# ComEd Variable Speed Drive Pilot Impact Evaluation Report

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

**Presented to**
**ComEd**

**FINAL**

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## 1. Introduction

This report presents the results of the impact evaluation of ComEd's CY2018 Variable Speed Drive (VSD) Energy Savings in Refrigeration Condensers Pilot (VSD Pilot). It presents a summary of the energy and demand impacts for the pilot 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 Illinois Technical Reference Manual (IL 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 supermarkets in CY2018.[3] Across these stores, the pilot distributed VSDs to 20 condensers, 16 of which had operational VSDs (Table 2-1); for more information about the individual condenser units see Table 7-1 in the appendix.

**Table 2-1. CY2018 Volumetric Findings Detail**

| Participation | Supermarkets |
|---|---|
| Participants | 4 |
| Total Measures | 1 |
| Distributed Projects* | 20 |
| Evaluated Projects† | 14 |
| Projects Included in Total Savings‡ | 16 |

*There were 20 condensers in the pilot for which VSDs were installed.
†Six projects were not evaluated; four because the VSDs were not operational and two because of data inconsistencies.
‡Savings were counted for the 16 projects with operational VSDs.
*Source: Implementer data and Navigant team analysis*

## 3. Program Savings Detail

Table 3-1 summarizes the incremental energy and demand savings the VSD Pilot achieved in CY2018. This evaluation did not assess gas or demand savings. The gross realization rate for the program was 121%. This high realization rate occurred because Navigant attributed savings to two projects with operational VSDs which the pilot implementer did not estimate ex-ante savings for.

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[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. 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 | 1.21 | NA | NA |
| Verified Gross Savings | 197,487 | NA | NA |
| Program Net-to-Gross Ratio (NTG) | 0.70 | NA | NA |
| Verified Net Savings | 138,241 | 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 | 1.21 | NA | NA |
| Verified Gross Savings | 197,487 | NA | NA |
| Program Net-to-Gross Ratio (NTG) | 0.70 | NA | NA |
| Verified Net Savings | 138,241 | NA | NA |

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*

## 4. Cumulative Persisting Annual Savings

The measure-specific and total ex ante gross savings for the VSD Pilot and the cumulative persisting annual savings (CPAS) for the measures installed in CY2018 are shown in Table 4-1 and Figure 4-1. The total CPAS across all measures installed in CY2018 is 138,241 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).

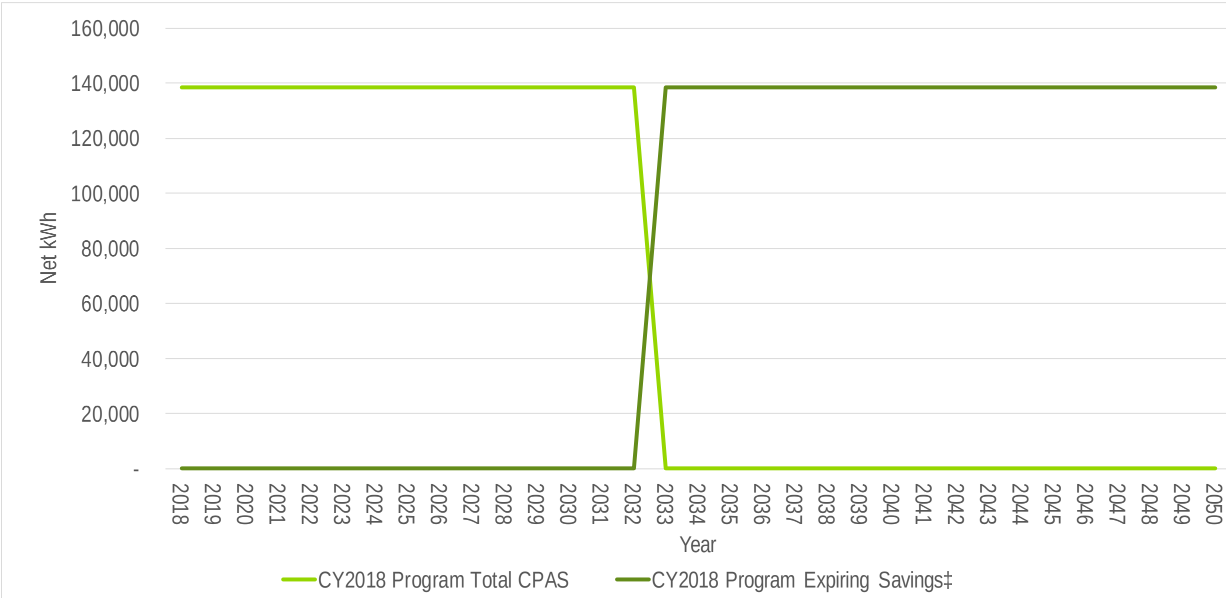
### Table 4-1. Cumulative Persisting Annual Savings (CPAS) – Electric

| End Use Type | Research Category | EUL | CY2018 Verified Gross Savings (Therms) | NTG* | Lifetime Net Savings† | Verified Net Therms Savings 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refrigeration | VSD | 15.0 | 197,487 | 0.7 | 2,073,614 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 |
| CY2018 Program Total Electric CPAS | | | 197,487 | | 2,073,614 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 |
| CY2018 Program Expiring Electric Savings‡ | | | | | | | - | - | - | - | - | - | - | - |

| End Use Type | Research Category | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refrigeration | VSD | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | | | | | | |
| CY2018 Program Total Electric CPAS | | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | - | - | - | - | - | - |
| CY2018 Program Expiring Electric Savings‡ | | - | - | - | - | - | - | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 | 138,241 |

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 4-1. Cumulative Persisting Annual Savings**




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

# 5. Program Savings by Measure

The evaluation analyzed savings for the VSD Pilot 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 VSD Pilot 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 VSD Pilot were 138,241 kWh. These savings verify the viability of VSDs applied to refrigeration condensers.

**Finding 2.** Navigant calculated gross savings of 197,487 kWh, or 1,451 kWh per horsepower, which resulted in a gross realization rate of 121%. The realization rate was higher than 100% because Navigant counted savings for condenser units with irregular data while the implementer did not. For the condensers which were analyzed by both Navigant and the implementer the realization rate was 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 VSD Pilot 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 stores, 14 of which we used in the analysis and 16 of which we counted for total savings. The implementer did not collect data on four of the condensers because VSDs were installed but not in use during the analysis period; Navigant did not attribute any savings to these condensers. Two units had data irregularities and therefore could not be analyzed directly; Navigant attributed savings to these units based on average savings per horsepower across the 14 analyzed units. 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‡ | Included in Total Savings§ |
|---|---|---|---|---|---|
| East State | Rack A | 15 | Yes | Yes | Yes |
| | Rack C | 18 | Yes | Yes | Yes |
| | Rack D North | 12 | Yes | No | Yes |
| | Rack D South | 12 | Yes | No | Yes |
| Loves Park | Rack A East (A) | 9 | Yes | Yes | Yes |
| | Rack A West (A2) | 9 | Yes | Yes | Yes |
| | Rack B East (B) | 9 | Yes | Yes | Yes |
| | Rack B West (B2) | 9 | Yes | Yes | Yes |
| | Rack C | NA | No | No | No |
| Charles Street | Protocol A | NA | No | No | No |
| | Protocol B | NA | No | No | No |
| | Protocol C | 3 | Yes | Yes | Yes |
| | Protocol D | 6 | Yes | Yes | Yes |
| | Protocol E | 6 | Yes | Yes | Yes |
| | Protocol F | 6 | Yes | Yes | Yes |
| | Protocol G | 6 | Yes | Yes | Yes |
| | Protocol H | 6 | Yes | Yes | Yes |
| | Protocol I | 6 | Yes | Yes | Yes |
| Roscoe | Rack A | NA | No | No | No |
| | Rack B | 7 | Yes | Yes | Yes |

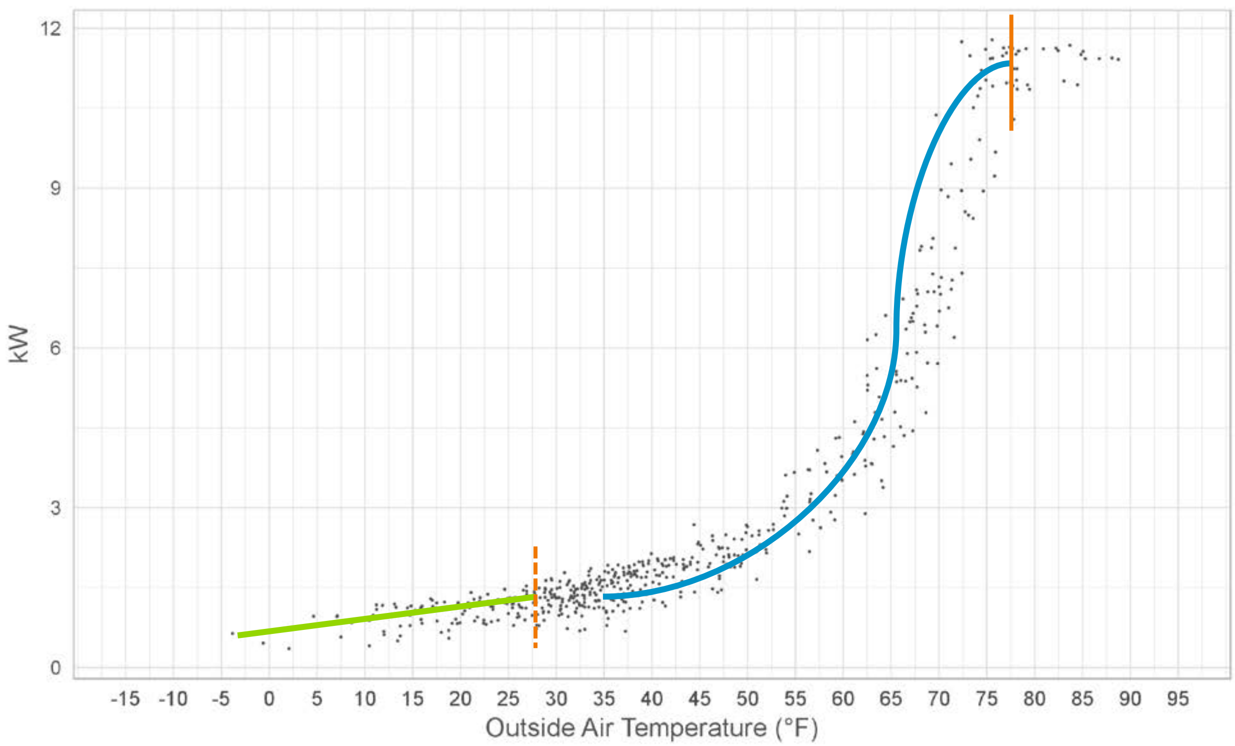
* Horsepower was not provided for the units where the VSD was not used.
† Four units were retrofitted for VSDs but did not have them in use during the study period. The implementer did not collect data for these units.
‡ In addition to the four units without operational VSDs, the implementer identified two other units with data irregularities relating to unknown onsite events affecting power consumption. Due to the data irregularities these units could not be included in Navigant's analysis.
§ Navigant used average energy savings per horsepower from the 14 units analyzed to estimate savings for the 2 condensers with data irregularities.
*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)**

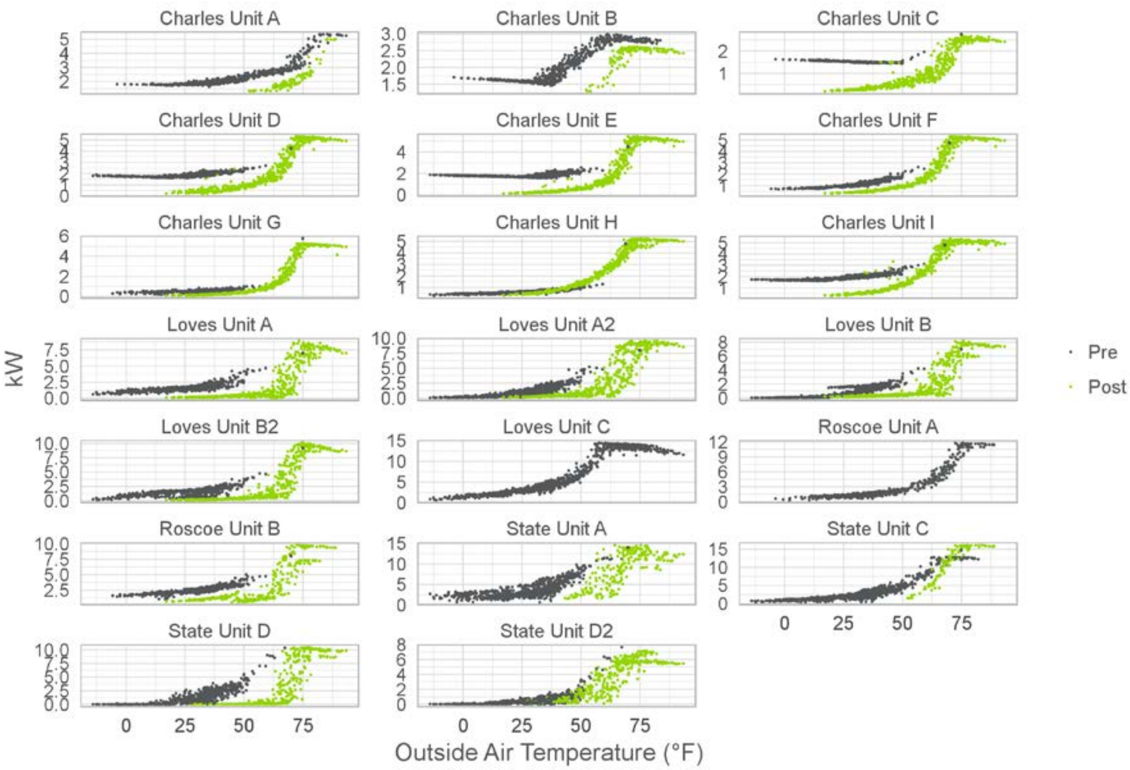



*Source: Seventhwave eGauge data and Navigant team analysis.*

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

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

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**

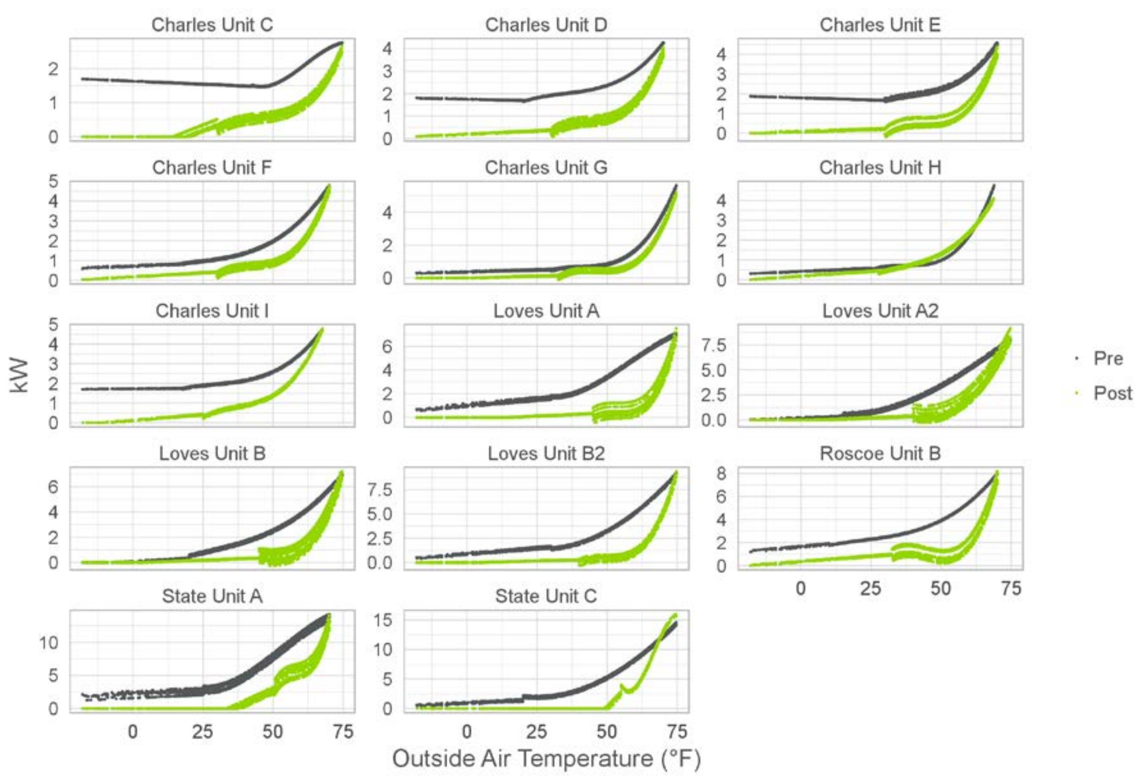
(b) $$kW_{dt} = \beta_0 + \beta_1 Hour_t + \beta_2 Weekend_d + \beta_3 OAT_{dt} \quad \text{for } OAT_{dt} \leq C$$

## 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 197,487 kWh and the gross realization rate was 121%. Navigant also calculated the verified gross savings per horsepower which averaged 1,451 kWh per horsepower.[9]

[9] As discussed in Section 7.1, the East State Rack D North and South units were not analyzed by the implementer or Navigant due to data irregularities. Since these units had operational VSDs, Navigant attributed savings to them based on the average savings per horsepower across the 14 analyzed units.

**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 |
| East State Rack D North | NA | 17,412 | NA | 1,451 |
| East State Rack D South | NA | 17,412 | NA | 1,451 |

* Roscoe Unit B is incorrectly labelled Roscoe Unit A in Table 5 of the implementer's report.
NA = Not available
*Source: Implementer report[10] 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.

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

**Table 9-1. Total Resource Cost Savings Summary**

| End Use Type | Research Category | Units | Quantity | Effective Useful Life | Verified Gross Savings (kWh) | Verified Gross Peak Demand Reduction (kW) | Verified Gross Savings Therms | Gross Heating Penalty (kWh) | Gross Heating Penalty (Therms) | NTG Ratio (kWh) | NTG Ratio (kW) | NTG Ratio (Therms) | Verified Net Savings (kWh) | Verified Net Peak Demand Reduction (kW) | Verified Net Savings Therms | Net Heating Penalty (kWh) | Net Heating Penalty (Therms) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refrigeration | VSD | Condenser | 16 | 15.0 | 197,487 | NA | NA | NA | NA | 0.70 | NA | NA | 138,241 | NA | NA | NA | NA |

NA = Not Available

*Source: ComEd tracking data and Navigant team analysis.*