ComEd Energy Efficiency Program

Switched-Reluctance Motor Field Evaluation

Final Report

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Prepared for
Commonwealth Edison Company

Prepared by
Slipstream

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ComEd Energy Efficiency Program

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Table of Contents

Switched-Reluctance Motor Field Evaluation Final Report 1

Table of Contents 3

1.0 Executive Summary 5

2.0 Introduction and Objectives 6

3.0 Site Descriptions 7

Schaumburg, Illinois 7

Countryside, Illinois 7

Norridge, Illinois 8

4.0 RTU Fan Motor Retrofit 10

Retrofit Process 10

SRM System Principle of Operation 10

SRM System Operational Settings 10

5.0 Measurement and Verification Methodology 12

Measurement Design 12

Sample 13

Savings Calculation Methodology 14

Compressor Energy Estimation 14

Fan Energy Estimation 16

Total RTU Energy Estimation 20

Peak Savings Estimation 20

Baseline Creation 21

Annualized Savings Methods 21

Interview Design 22

Market Extrapolation Methodology 22

6.0 Findings 25

Compressor Energy Consumption 25

Fan Energy Consumption 25

Peak Fan Power Consumption 27

Results in Context of Previous Studies 27

Summary of Interview Results 28

Manufacturer Interview 28

Installer Interviews 29

Retrofit Observations 29

Market Extrapolation Results 30
Conclusions and Recommendations 32
References 33
Appendix A — Monitoring and Site Details 34
Installation 34
Appendix B — Interview Guide 36
Appendix C — Empirical Models 41
Fan Energy Baseline 41
Compressor Energy Change Pre-to-Post Retrofit 43
Temperature Ranges 43

1.0 Executive Summary

Slipstream conducted a field investigation of the software controlled, switched-reluctance motors (hereafter called the *SRM System*) installed at three commercial sites: one office building in Schaumburg, Illinois and two retail stores in Countryside and Norridge, Illinois. This study evaulated the SRM System manufactured by Turntide. The primary objective of the project was to assess the impact of applying the SRM System in retrofitting constant-speed induction rooftop units (RTUs) supply fan motors in terms of energy performance and installation procedures, and then extrapolate any savings to ComEd service territory. This report is based on the data collected from system monitoring that started in July 2020, ended in February 2022, and covers cooling, heating and shoulder season operations.

We found 61 (±9) percent annual energy savings for the RTU supply fans under study. This represents 39 percent annual savings at the RTU level. This report also includes a market extrapolation to demonstrate the technical potential for energy savings, wherin we found that retrofitting of all RTUs with single-speed fan motors in ComEd territory with an SRM System would save 907 million kWh and 100 million dollars annually. Finally, we include observations from interviews with SRM System manufacturers, third-party installers and our own observations regarding the installation process.

2.0 Introduction and Objectives

Between July 2020 and Feburary 2022, Slipstream conducted a field investigation of switched-reluctance motors in a project funded by Commonwealth Edison (ComEd) Energy Efficiency Program.

For this pilot, the Turntide Smart Motor System technology was used at a commercial office building in Schaumburg, Illinois and two retail stores in Countryside and Norridge, Illinois. Switched-reluctance motors, or SRMs, operate by reluctance torque, and their stator poles are driven by DC power, resulting in higher-efficiency operation compared to constant-speed induction induction motors. Turntide paired its high-rotor SRM with a software-driven-motor controller to make a "smart" or software-controlled system: the *SRM System*. The SRM System can replace fan motors in RTUs and some other HVAC equipment from 1 to 20 hp capacity.

The SRM System is new to the market in the last few years; so far two other parties have performed studies of the SRM System performance. In 2018, Southern California Edison performed a study (SCE 2018) comparing the performance of a 3 hp SRM System with two scenarios: a 3 hp induction motor with VFD in a laboratory setting and a 3 hp single-speed induction motor in a field setting. A 2020 study (NREL 2020) performed by the National Renewable Energy Laboratory (NREL) for ComEd compared the performance of three RTU technologies, one of which was the SRM System, using simulation methods. The results of these studies are discussed in the Findings section of this report alongside our own results, providing a broader understanding of field data related to this technology.

This report investigates the benefits and potential of the SRM System. The primary quantitative benefits we measured are energy savings and peak power savings. Two additional benefits of the SRM System are flexible-remote configuration and ongoing data-collection capabilities, both making operational abnormalities visible and addressable to both the motor manufacturer and, through a web portal, the building owner/operator.

The primary objective of this study is to compare the energy usage of the SRM System to constant-speed induction motors in rooftop unit (RTU) supply fans, in terms of energy performance and installation procedure. This report examined the following key questions:

- What is the typical annual energy (kWh) savings of SRM System in RTU supply-fan motors at a commercial property? What is the corresponding peak power (kW) reduction?
- What effect, if any, does the SRM System have on total RTU energy consumption?
- What is the estimated annual energy (kWh) savings for the SRM System for each of the building and system types represented in this study in ComEd territory?
- What is the total resulting technical potential for this technology in ComEd territory?
- Are there any aspects of installation or operation of the SRM System (from the perspective of building owners and/or contractors) that could affect the ease and scale of future program deployment of SRM technology?

3.0 Site Descriptions

Schaumburg, Illinois

One testing site for the SRM System retrofit was a roughly 5,000 square feet (ft^2) bank (office building) in Schaumburg, IL shown in Figure 1. Aside from the customer-facing banking on the first floor of the building, there is also an accounting firm located on the second floor as well as some unoccupied tenant space. This accounting firm only occupies a small portion of the space on the second level while the first floor is fully occupied. The building is typically occupied during standard business hours.

Figure 1. Schaumburg, Illinois site

There are two 12.5-ton RTUs at this site, shown in the red boxes on the Google Maps image above. One RTU serves the first floor of the building, and one RTU serves the second floor. The characteristics of these RTUs are shown in Table 1, below. Both RTUs operate using a two-stage compressor setup with a single supply fan.

Countryside, Illinois

This building is a roughly 22,000 ft^2 retail store and is a single level with the east and west and a portion of the north walls exposed. At this site we installed measurement and verification (M&V) equipment on all four RTUs shown in Figure 2. The RTUs range from 10-ton to 20-ton and serve different sections of the building, with RTU 3 and 4 serving the two western-most zones of the building. The characteristics of these RTUs are shown in Table 1, below. All RTUs operate using a two-stage compressor setup with a single supply fan.

Figure 2. Countryside, Illinois site

Norridge, Illinois

This building is also a roughly 18,000 ft^2 retail store with a single level with the north, south and a small portion of the east walls exposed. At this site we installed measurement and verification (M&V) equipment on both RTUs shown in Figure 3. Table 1 shows the characteristics of all RTUs that remained in the study. These RTUs range in cooling capacity from 10 to 20 tons and have 3 to 7.5hp motor capacities. All systems were equipped with two-stage heating and cooling.

Figure 3. Norridge, Illinois site

Table 1. Properties of RTUs across all sites

Site	Schaumburg 1	Schaumburg 2	Countryside 3	Countryside 4	Norridge 2
Make	Carrier	Carrier	Trane	Trane	Trane
Model	48TME014-A-501--	48TME014-A-501--	YFD181C4HACA	YHC120A4RMA1RF001C1B006A6	YSD240F4RLA0000
Tonnage	12.5	12.5	15	10	20
Pre fan (hp)	5	5	5	3	7.5
Post fan (hp)	3	5	5	3	7.5
Compressors	2 (scroll)	2 (scroll)	2 (scroll)	2 (scroll)	2 (scroll)

4.0 RTU Fan Motor Retrofit

Retrofit Process

The process for retrofitting the SRM System onto an existing RTU includes the following steps:

- Determine the motor controller location within the RTU.
- Determine how to integrate the new control wiring into the existing control wiring.
- Determine the placement of the remote monitoring kits, both the number of them and the ideal locations.
- Lastly, the installer must consider the unit location in reference to building occupants below due to previous feedback vibration noise that can be partially remedied through noise-isolation feet.
- The motor installation then needs to be integrated with the SRM System controls and logging capabilities and is installed similarly to constant-speed induction motors.

Schaumburg: This site observed pre-retrofit compressor operation, so the data is included in the compressor, fan, total RTU energy and peak power analyses.

Countryside: Two of the four RTUs were removed from the sample because they lacked sufficient pre-retrofit fan operation to create a baseline. The two RTUs that remained in the study did not observe pre-retrofit compressor operation and are not included in the compressor and total RTU energy analyses.

Norridge: This site was retrofit with two 7.5hp SRM System. Following the installation of the M&V equipment, a third party unaware of the pilot taking place removed the SRM Systems from both RTUs. Of these, one RTU had sufficient pre-retrofit fan operation to create a baseline and be considered as part of the savings analysis but did not observe pre-retrofit compressor operation so is not included in the compressor and total RTU energy analyses.

SRM System Principle of Operation

The main way in which the SRM System saves energy is its ability to run at multiple speeds thereby varying airflows compared to a constant-speed induction motor. It uses software to program and remotely configure different speeds that correspond to different control modes like heating, cooling and ventilation. A constant-speed induction fan runs either at 100 percent speed or zero. Remote diagnosis of motor issues can also contribute to energy savings.

SRM System Operational Settings

Along with software that can remotely control fan-speed settings and gather data, the SRM System can gets programmed for distinct revolutions per minute (RPMs) or speeds. Table 2 shows SRM System speed settings for the 3, 5 and 7.5 hp fan motors used in this study. However, both RTUs at the Countryside site applied a higher speed (83%) settings for roughly six of the 11-month study period when in stage-one cooling. We also observed much shorter time periods when the fans speeds were likely misapplied to run at lower speed than shown in Table 2.

Table 2. SRM System operational settings

Mode	Percentage of full-speed operation	RPMs (max=1,725)
Vent	40%	690
Cool 1	75%	1,294
Cool 2	90%	1,533
Heat 1	90%	1,533
Heat 2	90%	1,533

On a different system, the SRM System helped find energy savings by re-sizing a motor. Through the data logging capabilities, the SRM System manufacturer identified that a 5hp-SRM System retrofit onto what had been a 5hp constant-speed induction supply fan motor, was oversized and was right-size to a 3hp system at Schaumburg 1. We also did not specifically quantify the energy savings as a result of the rightsizing of this motor.

5.0 Measurement and Verification Methodology

Measurement Design

To determine energy savings, we used a pre-to-post-retrofit experimental design, which involved four primary steps for measurement:

1) Installation of measurement devices
2) Pre-retrofit monitoring period
3) SRM System retrofit
4) Post-retrofit with a multiple-speed-experimental-test period

During Steps 1 and 2, we installed power, temperature, relative humidity, air velocity sensors at the study sites. We recorded one-minute average power consumption using Wattnode power meters paired with high-accuracy current transducers (CT) to measure the existing constant-speed-induction motors in RTU supply fans for two weeks prior to the retrofit of the same RTU supply fans with SRM Systems. We also used eGauge power meters, also at one-minute intervals to measure compressor power draw. Table 3 describes the data points measured, indicators, measurement intervals and devices used for measurement.

Table 3. Summary of data collected

Data Point	Indicator Measured	Interval	Device Data Source (model #)
Motor	Fan motor power consumption	1-minute	Wattnode (WND-WR-MB) eGauge (added 03/2021)
Compressor	Compressor power consumption	1-minute	eGauge (EG4115)
Supply air	Air temperature (F) /velocity (fps)	1-minute	Hobo logger (MX1104) and sensor (t-dci-f300-1x3)
Building Zone temperature	Air temperature for each zone	1-minute	Hobo logger (MX1101)
Outside Air Conditions (Chicago O'Hare Airport)	Dry bulb temp, relative humidity, barometric pressure	1-hour	National Centers for Environmental Information (https://www.ncei.noaa.gov/data/global-hourly)
Typical Meteorological Year (TMY3) Outside Air Conditions (Chicago O'Hare Airport)	Dry bulb temp, relative humidity, barometric pressure	1-hour	National Solar Radiation Database (https://nsrdb.nrel.gov/data-sets/archives.html)

We installed one eGauge power meter and one Wattnode power meter per RTU, which measure and recorded fan-motor and compressor power. The Wattnode devices are included with the SRM System monitoring package. The resulting data, visible on an SRM System portal, comes with limited abilities for data retrieval (for outside parties) so we added an additional eGauge on the supply fan motors on March 11th, 2021 at one site. Due to the creation of an application available to building owners, data retrieval has since become easier. We did not, however, directly measure total RTU power as it mostly includes compressors, supply fan and condenser fan motors. The power measurements missing from our monitoring are the condenser-fan-motor power and power for the RTU control circuits, which should be very small and near constant. For constant-speed motors, the assumption is that the condenser-fan-motor power is constant in both pre- and post-retrofit scenarios. Two slight variations in the wiring of measurement equipment are shown in *Appendix A — Monitoring and Site Details: Installation*. In addition to electrical energy measurements, we placed temperature and relative humidity loggers in each of the zones and relative humidity and air-velocity loggers in the supply air ducts. Cellular modems allowed us to retrieve all data collected remotely.

In Step 3, existing motors were replaced with the SRM Systems. Additional motor parameters were configured to be collected through the SRM System including motor revolutions per minute (RPMs), mode, efficiency, warning and error counts. We obtained a portion of these data from SRM System for our data analysis.

In Step 4, following retrofit with SRM Systems, we continued collecting one-minute power data. This step allowed us to make two comparisons. The SRM motors were first configured for a one-week period of constant speed operation to make a comparison of constant speed operation pre- and post- the SRM System retrofit. Second, and more importantly, the motors were remotely configured for multiple-speed operation for the remainder of the pilot period. This second case is how the SRM System usually operates and constitutes the test case this report is based on.

Sample

After initial monitoring we removed four RTUs from our data analysis for the following reasons:

- Occupancy changes related to the COVID-19 pandemic caused the zone of the building served by this RTU not to enter cooling operation (one RTU).
- The pre-retrofit monitoring period captured insufficient operation to establish baseline operation (two RTUs).
- The SRM Systems were mistakenly removed from operation by an HVAC contractor due to a lack of communication with the building owner (two RTUs). One of these still provided sufficient data to establish baseline operation but is not included in the final estimates for energy savings.

The final data sample includes data collected from five RTUs with constant-speed induction motors. This report is therefore based on a data sample from five motors at three sites with three 3hp and one 5hp and one 7.5hp SRM System, shown in Table 4.

Table 4. Sample characteristics

Site	Building type	Final motor count	Motor size (hp)
Schaumburg	Office	2	3 & 5
Countryside	Retail	2	3 & 3
Norridge*	Retail	1	7.5
Total	**Office/Retail**	**5**	**3, 5, 7.5**

*Although we annualized fan energy savings for this site, we did not include them in the overall fan savings estimate in Table 9.

Savings Calculation Methodology

The core objective of this study was to understand differences in energy consumption at the RTU level as a result of retrofitting an SRM System to the existing supply fans. In addition, we wanted to understand a potential second-order effect: If compressor energy usage changed as a result of (1) varying fan speed changing the volume of air delivered to spaces or (2) impacts from reduced fan heat. We therefore analyzed the energy usage of the fans and compressors separately for pre- and post-retrofit, comparing regression models of pre- to post- in each case.

Compressor Energy Estimation

Instead of directly calculating compressor energy pre- and post-retrofit, we fit compressor energy data to a single, cooling change-point, multiple-regression model shown in Equation 2 to indicate evidence of a difference.

$$Energy_{comp} = \beta_1 CDD + \beta_2 (CDD * Post) + \beta_3 Weekend + \varepsilon \qquad \text{Equation 1}$$

Where:

$Energy_{comp}$ is the daily energy (kWh) consumed by both compressors when operated in cooling mode.

CDD is daily-cooling-degree days, defined as:

$CDD = T_{outdoor}$, for $T_{outdoor} > T_{bal,\ clg}$

$CDD = 0$, for $T_{outdoor} \leq T_{bal,\ clg}$

*CDD*Post* accounts for whether the expected mean change in energy from pre- and post-retrofit is different between the two scenarios.

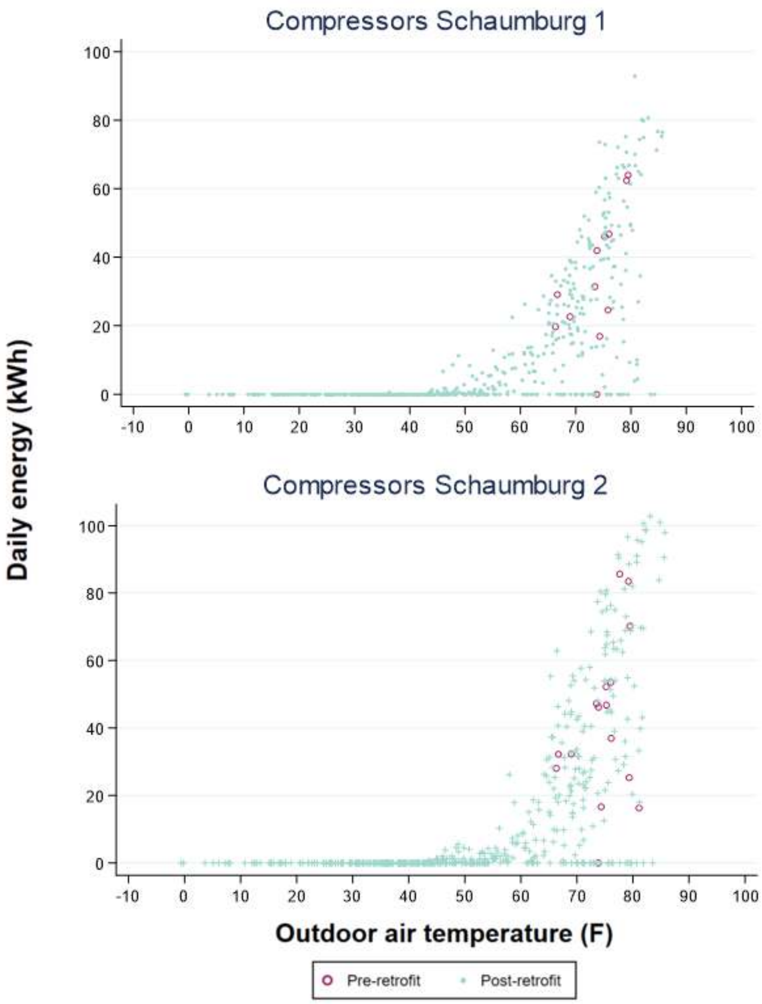
Weekend is a categorical variable accounting for the variation in average fan energy between weekdays, Saturdays and Sundays. Differences in these days are due to store hours.

ε is any variation in energy consumption unexplained by the model.

Equation 1 is consistent with compressor operation consuming no energy at temperatures higher than the cooling balance-point so excludes an intercept term and a non-interacted dummy variable for pre-versus-post retrofit. The compressor model was run in order to detect a significant difference between pre- and post-retrofit.

Only two of the five sites (Schaumburg 1 and 2) recorded sufficient pre-retrofit compressor data to test for difference in pre-to-post retrofit compressor energy consumption. Figure 4**Error! Reference source not found.** shows daily average compressor energy consumption by retrofit scenario for the two Schaumburg sites only. Pre-retrofit (circles) are shown in relation to the operation with the SRM System (triangles). There is noticeably little differentiation between pre- and post-retrofit daily-compressor energy.

Figure 4. Daily compressor energy by retrofit scenario



Fan Energy Estimation

We fit the collected data to a multiple-regression-change-point model using daily energy sums to determine savings for the supply fans. In this specification, fan energy is a function of both heating and cooling degree days and a weekend categorical variable, as shown in Equation 2.

$$Energy_{fan} = \beta_0 + \beta_1 HDD + \beta_2 CDD + \beta_3 Weekend + \varepsilon \qquad \text{Equation 2}$$

Where:

$Energy_{fan}$ is the daily energy (kWh) consumed by the fan when operated in heating, ventilation and cooling modes.

HDD is daily-heating-degree days, defined as:

$HDD = T_{outdoor}$, for $T_{outdoor} < T_{bal,\ htg}$

$HDD = 0$, for $T_{outdoor} \geq T_{bal,\ htg}$

CDD is daily-cooling-degree days, defined as:

$CDD = T_{outdoor}$, for $T_{outdoor} > T_{bal,\ clg}$

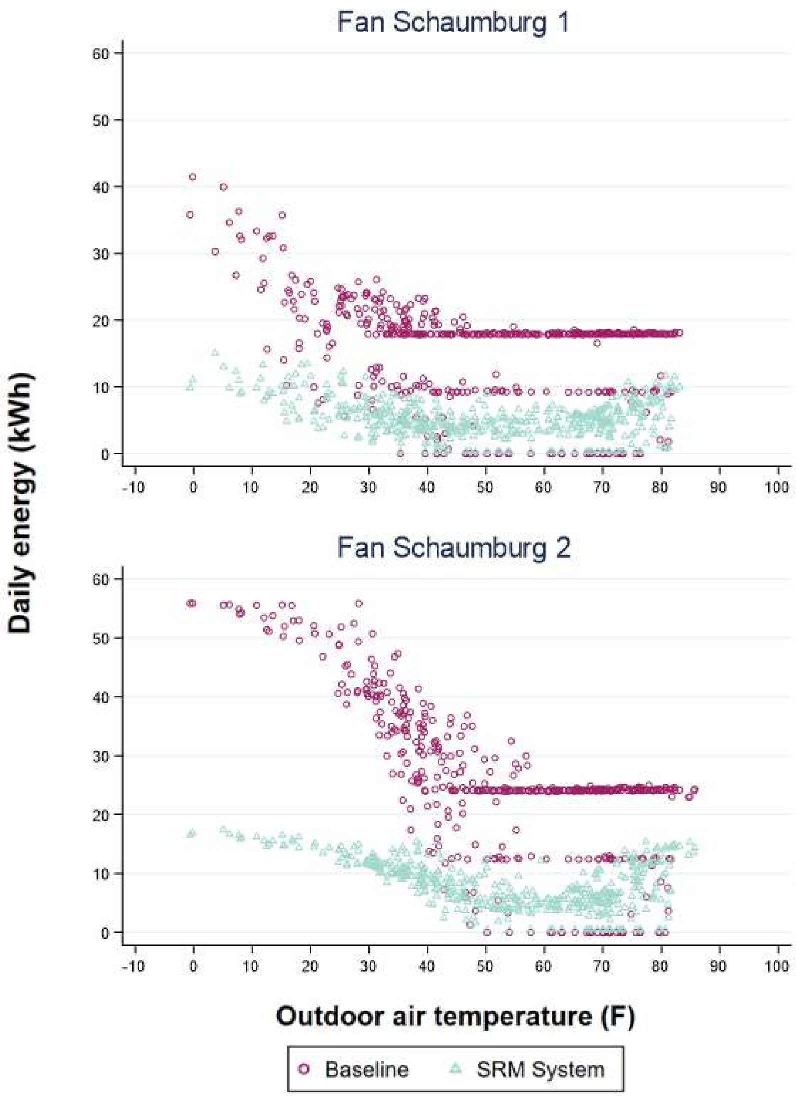
$CDD = 0$, for $T_{outdoor} \leq T_{bal,\ clg}$

Weekend is a categorical variable accounting for the variation in average fan energy between weekdays, Saturdays and Sundays. Differences in these days are due to store hours.

ε is any variation in energy consumption unexplained by the model.

Figure 5 shows the baseline (circles) in relation to the operation with the SRM System (triangles) and highlights some important features of the RTU operation at this building.

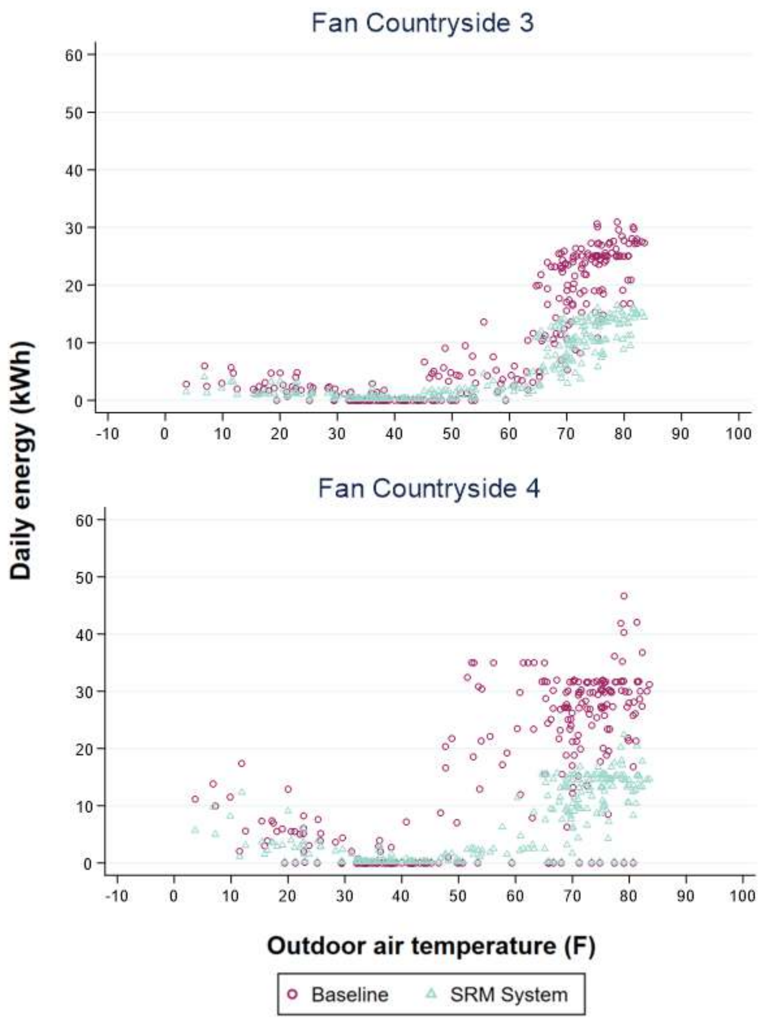
Figure 5. Schaumburg daily fan energy by retrofit scenario



This is an office building with two levels. The first level (Schaumburg 1) is occupied during business hours. The second level (Schaumburg 2) is only sparsely occupied during business hours. The first floor is also less exposed to outdoor conditions. The four exterior walls and the roof on the second level are exposed, compared to only the four exterior walls on the first level. This difference in exposure is reflected in baseline and, to a lesser extent, SRM System operation at lower daily energy consumption at Schaumburg 1 and is most clear in the higher energy consumption at lower outdoor air temperatures. Higher outdoor air temperatures require active cooling, which is reflected in baseline-fan operation being nearly constant with three distinct levels showing weekdays (highest level), Saturdays (mid-level) and Sundays (lowest level). These RTUs are in an occupied mode from 8AM to 7PM on weekdays and from 8AM to 1PM on Saturdays, during which time the fans run constantly for ventilation. All other times (including all day Sundays), the system is in an unoccupied mode and the fan only runs when there is a call for heating or cooling. Figure 5 shows savings from the SRM system as the difference (daily kWh) between the baseline and SRM System daily energy sums. Energy savings at Schaumburg 1 comes mostly from heating and ventilation.

Error! Not a valid bookmark self-reference. shows baseline and SRM System operation at the Countryside site. Different from the standalone building with two levels at Schaumburg, the Countryside site is a retail store with the front and back and roof of the store exposed to outdoor conditions, but the side walls adjoin other buildings.

Figure 6. Countryside daily fan energy by retrofit scenario



Daily fan energy, shown in

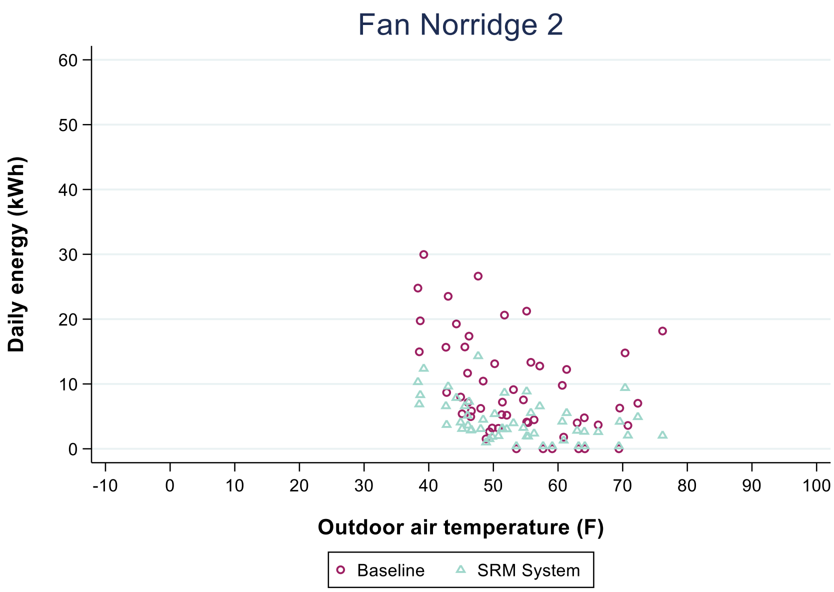
Error! **Not a valid bookmark self-reference.** shows baseline and SRM System operation at the Countryside site. Different from the standalone building with two levels at Schaumburg, the Countryside site is a retail store with the front and back and roof of the store exposed to outdoor conditions, but the side walls adjoin other buildings.

Figure 6, reflects this in higher outdoor air temperatures with the building requiring more fan energy to cool than to heat the building, where there is less difference between baseline and SRM

System fan energy consumption. Also different from Schaumburg, this building does not constantly ventilate during occupied hours, which are weekdays and Saturdays 9AM to 9PM and Sundays 9AM to 6PM. As these RTUs meet indoor setpoints, the fans turn off rather than continuing to ventilate. One exception to this was a period of roughly one month in the fall of 2021 on Countryside 4. Although we were unable to establish a change in the control sequence from the building operator, nearly constant ventilation occurred during occupied hours, which is represented by the baseline points (circles) from roughly 50° F to 65° F. Overall at the Countryside site, energy savings during cooling periods represent a majority of the savings.

Figure 7 show baseline compared to SRM Retrofit scenarios for Norridge 2. The most salient feature of Figure 7 is the short outdoor air temperature range over which data were observed.

Figure 7. Norridge daily fan energy by retrofit scenario



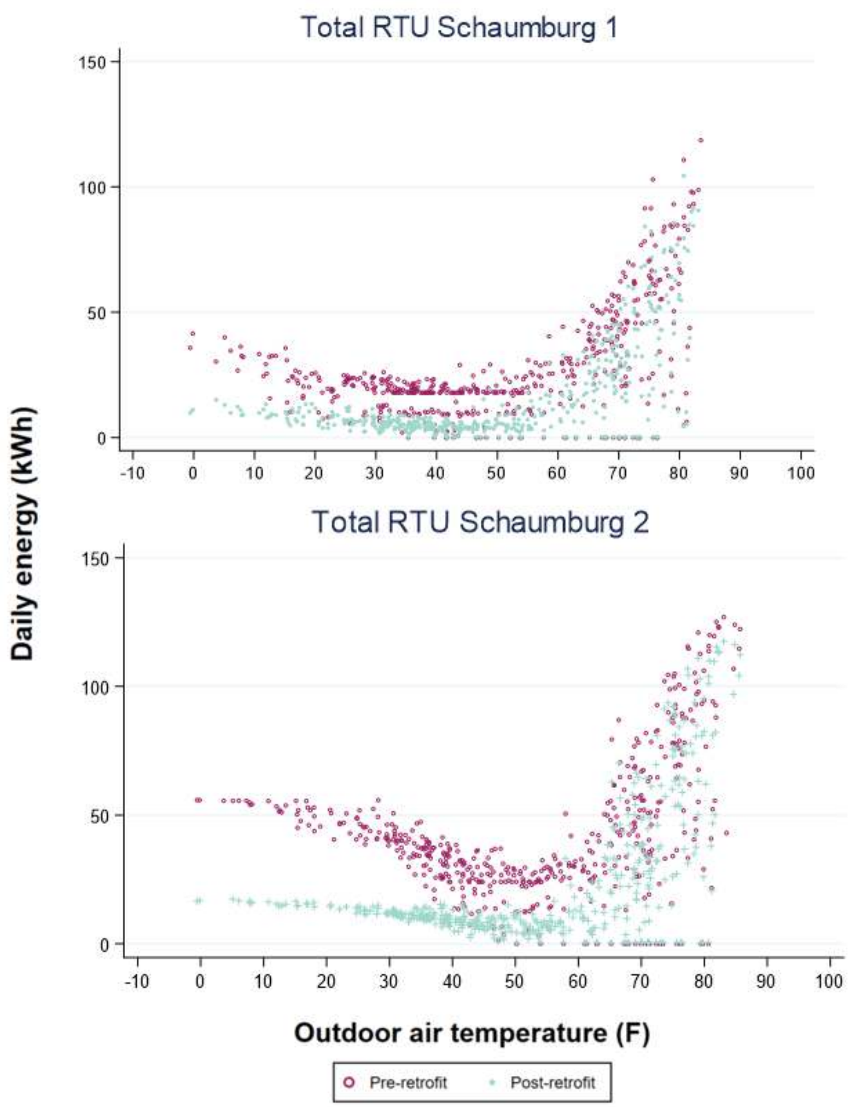
This is the result of a miscommunication between the building owner and their mechanical contractor that ended in the SRM Systems being removed only a few months after the beginning of the study period. However, we were able to create a baseline and calculated the difference in annual energy consumption. Nevertheless, we do not use this site to project average annual savings to ComEd service territory for this measure.

Overall, this sample shows that fan operation is dependent upon building characteristics and the way buildings are controlled.

Total RTU Energy Estimation

To estimate the annual energy consumption at the RTU-level, we used the same model (Equation 2) as the fan energy estimation but instead of fan energy, we used the sum of fan and compressor energy, or total RTU electrical energy, as the dependent variable. Figure 8 largely reflects the dynamics described above for the fan energy descriptions, namely that the second level (Schaumburg 2) has slightly increased heating and cooling loads.

Figure 8. Daily total RTU energy by retrofit scenario



Peak Savings Estimation

We estimated peak power reductions as levels of average hourly power in the baseline versus SRM System operation. The difference between represents peak power savings. We used an outdoor air temperature threshold of 89.0° F as a 1 percent design condition from the ASHRAE Fundamentals Handbook. Additionally, we filtered to weekday afternoons between from 12 to 5PM. We assumed these thresholds to incur peak average hourly power draw on the SRM System and baseline and also assumed a coincidence factor of 1.0.

Baseline Creation

Since this study measured incumbent fans for two weeks at constant speed, we calculated the baseline using the average power when operating (fan ON), then assigned this wattage to all post-retrofit minutes where the fan operated. This is based on the assumption that without the retrofit the fan would have still operated but would have drawn the mean pre-retrofit level of power. This avoids an assumed equivalence between pre- and post-retrofit fan runtimes that could not be verified across the entire annual outdoor air temperature range. Our estimate of annual energy savings is based on the difference between average-daily-fan-energy consumption over the study period. See *Appendix C—Empirical Energy Models: Fan Energy Baseline* for more details.

Annualized Savings Methods

We first aggregated fan, compressor and total RTU electrical power measurements from 1-minute to daily-energy sums. The process we used to arrive at annualize savings at the fan motor and total-RTU level estimates at all RTUs was to apply the models described above (Equations 1 and 2) to the observed data for the baseline and SRM System scenarios shown in Figure 5Figure 6Figure 7. As noted above, the compressor analysis did *not* involve a baseline in the same way because we were able to use observed pre- and post-retrofit compressor data without the assumption of runtime equivalence. We derived all modeling parameters from a combination of Slipstream and SRM System data collection and processed this data using the statistical software package Stata. We created the heating- and cooling-degree days (from Equations 1 and 2) by empirically deriving the unique energy-temperature relationship showing at which outdoor air temperature each RTU transitioned between heating, ventilation and cooling modes. We then applied the model coefficients to a daily, typical-meteorological-year (TMY) data for Chicago O'Hare airport to predict annualized estimates of energy consumption in the baseline and SRM System scenarios. Differencing the two scenarios' annual energy summations provides the resulting estimate of energy savings. Peak power savings was done slightly differently in that we aggregated 1-minute interval power data to hourly averages and did not annualize this using TMY data. These estimates are derived only from observed data.

We dealt with statistical uncertainty associated with the modeling process through a procedure known as 'bootstrapping' where repeated re-sampling re-fits the models and recalculates the results. The standard deviation of each statistic of interest across the resamples is taken as an estimate of the standard error of the statistic of interest to construct 90% confidence intervals around the point estimates of energy consumption.

Interview Design

Our interviews were designed to assess any retrofit implementation issues associated with the installation of the SRM system, technical or supply chain issues, building owner perception and acceptance of the technology and occupant comfort. We conducted the following interviews:

- with the installers ideally immediately after the SRM System retrofit
- with the building owner and/or facility manager at each site after one month of use
- with the manufacturer
- we also observed a retrofit and noted observations as well as interviewed the installers during the retrofit

The general interview guide we created for these purposes is included in *Appendix B — Interview* .

Market Extrapolation Methodology

In the steps below we outline our methods for determining the estimated annual energy savings that results from SRM System retrofits by motor size (hp) in ComEd service territory. We also describe how we calculated the total resulting technical potential for the territory, using data from multiple sources including the field data collected from this project.

To perform the market extrapolation calculations, we used data from three sources: 2012 Commercial Buildings Energy Consumption Survey (CBECS), the Minnesota RTU Characterization study performed by Slipstream (then Seventhwave) and the Center for Energy and Environment (CEE) in 2017, and Nicor Gas Commercial RTU Characterization - Phase 1 (preliminary data) from the Gas Technology Institute (GTI).

As a first step, we used the CBECS data from the East North Central (ENC) census division and applied a scaling factor to the numbers (by building type) of buildings, square footage and fan-energy usage to account for the portion of the division that is the state of Illinois (27%) and then the portion of Illinois in ComEd territory (70%). Step 1 shows how this scaling is applied to determine the number for a single building type. Because the CBECS data is from 2012, we included an annual percent growth factor (2%) to all variables.

$$N_{office\_bldgs_{ComEd}} = N_{office\_bldgs_{ENC\_CBECS}} * 0.27 * 0.7 * 1.02^{10} \qquad \text{Step 1}$$

The number of buildings and square footage came directly from CBECS, but the fan energy usage had to be calculated. To calculate this, in Step 2, we used the electricity usage for ventilation from CBECS and scaled it by the percentage of building served by "packaged units", which is the closest proxy to RTUs in the CBECS data. Also necessary was filtering to only the RTUs that fit the <20 hp motor-size range available for SRM System retrofits. To estimate the percentage of RTUs that fall within the <20 hp motor-size range, we used the preliminary results from an RTU characterization study in Illinois, shown in Table 5. This data does not allow us to determine the fraction of RTUs that have a motor that is greater than 10 hp and less than 20 hp, so, to be conservative, we assumed at least ~92% of RTUs have <20 hp motors.

Table 5: Fan Power of RTUs (adapted from GTI 2021)

Fan power (motor hp)	Fraction of RTUs (%)
Fractional	25
1 to 1.5	11
1.5 to 2	2
2 to 3	27
3 to 5	18
5 to 7.5	5
7.5 to 10	3
>10	8

$$Energy_{RTU_{Fan}} = Energy_{vent} * Percent_{package\,d_{unit}} * Percent_{Motors\_\leq\_20hp} \qquad \text{Step 2}$$

In Step 3 we applied the percentage savings value based on the results of this study and savings reported in literature. We also applied a factor to account for the portion of RTUs that have a single-speed fan and would therefore be realistic candidates for this SRM retrofit (Table 6).

Table 6: Fan Speed of RTUs (adapted from GTI 2021)

Fan speed	Fraction of RTUs (%)
Single	45
Two	14
Three	4
Multiple	13
Variable	24

$$Energy_{potential_{savings}} = Energy_{potential} * \%Energy_{Savings} * \%Single_{speed} \qquad \text{Step 3}$$

We applied the overall fan energy savings we expected from our study of SRM System retrofits to calculate the total technical potential in ComEd territory. The ComEd commercial electricity rate ($0.11/kWh) can be applied to this total to get total-cost savings as well. Because our field study only included the building types Office and Retail, we only included the expected savings for those building types in the ComEd territory, as motor size and savings may differ for other building type categories.

In Step 4, we estimated the number of RTUs in ComEd service territory. We made this estimation using a metric from the Seventhwave & CEE RTU characterization study, which found the average number of RTUs per commercial building is 6.5. We assume this metric is applicable to the ComEd service territory.

$$N_{RTUs} = N_{buildings} * RTUs_{commercial_{bldgs}} \qquad \text{Step 4}$$

We then used the proportion of RTUs by motor size from the GTI RTU study, shown in Table 5, to calculate the estimated number of RTUs in ComEd territory with each motor size.

Finally, in Step 5, we calculated the fan-energy savings by motor size across the territory by applying each fan power fraction of RTUs from Table 5 to the potential total energy savings for all buildings.

$$Energy_{potential_{savings\_motor\_size}} = Energy_{potential_{savings}} * \%Motor_{size} \quad \text{Step 5}$$

6.0 Findings

Our findings encompass the electrical energy consumed by five metered supply fans across at least one heating and cooling season. This section discusses the impact on fan and compressor energy and includes a comparison of our findings to previous SRM System studies.

Compressor Energy Consumption

Compressor energy is consumed by the RTUs whenever building spaces call for cooling. On the logic that the SRM System reduces fan speed when on and thus reduces total airflow, we wanted to discern if an increase in compressor energy consumption was a possible secondary effect. We interrogated the assumption that the SRM System induced *no* change in the levels of compressor energy consumption by using the model described in Equation 2 to assess if the average change from pre- to post-retrofit differed significantly. We observed no statistically-significant difference in compressor-energy consumption pre- to post-retrofit. See *Appendix C — Empirical Models: Compressor Energy Change Pre-to-Post Retrofit for more detail.* While only two of the five RTUs in the study delivered sufficient pre-retrofit compressor activity to be included in the analysis of compressor energy consumption pre- versus post-retrofit, this outcomes suggests that fan energy consumption is the only source of energy savings in the RTUs observed in this study. One limitation of the data in this study is the limited temperature range over which compressor activity was observed pre- to post-retrofit. For more detail See *Appendix C — Empirical Models: Temperature ranges*.

Fan Energy Consumption

Table 7 shows the results of annualized-fan-energy model results from Equation 1. Fan energy savings from the SRM System range from 48 to 69 percent. Fan savings as a portion of total RTU savings represent from 35 to 43 percent. The 90 percent confidence intervals for these measurements are shown in parenthesis. Norridge 2, Countryside 3 and 4 are not included in the estimates of total RTU savings for two reasons. First, we observed no compressor operation in the pre-retrofit period so we could not verify that the compressor energy did not change as a result of the SRM System. Second, Norridge 2 is not included in the overall savings percentage shown in Table 8 because the sparse data resulted in a poor ability of our models to explain the variation in the observed data. Aside from Norridge 2, our models explained between 69 to 86 percent of the variation in the observed data.

Table 7. Annual fan consumption and savings

	Fan				RTU	
RTU	**Baseline usage (kWh)**	**SRM System usage (kWh)**	**Annual savings (kWh)**	**Annual savings (%)**	**Total usage (kWh)**	**Total usage (%)**
Countryside 3	2,910	1,510	1,400 (± 110)	48 (± 1)	N/A	N/A
Countryside 4	4,670	1,880	2,790 (± 410)	60 (± 4)	N/A	N/A
Norridge 2	7,050	2,900	4,150 (± 5,030)	59 (±68)	N/A	N/A
Schaumburg 1	5,949	1,940	4,000 (± 85)	67 (±1)	11,420	35
Schaumburg 2	10,180	3,120	7,060 (± 170)	69 (±1)	16,300	43

Table 8 shows our overall estimates of energy savings as percentages. Baseline versus SRM System, we estimate 61 percent savings and are 90 percent confident that the savings associated with the SRM System is between 52 and 70 percent. We also estimate that this fan energy savings represents 39 percent of the total electrical energy supplied to these RTUs in an average year with the 90 percent confidence interval show in parentheses.

Table 8. Overall fan and total RTU savings

Overall fan energy savings (%)	Fan energy savings portion of total RTU energy (%)
61 (±9)	39

Furthermore, Table 9 shows our estimates of the percentage of fan energy savings across heating, ventilation and cooling modes. These percentages largely follow the operational patterns shown in Figure 5,

Error! Not a valid bookmark self-reference. shows baseline and SRM System operation at the Countryside site. Different from the standalone building with two levels at Schaumburg, the Countryside site is a retail store with the front and back and roof of the store exposed to outdoor conditions, but the side walls adjoin other buildings.

Figure 6 andFigure 7. In general, the SRM Systems at Countryside 3 and 4 deliver most savings in cooling mode. The RTUs at Schaumburg show savings resulting from operation in different modes. Schaumburg 1 had roughly 80 percent of its savings from heating and ventilation mode with roughly 20 percent coming from cooling operation. Schaumburg 2 shows almost 75 percent of its savings from heating mode.

Table 9. Fan energy savings by mode

	Fan savings by mode (%)		
Site	**Heating**	**Ventilation**	**Cooling**
Countryside 3	5	6	89
Countryside 4	10	13	77
Norridge 2	78	5	17
Schaumburg 1	41	41	18
Schaumburg 2	72	18	11

Peak Fan Power Consumption

Table 10 shows average-hourly-peak power when the outdoor air temperature is above 89.0° F. We observed these conditions for a total of 49 to 74 hours in our data sample. Annual peak power savings ranged from 0.23 to 1.1kW representing a reduction of 21 to 50 percent. We excluded Norridge 2 from estimation because it failed to reach peak conditions in this pilot. The 90 percent confidence intervals are shown in parentheses.

Table 10. Peak power savings

Site	Pre-retrofit usage (kW)	Post-retrofit usage (kW)	Annual savings (kW)	Annual savings (%)
Countryside 3	2.1	1.1	0.96 (± 0)	46 (± 1)
Countryside 4	1.1	0.85	0.23 (± 0)	21 (± 2)
Norridge 2	N/A	N/A	N/A	N/A
Schaumburg 1	1.6	0.87	0.71 (± 0)	45 (± 4)
Schaumburg 2	2.1	1.1	1.1 (± 0)	50 (± 4)

Results in Context of Previous Studies

In Table 11 we summarize the results of the two other studies mentioned in the *2.0 Introduction and Objectives,* alongside the findings from this study. Of the studies below, the most comparable to this was conducted by Southern California Edison in field testing induction motors. Southern California Edison reported 57 percent savings, comparable to our reported 61 percent.

Table 11. Savings in context

Investigator	So. Cal. Edison	So. Cal. Edison	So. Cal. Edison	NREL	Slipstream
Number of Savings Assessments	n=1	n=1	n=1	n=5	n=5
RTU Capacity	10 ton	10 ton	10 ton	10 ton	10-20 ton
Motor Size	3 hp	3 hp	3 hp	-	3, 5, 7.5 hp
Research setting	Laboratory: induction vs. SRM varied speed	Laboratory: induction with VFD vs. SRM varied speed	Field test: induction vs. SRM varied speed	Simulation: induction vs. SRM varied speed	Field test: induction vs. SRM varied speed
Fan Energy Savings	50%	11%	57%	32-46% depending on building type	61% (±9) and 39% of total RTU energy

Summary of Interview Results

Manufacturer Interview

We interviewed the Customer Success Project Manager at SRM System manufacturer, who manages pilot and rollout projects from purchase order to motor install. We gained the following takeaways from this interview:

Installation & Training

- The SRM Motor system installation is different, but not more difficult, than a normal motor installation. Since the motor comes with a motor controller, installation can be most easily compared to an AC induction motor + VFD installation.
- The motor controller can be mounted in any orientation. With the appropriate enclosure, the motor controller can be mounted externally, although, for HVAC applications there is almost always ample room within the HVAC unit.
- Installing the SRM System does not require additional qualifications beyond a typical HVAC motor retrofit. Like the installation of AC induction motors, the work requires heavy tooling and high voltage, so local codes and standards must be abided by.
- Training typically consists of taking a 3–4-hour online course provided by the manufacturer, plus a video conference to clarify questions or challenges.
- Depending on the installation, the manufacturer of the SRM System can offer a Solutions Engineer to be on site during the beginning of installations to go through the first steps.
- Most technicians have been found to be proficient after one or two SRM System installations.
- The SRM System manufacturer has created a portfolio for technical support throughout the lifetime of a project, which includes access to the Technical Services Team during business hours, a Mobile Commissioning app.
- The SRM System sells through distribution with companies like Rexel, a nationwide distributor.
- The SRM System manufacturer stated that the material and processes required to manufacture their motors are less complex than those for AC induction motors enhancing their ability to ramp up production.
- The motor-speed profiles for large SRM System rollouts are predetermined by an agreement between the customer and the manufacturer of this SRM System, Turntide.
- Remote monitoring and data collection configuration must be done by the particular SRM System manufacturer for this study, Turntide. There is however, a newly released platform where the user can participate in an online training to configure their own site once they have login credentials. For one-off installations, motor-speed profiles can be selected by an HVAC installer through a mobile app. Otherwise, the speed profiles are set to predetermined defaults.

Building Occupant Impact

- The SRM System operated at a different noise frequency spectrum than AC induction motors, which can lead to customer comments or even complaints. The “different” motor sound is sometimes identified by customers. In most situations, the building and HVAC systems solve this problem on their own: walls, insulation and ducting cause physical barriers between occupants and the motor itself.

- For instances where occupants must be close to the motors, the manufacturer has developed a Q-series motor specifically designed to produce less noise in critical areas. Moreover, the SRM System motors are software driven, and their team of engineers is constantly refining the algorithm of how the motor is controlled to mitigate noise. These improvements to the motor control can be retroactively implemented to existing motors through firmware upgrades.

Installer Interviews

We interviewed three installers: the building facility manager for one of the sites, and two other installers hired to assist with the installations. We gained the following takeaways from these interviews:

- Though none of the installers had prior experience with the SRM System, all installers stated that the actual fan motor retrofit was very comparable to the retrofit of a constant-speed induction motor. They noted that the SRM System retrofit is similar to a VFD retrofit because not only is the motor replaced but a motor controller is also installed.
- The extra labor for the SRM System retrofits is solely associated with installing the motor controller and performing the calibration sequence. The labor for the fan motor replacement is comparable to that of a constant-speed induction motor replacement.
- The installers felt that the video and training they received was sufficient for knowing how to perform the motor retrofit.

Retrofit Observations

We observed the retrofit of one motor from start to finish and noted some observations, the most difficult steps and areas for improvement:

- The SRM System provides a previously unavailable ability to see motor operation through data-visualization on a user portal. An example is that the manufacturer was able to identify that the incumbent motor on one of the RTUs was oversized resulting in the motor being resized from 5 to 3hp. This resulted in a short period of data to compare multi-speed operation of the 5hp with the multi-speed operation of a 3hp motor.
- A second benefit of the data visualization allowed the manufacturer to identify a cycling abnormality that had caused the RTU to go from cooling stage 1 to stage 2 at one-minute increments. Given the ability to remotely control the RTU, signaling was reconfigured with a five-minute delay for cooling stage 2 thus decreasing the number of compressor cycles per day and while not necessarily saving energy reducing compressor wear to extend the life of the compressors.
- There was a consensus that the most difficult part of the retrofit was deciding where to interrupt the existing control wiring to insert the motor controller. This challenge is usually addressed through brainstorming, looking at wiring diagrams, thinking carefully through the process, and doing a test to see if the chosen method and location were successful.
- Another challenge is simply establishing the optimal workflow. This is only a challenge for most installers for the first 1-2 retrofits that they perform, as they are learning how to apply what they learned in the online training to the equipment on-site.
- The installers hoisted the motors up a hatch-ladder to the roof using a rope; the motors had a loop for attachment. This is likely how installers would bring a constant-speed induction

motor to the roof, so this is not just an SRM motor issue, but it's worth noting the challenge. This is a point where safety needs to be observed.

- The optional "motor foot spacers" that come with SRM motors did create some difficulty for the installers in securing the motor base, as there was not enough room to work. The installers suggested that those spacers should already come mounted on the motor because they will always be useful and never in the way.

Market Extrapolation Results

Using CBECS data and the methods described earlier, we estimated the number of buildings, total area and fan energy consumption by building type in ComEd territory (Table 12). We can see that the two building types represented in this study (office and retail), make up ~30% of the number, ~25% of the area and ~41% of RTU fan energy usage of commercial buildings in ComEd territory.

Table 12: Estimated number of buildings, area and annual RTU fan energy consumption in ComEd territory.

Building Type	**Number of Buildings (Thousands) (% of total)**		**Total Area (Million Sq. Ft.) (% of total)**		**Fan Energy (Million kWh) (% of total)**	
Refrigerated warehouse	0.3	0.2%	28.2	0.9%	2.2	0.1%
Public order and safety	3.6	2.2%	57.5	1.9%	14.2	0.4%
Vacant	5.5	3.3%	80.9	2.7%	24.0	0.7%
Laboratory	0.2	0.1%	18.4	0.6%	37.4	1.1%
Food sales	4.7	2.8%	23.3	0.8%	43.3	1.3%
Religious worship	11.8	7.0%	152.9	5.1%	57.4	1.7%
Enclosed mall	0.08	0.0%	27.2	0.9%	60.6	1.8%
Nonrefrigerated warehouse	18.2	10.9%	343.2	11.5%	80.2	2.4%
Lodging	1.2	0.7%	91.0	3.1%	83.7	2.4%
Nursing	1.0	0.6%	64.6	2.2%	101.3	3.1%
Inpatient health care	0.2	0.1%	82.1	2.8%	121.3	3.7%
Service	24.0	14.3%	198.7	6.7%	128.5	3.9%
Public assembly	15.3	9.1%	284.9	9.6%	132.2	4.0%
Outpatient health care	4.6	2.7%	44.5	1.5%	142.8	4.3%
Education	10.2	6.1%	517.7	17.4%	164.3	5.0%
Food service	10.5	6.3%	76.1	2.6%	258.1	7.8%
Retail other than mall	14.6	8.7%	175.8	5.9%	462.9	14.0%
Strip shopping mall	5.0	3.0%	147.8	5.0%	494.2	15.0%
Office	36.1	21.6%	566.7	19.0%	900.0	27.2%
Total	**167.1**	**100.0%**	**2,981.4**	**100.0%**	**3304.5**	**100.0%**

Incorporating the savings factor that we found in our field study, we calculated the total fan savings for all office and all retail buildings in ComEd territory as well as the total technical potential for the entire territory (Table 13). Overall, retrofit of all RTUs with single speed fan motors in ComEd territory with an SRM motor would save 907 million kWh and 100 million dollars annually.

Table 13: Fan savings and cost savings for office, retail and all buildings in ComEd territory.

Building Type	Fan Savings (million kWh)	Cost Savings (million $)
Office	247	27
Retail other than mall	127	14
All building types	**907**	**100**

We estimate that there are ~1,086,000 RTUs on commercial buildings in the ComEd territory. Using the previous information from Table 5, we can isolate the fan savings by motor size as well as number of RTUs in each motor size category. The values in Table 13 and Table 14 include the assumption that the fan savings we found in our field study would be comparable for all motor sizes 20 hp and below. Because our study included fan motors with sizes 3 hp, 5 hp and 7.5 hp, we can be more confident about our calculations for those categories.

Table 14: Fan savings by motor size in ComEd territory (adapted from GTI 2021).

Fan power (motor hp)	Fraction of RTUs (%)	Number of Units (Thousands)	Fan Savings (Million kWh)
Fractional	25	271.6	227
1 to 1.5	11	119.5	100
1.5 to 2	2	21.7	18
2 to 3	27	293.4	245
3 to 5	18	195.6	163
5 to 7.5	5	54.3	45
7.5 to 10	3	32.6	27
>10	8	86.9	73

Conclusions and Recommendations

The SRM System has provided 61 (±9) percent annual fan energy savings, representing 39 percent of total RTU savings with evidence from this pilot suggesting no significant impact on compressor energy. The magnitude of savings attributable to the SRM System across heating, ventilation and cooling modes differs based on the nature of the building and the control sequence. We also found a peak power reduction representing 21 to 50 percent savings.

We estimate that retrofitting of all RTUs with single-speed fan motors in ComEd territory with an SRM System would save 907 million kWh and 100 million dollars annually. Most of these savings would come from retrofitting motors <5 hp because that range accounts for approximately 83% of RTUs in ComEd territory.

The interviews with the manufacturer and installers have shown us that all parties agree that the motor retrofit itself is very standard and straightforward. Though the SRM System installation requires the step of installing the controller, this is similar to a step required in a VFD retrofit, and all installers we spoke with felt that they had received enough training to complete the task successfully. The thorough training sequence provided by the manufacturer for installers combined with the relatively less complex motor manufacturing process suggest that this technology could be feasibly scaled across the ComEd territory.

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Appendix A — Monitoring and Site Details

Installation

Figure 9 shows the monitoring equipment networked to measure supply fan and compressor power consumption before retrofit of the SRM System.

Figure 9. Incumbent motor monitoring diagram

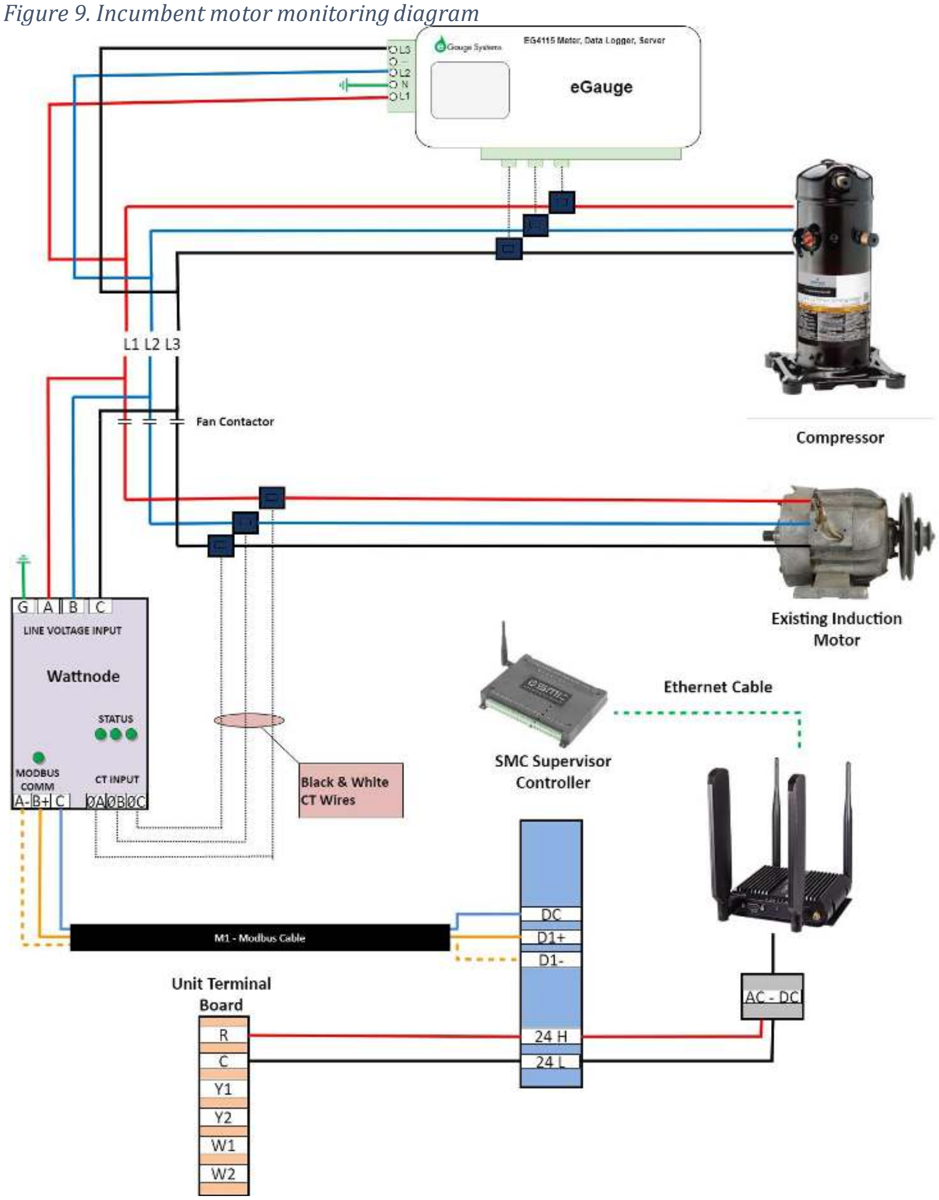
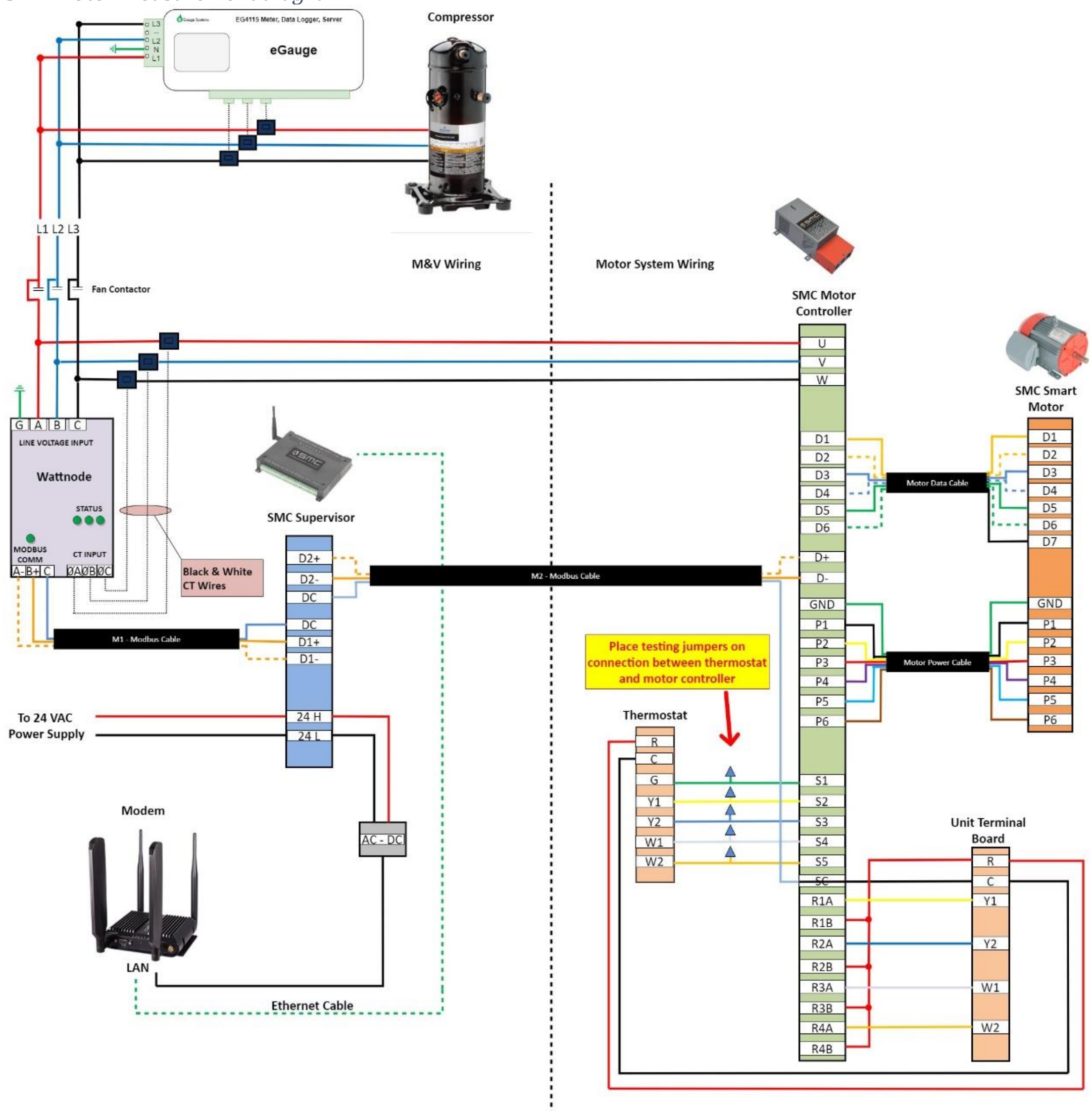


Figure 10 shows post-retrofit measurement equipment.

Figure 10. SRM motor measurement diagram



Appendix B — Interview Guide

SRM Pilot Interview

Building Owners/Facility Mangers/Contractors/Manufacturer

Interview details

Date		
Name		
Title		
Company		
Interviewer(s)		

Project Overview

We will provide a project overview and background in our email to the interviewee when we request a time to schedule the phone interview with them.

Interview Questions for Contractors

1. Could you describe the work your organization does? What role do you perform at your organization?
2. What was your role in the X project?
3. How many RTU motor replacements do you do in a given week/month? Have you installed these SRM motors elsewhere other than this project? Can you list them and their location?
4. In a typical motor retrofit project, how do you decide which new motor to use?
5. From where do you procure the new motors?
   a. How did you go about finding this supplier? Did you have any difficulties?
   b. In general, is it preferable to procure from local suppliers or directly from the manufacturers? What about in the case of SRM motors?

   c. How widely available are SRM motors for this application? Do all your suppliers carry these motors? Did you have any difficulties finding them?
   d. Is there anything about the supply chain that could have made the installation easier?

6. Describe the installation process. Take us through it – Are there any differences between a typical motor replacement and SRM motors? What are the main differences? Is software setup a part of the process?

7. Did you experience any difficulties in completing the project? What do you see as the biggest challenge in installing these motors? How long did the project from the time you arrived onsite until you were able to leave from beginning to end? What is the most time-intensive part of installing the SRM motors?

8. What are the key differences between SRM motors versus typical motors in RTU motor retrofits - in what ways does the installation of this product differ from similar supply fans in terms of:
   a. Labor?
   b. Materials?
   c. Workflow?
   d. On-site logistics?
   e. Safety?
   f. Training?

9. What are the primary items that you typically conduct quality checks for?

10. When installing the SRM, do you make any changes to the HVAC system or building controls? What are they? Does the RTU controller wiring and software setup require any changes to the HVAC system or building controls?

11. Was any special training required to install and/or commission the SRM motors?

12. Is there anything you would have liked to know before the installation of these SRM motors?

13. Have you heard of any issues with the SRM motors after installation? As far as you know, have there been any problems with the motors after installation?

Interview Questions for Building Owners/Facility Managers

1. Could you describe the work your organization does? What role do you perform at your organization?

2. Regarding your participation in this pilot, as the install of the SRM motors impacted the building in general?
    a. How did the installation affect the building and business?
        i. Did you notice any changes after the installation?
        ii. Was it like previous HVAC installations or different? If different, how so?
    b. Did the installation affect building operations in any significant way?
    c. Did the function of the new equipment affect the building operations in any significant way?

3. How do you expect the installation and use of the new equipment to affect the building into the future?

4. Is there anything you would have liked to know before the installation of these SRM motors?

5. Have you experienced higher or lower occupant comfort complaints that you think could be caused by the new motors?

6. Have you heard of any issues with the SRM motors after installation? As far as you know, have there been any problems with the motors after installation?

Interview Questions for Manufacturers

1. What is your role at the SRM System manufacturer and with regard to facilitating installation of SRMs?

2. How is the installation of these motors different from that of constant-speed induction motors?

3. What is your business plan for scaling up the distribution of SRM motors in the ComEd territory, so it is easier for local contractors to procure SRM motors for RTU retrofits?

4. Who is qualified to install SRM motors? Is there any expertise required to specify one of these motors as opposed to constant-speed induction motors for this application?
    a. Does it have to be an engineer, or can it be done by someone else?
    b. Does it have to be someone from the SRM System?

5. What costs are involved in the training?
    a. Who pays for the training?
    b. Is the cost of training included in the motor package?
    c. Are there any other costs in addition to the training?
        i. If so, who pays for them?

6. How can customers get technical support before and after the SRM installation?

7. How can customers monitor and control the motor remotely?
    a. Will customers be able to monitor/control their motors (i.e. change setpoints)?
    b. Will customers be able to download data directly from the website?
    c. Do you expect customers to actively monitor these motors using the data available on the website?

8. Will installers be able to get these motors/parts through suppliers or must they go directly to the SRM System manufacturer?

9. Have you heard of any issues with the SRM motors after installation? Any complaints that you are aware of? Has this been resolved? How?

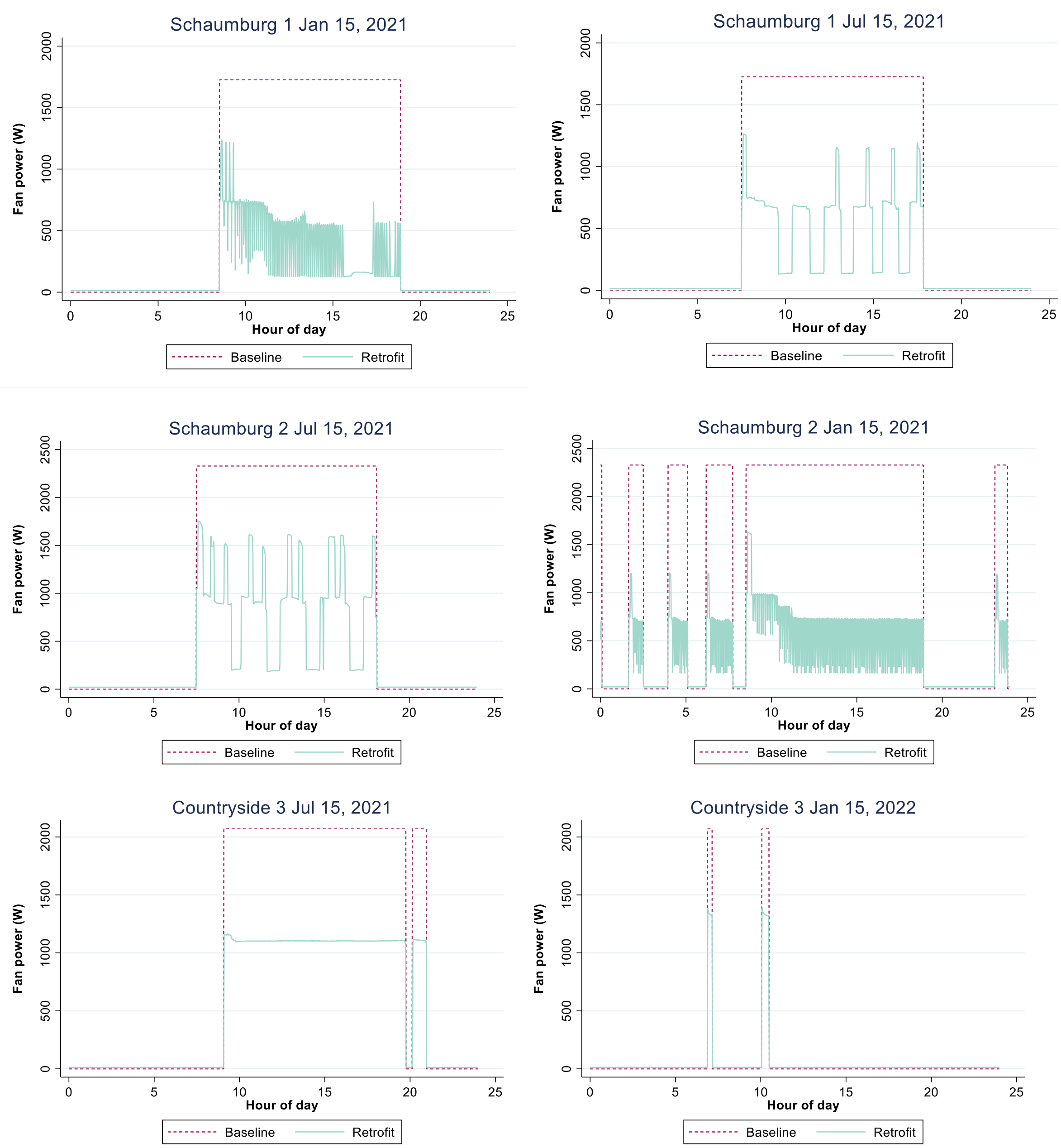
10. How well can your current manufacturing facilities and raw material sourcing accommodate ramping up production of units for widespread adoption in the future?

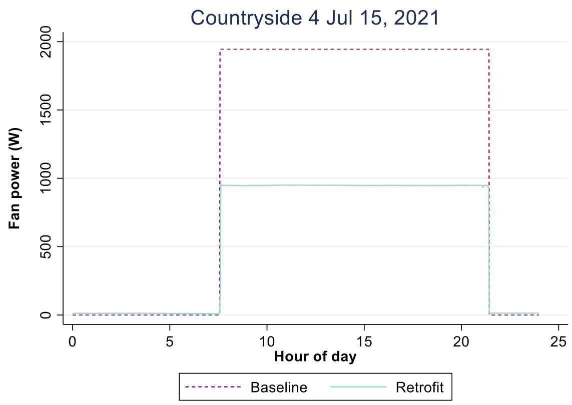
Appendix C — Empirical Models

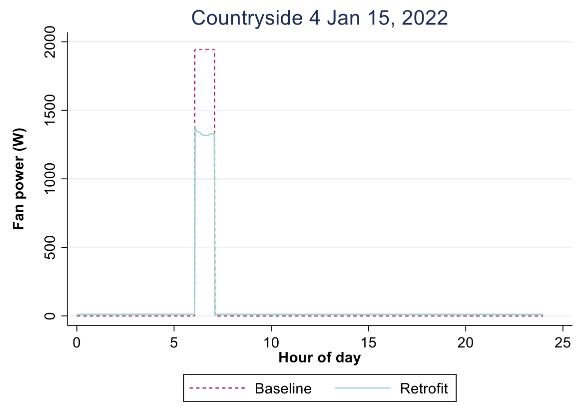
Fan Energy Baseline

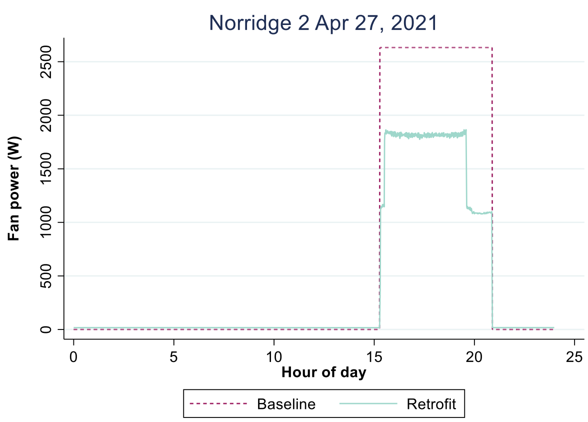
Figure 11 shows the baseline constructed by applying average pre-retrofit wattage to each minute the fan was on post-retrofit for each of the RTUs in the study. Each pane of Figure 11 shows the baseline and the observed post-retrofit fan wattage across a day of cooling and a day of heating operation.

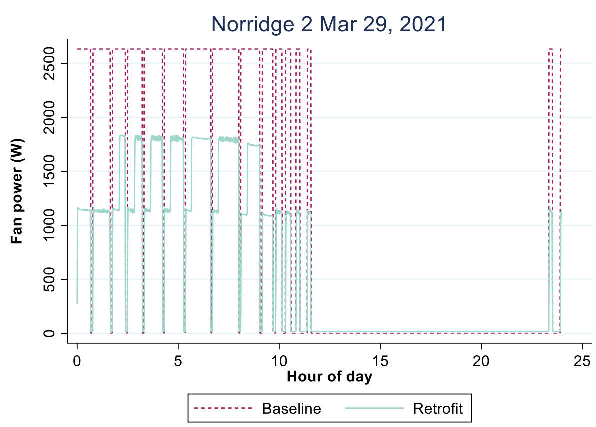
Figure 11. Observed data with extrapolated baseline




Countryside 4 Jul 15, 2021
Fan power (W)
0
500
1000
1500
2000
0
5
10
15
20
25
Hour of day
Baseline
Retrofit


Countryside 4 Jan 15, 2022
Fan power (W)
0
500
1000
1500
2000
0
5
10
15
20
25
Hour of day
Baseline
Retrofit

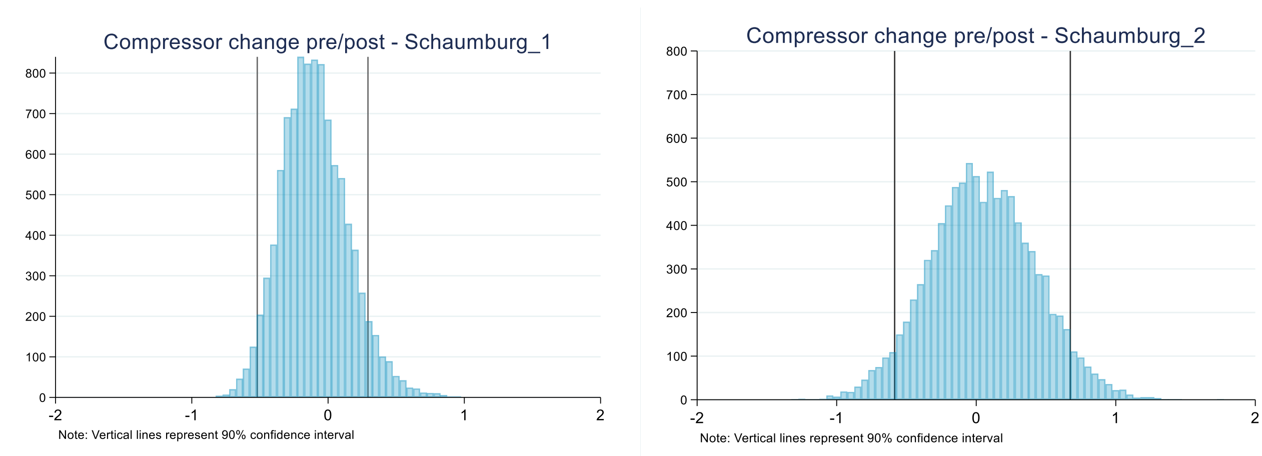

Norridge 2 Apr 27, 2021
Fan power (W)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Hour of day
Baseline
Retrofit


Norridge 2 Mar 29, 2021
Fan power (W)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Hour of day
Baseline
Retrofit

Compressor Energy Change Pre-to-Post Retrofit

Figure 12 shows the distribution of the simulation results and their 90 percent confidence interval overlapping zero. In other words, the models do not definitively show that the difference between pre- and post-retrofit-energy consumption is different from zero. This is the result of 10,000 model simulations, shown in Figure 12 on the y-axis as the frequency of simulations with a coefficient for whether a change was observed. The x-axis shows the magnitude of the coefficient. Overall, both RTUs show that the average model run shows no change in daily compressor energy pre- to post-retrofit. This result confirms that there is no evidence supporting the hypothesis that any change in energy results from modified compressor activity after installing the SRM System.

Figure 12. Mean change in Compressor energy consumption pre- to post-retrofit



Temperature Ranges

Figure 13 shows how well the OAT range of the pre- and post-retrofit overlap for comparison. While the baseline data gathered are completely covered by SRM System data, the baseline data gathered from this pilot was relatively sparse in comparison to SRM System compressor activity. Future research to further discern the effect of the SRM System on compressor energy consumption is warranted.

Figure 13. Temperature ranges of cleaned data set