is less cost-effective compared to SP replacements. Program administrators that use a blended SP/permanent split capacitor (PSC) baseline should consider using a SP only baseline.[29]
- The majority of installed motors are rated at 1/15 horsepower, but we observed motors ranging from 12 Watts (equivalent to 1/62 hp) to 1/4 hp. The average rated horsepower from our sample was 1/12 hp.
- Operating power varies for both baseline SP motors and uncontrolled ECMs. This variation is caused by multiple factors, including differences in rated motor horsepower and efficiency, diameter and pitch of attached fans, and airflow restrictions. Cadmus tested the impact of airflow

[29] Contractors confirmed SP motors are the predominant equipment used on evaporator fan motors for commercial refrigeration applications. Since they are less efficient than PSC motors, they are also more likely to be targeted for upgrades.

restrictions on motor power. Refer for Appendix B. Airflow Restriction Testing for the results of the testing. See Section 3.5.2.1 for more detail on the observed variation in operating power.

- The rated horsepower of pre-installation and post-installation motors do not always match. For example, a 1/15-hp SP motor might be replaced with a 1/20-hp ECM, or vice versa. This is due to geometrical constraints and equipment availability.
- One pre-retrofit small grocery site (Site 27. EF-A: Small Grocery) had uncontrolled SP motors that exhibited an average run time of 51%. We confirmed that the motors did not have controls but noted that the power consumption fluctuated rapidly and turned off frequently. This indicated the motor was malfunctioning, which is expected for a small percentage of baseline condition motors.

5.1.3 Evaporator Fan Controls

- Evaporator fan controls reduce run time by 32% compared to fans without controls.
- Controlled evaporator fan motors operate more frequently during peak periods than periods of inactivity, but continue to turn on and off throughout the day and are therefore still a good measure for peak demand savings.
- The average run time for controlled motors varies. This variation is caused by multiple factors, including the control type (ON/OFF style controls which vary the runtime of the motor, versus multi-speed controls which vary the speed and runtime of the motor), space temperature settings, and condition of refrigeration equipment. See Section 3.5.2.1 for more detail on the observed variation in operating power.
- The two types of EF controls (ON/OFF and multi-speed) perform differently. ON/OFF controls resulted in slightly greater energy and peak demand savings than multi-speed controls.
- At two of the sites we included in our analysis, controls were disconnected by the customer. Future metering studies of controls such as these should include investigations of customer behavior to understand whether controls are routinely disconnected by the customer, and if so, the reasons why.

5.1.4 Anti-Sweat Door Heater Controls

- ASDH controls reduce run time by 45% compared to door heaters without controls.
- Controlled ASDHs operate more frequently during peak periods than periods of inactivity, but continue to turn on and off throughout the day and are therefore still a good measure for peak demand savings.
- The two types of door heater controls (micropulse and ON/OFF) perform differently. Micropulse controls resulted in greater energy and peak demand savings than ON/OFF controls.
- There is variation in the run time of uncontrolled ASDH due to manual operation. At one site (2. DH-A: Liquor Store), site personnel manually turned the heaters on and off every night. Through discussions with contractors, we confirmed this is fairly common operating condition (Section 3.5.2.2).

- The average run time of controlled ASDH varies. This is caused by a variety of factors including type of control and type of sensor.
- ASDH operating power varies depending on the make, model, and condition of the heater.
- Three sites with the same control manufacturer and implementation contractor exhibited no savings despite installed controls.

5.1.5 Recommendations

- We recommend the PAs adopt the savings estimates from this study as TRM estimates for the average population. Based on our review of PA tracking data, our estimates are representative of the case types (coolers vs. freezers and walk-ins vs. reach-ins) in which measures are installed. We recommend PAs continue to track these differentiators and recommend additional evaluation research to grow the sample and develop case-specific results.

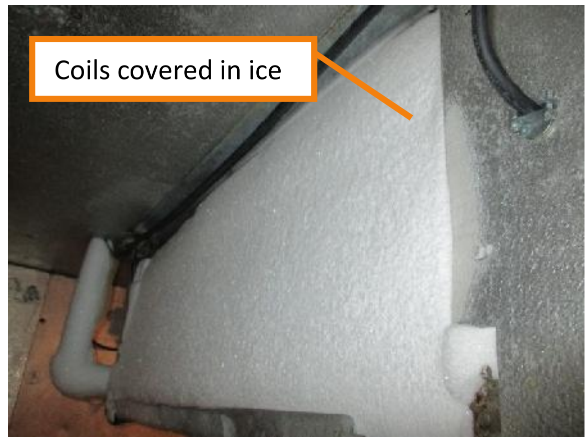
- Current PA estimates of savings are inconsistent in the region due to a variety of sources of assumptions. However, and the evaluation team recommends all PAs adopt the savings results from this study, which represent the current, measured equipment performance in the region. Estimates between PAs should only vary by controller style, if applicable. Controls produced by different manufacturers operate using different strategies, which we observed to impact performance. We recommend sampling different control types during any future evaluations and that implementers record manufacturer and model information on all metered units.

- Cadmus' literature review found few to no studies with pre- and post-installation data, making this the first study with empirical evidence for these three measures. We recommend that any future studies be designed to supplement the data from this study, to increase sample sizes, given the range of performance observed in this study.
- To facilitate future evaluations and updates to savings evaluations, we recommend that implementers record baseline motor type, horsepower, manufacturer, model, and customer behavior as part of an ongoing data collection protocol.
- The power consumed by evaporator fan motors varied significantly between cases due to a variety of factors likely including rated hp, fan size, and airflow restrictions. Measurements of pre- and post-installation operation on single units gave the most reliable data on the impact of ECM retrofits. We recommend that in future studies, PAs work with implementation contractors to facilitate targeting measurements of pre- and post-installation data for each unit.

- Because the evaporator fan motors and ASDHs are located entirely within air-conditioned spaces, we do not expect the measure performance to vary significantly throughout the year. However, we only collected data during the summer and fall; to confirm this hypothesis we would require additional metering data from the winter and spring on the same units.

- The evaluation team observed many iced-up or dirty evaporator coils during the study (Figure 5). These conditions restrict air flow across the evaporator, causing evaporator fan motors to operate at higher powers and the refrigeration system to be less efficient. To enhance the impact of ECM retrofits and installing controls on evaporator fan motors, we recommend incentivizing refrigeration maintenance, such as coil cleaning, by possibly including a one-time coil maintenance with the installation of controls as part of the program delivery, as well as providing general customer education on this issue.

Figure 56. Examples of Poor Evaporator Coil Conditions



Appendix A. Secondary Data Review

Table 53. Descriptions of Secondary Data Sources

ID	Title	Reference	Description	Relevance for the NEEP CRL Study	Study Use
Metering Data					
1	Primary DMI metering data for coolers/ freezers in grocery stores, restaurants, and supermarkets	Primary metering data used to support: 2012 MA Custom Refrigeration Evaluation 2009 National Grid Custom Process Evaluation 2007 National Grid Custom Process Evaluation	**Site Data:** Facility type, location, cooler/freezer for evaporator fan and ASDH controls installed at seven sites. Duty cycle, median, average, min, max power. Pre- and post-installation motor W for evaporator fans. **Evaporator Fan Motor Data:** Less than 10 minutes of one-second interval data including instantaneous, average, max, and min motor power, voltage, and amps. One month of ON/OFF motor run time Oct/Nov. **ASDH Control Data:** Less than 10 minutes of one-second interval data including instantaneous, average, max, and min motor power, voltage, and amps. One month of ON/OFF motor run time. One month of one-minute amp readings on anti-sweat heaters in October and November.	Provides evaporator fan and anti-sweat heater power and run-time data for shoulder season in Massachusetts.	Used for evaporator fan motors and ASDH evaluation
2	Primary KEMA/DNV-GL metering data for coolers/ freezers in supermarkets and farms	Primary metering data used to support MA 2011 PY Custom Program.	**Site Data:** Facility type, location, cooler/freezer for evaporator fan and anti-sweat heater controls installed at seven sites. Duty cycle, median, average, min, max power. Pre- and post-installation motor W for evaporator fans. **Evaporator Fan Motor Data:** 1—2 months of 5—10-minute interval power, voltage, amps. Nov-Feb. **ASDH Control Data:**	Data shows evaporator fan and anti-sweat heater power data for winter season in Massachusetts.	Used for evaporator fan motors and ASDH evaluation

ID	Title	Reference	Description	Relevance for the NEEP CRL Study	Study Use
			1—2 months of 5—10-minute interval power, voltage, amps. Nov-Feb.		
3	Primary Michaels/EMI metering data for coolers/ freezers in retail stores	Primary metering data used to support CT 2013 evaluation	Post-installation amp metering for evaporator fans and ASDH. **Evaporator Fan Motor Data:** 1-2 months of 5-minute interval amps. Jun-Aug. **ASDH Control Data:** 1-2 months of 5-minute interval amps. Jun-Aug.	Shows amp data for evaporator fans and ASDH in summer months; however, no hp, motor type, control type, or quantity of motors or doors is provided.	Not used (not hp data available)
Reports / Work					
1	Efficiency Maine Commercial TRM	Prescriptive Refrigeration: Evaporator Fan Motor Control for Cooler/Freezer, Code R10. 2013, August 30. Retrieved from Commercial Technical Reference Manual Version 2014.1: http://www.efficiencymaine.com/docs/EMT-Commercial-TRM.pdf	Provides key assumptions for Maine on evaporator fan motor controls and ASDH controls. For evaporator fans, assumptions include pre- and post-installation motor load, duty cycle of compressor, impact of interactive effects, in service rates, energy and demand realization rates, summer and winter coincidence factors, free ridership, spillover, equipment life, and equipment cost. For ASDH controls, assumptions include heater load, savings factor, impact of interactive effects, in service rates, energy and demand realization rates, summer and winter coincidence factors, free ridership, spillover, equipment life, and equipment cost.	Pre- and post-installation assumptions for evaporator fan controls and ASDH controls in Maine.	Qualitative
2	Energy Savings Potential and R&D Opportunities for Commercial Refrigeration	Navigant Consulting, Inc. 2009. Energy Savings Potential and R&D Opportunities for Commercial Refrigeration.	Provides equipment specifications and duty cycle assumptions for evaporator fan controls, ECMs, and ASDHs. Also calculates potential energy savings and payback period for a typical walk-in cooler consuming 42,182 kWh/yr and a typical walk-in freezer consuming 15,524 kWh/yr.	Operating assumptions and estimated savings for evaporator fan motor controls, ECMs, and ASDH controls.	Qualitative

ID	Title	Reference	Description	Relevance for the NEEP CRL Study	Study Use
3	EnergyIdeas Clearinghouse Product & Technology Review	EnergyIdeas Clearinghouse. 2008, December. Product and Technology Reviews: Frigitek® Control. Retrieved from EnergyIdeas Clearinghouse: http://www.energyideas.org/documents/Factsheets/PTR/Frigitek-Dec08.pdf	Provides Frigitek manufacturer's savings claims on evaporator fan motor controls. Also includes assumptions on motor efficiency, rpm, duty cycle, and costs.	Operating assumptions and estimated savings for evaporator fan motor controls.	Qualitative
4	Energy Savings Potential for Commercial Refrigeration Equipment	Arthur D. Little. (1996). Energy Savings Potential for Commercial Refrigeration Equipment.	Provides assumptions for on pre- and post-installation duty cycle for evaporator fan controls and annual savings estimations for evaporator fan controls and ASDH controls.	Operating assumptions and estimated savings for evaporator fan controls and ASDH controls.	Qualitative
5	Efficient Evaporator Fan Motors (Shaded Pole to ECM)	Southern California Edison Company. (2007). Efficient Evaporator Fan Motors (Shaded Pole to ECM).	Provides estimated savings and input assumptions for SP to ECM retrofits. Estimated savings and assumptions are provided for coolers and freezers for restaurants and grocery stores.	Operating assumptions and estimated savings for SP to ECM retrofits for restaurants and grocery.	Qualitative
6	Response to questions on Anti-Sweat Heater (ASH) Control Savings Work Paper	Memo between Cadmus and CLEAResult (November 2012). *Response to questions on Anti-Sweat Heater (ASH) Control Savings Work Paper*	Savings and key assumptions for low temperature and medium temperature ASDH controls from six sources. Savings include kWh/linear foot and kW/linear foot. Key assumptions include ASH power and EEER. Savings were calculated for the El Dorado, Arizona, climate zone using 8,760 data.	Key assumptions for ASDH controls.	Qualitative
7	Field Testing of ECMs for Supermarket Display Cases	Foster-Miller, Inc. 1995. *Field Testing of Electronically Commutated Motors for Supermarket Display Cases*	Provides energy and demand savings results from field testing of ECMs in a 29-door frozen food case in a 42,000 sq ft supermarket in Menlo Park, California. Measurements were taken over three months before and after the motors were installed.	Energy savings of ECM retrofits from field testing in Menlo Park, California.	Qualitative

ID	Title	Reference	Description	Relevance for the NEEP CRL Study	Study Use
8	RTF Anti-sweat Heater Controls Workbook v2.0	Regional Technical Forum. 2013, October 9. *Commercial: Grocery - Anti-Sweat Heater Controls v2.0*. Retrieved from Regional Technical Forum	Provides possible pre- and post-installation energy consumptions of ASDH controls and explanation of sources.	Estimated pre- and post-installation energy consumption data for ASDH controls.	Qualitative
9	RTF Walk-in Evaporator Fan ECM Motor Controls Workbook v1.2	Regional Technical Forum. 2014, March 19. *Commercial: Grocery - Walk-in Evaporator Fan ECM Motor Controllers v1.2.* Retrieved from Regional Technical Forum	Provides possible evaporator fan power, run time, EER, and fan speed after installation of controls installed on ECMs and gives explanation of sources.	Key assumptions for evaporator fan controls installed on ECMs.	Qualitative
10	RTF Walk-in Evaporator Fan Shaded Pole Motor Controls Workbook v1.0	Regional Technical Forum. 2012, December 11. *Commercial: Grocery - Walk-in Evaporator Fan Shaded Pole Motor Controllers v1.0.* Retrieved from Regional Technical Forum	Provides possible evaporator fan motor power, EER, and fan speed after installation of controls on SP motor and gives explanation of sources.	Key assumptions for evaporator fan controls installed on SP motors.	Qualitative

Appendix B. Airflow Restriction Testing

A key observation from the CRL study is that the average power for SP motors or ECMs varies significantly across the sites, even for the same motor size as rated in amps This variation is due to a number of factors including the range in rated horsepower and efficiency of the motors metered, the diameter and pitch of attached fans, and airflow restrictions. To assess the impact of airflow restrictions on fan motor power, the evaluation team tested the operating power of SP motors and ECMs under varying airflow conditions.

The evaluation team conducted testing on a set of two isolated fans—one SP motor and one ECM, as shown in Figure 57. The motors powering these fans were rated 1.6 amps with no nameplate horsepower, but were consistent with the observed 1/15 hp motors. The team used builder's foam to block the coil suction side of the fans at levels of 0%, 25%, 50%, and 100% to represent different airflow restrictions that could be caused by storage materials blocking the suction side. We performed an additional test in which we blocked 50% of the discharge side of the fan.

For airflow restrictions on the suction side of the fan, the SP motor and ECM behaved similarly. For both motor types, the operating power increased as the airflow restriction increased. Because both increased, the savings remained fairly flat, ranging from 56 watts to 62 watts.

For airflow restrictions on the discharge side of the fan, the savings increased. The power used by the ECM ranged from 43 watts to 69 watts, or about 645 W/hp to 1,035 W/hp. The SP motor varied by a smaller percentage, ranging from 104 watts to 125 watts. The motor was either rated at 1/15 or 1/20 hp, therefore ranging from 1,560 W/hp to 2,500 W/hp, depending on the rating.

The range in operating power per horsepower supports the observed variations in field power metering data. These tests confirm that variation in W/hp is expected, that SP motors and ECM increase in power consumption as airflow is restricted, and that savings are relatively stable.

Figure 57. Impacts of Airflow Restrictions on Motor Operating Power (Coil=suction, Fan=discharge)