ComEd Schnucks Variable Speed Drive Pilot Impact Evaluation Report

Energy Efficiency / Demand Response Plan:
Program Year 2018 (CY2018)
(1/1/2018-12/31/2018)

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DRAFT

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1. Introduction

This report presents the results of the impact evaluation of ComEd's CY2018 Schnucks Variable Speed Drive (VSD) Pilot Program. It presents a summary of the energy and demand impacts for the pilot program and broken out by relevant measure and program structure details. The appendix presents the impact analysis methodology. CY2018 covers January 1, 2018 through December 31, 2018.

2. Program Description

This pilot was designed to test the application of VSDs to refrigeration condensers in supermarkets. The VSDs deliver energy savings by reducing the fan motor speed. The IL Technical Reference Manual (TRM) Version 6.0 includes VSD measures for pumps and HVAC systems[1] but not for refrigeration, necessitating this custom evaluation. This measure does appear in IL TRM Version 7.0 which will be applicable in CY2019.[2]

The pilot included four participating Schnucks supermarkets in CY2018.[3] Across these stores, the pilot program distributed VSDs to 20 condensers, 14 of which were included in this evaluation; for more information see Table 8-1.

Table 2-1. CY2018 Volumetric Findings Detail

Participation	Schnucks Supermarkets
Participants	4
Total Measures	1
Distributed Projects	20
Evaluated Projects	14

Source: Implementer data and Navigant team analysis

3. Cumulative Persisting Annual Savings

The measure-specific and total ex ante gross savings for the Schnucks VSD Pilot Program and the cumulative persisting annual savings (CPAS) for the measures installed in CY2018 are shown in the following tables and figure. The total CPAS across all measures is 113,864 kWh. This evaluation did not assess gas savings. The Effective Useful Life (EUL) is 15 years, which is consistent with the EUL for other VSD applications and with the EUL for this measure in Version 7.0 of the IL TRM (since this measure doesn't appear in Version 6.0).

[1] See measures 4.4.17 and 4.4.26 in Version 6.0, Volume 4 of the IL TRM.
[2] See measure 4.6.12 in Version 7.0, Volume 4 of the IL TRM.
[3] These four stores were chosen to balance the two major refrigeration systems common to the region. For more information on the site selection see the implementer's report:

Seventhwave, 2019. *Variable Frequency Drive Energy Savings in Refrigeration Condensers: Field Test for ComEd Emerging Technologies.*

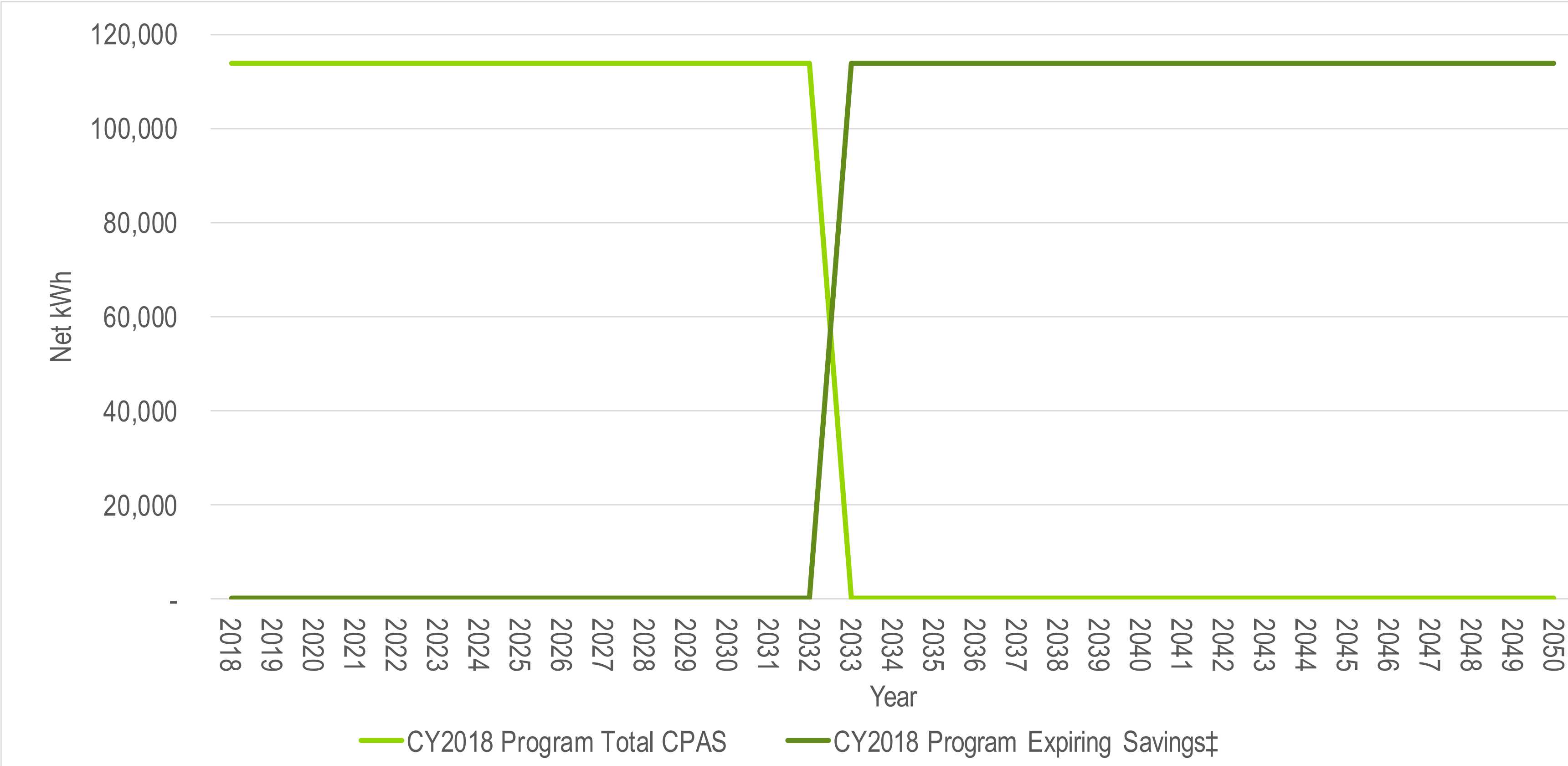
Table 3-1. Cumulative Persisting Annual Savings (CPAS) – Electric

End Use Type	Research Category	EUL	CY2018 Verified Gross Savings	NTG*	Lifetime Net Savings†	Verified Net kWh Savings 2018	2019	2020	2021	2022	2023	2024	2025	2026
Refrigeration	VSD	15.0	162,663	0.70	1,707,962	113,864	113,864	113,864	113,864	113,864	113,864	113,864	113,864	113,864
CY2018 Program Total Electric CPAS			**162,663**		**1,707,962**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**
CY2018 Program Expiring Electric Savings‡							**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

End Use Type	Research Category	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Refrigeration	VSD	113,864	113,864	113,864	113,864	113,864	113,864						
CY2018 Program Total Electric CPAS		**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**-**	**-**	**-**	**-**	**-**	**-**
CY2018 Program Expiring Electric Savings‡		**-**	**-**	**-**	**-**	**-**	**-**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**	**113,864**

Note: The green highlighted cell shows program total first year electric savings.
* A deemed value. Source: ComEd CY2018 and CY2019 Pilot Programs' Net-to-Gross Values memo, which is to be found on the IL SAG web site here: http://ilsag.info/net-to-gross-framework.html.
† Lifetime savings are the sum of CPAS savings through the EUL.
‡ Expiring savings are equal to CPAS Yn-1 - CPAS Yn + Expiring Savings Yn-1.
Source: Navigant analysis

Figure 3-1. Cumulative Persisting Annual Savings



‡ Expiring savings are equal to CPAS Yn-1 - CPAS Yn + Expiring Savings Yn-1.
Source: Navigant analysis

4. Program Savings Detail

Table 4-1 summarizes the incremental energy and demand savings the Schnucks VSD Pilot Program achieved in CY2018. This evaluation did not assess gas or demand savings.

Table 4-1. CY2018 Total Annual Incremental Electric Savings

Savings Category	Energy Savings (kWh)	Demand Savings (kW)	Summer Peak Demand Savings (kW)
Electricity			
Ex Ante Gross Savings	163,070	NA	NA
Program Gross Realization Rate	1.00	NA	NA
Verified Gross Savings	162,663	NA	NA
Program Net-to-Gross Ratio (NTG)	0.70	NA	NA
Verified Net Savings	113,864	NA	NA
Converted from Gas*			
Ex Ante Gross Savings	NA	NA	NA
Program Gross Realization Rate	NA	NA	NA
Verified Gross Savings	NA	NA	NA
Program Net-to-Gross Ratio (NTG)	NA	NA	NA
Verified Net Savings	NA	NA	NA
Total Electric Plus Gas			
Ex Ante Gross Savings	163,070	NA	NA
Program Gross Realization Rate	1.00	NA	NA
Verified Gross Savings	162,663	NA	NA
Program Net-to-Gross Ratio (NTG)	0.70	NA	NA
Verified Net Savings	113,864	NA	NA

* Gas savings converted to kWh by multiplying therms * 29.31 (which is based on 100,000 Btu/therm and 3,412 Btu/kWh).
NA = Not Available
Note: The coincident Summer Peak period is defined as 1:00-5:00 PM Central Prevailing Time on non-holiday weekdays, June through August.
Source: ComEd tracking data and Navigant team analysis

5. Program Savings by Measure

The evaluation analyzed savings for the Schnucks VSD Pilot Program at a condenser level and does not have measure-level savings. For more information about condenser level savings see Appendix 2.

6. Impact Analysis Findings and Recommendations

6.1 Impact Parameter Estimates

The Schnucks VSD Program does not have relevant impact parameters.

6.2 Other Impact Findings and Recommendations

The evaluation team has developed recommendations based on findings from the CY2018 evaluation, as follows:

Finding 1. Verified CY2018 net savings for the Schnucks VSD Pilot Program were 113,864 kWh. These savings verify the viability of VSDs applied to refrigeration condensers.

Finding 2. Gross savings were 162,663 kWh, or 1,451 kWh per horsepower, which was a gross realization rate of 100%. However, that value masks variation across the individual condensers which had realization rates ranging from -30% to 130%. The main cause of variation was the difference in modeling between the implementer and Navigant. The differences in modeling would likely have a smaller impact if power data were collected over a longer period such that a broader range of temperatures occurred in both the pre- and post-periods.

Recommendation 1. Navigant recommends that future research on this technology collect data over a broader range of temperatures so that savings estimates can be updated based on more actual, and fewer modeled, data points.

7. Appendix 1. Impact Analysis Methodology

The Schnucks VSD Pilot Program study period covered December 2017 through mid-July 2018, with the pre- and post-retrofit periods each covering roughly two and one-half months. Over this timeframe, the implementer collected power consumption data with eGauge devices. The implementer averaged power values over four-hour intervals to remove the effects of short-term compressor and condenser fan cycling. Additional information about the implementer's data collection is available in their program report.[4]

To estimate energy savings, Navigant compared modeled condenser usage during the pre- and post-periods. For each condenser, Navigant used regression modeling to determine the relationship between power and relevant explanatory variables including outdoor temperature, hour of the day, and whether the day was a weekday, or weekend or holiday. We then combined the regression estimates with normalized (TMY3) weather data[5] to predict power values along the entire TMY temperature range for the pre- and post-periods. Program savings were calculated as the difference in modeled power between the pre- and post-period.

7.1 Data Description

Navigant received data for 20 condensers, across four Schnucks stores, 14 of which we used in the analysis. The implementer did not collect data on four of the condensers because VSDs were installed but not in use during the analysis period. Navigant (and the implementer in their analysis) discarded two more condensers' data due to irregularities identified by the implementer relating to unknown onsite events that affected power consumption. Table 7-1 summarizes the condenser units in the analysis.

[4] Seventhwave, 2019. *Variable Frequency Drive Energy Savings in Refrigeration Condensers: Field Test for ComEd Emerging Technologies.*

[5] See http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/ for more information.

Table 7-1. Condenser Unit Summary

Store	Unit	Horsepower*	VSD Used†	Included in Analysis‡
East State	Rack A	15	Yes	Yes
	Rack C	18	Yes	Yes
	Rack D North	NA	Yes	No
	Rack D South	NA	Yes	No
Loves Park	Rack A East (A)	9	Yes	Yes
	Rack A West (A2)	9	Yes	Yes
	Rack B East (B)	9	Yes	Yes
	Rack B West (B2)	9	Yes	Yes
	Rack C	NA	No	No
Charles Street	Protocol A	NA	No	No
	Protocol B	NA	No	No
	Protocol C	3	Yes	Yes
	Protocol D	6	Yes	Yes
	Protocol E	6	Yes	Yes
	Protocol F	6	Yes	Yes
	Protocol G	6	Yes	Yes
	Protocol H	6	Yes	Yes
	Protocol I	6	Yes	Yes
Roscoe	Rack A	NA	No	No
	Rack B	7	Yes	Yes

* Horsepower was not provided for the units not in the analysis.

† Four units were retrofitted for VSDs but did not have them in use during the study period. The implementer did not collect data for these units.

‡ In addition to the four units without VSDs in use, two other units were not included in the analysis due to data irregularities identified by the implementer relating to unknown onsite events that affected power consumption.

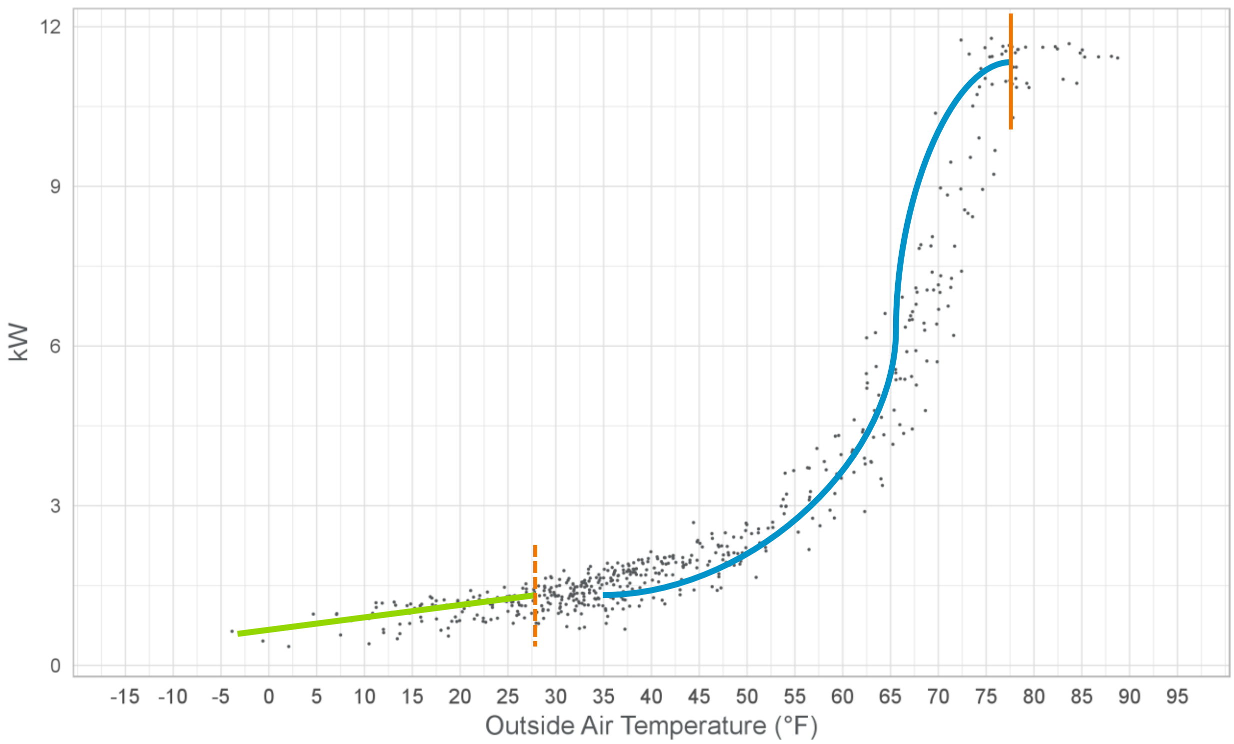
Source: ComEd tracking data and Navigant team analysis.

7.2 Condenser Power Profile

Figure 7-1 shows a typical condenser system power profile with each dot representing a four-hour average kW value. The condenser fan power profile appears as an *S* shape, also referred to as a cubic polynomial. Importantly, power values flatten out at higher temperatures when the fan is running at full power. Above this temperature, fans bypass the VSD, and consequently, the technology does not offer any energy savings. In Figure 7-1, that temperature cutoff is roughly 75°F. Also, the bottom tail of the profile flattens out to a straight line, i.e., a linear relationship between power and temperature, around 30°F.

To address the specific shape of this profile, Navigant visually identified an upper inflection point (shown as the solid orange vertical line in Figure 7-1) for each condenser where power values flattened out. Navigant removed observations above that temperature because the VSDs do not offer energy savings beyond that inflection point. Navigant also identified a lower inflection point (shown as the dashed orange line in Figure 7-1) where the bottom tail of the profile flattened out and the power observations have a linear relationship to temperature. To evaluate savings between these inflection points (along the curved blue line in Figure 7-1), Navigant ran a regression model including outdoor temperature as a cubic polynomial (see Equation 7-1a). At temperatures below the lower inflection point (along the straight green line in Figure 7-1) Navigant used a regression model that was linear in temperature to estimate savings (see Equation 7-1b).

Figure 7-1. Typical Condenser Fan Power Profile (Roscoe Unit A Pre-Period)

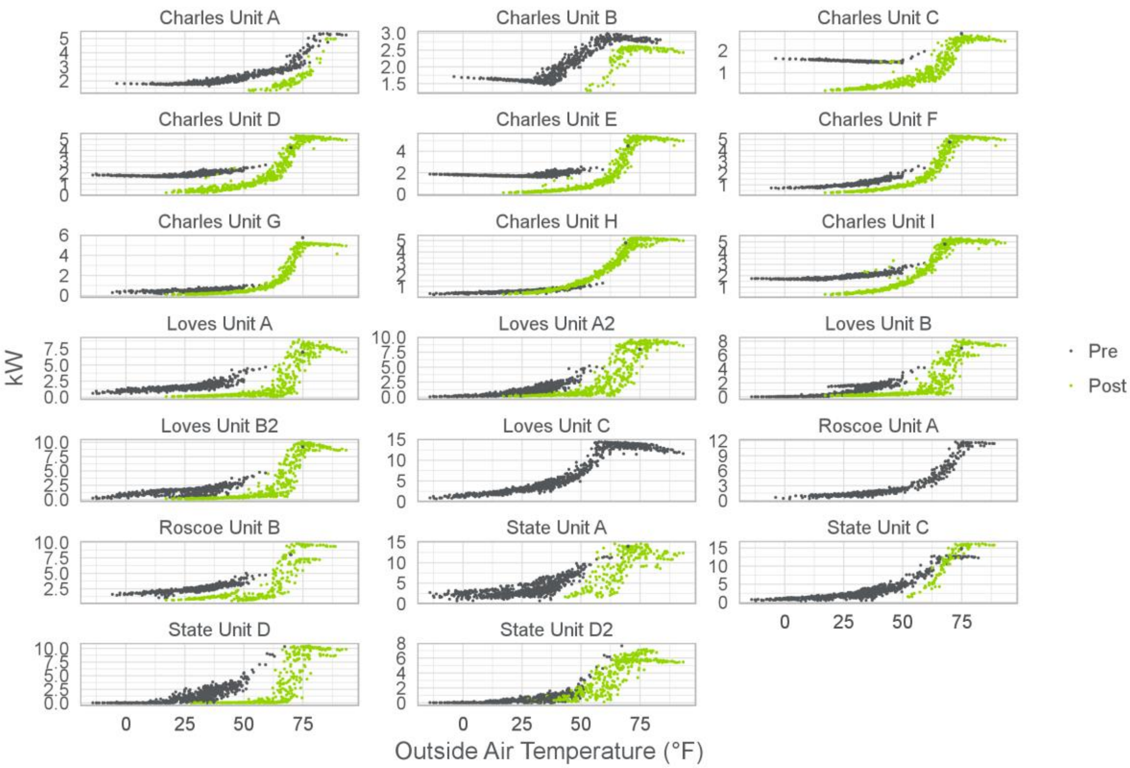


Source: Seventhwave eGauge data and Navigant team analysis.

Figure 7-2 provides the raw pre- and post-period four-hour interval data for each condenser unit.[6] Most of the units clearly show the pattern described above, with a linear relationship between power and temperature below a certain temperature, flat power above a certain temperature, and an *S* shape in between.

[6] For most condensers, one point was added to the pre-period data to anchor the upper end of the distribution to the upper inflection point. The can be seen by the single gray dot appearing in the upper right of most of the individual condenser plots.

Figure 7-2. Raw Data by Condenser



Source: Seventhwave eGauge data and Navigant team analysis.

7.3 Regression Analysis

Navigant ran piecewise regression models for each condenser where the regression was linear in temperature below a certain temperature value (the lower inflection point in Figure 7-1) and cubic in temperature above that value (up to the upper inflection point in Figure 7-1). Equation 7-1 shows the piecewise specification.

Equation 7-1. Regression Model

(a) $$kW_{dt} = \beta_1 Hour_t + \beta_2 Weekend_d + \beta_3 OAT_{dt} + \beta_4 OAT_{dt}^2 + \beta_5 OAT_{dt}^3 \qquad \text{for } OAT_{dt} > C$$

(b) $$kW_{dt} = \beta_1 Hour_t + \beta_2 Weekend_d + \beta_3 OAT_{dt} \qquad \text{for } OAT_{dt} \leq C$$

Where:

kW_{dt}	Four-hour averaged power (kW) on day *d* during four-hour period *t*
$Hour_t$	A factor variable indicating the four-hour period *t* (either 0, 4, 8, 12, 16, or 20)
$Weekend_d$	A binary variable equal to 1 if day *d* is a weekday and 0 if it is a weekend or holiday
OAT_{dt}	Four-hour averaged outside air temperature on day *d* during four-hour period *t*

Navigant modified the regression shown in Figure 7-1 for the Charles Street condensers which had a microchannel causing one fan to run continuously, meaning these units could never reach zero power. To model this dynamic, Navigant used an intercept to estimate the minimum power level for the lower-temperature tail as shown in Equation 7-2.

Equation 7-2. Regression Model for Charles Street

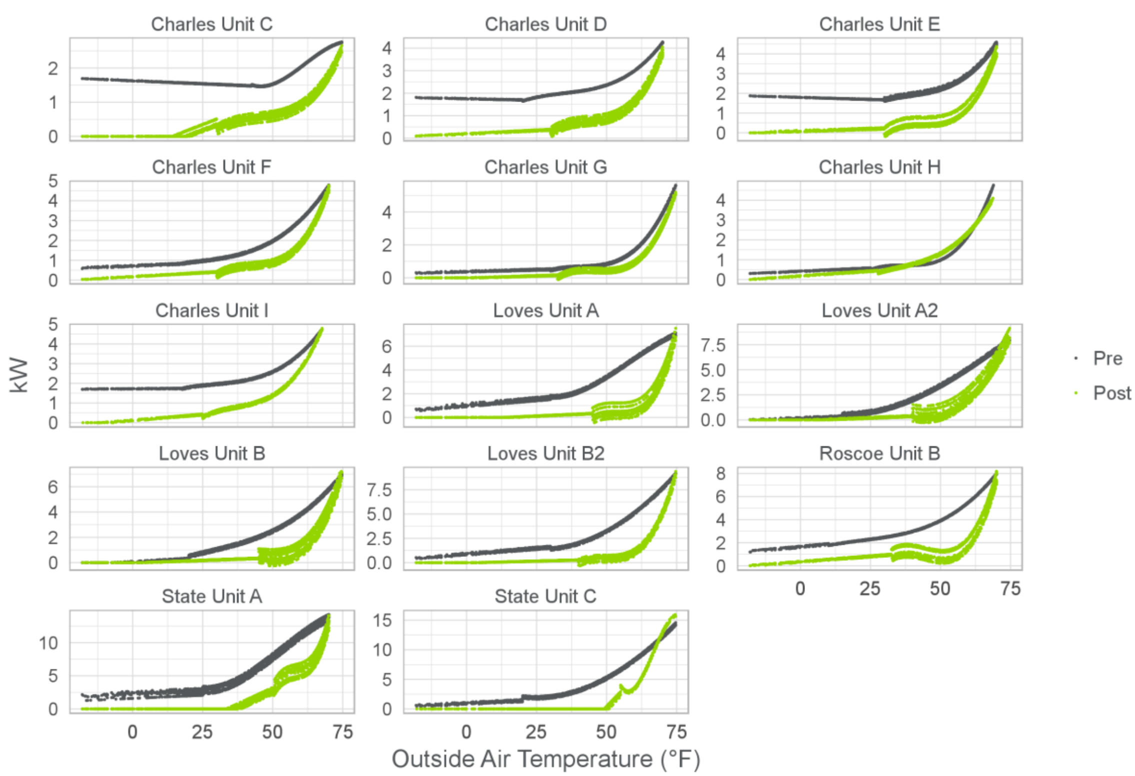
(b) $$kW_{dt} = \beta_0 + \beta_1 Hour_t + \beta_2 Weekend_d + \beta_3 OAT_{dt}$$ for $OAT_{dt} \leq C$

7.4 Modeling Condenser Power

To provide insight into condenser fan performance along a broad range of temperatures, Navigant used Rockford Airport[7] TMY data. Navigant first averaged temperatures over four-hour periods to match the frequency and hours of the implementer's eGauge data. Then Navigant used the TMY data and estimated regression coefficients to predict condenser power separately for each temperature range (the green and blue lines in Figure 7-1).[8]

Figure 7-3 shows the predicted power values compared to outdoor temperature. The thickness of the lines occurs because we are plotting a multivariable regression model in two dimensions and thus we may have multiple power values predicted for the same temperature values (because the hour of the day or weekend variables differed). In several instances, Navigant estimated power values of zero, which is possible for condenser fans without microchannels at low temperatures (e.g., Loves Unit B).

Figure 7-3. Modeled Power by Condenser



Source: Implementer eGauge data and Navigant team analysis.

[7] All the condenser units were located in the Rockford area.
[8] Navigant did two things to ensure appropriate modeled power values. First, because many condensers (e.g., Charles Unit E) had sparse power data at higher temperatures, we used artificial observation anchors to cause the pre- and post-period curves to converge at the temperature and power inflection points seen in Figure 7-2. Second, we ensured that modeled power values did not fall below zero.

7.5 Calculating Energy Savings

The area between the pre and post modeled data for each unit in Figure 7-3 represents program energy savings. Navigant took several steps to quantify this value.

1. For each TMY temperature observation, Navigant subtracted the predicted post-period power value from the pre-period value to get kW savings.
2. The modeled observations were then grouped into bins with the same:
    - 5°F temperature range
    - Weekday and weekend or holiday status
    - Four-hour period
3. Navigant then determined the number of hours of the year in each five-degree temperature range according to the TMY data.
4. Finally, the kW savings for each modeled observation (calculated in step 1) were multiplied by the number of hours of the year in the TMY data in the same five-degree temperature range (calculated in step 3) and then divided by the number of bins those hours covered (calculated in step 2) to get kWh savings. This calculation is shown in Equation 7-3.

Equation 7-3. Energy Savings Calculation

$$kWh\_Savings = \frac{kW\_Savings * Number\_Hours}{Number\_Bins}$$

The number of hours and number of bins are best explained by example. Say the TMY data had four hours of the year with temperatures between -25 and -20°F and that these hours all occurred at 4 am with two happening on weekdays and two on weekends. These four hours cover two bins:

- -25 to -20°F in the four-hour period including 4 am on a weekday
- -25 to -20°F in the four-hour period including 4 am on a weekend or holiday

This means we have eight observations of TMY data across these four hours. Each observation has a kW value which gets multiplied by four (the number of hours) and then divided by two (the number of bins).

The steps above calculate savings for each observation and total savings were calculated by summing across all the observations. Savings by condenser unit were found by summing the observations for each condenser unit separately.

8. Appendix 2. Impact Analysis Detail

Table 8-1 shows CY2018 savings by condenser unit. Across all condenser units, the verified gross savings were 162,663 kWh and the gross realization rate was 100%. Navigant also calculated the verified gross savings per horsepower which averaged 1,451 kWh per horsepower.

Table 8-1. CY2018 Verified Savings by Unit

Condenser Unit	Ex Ante Gross Savings (kWh)	Verified Gross Savings (kWh)	Gross Realization Rate	Verified Gross Savings (kWh/Horsepower)
East State Unit A	20,890	27,229	1.30	1,815
Charles St. Unit G	3,290	3,953	1.20	659
Charles St. Unit C	7,620	8,463	1.11	2,821
Loves Park Unit A2	10,520	11,644	1.11	1,294
Charles St. Unit F	5,540	5,631	1.02	939
Roscoe Unit B*	14,650	14,166	0.97	2,024
East State Unit C	18,470	17,765	0.96	987
Charles St. Unit I	8,320	7,966	0.96	1,328
Loves Park Unit B	11,020	10,464	0.95	1,163
Loves Park Unit A	19,420	18,231	0.94	2,026
Loves Park Unit B2	17,960	16,659	0.93	1,851
Charles St. Unit D	12,460	9,835	0.79	1,639
Charles St. Unit E	13,590	10,453	0.77	1,742
Charles St. Unit H	-680	202	-0.30	34

* Roscoe Unit B is incorrectly labelled Roscoe Unit A in Table 5 of the implementer's report.
Source: Implementer report[9] and Navigant team analysis.

9. Appendix 3. Total Resource Cost Detail

Table 9-1, below, shows the Total Resource Cost (TRC) table. It includes only the cost-effectiveness analysis inputs available at the time of finalizing this impact evaluation report. Additional required cost data (e.g., measure costs, program level incentive and non-incentive costs) are not included in this table and will be provided to evaluation later.

Table 9-1. Total Resource Cost Savings Summary

End Use Type	Research Category	Units	Quantity	Effective Useful Life	Ex Ante Gross Savings (kWh)	Ex Ante Gross Peak Demand Reduction (kW)	Verified Gross Savings (kWh)	Verified Gross Peak Demand Reduction (kW)
Refrigeration	VSD	Condenser	14	15.0	163,070	NA	162,663	NA

NA = Not Available
Source: ComEd tracking data and Navigant team analysis.

[9] Seventhwave, 2019. *Variable Frequency Drive Energy Savings in Refrigeration Condensers: Field Test for ComEd Emerging Technologies*. Page 13.