Warming Up to Direct Install Refrigeration Measures

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ABSTRACT

Direct install programs have focused primarily on high-savings, cost-effective lighting retrofits, often giving refrigeration measures the cold shoulder. In trying to deliver deeper savings for customers, however, program administrators are incorporating more measures that improve refrigeration equipment efficiency. A subset of common refrigeration measures, simple to install and unobtrusive to customers, are providing reliable energy savings and demand reductions during peak periods.

Opportunities for efficiency extend beyond refrigerated warehouses and large grocery store market segments. Refrigeration measures prove appropriate for many large and small commercial businesses throughout the country—any business with food service (restaurants), smaller food retail (convenience stores), or conditioned storage (food distributors), regardless of size or location.

On behalf of its Evaluation, Measurement, and Verification (EM&V) Forum membership, the Northeast Energy Efficiency Partnerships (NEEP) conducted a multistate pre- and post-installation study of the performance of common refrigeration retrofit measures. The study examined baseline (pre-retrofit) and installed (post-retrofit) equipment performance and developed hourly savings loadshapes for these most common, highest-savings refrigeration measures:

- Upgrading motors on evaporator fans in reach-in or walk-in refrigerated spaces
- Adding controls for evaporator fan motors in the same spaces
- Adding controls to anti-sweat door heaters in in the same spaces

This paper discusses the study methods and results, key issues such as managing bias while leveraging implementers for pre- and post-installation data collection, using secondary data to guide sample design and to enhance the study sample; modeling the interactive impacts on refrigeration energy consumption, and addressing the competing interests of *technology* versus *impact* evaluation.

Introduction

In 2014, the Northeast Energy Efficiency Partnerships' (NEEP) Evaluation, Measurement, and Verification (EM&V) Forum commissioned a loadshape study to examine the hourly impacts of the three commercial refrigeration retrofit measures most common among energy efficiency programs in the Northeast and Mid-Atlantic states. Conducted by Cadmus and DMI, the commercial refrigeration loadshape (CRL) study is the fourth in the EM&V Forum's series of loadshape studies, after its commercial lighting, unitary HVAC, and variable speed drive studies (Cadmus 2015).

The CRL study examined the three most common direct install refrigeration retrofit measures implemented by program administrators in the Northeast—evaporator fan motor retrofits, evaporator fan motor controls, and anti-condensate door heater controls.

Evaporator fan motor retrofits install electronically-commutated motors (ECMs) in walk-in and reach-in refrigerated cases, replacing shaded pole (SP) and permanent split capacitor (PSC) motors. The ECMs save energy through reduced power requirements to circulate the same volume of air compared to SP and PSC motors.

Figure 1 demonstrates the power reduction of an motor replacement from our sample that is representative of the typical behavior we observed. (Unless otherwise noted, all figures in this paper are from Cadmus' CRL study.) Before the retrofit, the baseline motor operated continuously at an average power of 55 watts. After the new ECM was installed in mid-September, the new motor drew an average power of 20 watts, for an average power reduction of 35 watts.

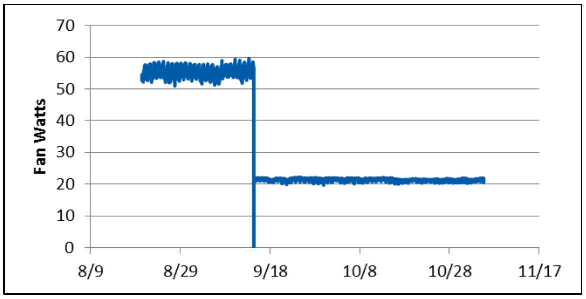

Figure 1. Power Impact of an Example Motor Retrofit

Evaporator fan motor controls vary the speed or operation of an evaporator fan to maintain temperature and humidity setpoints in the refrigerated space. These controls reduce energy consumption by reducing the equivalent full load run time of the fan motors. As demonstrated in Figure 2, fans without controls often operate continuously at constant power. Although controls can be installed on SP or PSC motors, evaporator fan controls are often installed at the same time as an evaporator fan motor retrofit so the new controls are installed on a new ECM. The figure also demonstrates fan control operation for two types of controls—multispeed and on/off controls. Multispeed controls vary the fan motor between high and low speed settings depending on the cooling requirement in the space. Similarly, on/off controls turn the motor on and off in response to space cooling loads.

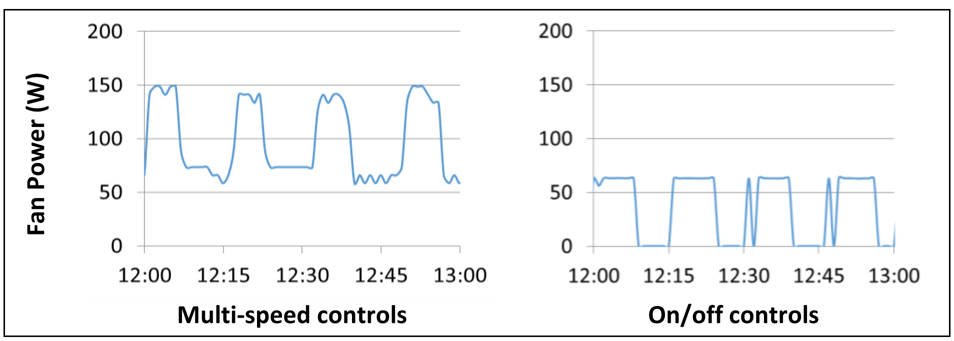

Figure 2. Examples of Evaporator Fan Motor Operation with Controls

Anti-sweat door heater controls use humidity sensors to control the resistance heat required to prevent or eliminate condensate on refrigerated display cases. Door heater controls reduce energy consumption by decreasing the run time of the door heaters compared to uncontrolled door heaters that usually operate continuously at full power. Figure 3 demonstrates two types of door heater controls observed in the CRL study. On/off controllers turn the heaters on and off in response to measured moisture levels on the door. Micropulse controllers use high-frequency signals to modulate power to the door heaters in response to detected humidity levels.

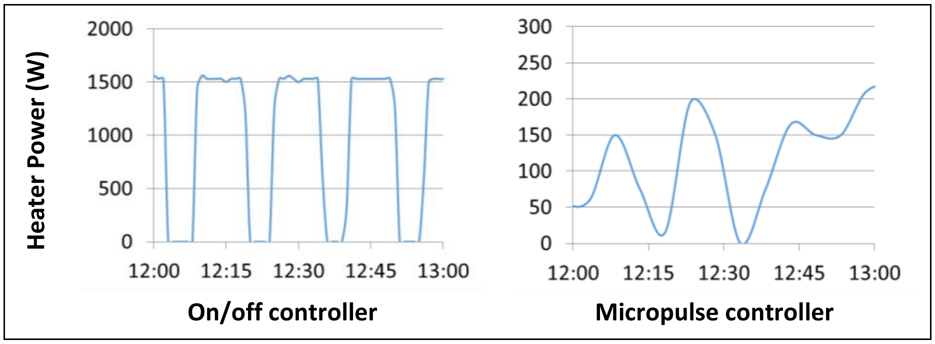

Figure 3. Examples of Door Heater Operation with Controls

All three measures also reduce energy consumption through interactive impacts on the refrigeration system. Since each piece of equipment resides inside the refrigerated space—whether reach-in cooler or walk-in freezer—equipment efficiency improvements also reduce the system's heat-rejection requirements. We discuss the method and results of these interactive effects later in this paper.

Study Methods

Cadmus developed savings loadshapes and key savings parameters for each refrigeration retrofit measure through primary and secondary data collection and analysis.[1] We collected secondary data from a recent study of door heater controls in Connecticut conducted by DNV-GL (The United Illuminating Company 2012) and research conducted by DMI on evaporator fan motors in Massachusetts (KEMA et al. 2013). Figure 4 shows the number of each type of measurement—including both primary and secondary data—used to develop the CRL study results.

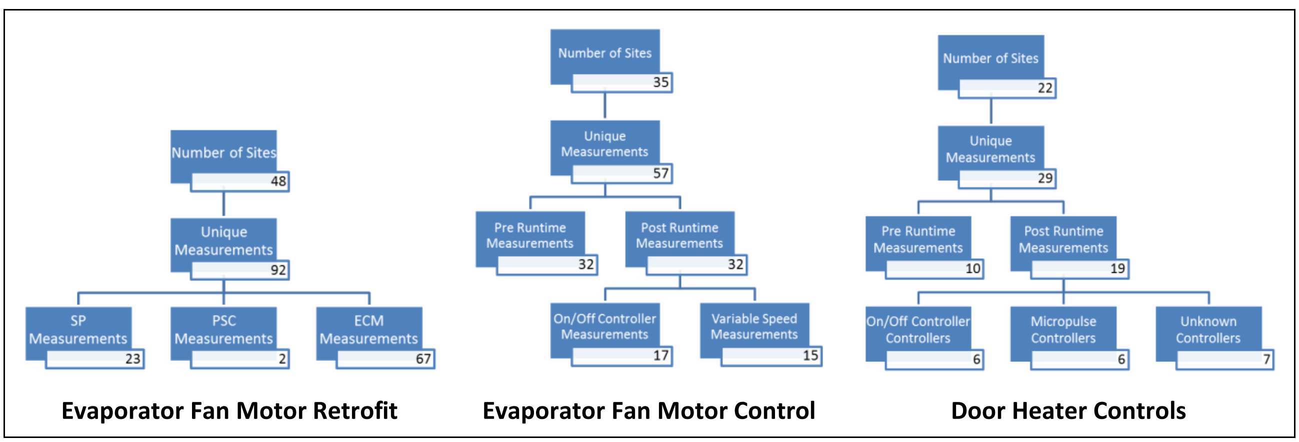

Figure 4. Pre-Installation and Post-Installation Measurement Sample for Refrigeration Measures

Unique measurements refer to data measured on a single circuit with one or more evaporator fan/door heater. On average, there were three motors and eight door heaters per unique measurement of evaporator fans and door heaters respectively. For **evaporator fan motor retrofits**, Cadmus collected 92 unique measurements at 48. We collected measurements before and after installation at nine sites; the remaining sites provided data either before or after installation only. The majority of our measurements were in coolers (80% coolers, 10% freezers, 9% unknown) and walk-in spaces (53% walk-in, 11%

[1] Secondary data refers to existing meter data or results from previously completed evaluations or other available literature.

reach-in, and 36% unknown).[2]

For **evaporator fan controls**, Cadmus collected 57 unique measurements at 35 sites. We collected measurements before and after installation at nine sites; the remaining sites provided data either before or after installation only. The majority of measurements were in coolers (93% coolers and 7% freezers) and walk-in spaces (79% walk-in and 21% reach-in).

For **door heater controls**, we collected 29 unique measurements at 22 sites. We collected measurements before and after installation at three sites; the remaining sites provided data either before or after installation only. 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).

Cadmus used six major steps to develop the total savings loadshapes including data collection, data analysis, and aggregation methods (as shown in Figure 5). **Step 1** involved primary and secondary data collection. All data used in the CRL study was based on field verification and metering. For the CRL study, 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 power per horsepower) and profiles (e.g., hourly runtime) 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 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.[3]

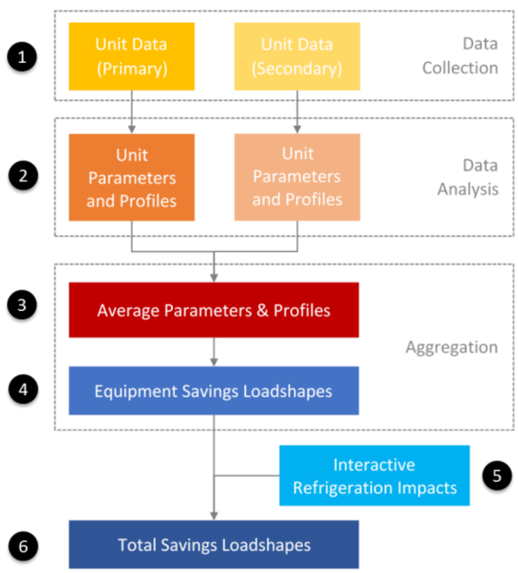

Figure 5. Loadshape Analysis Methods

In **Step 4**, we applied the population average pre and post 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. In **Step 5**, we developed the model to estimate the interactive impacts of the equipment retrofit on refrigeration system loads and power. These interactive impacts result in additional savings due to the reduced heat rejection

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

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

requirements on the refrigeration system. Finally, in **Step 6**, we applied the interactive refrigeration impacts model to the equipment savings loadshapes to calculate the total savings loadshapes. The total savings loadshapes represents the combined impacts of the equipment retrofit and reduced refrigeration load. We separated Steps 5 and 6 from Step 4 to distinguish between savings from the equipment replacement 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.

Leveraging Secondary Data

As the evaluation industry continues to grow, so should libraries of available metered data and evaluators' use of these resources for future evaluation planning and analysis. Cadmus used secondary data in two ways. First, we collected and analyzed available secondary data from completed evaluations, technology assessments, and TRMs from the Northeast to establish the sampling approach and metering protocols for the overall analysis plan. 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 controller 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, we added any secondary data that met the minimum data collection requirements (e.g., metering duration) to the primary data set to create a more robust sample. 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.

Collecting Pre-Installation Data

In most direct installation programs, the implementer manages most of the installation process by recruiting and screening eligible customers, administering pre-installation audits, determining the measures planned for installation, and managing the scheduling of participation activities. To set up pre-installation metering and collect other data before measure installation, the evaluator must coordinate with the implementer and avoid unnecessary delays in the final measure installation and payment of incentives. However, this approach introduces opportunities for selection bias and performance bias.

Selection Bias

Collecting pre-installation 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. The evaluator can minimize the risk of this bias by coordinating with the implementer and the program administrator. In the CRL study, Cadmus coordinated directly with the implementer in each state to identify eligible customer sites that could delay having the measure installed by at least two weeks (to allow for sufficient pre-installation metering). For convenience and to minimize customer burden, the implementer recruited the sites for inspection and metering and scheduled all pre-installation 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.

Performance Bias

Any pre-installation evaluation activities may also introduce performance bias in the overall program and measure performance—just the presence of additional evaluation oversight could influence the behavior of the implementer or customer. (Usually evaluations do not begin until after the implementation processes is complete in a specific attempt to limit this possible influence on program outcomes.) Because the implementer understands that the evaluation results are a report on the success (or not) of the program, he or she may be more diligent with the measure installation, savings estimation, data tracking, customer service, etc. Also, the additional oversight activity spurred by the evaluation—especially if there is any measurement involved—could influence how that customer uses the measure to achieve savings.

Although these biases were unavoidable in the CRL study, 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 in the CRL study, installation is relatively simple—it either works or it does not—so the implementer or customer has little influence on the measure performance. The motor 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 customer. More complex measures—especially those that rely on post-installation commissioning and customer maintenance, such as energy management systems—are more vulnerable to performance bias.

Because the CRL study sample also included sites with only post-installation data, we could compare these data from sites with and without evaluation influence to determine if the pre-installation evaluation activity may have influenced post-installation results. We recommend designing this comparison into the evaluation sample for any studies that may be vulnerable to this performance bias.

Equipment Savings Loadshape Results

As noted in Step 4 of the analysis methods (Figure 5, above), the CRL study developed equipment savings loadshapes that estimate the hourly savings for each retrofit 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) or peak demand savings (e.g., the average hourly savings during peak hours). Figure 6 shows the equipment savings loadshape (in watts per horsepower) for an evaporator fan motor replacing a SP motor. The loadshape shows a continuous average savings value just under 1.2 kilowatts per horsepower with minimal variation with time of day or day type.

Figure 6. Equipment Savings Loadshape for Motor Retrofit (Typical Week)

Figure 7 shows the equipment savings loadshapes for multiple types of evaporator fan controls installed on SP motors and ECMs. 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 level of activity in the store. When the refrigerator doors are opened and closed frequently, the cooling system has to work harder to maintain the setpoint in the space. Therefore, the evaporator fans controllers must operate the motors more of the time, reducing the amount of savings. We observed that savings for on/off controls tend to be higher than savings for multispeed controls. Additionally, savings for controls on SP motors are higher than for EC motors due to the higher demand of the less efficient SP motor.

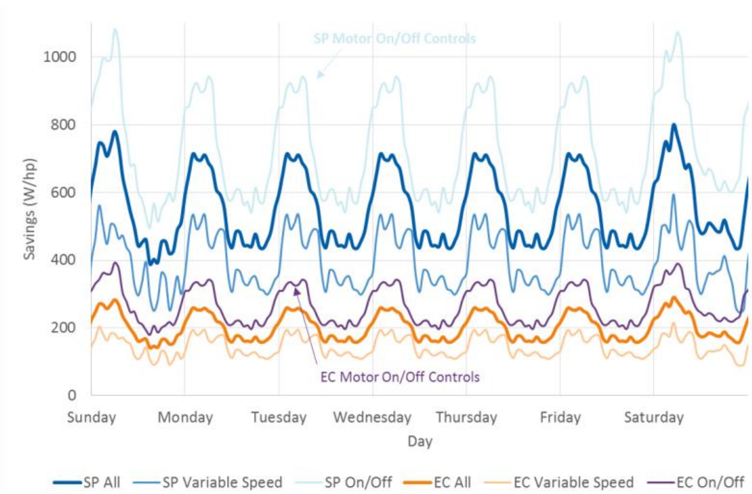

Figure 7. Equipment Savings Loadshape for Motor Controls (Typical Week)

Figure 8 shows the equipment savings loadshapes for multiple types of door heater controls, as well as an average loadshape for all controls. 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 micropulsing and unknown control types[4] tended to save more

[4] 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.

than the on/off door heater controls.

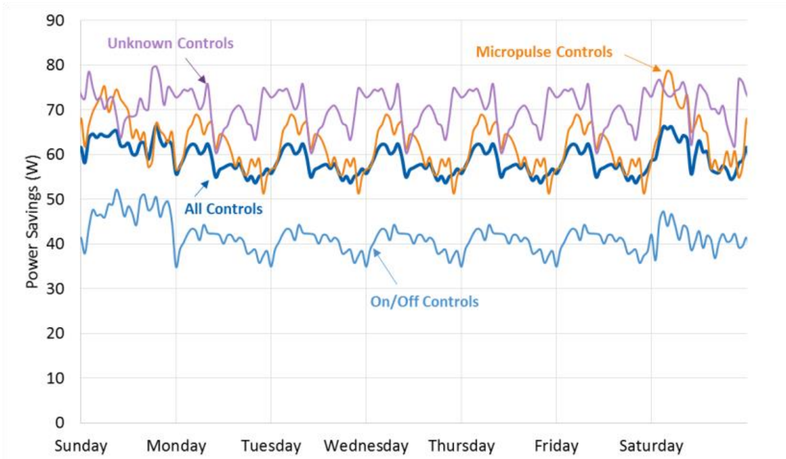

Figure 8. Savings Loadshape for Door Heater Controls (Typical Week)

Results Compared to Existing TRM Estimates

We compared the evaluated parameters from the CRL study to existing parameters used in TRMs across the Northeast. The following figures demonstrate these comparisons for each retrofit measure. Figure 9 compares the three key parameters for estimating savings from evaporator fan motor retrofits: ECM power, baseline motor power, and average load reduction factor.

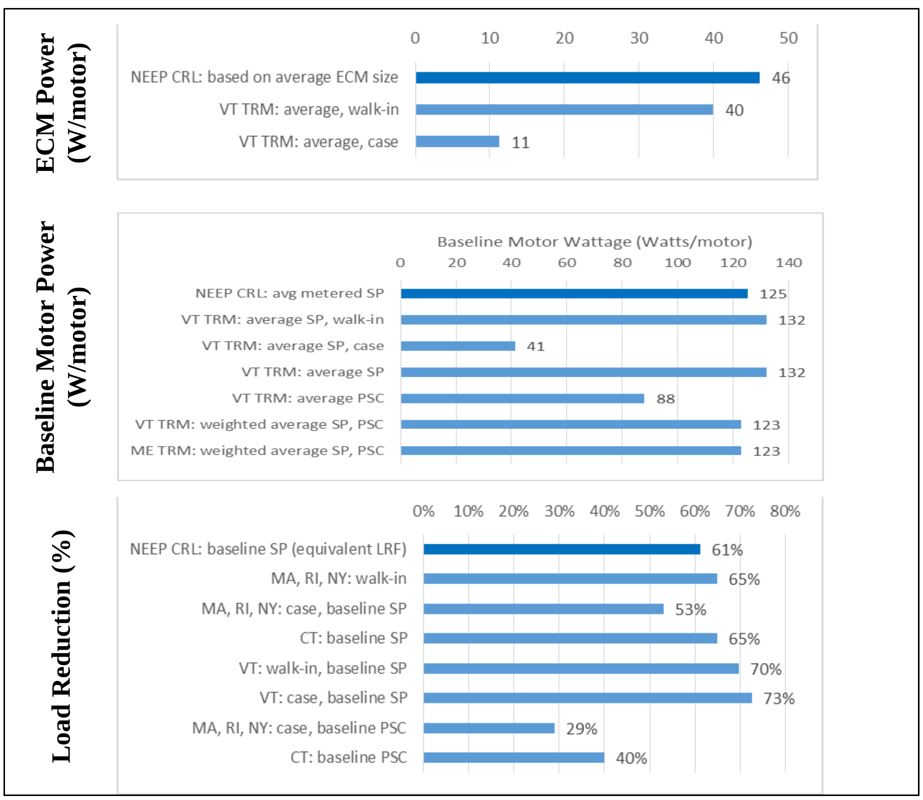

Figure 9. Key Parameters for Evaporator Fan Motor Retrofits

Figure 10 compares the key parameter (percentage run time for the fan with controls) for estimating savings from evaporator fan controls. The percentage runtime value represents the equivalent full load runtime. A lower percentage runtime value results in higher energy savings. The baseline motor power shows is the average of only metered SP motors. We observed very few PSC motors in the field so we removed them from our baseline condition.

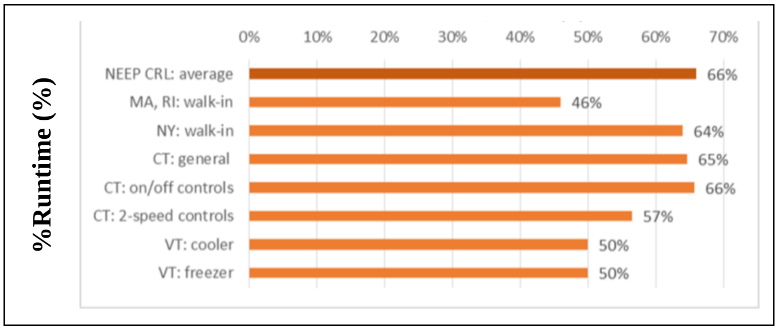

Figure 10. Key Parameters for Evaporator Fan Controls

Figure 11 compares the key parameters for estimating savings from door heater controls: average heater power per door and percentage off time with controls (% Off). The percentage off time represents the equivalent full load off time. A higher percentage off value results in higher energy savings.

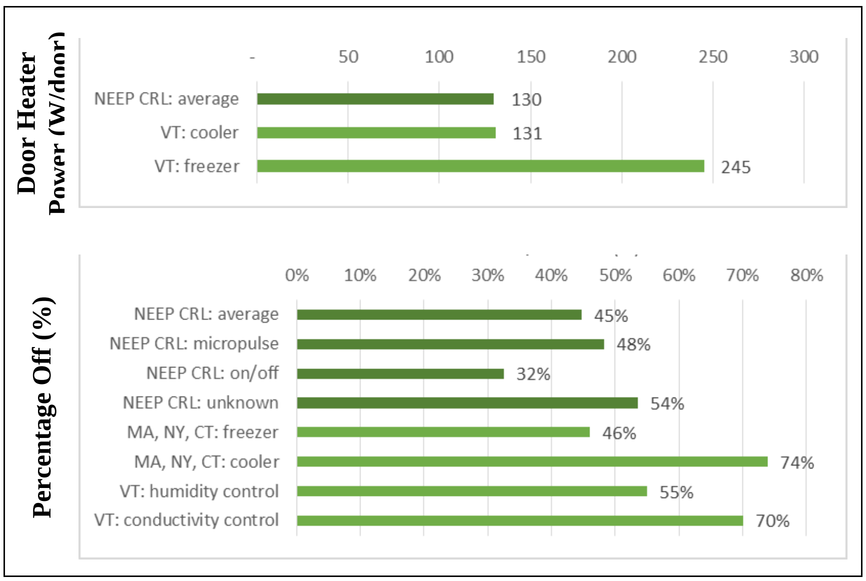

Figure 11. Key Parameters for Door Heater Controls

Interactive Impacts

As noted in step 5, interactive refrigeration impacts, and step 6, total savings loadshapes (described in the text following Figure 5, Loadshape Analysis Methods flow chart), the *total* savings from these refrigeration retrofit measures include savings resulting from the reduced heat that must be rejected by the refrigeration equipment. For a motor retrofit inside a refrigerated space, for example, the total savings include both the direct power reduction of the more efficient fan motor and the reduced load due to reduced waste heat from the motors in the refrigerated space.

We developed an Excel-based calculator to estimate these interactive impacts for each hour of the year, based on the hourly equipment savings loadshape and ambient weather data. Figure 12 shows our process for calculating these additional savings due to the reduced refrigeration load. Starting with the hourly estimates of equipment savings, we convert the reduced equipment power requirements to reduced refrigeration load using a simple unit conversion. The model also estimates scaling factors to account for the fraction of reduced refrigeration load that must be served by the refrigeration system. We assume that that 100% of the motor power must be removed by 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.

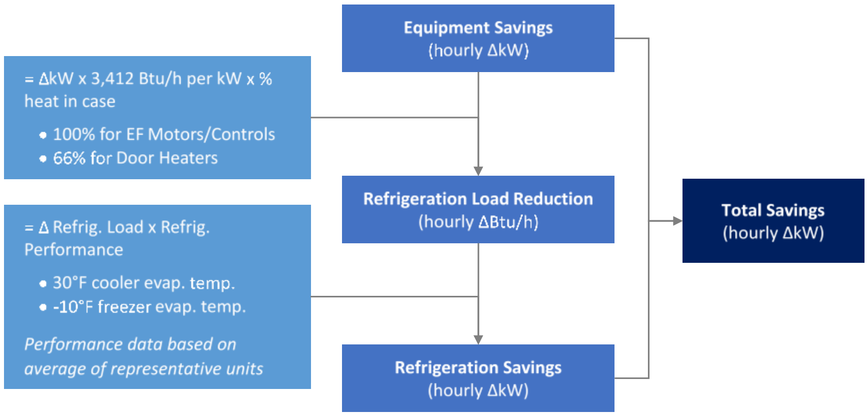

Figure 12. Analysis Steps for Calculating Refrigeration Impacts

The next step is to estimate the reduction in refrigeration system energy due to the reduction in refrigeration load. We developed a model to estimate this refrigeration performance (kW/ton) based on performance curves for the 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 [NOAA] typical meteorological year 3 [TMY3] weather data records).

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. Figure 13 compares our modeled interactive bonus factor with similar factors from TRMs in the Northeast.

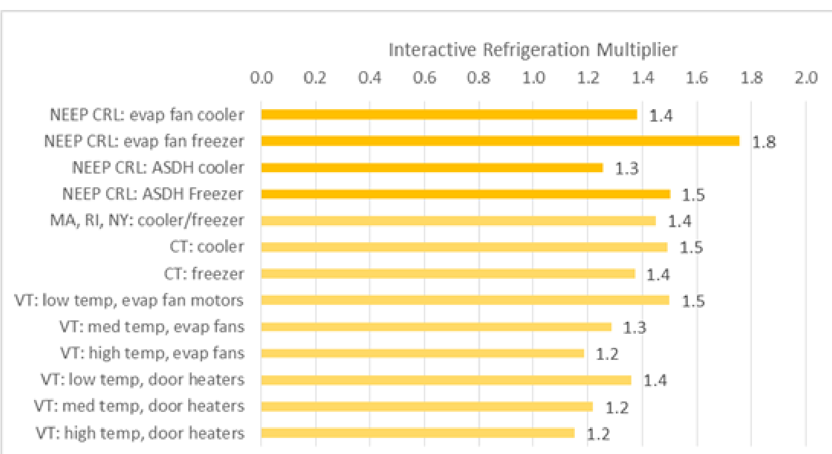

Figure 13. Comparing Interactive Refrigeration Impacts

The CRL study bonus factor for equipment retrofits in coolers is similar to the factors included in TRMs across the Northeast. However, in freezers, the CRL study bonus factor for equipment retrofits is 20% to 50% higher than TRM estimates due to the higher proportion of small refrigeration systems observed in the study sample. The TRM estimates are probably based on a population, such as supermarkets, that has a significant percentage of central refrigeration systems (e.g., supermarkets). The majority of CRL study participants have small, air-cooled, split systems with lower performance and therefore higher savings compared to larger, central systems.

Balancing Impact vs. Technology Evaluation

A true *impact* evaluation (which should strictly report on the actual outcomes of a program's performance) should be balanced with a *technology* evaluation (which focuses on the expected performance of a measure when operating as expected). Both types of studies are important for estimating key savings metrics for energy efficiency programs, but one method may be more retrospective while the other is more prospective.

In the CRL study, we encountered many instances of conflict between impact and technology evaluations, for which we had to determine the most appropriate use of data to meet the objectives of the CRL study. The following are examples of such conflicts with our final treatment and rationale:

- **Evaporator fan motor retrofit.** We performed pre- and post-installation metering on a motor retrofit project that ultimately did not participate in an energy efficiency program. We discuss if the data were still valid since the project was not part of the program participant population and eventually decided to keep the data since the measure performance is probably representative of similar program installations.
- **Evaporator fan motor control.** During our pre-installation metering of evaporator fans, we found one site that had existing controls on SP motors. Implementers confirmed that is was unusual to see existing controls on SP motors, so we did not include this SP-controller data with the pre-installation dataset. However, we did use the meter data in the estimates of average SP motor power draw per horsepower.
- **Evaporator fan motor control.** Our post-installation evaporator fan control measurements found two instances where the fan controls had been disconnected. Through discussions with the implementers, we learned that it was not uncommon for customers to disconnect equipment, even if only a temporary turn off was intended. Therefore, since we would expect customers to behave similarly in future programs, we included these data points in the post-installation dataset even though the technology was not performing.
- **Door heater control**. Our post-installation door heater control measurements found three units for which the controls had no impact on energy consumption. Although we could not firmly establish the reason for non-performance, we confirmed that the three units were installed in the same state and by the same installer. We decided these controls did not fairly represent the success of controls in other states, so we dropped these non-working units from the evaluation sample. Therefore, the results of the door heater study represent the savings achieved by a working door heater control.

As evaluations push for more real-time results and prospective research, key decisions such as these may be more common. Based on the CRL study experience (and similar issues in the previous NEEP variable speed drive loadshape study), we recommend that future study sponsors, evaluation implementers, and any stakeholders have early buy-in on the key study objectives and the most important use of the study results. These early decisions should then drive the reasoning for *impact* versus *technology* treatment decisions during the source of the study.

References

Cadmus. *Commercial Refrigeration Loadshape Project.* July 2015. Unpublished report.

DNV-GL. C9: Impact Evaluation of the Connecticut Small Business Energy Advantage (SBEA) Program. 2014. http://www.energizect.com/government-municipalities/sbea-impact-evaluation-c9-may-2014-2.

Efficiency Vermont. *Technical Reference User Manual.* Available online at: https://www.veic.org/documents/default-source/resources/reports/trm-user-manual-excerpts.pdf

KEMA, Inc., DMI Inc., and SBW. *Impact Evaluation of 2011 Custom Refrigeration, Motor and Other Installations – Final Report.* Prepared for the Massachusetts Program Administrators and Massachusetts Energy Efficiency Advisory Council. June 2013. Available online at: http://ma-eeac.org/wordpress/wp-content/uploads/Impact-Evaluation-of-2011-Custom-Refrigeration-Motor-and-Other-Impact-Evaluation-Final-Report-6.18.13.pdf

Mass Save. *Massachusetts Technical Reference Manual*, 2013-2015 Program Years – Plan Version. October 2012. Available online at: http://ma-eeac.org/wordpress/wp-content/uploads/TRM_PLAN_2013-15.pdf

New York State Department of Public Service. *New York Standard Approach for Estimating Energy Savings from Energy-Efficiency Measures. Version 3.* 2015. http://www3.dps.ny.gov/W/PSCWeb.nsf/ca7cd46b41e6d01f0525685800545955/06f2fee55575bd8a852576e4006f9af7/$FILE/TRM%20Version%203%20-%20June%201,%202015.pdf

The United Illuminating Company. *Connecticut Program Savings Document for 2012 Program Year.* 2012. Available online at: http://www.energizect.com/sites/default/files/2012%20CT%20Program%20Savings%20Documentation%20FINAL.pdf