Overcoming the Market Barriers for Rooftop Unit (RTU) Retrofit Enhancement

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Prepared for: Minnesota Department of Commerce, Division of Energy Resources

Prepared by: Center for Energy and Environment

Prepared by:
Alex Haynor
Mason Miller
Ben Schoenbauer

Center for Energy and Environment
212 3rd Ave N, Suite 560
Minneapolis, MN 55401
mncee.org

Contract Number: 187297

Prepared for Minnesota Department of Commerce, Division of Energy Resources:
Grace Arnold, Commissioner, Department of Commerce
Michelle Gransee, Deputy Commissioner, Department of Commerce, Division of Energy Resources

Mary Sue Lobenstein, Project Manager, Department of Commerce, Division of Energy Resources
Phone: 651-539-1872
Email: marysue.lobenstein@state.mn.us

Lindsay Anderson, Project Manager, Department of Commerce, Division of Energy Resources
Phone: 651-539-1771
Email: lindsay.anderson@state.mn.us

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Definition of Terms and Acronyms

RTU – rooftop unit

VFD – variable frequency drive

DCV – demand control ventilation

SRM – switched reluctance motor

FDD – fault detection and diagnostics

SEER – seasonal energy efficiency ratio

BMS – building management system

RH – relative humidity

NOAA – National Oceanic and Atmospheric Administration

OAT – outside air temperature

CEE – Center for Energy and Environment

CARD – Conservation Applied Research and Development

DOAS – dedicated outdoor air system

DX – direct expansion

VRF – variable refrigerant flow

TRM – Technical Reference Manual

SAT– supply air temperature

OAO– Outdoor Air Optimization

ARC– Advanced rooftop controls

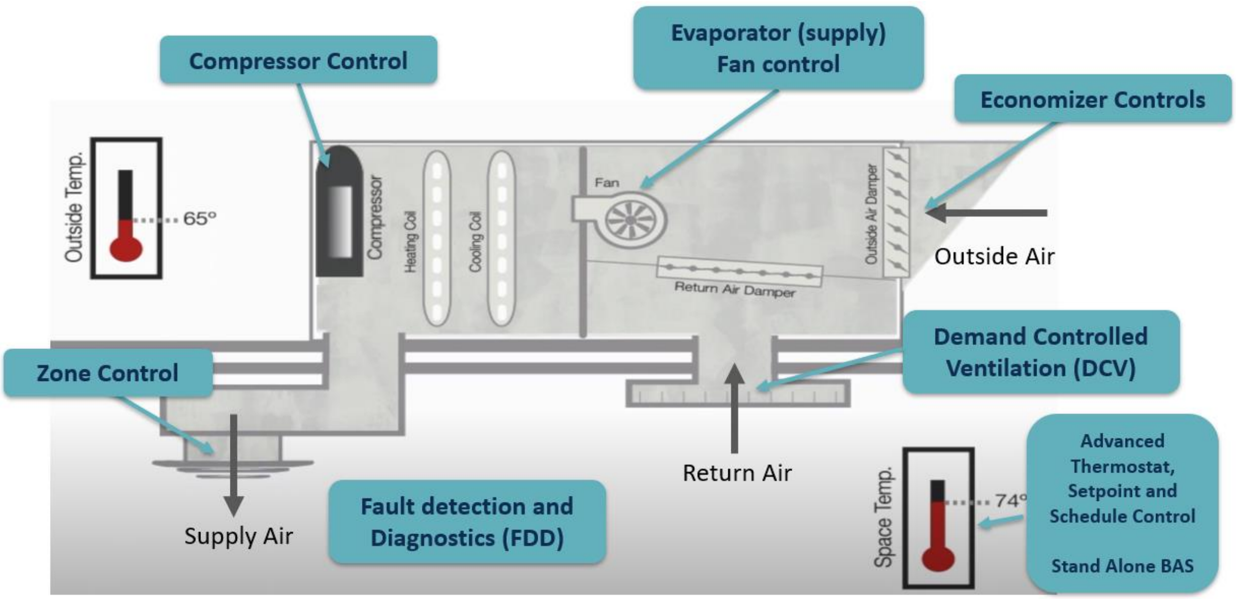
NJBPU - New Jersey Board of Public Utilities

BPA– Bonneville Power Administration

Executive Summary

This study sought to determine market barriers to implementing retrofit technologies available for packaged rooftop units (RTUs) and determine ways to overcome them. A packaged RTU is an HVAC system that provides heating and cooling equipment packaged in a single box to fully condition a space. These systems are found on a wide variety of building types throughout Minnesota, including office, retail, industrial, and other various commercial buildings.

Figure 1. RTU retrofit options



The research team conducted the following tasks to compile information.

- Performed a market scan to determine the available technologies that exist for RTU retrofits.
- Conducted interviews with key utility staff, including five investor-owned and public utilities in Minnesota, as well as six national utilities to gain insight on their approaches toward incentives and challenges and their overall thoughts on the market.
- Conducted interviews with 14 industry professionals, including mechanical contractors, distributors, manufacturers or retrofit technology producers, and building owners. These key market actors were crucial for information as they influence the RTU market.
- Performed field measurements on five different RTU retrofit approaches.

Utility Program Overview

Using different program approaches, Minnesota utilities have achieved varying levels of success in providing equipment rebates for high efficiency RTUs and RTU retrofit technologies. Utilities that were interviewed provide prescriptive rebate catalogs, custom rebate opportunities, or both for RTUs and

RTU retrofits as part of their HVAC offerings. While custom rebates are common among all interviewed utilities, prescriptive rebates varied. In general, Minnesota utilities rely on their trade allies and various advertising methods (such as newsletters, emails, and paper ads) to attract participation, with trade allies having the most significant influence.

During the discussions, several barriers to implementation were highlighted, such as customers and contractors lacking knowledge of retrofit technologies, a tendency to wait for RTU failure before replacing with a new unit, complications in the supply chain with long delivery lead times, split incentives between owners and tenants for leased facilities, and increased pressure on building owners to consider first costs related to HVAC equipment, whether to retrofit or replace an RTU at failure.

Utilities outside of Minnesota were interviewed to find successful programs that can be adapted to Minnesota's market. The interviewees revealed that low participation numbers prompted them to explore alternative ways of engaging with the RTU and RTU retrofit markets. Midstream programs were especially prevalent among utilities located outside Minnesota, with all utilities either currently offering midstream incentives or considering adding them to their programs. Other types of RTU programs were adopted by fewer utilities interviewed.

Market Overview

HVAC contractors play a large role when it comes to implementing RTU retrofit technologies. Building owners and facility managers rely on contractor recommendations, whether on replacement or retrofit, and are generally not aware of the available options. Many market actors were interviewed for this project (manufacturers, distributors, and buildings owners), and contractors were a focus of the interview process.

All the interviewees indicated that most customers rely heavily on contractor recommendations when purchasing new equipment or repairing existing equipment. It is commonly understood that RTUs are typically replaced only when they have failed, which often results in building owners and contractors making rushed decisions to install a working HVAC system. This can lead to the purchase of low-cost, standard efficiency systems without considering the long-term benefits and potential cost savings of more advanced and efficient technologies.

Cost is a major factor at the time of replacement and customers are likely to choose the lowest cost option. In addition, RTUs exist on a wide variety of building types and ownership structures, including owner-occupied or leased buildings. The cost of a new RTU or retrofit can be paid by different parties depending on the building's ownership and leasing arrangements. In most cases, the building owner is responsible for the cost of purchasing and installing a new RTU, and if the tenant is responsible for paying for the utility bills, equipment efficiency upgrades can become a complicated decision.

Interview takeaways:

- All interview groups favor prescriptive rebates over custom rebates due to simplicity.
- Contractor education and engagement is crucial for more implementation of RTU retrofit technologies.

- Manufacturers have had success reaching out to customers directly.
- Owner-occupied buildings such as retail, restaurants, etc. offer the greatest potential for RTU retrofits.
- While many new RTUs have incorporated variable speed evaporator fans, there is still opportunity for various technologies, as well as retrofitting existing RTUs more than five years old.

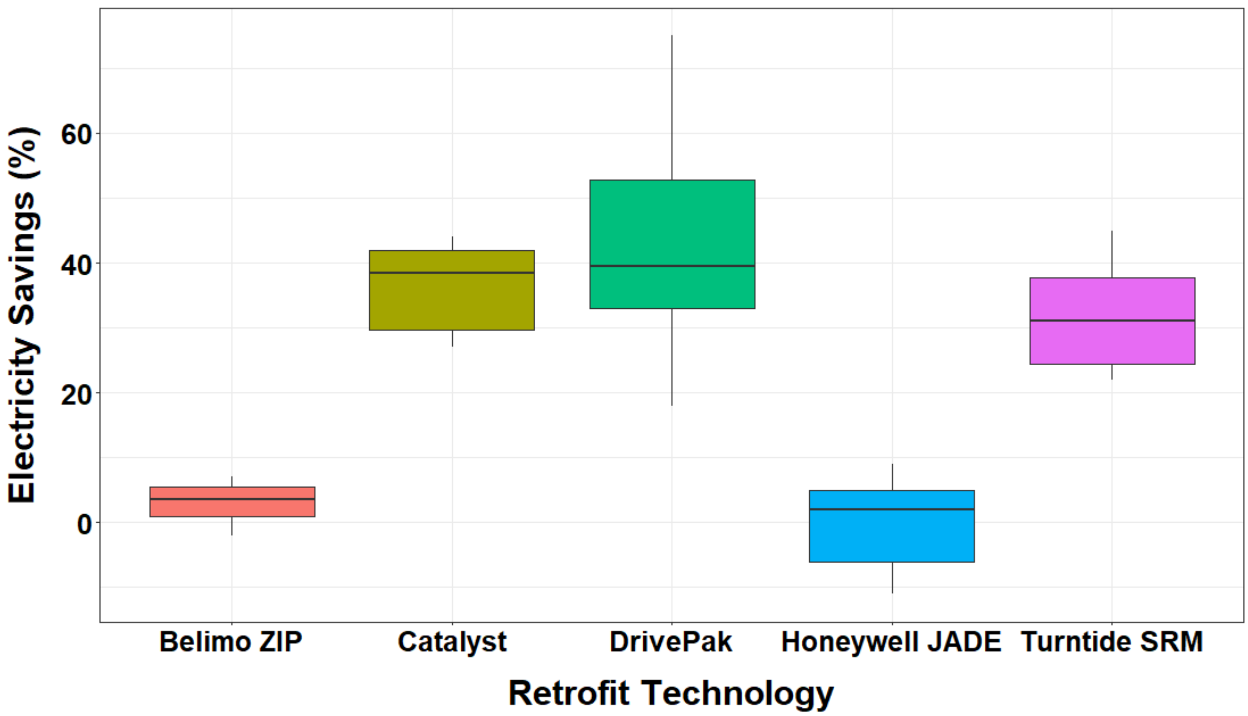
Technologies and Savings

The project team conducted a market assessment to identify available technologies for retrofit, and many options were identified. Five packages were field tested: Catalyst, Turntide, and DrivePak, which vary the speed of the evaporator fan, and Honeywell JADE and Belimo ZIP, which are advanced economizer packages. These technologies were tested using short-term measurements and a variety of analysis approaches to determine annual energy consumption for baseline (pre-retrofit period) and after retrofit operation. Electricity savings varied significantly for each RTU depending on building type, space type, thermostat setpoints, fan configuration, and RTU size. The results are summarized in Table 1 and Figure 2.

Table 1. Field site savings overview

Technology	Average RTU Size (Tons)	Average RTU Annual Electricity Savings %	Average RTU Annual Electricity Savings (kWh)
Catalyst	6	36%	2,702
Turntide	9	33%	3,556
DrivePak	7	43%	3,592
Honeywell Jade	5	0%	-5
Belimo ZIP	7	3%	140

Figure 2. Electricity savings by technology



Energy savings were also modeled for larger RTUs (not included in the field measurements), and the results showed that payback periods can be as low as one to two years or less for larger RTUs that experience more system runtime.

Conclusion

RTU retrofit technologies have demonstrated the potential to offer energy savings for a significant portion of existing RTUs throughout Minnesota. Many products have been introduced to the market that can provide energy savings, as well as non-energy benefits. The results of this project and past research have proven that these technologies can achieve substantial energy savings — however, they have not been widely adopted due to lack of market awareness. Contractors, while familiar with how the technologies work, are generally unfamiliar with the specific packages outlined by this project. Market adoption will require proper education and guidance for RTU retrofit technologies. The market for these technologies has grown rapidly, with many manufacturers offering more customizable and cost-effective options. Minnesota utility programs currently offer incentives for retrofitting an RTU, both prescriptive and custom options. Custom rebates steer contractors away from recommending these products due to the time-consuming and complicated process. Offering more prescriptive rebates, simplifying the custom rebate process, and introducing midstream incentives can offer a path toward implementation of RTU retrofit technologies.

Introduction

Background

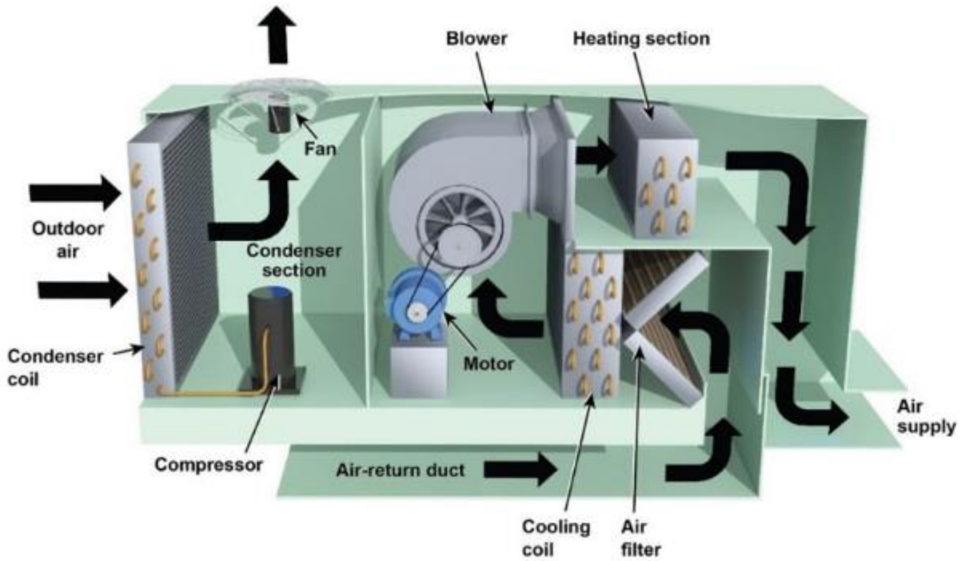
The research in this report was conducted by Center for Energy and Environment (CEE) to develop strategies to overcome the market barriers to proven energy efficiency improvements of existing rooftop units (RTUs).This project was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources, through the Conservation Applied Research (CARD) program. The report presents findings from 2021 to 2023 as a result of the following project tasks:

- Technology assessment of available RTU retrofit technologies
- Interviews with key industry professionals and utility representatives to determine the current state of the market, and any perceived barriers to implementation
- Field measurements across eight field sites and five different retrofit technologies
- Results and recommendations for RTU retrofit energy and cost savings, and recommendations for retrofit potential in Minnesota

Approximately 80% of commercial buildings in Minnesota are served by rooftop units (RTUs), which are generally standard efficiency systems (Seventhwave, 2017). Packaged RTUs serve many different building types throughout Minnesota, including office buildings, food service and sales, strip malls, education, and warehouse, to name a few. A packaged RTU is an HVAC system that contains the components to both heat and cool a space. There are many HVAC systems that reside on a flat roof, provide space conditioning, and might be considered “rooftop units,” such as dedicated outdoor air system (DOAS), heat pumps, variable refrigerant flow (VRF), air conditioners, cooling towers, and others. This study focused on packaged RTUs, specifically units that provide gas heating and direct expansion (DX) cooling.

There are a few important factors that differentiate a packaged RTU from a typical heating and cooling system, such as a residential furnace and air conditioner. First, RTUs reside on rooftops, which requires coordinated installation and often using cranes to lift and set units in place. Curb size, roof type (e.g., ballasted), and ductwork configuration are also key considerations for determining RTU installation or replacement logistics. RTU sizing varies significantly based on the space it serves. RTU size is denoted by the cooling capacity in tons (1 ton = 12,000 BTU per hour) and ranges from three tons to above 150 tons. RTUs under 15 tons were the focus of this project.

Figure 3. Typical packaged RTU configuration (Galgon, 2022)



A key component of a packaged RTU is the damper system that opens and closes to route return air and outside air throughout the unit. An outside air damper, called an economizer, is used to allow fresh air to enter the RTU, receive conditioning (when heating or cooling), and provide ventilation in the space. RTUs are often set to operate these dampers so they always provide a fraction of outside air, generally 5%–10%. This percentage is called the minimum position, meaning the outside air damper will never allow less than that percentage of outside air any time the evaporator fan runs. This fraction is adjusted based on the space type — for example, a space with a high density of occupants will require more ventilation than a warehouse setting. In addition to providing fresh air for ventilation, economizers have the ability cool a space if the outside conditions are favorable, called free cooling. Economizers use dry bulb temperature sensors or enthalpy sensors (both temperature and humidity) to decide if the outside air is fit to properly cool the space. When an RTU runs in economizing mode, the outside air damper opens to 100% to provide fresh, cool air to act as the sole cooling source. During this operation, the compressor does not run, providing significant energy savings.

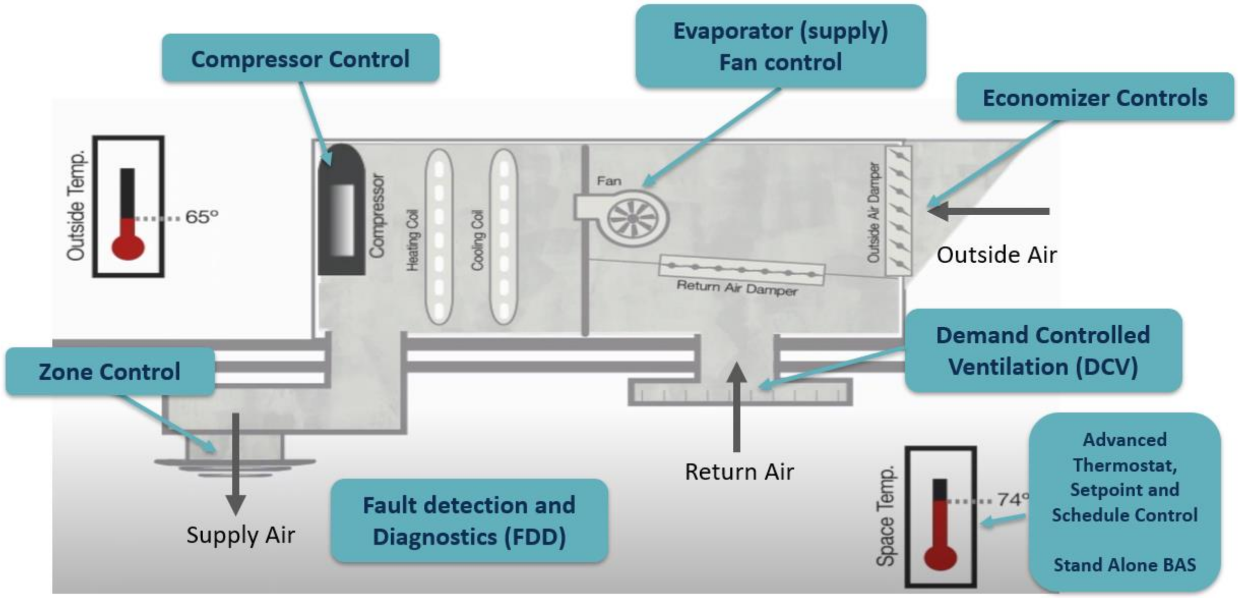
Economizers are notoriously unreliable and often experience temperature sensor or actuator failure, which renders the outside air damper useless. If the damper fails in the open position, 100% outside air will pass through the RTU and can cause very cold or hot air (depending on the season), which can increase runtime in heating or cooling modes as the system tries to condition extreme temperatures air and, in some cases, humidity. If the outside air damper is stuck in the closed position, the space will not receive any fresh air for ventilation making indoor conditions stuffy and uncomfortable for occupants. Both situations are common in existing RTUs, making the systems inefficient with inadequate space conditioning.

Figure 4. Site-2, RTU-1 and RTU-2

Products have advanced significantly in the last ten years and are now commercially available for retrofitting an RTU, making them a viable option for existing packaged RTUs. Since RTUs are typically used for more than 20 years prior to replacement on failure, many existing RTUs fall in the age range that can be benefitted by retrofit. Available retrofit technologies for RTUs include a variety of methods to achieve energy savings, including reducing the speed of the evaporator fan; advanced economizer control and demand control ventilation for free cooling and to provide the correct amount of fresh air for ventilation; and zoning controls to prevent over conditioning. RTU retrofit enhancements offer tremendous potential in Minnesota's existing RTU market. Technologies of interest for the research team included the following.

- Variable frequency drives, both on the evaporator fan and compressor
- Advanced economizer controls
- High-efficiency motors
- Smart and programmable thermostats
- Demand control ventilation
- Dynamic zone balancing
- Automated fault detection and diagnostics
- RTU coordinating controls

Figure 5. Available RTU retrofit options



When retrofitting an RTU, efficiency gains come predominantly from electricity savings. This is because variable speed fans and high-efficiency evaporator fan motors are one of the most common retrofits, and fan speeds can be significantly lowered for long periods of time, resulting in significant savings. Reducing gas consumption is less common but possible with a number of retrofits. Economizer upgrades, thermostat scheduling, DCV, zoning, and FDD can all provide gas savings. A full list of savings measures is listed in Table 2.

Table 2. RTU retrofit savings, electricity and gas

Energy Saving Measure	Electricity Savings	Gas Savings
VFD and SRM	Yes	No
Advanced economizer controls	Yes	No
High-efficiency motors	Yes	No
Thermostat upgrades	Yes	Yes
DCV	No	Yes
Dynamic zone balancing	Yes	Yes
AFDD	Yes	Yes
RTU coordinating controls	Yes	No

Pathway To Implementation

RTU retrofits continue to be uncommon. A lack of understanding of market barriers to adoption of available RTU retrofit technologies has inhibited their uptake. This research found that building owners and decision makers in charge of purchasing HVAC equipment are unfamiliar with RTU systems and the available efficiency upgrades. In addition, RTU upgrades and replacements are often only considered when they fail and a quick decision is made to install a functioning, standard efficiency RTU. The key personnel for making decisions impacting the performance of RTUs are building owners, facility managers, HVAC contractors, distributors, and manufacturers of RTU retrofits. These stakeholders play a key role in the supply chain, but mechanical contractors are pivotal as they interact directly with customers.

A strong relationship between mechanical contractors and manufacturers is essential for the success of both parties in the RTU retrofit market. Contractors are typically responsible for installing and maintaining HVAC systems in buildings, while manufacturers develop and supply RTU retrofit packages designed to improve the efficiency and performance of existing units. Contractors often represent certain packages and work closely with manufacturers to ensure that the products they install are high quality and meet their clients' needs. This collaboration allows contractors to provide customers with a range of retrofit options and ensure that they are installed correctly, while manufacturers benefit from increased sales and brand recognition.

Further, the payment arrangement for utility bills in leased versus owner-occupied buildings can impact interest in energy efficient RTU upgrades. Leased and owner-occupied buildings served by RTUs can have varying arrangements regarding responsibility for utility bills and equipment purchases. In an owner-occupied building, the owner is responsible for paying utility bills, and has a direct financial incentive to make the RTUs as efficient as possible. In a leased building, the tenant is often responsible for paying the utility bills, which can mean the tenant directly benefits from a more efficient system, while the building owner does not.

Previous Work

Two previous CARD projects have been completed by Center for Energy and Environment (CEE) related to RTUs that informed the thought process behind this project, the Advanced Rooftop HVAC Unit Controls Pilot and the Market (CEE, 2014) and Performance Characterization of Commercial Rooftop Units (Seventhwave, 2017). The former study field tested three retrofit packages, Catalyst, Digi-RTU, and Premium Ventilation, through installation of 60 RTUs across six test sites. These retrofit solutions were in early stages of development and changed significantly throughout the project. Results varied, but RTUs with VFDs installed showed electricity savings around 30% and the premium ventilation package around 15%. The latter had two phases. The first characterized the existing RTU and new/replacement market and the second performed field measurements to characterize gas and electricity consumption for Minnesota RTUs. The team collected building level and existing RTU data for 101 surveyed buildings and analyzed the new and replacement market for RTUs in Minnesota. Results from the market characterization work guided this work and provided a framework for the existing RTU market. These are listed below.

- There are currently 20,700 ±3,100 Minnesota buildings with RTUs. Approximately 80% of commercial buildings are served by RTUs.
- There are approximately 136,000 ±30,000 existing RTUs in Minnesota. On average, commercial buildings served by RTUs have six to seven RTUs on site.
- The average age of an existing RTU in Minnesota is 13.1 years.
- The total estimated cooling capacity of RTUs in Minnesota is roughly 1.3 million tons with an average of 10.7 tons per RTU. The average full-load cooling efficiency is 10.6 IEER, while the average for part-load cooling efficiencies is 11.2.
- The total estimated heating capacity of RTUs in Minnesota is approximately 23.8 million MBH with an average of 205 MBH per RTU.

Methodology

Research Questions

RTU retrofit technologies are known to be cost-effective options to make RTUs more efficient, but have made little market penetration in RTUs in Minnesota. These packages have been proven by past CARD research projects (2014 Advanced Pilot Controls, (CEE, 2014)), but product advancements were made throughout the project, and since then many others have come to market. The project team looked to discover the various retrofit options that currently exist, their benefits and drawbacks, and overall potential in the Minnesota market.

In addition to available technologies, the team looked to discover the impact of Minnesota utility CIP offerings to the market of RTU retrofits. This study was necessary to assess existing programs, both throughout Minnesota as well as national programs, to determine what has been successful and provide recommendations for possible implementation throughout Minnesota programs. Retrofit technologies for packaged RTUs have proven savings, and can offer significant savings for HVAC equipment that serves a large portion of Minnesota buildings. The project aimed to achieve the following objectives:

1. Identify the key industry professionals who are leading the adoption of high-efficiency RTU equipment, with a focus on retrofit technologies.
2. Provide detailed information about available retrofit packages.
3. Perform field measurements and model energy savings to better understand the performance of the latest retrofit packages, as well as their cost-effectiveness.
4. Explore the barriers that currently exist in the market for RTU retrofit packages and propose strategies to overcome them.
5. Analyze successful program approaches used by Minnesota utilities and other national utilities, with the goal of developing a framework to integrate into Minnesota programs.

Program Review

The project team conducted eleven interviews with five utilities in Minnesota and six utilities outside Minnesota. Each interview was roughly an hour in length and sought to gather information regarding HVAC programs that involve RTU and RTU retrofit technologies. For the interviews with utilities within Minnesota, the main goal was to gain a better understanding of where they have had success or challenges with the HVAC market and insight into each utility's approach to marketing and sales, trade ally engagement, project review, and rebate logistics. By conducting interviews with utilities outside Minnesota, the team gathered valuable information about which HVAC programs they offer, how they implement these programs, and what their successes and challenges have been. This clarified how their approaches may be transferable to Minnesota's RTU market. Other methods for gathering information about utility programs included reviewing utility websites and reading program filings, evaluation reports, efficiency plans, and rebate applications.

Interviews and Surveys

The research team conducted in-depth interviews with 14 industry professionals. These contacts were made through previous and current research, as well as an in-depth market scan to determine the major market actors involved in the Minnesota supply chain for efficient RTUs and RTU retrofit. Each formal interview used a survey instrument that started with a set of base questions, followed by questions tailored to each group for further understanding of the role each group plays in the supply chain of RTUs and RTU retrofit technologies. Interviews were conducted with five mechanical contractors, two building owners/facility managers, two distributors, and five manufacturers of RTU retrofit technologies.

In addition to industry professionals, the project attempted to interview 100 building owners to obtain information about their existing buildings, RTUs, and how familiar they were with available retrofit technologies. The goal was to gain a better understanding of the existing equipment in Minnesota and determine if building owners were informed of available efficiency upgrades by their servicing contractor or from their own research. The research team tried many avenues to find contacts and conduct interviews, including reaching out to a large list of contractors and distributors, conducting online research, and leveraging connections within CEE staff to identify potential contacts.

These efforts did not provide the required participants to draw significant conclusions.

Site Selection

The initial site selection method for this study was to identify field installations through contacts made from the technology assessment and interviews conducted with industry professionals. After conducting interviews, the team realized that installations were not as common as expected in the Minnesota market, and manufacturers were mostly unwilling to assist with recruitment efforts. The team relied on sites recruited through a combination of past contacts and the ability to purchase some of the equipment (Honeywell JADE and Belimo ZIP economizer packages). The team found eight total sites, six of which had field measurements taken on them, while the final two (sites 6 and 7) were calculated using real data from a previous field study (CARD RTU characterization (Seventhwave, 2017)).

The technology assessment analyzed the RTU retrofit package market to characterize the commercially available products, their fit to Minnesota RTUs, possible savings, and likelihood of installation. Based on this assessment retrofit packages were prioritized for evaluation. Five retrofit packages with varying RTU sizes, building types, space types, and thermostat configurations were field tested, listed in Table 3.

Table 3. Field sites

Site	Number of RTUs	Retrofit Technology
1	6	Catalyst
2	2	Turntide SRM
3	4	Turntide SRM

4	5	Honeywell JADE
5	4	Belimo ZIP
6	3	DrivePak
7	17	DrivePak
8	2	Turntide SRM

Field Monitoring

Forty-three RTU retrofits were studied at eight different sites for this research. Field measurements were conducted for each of the RTU retrofit packages selected for further evaluation. The original approach was to find test sites and RTUs that had been retrofitted with packages of interest and perform short-term field measurements to characterize the performance of the RTUs. This proved to be difficult, as retrofits were uncommon in Minnesota. In addition, it was difficult to retrieve contact information from stakeholders, such as manufacturers due to data privacy concerns.

The approach changed to include a pre and post period for each test site, which allowed for more accurate comparisons between the baseline operation to the RTU after retrofit.

The measurement approach and instrumentation varied based on the technology. Five different packages were field tested, three that varied the speed of the evaporator fan and two advanced economizer control packages. All field monitoring methods compared baseline RTU operation by conducting a pre-/post-test period (monitoring baseline operation, installing the retrofit, then monitoring for a similar period), using field data from past CARD projects, or measuring an already retrofitted unit with the ability to return the RTU back to its original conditions for measurement purposes.

Table 4. Field sites and monitoring approach

Site	Monitoring Approach	Field Measurement Time Period	Retrofit Technology	Parameters Measured	Equipment used
1	Short-term measurements pre/post	11/22/21–4/11/22	Catalyst	1: Total RTU current 2: Space temperature and RH	1: HOBO logger, current transformer 2: HOBO temperature and RH logger
2	Short-term measurements pre/post	3/15/23	Turntide SRM	1: Total RTU Current	1: Multimeter, real time power meter
3	Short-term measurements pre/post	12/14/21–2/28/22	Turntide SRM	1: Total RTU true power 2: Gas burner signal 3: Space	1,2: Wattnode, current transformers, Campbell data logger 2: HOBO temperature and RH logger

				temperature and RH	
4	Short-term measurements pre/post	3/25/22–11/11/22	Honeywell JADE economizer	1: Total RTU Current 2: Space temperature and RH 3: Cooling call signal	1: HOBO logger, current transformer 2: HOBO temperature and RH logger 3: Pulse Logger with HOBO pulse counter
5	Short-term measurements pre/post	3/25/22–11/11/22	Belimo ZIP economizer	1: Total RTU Current 2: Space temperature and RH 3: Cooling call signal	1: HOBO logger, current transformer 2: HOBO temperature and RH logger 3: Pulse Logger with HOBO pulse counter
6	Applying power values to measured field data	-	DrivePak	1: Total RTU current	1: Monnit 0-5 VDC logger, current transformer
7	Applying power values to measured field data	-	DrivePak	1: Total RTU current	1: Monnit 0-5 VDC logger, current transformer
8	Short-term measurements pre/post	4/11/23	Turntide SRM	1: Total RTU Current	1: Multimeter, real time power meter

Retrofit packages that varied the speed of the evaporator fan were monitored by measuring the power consumption of the RTU or the evaporator fan where applicable. The measurement methodology varied based on the installation type. True power was directly measured through installation of a power meter on the RTU for continuous measurement. For sites where direct measurement was not feasible, current measurement was correlated to true power consumption in each mode of operation during a one-time site visit. Then, a direct continuous current measurement was made and correlated to get a true power value.

RTUs with economizer control retrofits were monitored for baseline operation, as well after the installation of the economizer package for a post period.

For sites with extended monitoring periods, one-minute data was collected for various parameters, including current, true power and/or thermostat cooling call. This varied across the test sites depending on the technology monitored. Where space conditions were monitored, data was collected at 15-minute intervals for space temperature and RH data. Data was stored locally on data loggers and manually downloaded periodically throughout the monitoring period.

Data Analysis

Several analysis methods were employed to compute the energy savings and performance of the selected retrofit packages that were field tested. Out of the five packages chosen for testing, three involved reducing the speed of the evaporator fan with a VFD or SRM. This energy saving approach allows the RTU to use lower fan speeds during heating, cooling, and ventilation operation. Unlike traditional RTUs, which typically utilize single-speed evaporator fans that run at full capacity, decreasing the fan speed significantly reduces fan energy consumption and leads to substantial energy savings.

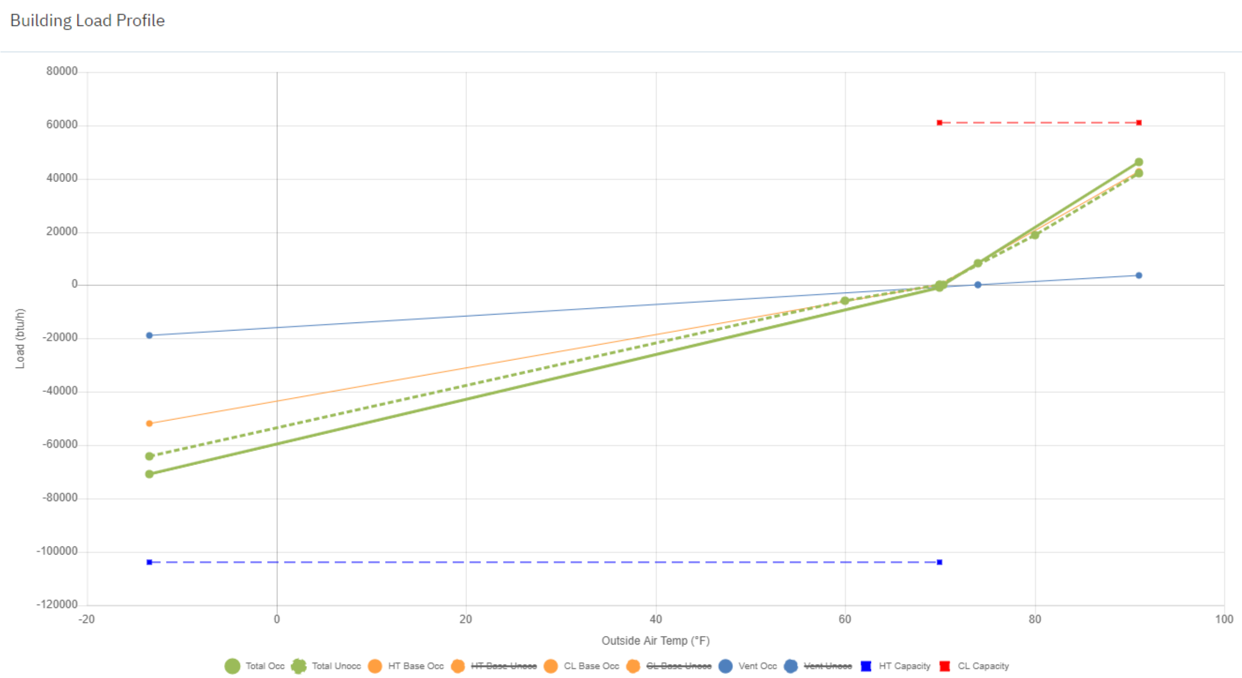
Two advanced economizer packagers were also studied as part of the project's analysis. These packages replaced malfunctioning controls and sensors on existing RTU economizers with more robust controls and additional sensors, which facilitate the use of outside air for ventilation and free cooling when available. During free cooling, the outside air damper fully opens, the return air damper closes, and the compressor remains off while outside air is used to condition the space. Free cooling is the primary energy savings method for these packages, but also ensures that the RTU dampers open and close to only provide the minimum amount of outside air to properly condition the space.

After collecting data for each RTU included in the field assessment, the project team employed one of the three approaches listed below to evaluate the energy savings potential of the retrofit solutions.

Approach 1 – VFD Energy Savings Calculations

A key component of the analysis was creating energy savings simulation using nameplate parameters of the measured RTUs, along with the measured field data, to create annual performance models at hourly intervals. These modeled savings were completed using a calculation tool developed for CEE's One-stop Efficiency Shop HVAC upgrade program (CEE, HVAC Upgrades, 2023), which provides evaluations of small commercial buildings, direct installs, and energy savings recommendations. The tool utilizes an 8,760 (hours per year) method to predict energy savings during a typical meteorological year. The energy use, both electric and gas, is modeled for each hour of the year based on estimated building loads for a typical building and utilizing TMY3 data for the selected location. Building type can be adjusted with to estimate the impact of varying space types. To predict annual energy savings, a baseline RTU was created for each test unit using nameplate information to determine various RTU component sizing (evaporator fan, heating and cooling capacity, etc.). The RTU was then duplicated and configured for a variable speed evaporator fan and modeled. Once annual energy consumption was determined for each RTU (pre and post retrofit), the models were compared to determine overall energy savings for the retrofit package. This approach was used for all field RTUs retrofitted with a technology that varied the speed of the evaporator fan (VFD and SRM). The output of the model provided cooling, heating, and fan runtime hours and energy consumption. Figure 6 shows an example of the building load profile for one of the test units in the project.

Figure 6. Modeled energy consumption regression for site-1, RTU-1



The calculator uses fan speed percentages as one of its inputs — since fan power was measured, speed was calculated directly from the power value using the fan affinity laws.

$$\frac{kW_2}{kW_1} = \left(\frac{n_2}{n_1}\right)^3$$

Where:

kW = power
n = Fan speed

Along with fan power and speed, the tool uses the following inputs to create annual usage profiles.

- Rated heating Input (btu/h)
- Heating efficiency %
- Rated cooling output (tons)
- Cooling efficiency (EER)
- Evaporator fan power (kW)
- Condenser fan horsepower
- Motor efficiency
- Load factor
- System airflow
- Outside air ventilation rate
- Reference city

- Thermostat temperature setpoints (occupied and unoccupied), fan configurations (on versus auto, and scheduling information
- Estimated heating balance point

This method was used for sites 1,2,3, and 8, the RTUs equipped with Catalyst and Turntide SRM retrofits.

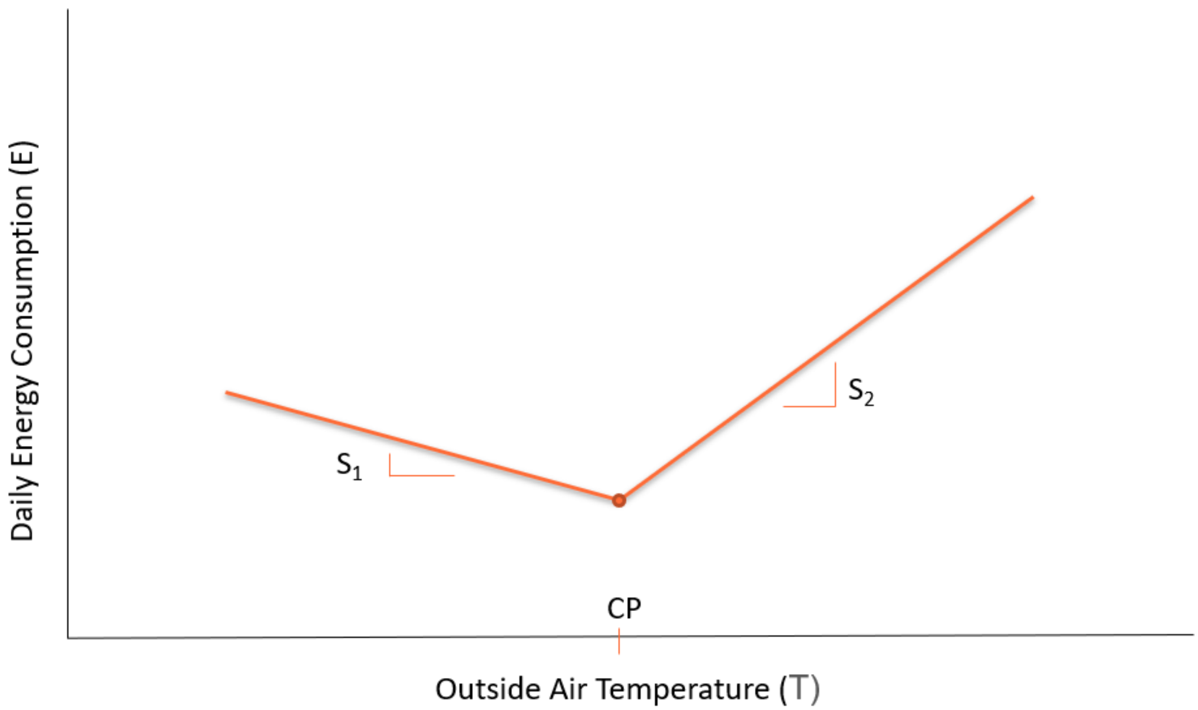
Approach 2 – VFD Energy Savings Calculations

The DrivePak retrofit package uses a VFD and sets fan speeds for each mode of operation. This simplified approach allowed the team to use a years' worth of field data for two sites and apply estimated fan percentages to produce a pre and post annual model. Electric data was summed for daily energy consumption and plotted against outside air temperature to create a changepoint model for the baseline RTU operation. Energy consumption was then normalized with TMY3 data to determine annual use before and after the changepoint and added together to produce annual electricity used for baseline RTU operation. The same process was used for the post retrofit period, using the following fan speeds. Fan speeds were estimated but represent typical VFD retrofit speeds found by this project and previous RTU research. In an actual installation, speeds are customized for each RTU at the time of installation.

Fan only: 40%
Cooling: 90%
Heating: 90%

Data from the pre and post test periods was then compared to establish annual electricity consumption for each and determine energy savings. This method was used for site-6 and site-7.

Figure 7. Changepoint regression analysis example



Equation:

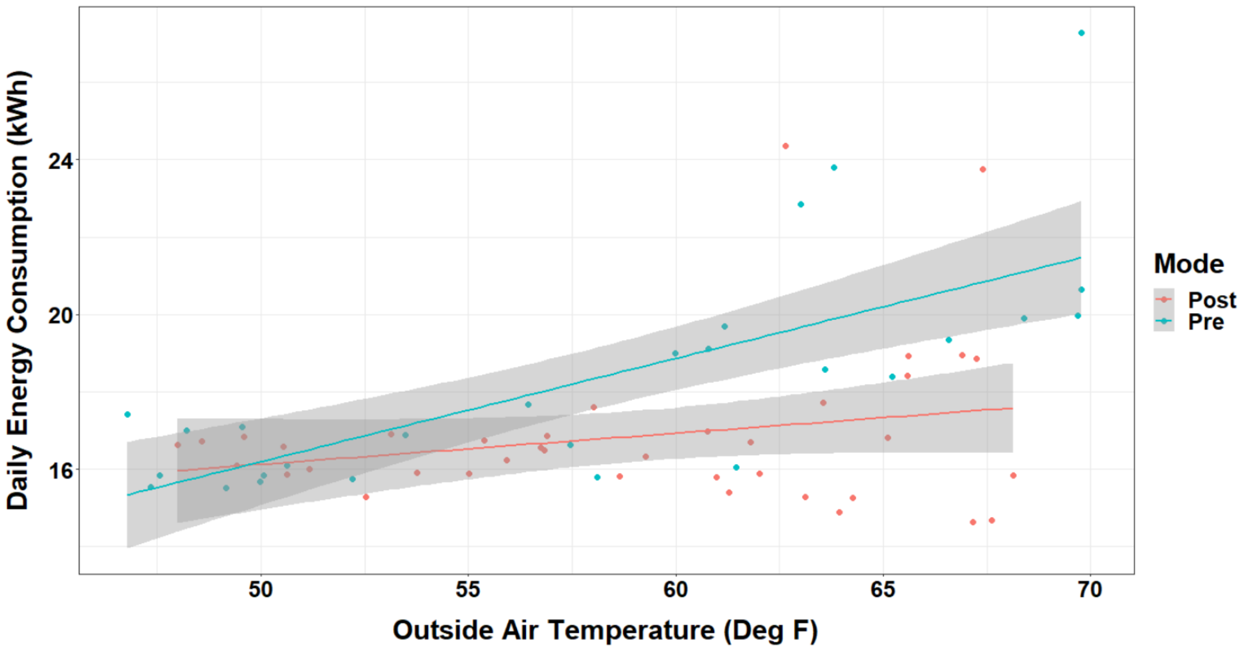
$$E = (S_1 * T_1 + Y_1) + (S_2 * T_2 + Y_2)$$

Where:
E = Electricity consumption (kWh)
CP = Changepoint
S_1 = Slope < CP
T_1 = Outside Air Temperature < CP
Y_1 = Y Intercept < CP
S_2 = Slope > CP
T_2 = Outside Air Temperature > CP
Y_2 = Y Intercept > CP

Approach 3 – Economizer Energy Savings Calculations

Data was analyzed for a pre (baseline RTU operation) period and post (after economizer package retrofit) period and compared. Analysis was completed by adding up daily energy consumption for each RTU and creating regressions versus outside air temperature. Data was gathered and analyzed during outside air temperatures that the project team expected to benefit from the economizer in free cooling mode, 45°F to 70°F. Method 3 differs from method 2 in that a simple linear regression was used to model electricity consumption. This data was normalized using a TMY3 data set to obtain annual usage data for the pre and post periods. A sample of a pre versus post regression is shown in Figure 8.

Figure 8. Pre and post regression, site-4, RTU-2



In addition to directly measured data for each RTU, outside air conditions were downloaded during each test period using data from the closest National Oceanic and Atmospheric Administration (NOAA) weather station. Dry bulb temperature from NOAA datasets was used to create regressions of daily energy consumption versus outside air temperature (OAT) for comparison when necessary.

Study Findings

Retrofit Technology Assessment

The project team conducted a market scan to identify the range of products that can be used for packaged RTU retrofitting. The following technologies are the most suitable and cost-effective retrofit options for RTUs in Minnesota, according to the project team's assessment.

Catalyst

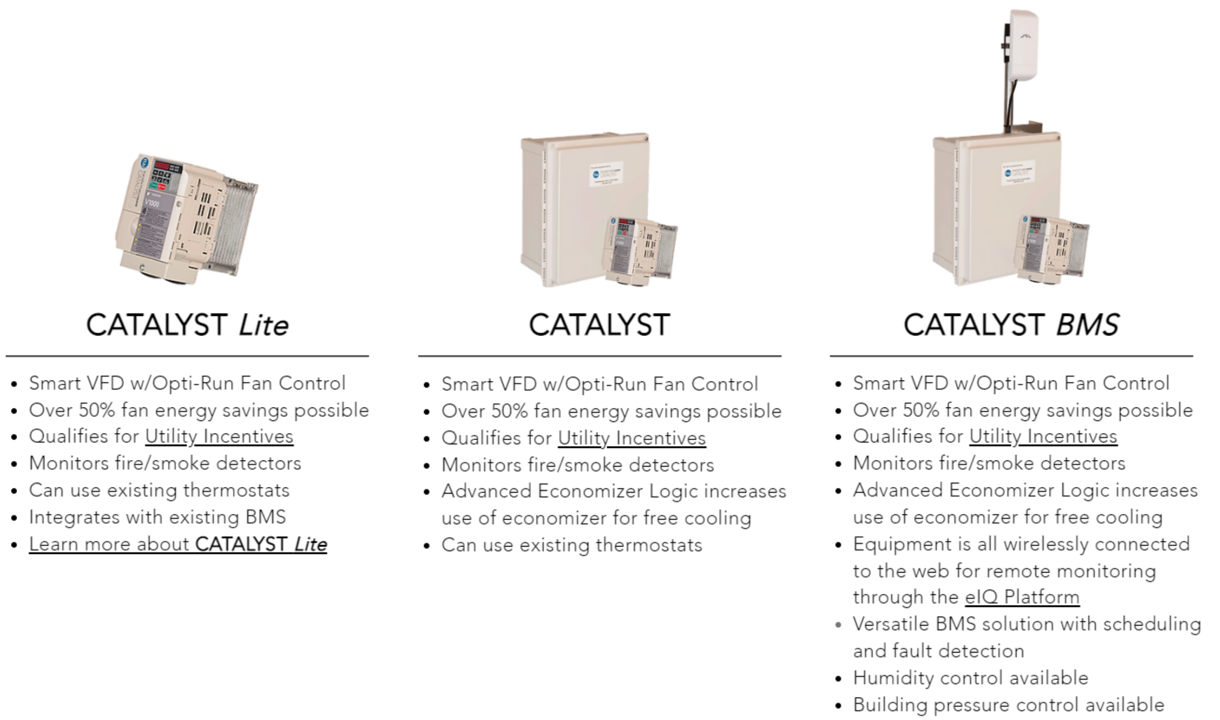
Catalyst is manufactured by Prostar Energy Solutions (formerly Transformative Wave) and was one of the first retrofit controllers to reach the market for RTU retrofit. Catalyst was previously studied by CEE in 2014 for the Advanced Rooftop HVAC Controls Pilot (CEE, 2014). CEE studied 12 RTUs retrofitted with catalyst controllers equipped with eIQ, an online service that allows customers live access to unit performance. The product offerings have expanded since 2013, now providing customers with three different versions of their product to choose from when considering a retrofit. Catalyst is manufactured by Prostar Energy Solutions (formerly Transformative Wave) and was one of the first retrofit controllers to reach the market for RTU retrofit. There are three versions offered, including Catalyst lite, Catalyst, and Catalyst BMS (formerly known as Catalyst with eIQ).

Catalyst lite is a bare bones VFD that pairs with an existing evaporator fan motor to provide variable speed operation. It is offered at the lowest price point across the three available options, and does not package any other savings opportunities, such as economizer controls and DCV.

Catalyst is the most popular version of the available options, and offers a VFD, advanced economizer controls, and demand control ventilation.

Catalyst BMS (building management system) offers the most options for customers and allows them to access their web-enabled communication platform to control all their installed networked Catalyst devices. eIQ allows customers to manage schedules and setpoint changes, set alarms and alerts, and view live operation of each installed system. This option is ideal for customers who do not already have BMS control and allows for a real-time look into system performance and configuration.

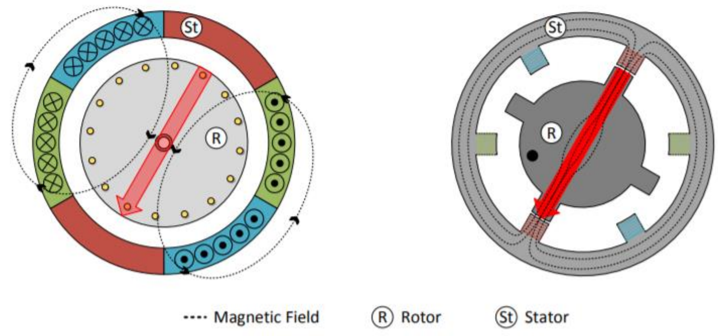
Figure 9. Catalyst retrofit options (Catalyst, 2023)



Turntide Switched Reluctance Motor

Induction motors are the most common type of motor for HVAC systems, as well as packaged RTUs, and include stators, rotors and wire windings that create electromagnetic poles. An induction motor utilizes stators, rotors, and wire winding that creates a rotating magnetic field by supplying current to the windings in the stator, which causes the rotor to turn. These motors are inefficient and do not allow for variable speed operation unless they are paired with a VFD. An SRM provides individual current signals to various coils along the stator to create electromagnets with which the rotor continuously tries to align. This current is switched on and off at the various coils thousands of times per second and can be varied to meet the fan speed requirements, thus the variable speed motor.

Figure 10. Induction and SRM motor (Turntide, 2023)



Turntide's patented Smart Motor System includes motor electronics, networking, and IoT platform capabilities. The motor is a high rotor pole switched reluctance motor (HRSRM), which offers higher efficiencies than a standard induction motor and is inherently variable speed. The controller communicates to a cloud-based manager to monitor motor operation and optimize for efficiency at any fan speed. The motor system has the capability to utilize various sensors such as temperature, pressure, CO_2, and control inputs such as cooling or heating status, 0-10V, 0-20mA, resistive, etc. to control the motor speed, direction, start/stop, and external outputs, such as controlling dampers or turning on and off compressors.

Digi-RTU

The Digi-RTU was previously studied by CEE in 2014 for the Advanced Rooftop HVAC Controls Pilot. Digi-RTU offers a unique retrofit product for RTUs. It not only offers evaporator fan savings from the use of a VFD, but also utilizes the VFD for compressor modulation during cooling events. According to the market study conducted by this project, Digi-RTU offers the only product that varies the capacity of a compressor. By modulating the capacity as well as the output of the evaporator fan, the Digi-RTU can more accurately meet the load of the space it is conditioning. Many RTUs are oversized for the space they serve, resulting in overheating, overcooling, and unit short cycling. With this product, variable compressor capacity allows for longer cooling events, increased comfort, and energy savings. In addition to a VFD to modulate evaporator fan speed and compressor capacity, Digi-RTU offers multiple other advanced features which have been added since their product launch and the previous work research conducted by CEE:

- Enhanced and integrated airside economizer
- DCV
- Smart peak demand control
- Remote monitoring and FDD

DrivePak

DrivePak is offered in two options for RTU retrofit: the DrivePak and DrivePak ARC. DrivePak ARC adds advanced economizer controls as well as DCV for additional savings, while DrivePak is simply a VFD to control the speed of the evaporator fan.

Enerfit

Enerfit is a VFD retrofit for single-zone RTUs that started product development in 2006. Enerfit employs cooling mode methodology that varies from other similar RTU retrofits. By utilizing staging compressors to maintain the temperature in the space and controlling the temperature of the air leaving the cooling coil through varying evaporator fan speed, the system can consistently limit the relative humidity to a maximum value. This results in fan energy savings, and reduced fan heat delivered to the space, and improved comfort due to lower space humidity.

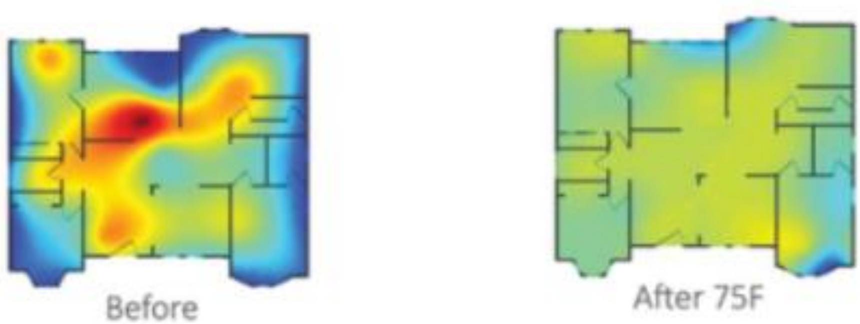
In addition to the VFD for evaporator fan savings, Enerfit offers optional advanced economizer control, BAS integration, and fault detection. Enerfit has also developed options for computer room air conditioners (CRACs), split systems, air source heat pumps, and geothermal heat pumps.

75F – Dynamic airflow balancing and outside air optimization

75F is a Minnesota company that offers a few unique technologies as RTU retrofits. Dynamic airflow balancing is a zone control retrofit and reduces over-conditioning of the area served by the RTU. It uses individual wireless zone sensors, zone dampers, and predictive machine learning algorithms to optimize heating and cooling capacity.

A large, single zone RTU is the most common installation due to the low upfront cost — however, they frequently waste energy and fail to provide optimal conditions for occupants since the entire space is conditioned by a single, centrally located thermostat. In a situation where one large RTU serves many space types, such as offices, cubicles, conference rooms and/or break rooms, dynamic airflow balancing can offer energy savings and increased occupant comfort by adjusting the zone dampers to only meet the load of each individual zone.

Figure 11. Dynamic zone balancing space temperature, before and after optimization (75F, 2023)



Outdoor air optimization (OAO) is a separate product sold by 75F that can be added to an RTU in addition to the dynamic zone balancing. OAO mixes advanced economizer controls, DCV, and real-time data to provide additional energy savings for RTUs. Paired with a central controller, customers can view live data, such as economizer damper positioning, free cooling versus compressor runtime, and CO_2 levels. The kit comes with an enthalpy sensor for mixed air temperature (MAT), thermistors for supply air temperature (SAT) and outside air temperature (OAT), and a current transformer to monitor current draw by the RTU. There are also additional optional sensors, including CO and NO_2, and differential pressure control for industrial or automotive settings.

Swarm Logic

Swarm Logic provides a method to dynamically synchronize RTUs through smart controllers. By coordinating across all RTUs on the same building, the controllers provide energy savings by only turning off RTUs that are not needed to run and reducing peak demand. The controllers use wireless communications to connect all RTUs to a cloud-based control center. Controllers use data across all RTUs every few minutes to run specific units to optimize operation.

JADE Economizer

The Honeywell JADE Economizer is a retrofit that provides advanced economizer controls. The Jade allows multiple sensor inputs, including MAT, OAT, outdoor air enthalpy, and CO_2. In addition to economizer controls, additional technologies can be incorporated in Honeywell's advanced RTU retrofit solution. This includes the Jade Economizer, a VFD, DCV, a web-enabled thermostat, FDD, and BAS integration.

ZIP Economizer

The Belimo ZIP Economizer is a retrofit solution for non-functioning economizers. During installation, the installer simply enters the zip code of the RTU location, and the ZIP economizer recognizes the climate zone and will set the high limit change over temperature. The ZIP package includes a ZIP Economizer, air sensors, energy module for Demand Control Ventilation (DCV) integration, a spring return actuator, and the necessary retrofit hardware needed for a drop-in replacement. It allows for plug in play of additional sensors as needed.

Table 5. Available packaged retrofit options

	Manufacturer									
	Prostar Energy Solutions	Bes-Tech	75F	NexRev	Enerfit	Prostar Energy Solutions	Swarm Logic	Turntide	Honeywell	Belimo
	Controller									
	Catalyst w/ eIQ	Digi-RTU	Dynamic Airflow Balancing/ Outdoor Air Optimization	Drivepak ARC	Enerfit	Catalyst	Swarm Logic	Switched Reluctance Motor	Jade Economizer	Zip Economizer
Basic Features										
Evaporator Fan Control	x	x		x	x	x		x	x	x

Demand Controlled Ventilation (DCV)	x	x	x	x	x	x			x	x
Advanced Economizer Controls	x	x	x	x	x	x			x	x
Fault Detection and Diagnostics (FDD)	x	x	x	x	x		x		x	x
Compressor Control		x								
Additional Features										
Advanced Thermostat Control	x	x	x					x		
Setpoint and Schedule Control	x	x	x					x		
Demand Response Capability	x	x					x			
Web User Interface	x	x	x				x	x		
BAS Integration	x	x			x	x	x	x		x
Stand Alone BAS	x	x	x							
Zone Control			x							
Multi-Unit Coordination	x						x			
Claimed Savings	25-50%	60%	25-40%	25-50%	50%	25-50%	15-30%	60-70%	30%	40%
Claimed Payback Period	2 years	2-4 years	2-5 years	1.5-2 years	3 years	2 years	1 year	1-4 years	Varies	Varies
Price	$$$$	$$$$	$$$$	$$$$	$$$	$$	$$	$	$	$

Controls

Upgrading thermostats for RTUs can achieve significant energy savings with low payback periods. The installation process for these upgrades is straightforward and requires minimal time and effort compared to more complicated retrofits. There are various thermostat options available for existing RTUs, with standard programmable thermostats being the most commonly found. However, these thermostats are limited in their capabilities, as they do not offer networking, multi-unit access, and integration with other retrofit technologies. Manufacturers offer multiple products that can be implemented on an RTU, and this report will focus on the best-fit options for RTUs that can also be integrated with other retrofit technologies.

EMS SI

Ecobee offers many thermostats that have been gaining popularity over the last few years. The Ecobee 3 Lite is a low voltage thermostat compatible with most RTUs. It is an Energy star certified, Wi-Fi enabled thermostat that can integrate with many technologies, such as Alexa and Apple Homekit, as well as a smart sensor for added comfort in areas that are not near the thermostat. The web interface allows for scheduling and setpoint changes across multi-unit installations.

Ecobee also offers the EMS Si, which is more tailored to commercial HVAC systems. It allows management of an unlimited number of thermostats across various locations with multiple users. Two temperature sensors can be added to the thermostat and programmed to control from various locations, as well as toggle occupied/unoccupied mode, shut down compressors, and adjust setpoint temperatures. In addition, users can set automatic alerts and service reminders, as well as run HVAC reports for remote diagnostics and troubleshooting.

Nest

Nest offers the standard Nest thermostat as well as the Nest Learning Thermostat. Both thermostats claim 10–15% energy savings. The learning thermostat adds additional capabilities like temperature preference and schedule learning, as well as an additional temperature sensor for control from multiple locations and compatibility with most HVAC systems.

Pelican Wireless Systems

Pelican offers an array of control options for commercial settings and RTUs. Multiple thermostat options, specifically the TS200H, TS250, and TS250H, offer built-in temperature and humidity sensors, temperature and CO_2 sensors, and temperature, humidity, and CO_2 sensors, respectively. Thermostats do not use site Wi-Fi but a gateway that is wired directly to an existing ethernet switch or router, or a cellular gateway to connect all devices to the Pelican app. Pelican allows up to 2000 thermostats on a single gateway and uses a mesh network to automatically connect to each other and the gateway.

In addition to thermostats, Pelican offers zone control as well as the PEARL economizer and DCV controller, which is installed on the roof and connects to the thermostat. All the thermostat and add-on controllers and sensors can be viewed by the main web interface, which allows scheduling, alarm notifications, all-unit control, and historical trend data.

LCBS Commercial Economizing Thermostat

The LCBS Connect system is a thermostat that is meant to be used with the LCBS controller. The controller is designed for installation on the roof and accommodates multiple sensors including economizer temperature and humidity, filter differential pressure sensors, current sensors, and photocell sensors.

Verasys

Johnson Controls offers the Verasys System, which paired with the smart building hub and constant volume controller, uses BACnet technology to control multiple devices and can connect with other equipment. The online portal allows mode changes, scheduling, and trending and reporting capabilities to achieve energy efficiency and other operating goals across multiple locations. The constant volume controller can connect to any smart equipment controllers that are mounted to the RTU.

Pivot

Trane Pivot is a smart thermostat designed for commercial use, providing facility managers and building operators with a centralized access and control of multiple buildings. The Pivot offers group scheduling and settings, adjusts RTUs based on outside conditions, and includes optimal start and stop features to maximize energy savings.

Table 6. Controls available for RTU retrofit

	Manufacturers					
	Pelican Wireless systems	Johnson Controls	Honeywell	Nest	Ecobee	Trane
Features	TS200 Series	Verasys System	LCBS Commercial Economizing Thermostat	Nest Thermostat, Nest Learning Thermostat	EMS Si	Pivot
Can be Integrated With	• Zone Controller • PEARL Economizer •	• Smart building Hub • Constant Volume Controller	• Smart VFD • LGW1000 Gateway	•Nest temperature sensor	• Additional Temperature Sensors	•Tracer Ensemble Cloud

	Temperature, humidity and CO2 sensors	● Smart Equipment Controllers				
Remote Monitoring	x	x	x	x	x	x
Realtime Alerts	x	x	x	x	x	x
multi-unit control	x	x	x	x	x	x
standalone BAS	x	x				
Historical Detailed data	x	x	x	x	x	x
Group scheduling and setpoint control	x	x			x	x
Optimal Start		x	x	x	x	x

Utility Program Review

Minnesota Utility Programs

Xcel Energy, Minnesota Power, CenterPoint Energy, Southern Minnesota Municipal Power Agency (SMMPA), and Great River Energy (GRE) all offer HVAC programs that include a prescriptive rebate catalog, custom rebate opportunities, or both for RTUs and RTU retrofits. With the exception of SMMPA, which has a business air conditioner tune-up program/rebate for participating utilities, none of the interviewed utilities discussed RTU offerings such as direct installs, tune-ups, early retirement, or mid-stream incentives (though some had these types of programs for categories other than RTUs) besides their prescriptive and custom rebates. In terms of program design, Minnesota Power is unique from the rest of Minnesota utilities in that they offer primarily custom rebates and use direct outreach to customers by their account managers as their main engagement tool. To identify new measures to offer in their HVAC portfolios, utilities follow tech trends and investigate new technologies that may save energy. None of the Minnesota utilities except Great River Energy (GRE) discussed any new technologies they are currently considering for their RTU programs. GRE is currently looking into heat pump applications for RTUs. Several interviewees mentioned discussions with customers about indoor air quality. With the ongoing pandemic, air quality has become a common concern for large buildings owners. However, no specific measures were offered to address indoor air quality concerns.

The interviewees agreed that it is a challenge to achieve large amounts of savings through RTU programs. One reason cited for this is that on a per-project basis, high efficiency RTUs do not always yield large savings over baseline efficiency units. This is likely because the term high efficiency typically refers only to the cooling side for RTUs. The heating efficiencies for high and ultra-high efficiency RTUs are typically the same as a baseline unit. In Minnesota's heating dominated climate, this significantly reduces the opportunities for savings from new RTUs (heat pump RTU implementation facilitated by the recently enacted ECO legislation may help address this issue). According to the utilities interviewed, most RTU related savings in their portfolios tend to come from the installation of variable frequency drives (VFDs) and install or repair of economizers.

Another challenge for achieving savings from RTU measures is the trend seen by Minnesota utilities that customers often operate their RTUs until failure before replacing. Customers are often reluctant to invest significant resources into retrofitting their existing RTUs, and more often than not wait to install new RTUs until after the existing unit has failed (this is true in 80%–90% of RTU installations based on interviewee estimates). There were many reasons mentioned for this, but the most common was that building owners often lack awareness about their equipment. Building owners, especially those that lease to tenants, are very concerned about first costs, and often have little incentive to reduce HVAC energy consumption because those costs are paid for by their tenants. Minnesota Power mentioned overcoming these challenges in some situations. They have seen success lowering the number of RTU replacements on failure by establishing and maintaining communication with their customers to guide them through the RTU replacement planning process before their units fail.

Minnesota utilities in general rely on their trade allies and general advertisements (newsletters, emails, and paper ads are common routes) to recruit participants. Trade allies typically have the closest relationships with the end user, so they are the most trusted and often have the most influence on what customers will buy. This means they play a key role in convincing customers to make RTU efficiency upgrades. However, many HVAC contractors do not actively pursue RTU retrofit opportunities or consistently recommend high efficiency RTU replacements, and as a result can often become a challenge for utility programs seeking to convince their customers to pursue these measures. None of the interviewees thought that certain types of customers were more or less likely to participate than others. Participation is often based on whose equipment happens to fail at that time.

Common complaints utilities have received regarding their HVAC programs are that the rebates are too low, and the rebate paperwork takes too much time. Common themes discussed that prevent contractors from recommending high efficiency units and RTU retrofits are that rebates need to be good enough for contractors to pay attention to them and make the rebates worth their time.

Table 7. Minnesota investor-owned utilities' RTU and RTU retrofit program/rebate offerings

Measure	Xcel	Otter	Minnesota	Minnesota	CenterPoint	Great River	Southern

Name	Energy	Tail Power	Power	Energy Resources	Energy	Energy	Minnesota Municipal Power Agency
Direct Expansion Units	x					x	x
Variable Frequency Drive or Adjustable Speed Drive	x	x				x	x
Economizer	x					x	
Demand Control Ventilation	x			x	x	x	
Controls						x	
Motors	x	x				x	x
Custom	x	x	x	x	x	x	x

a) Minnesota Power delivers their commercial offerings through a custom rebate program, which is why they have so few prescriptive measures.

b) Minnesota Energy Resources and CenterPoint Energy are gas-only and have limited options for RTU rebates.

Interview Summaries

Utilities Interviewed

- Xcel Energy
- Minnesota Power

- CenterPoint Energy
- Great River Energy
- Southern Minnesota Municipal Power Agency

Similarities

- VFDs, economizers, and high efficiency RTUs are the most common RTU savings measures. These savings opportunities come primarily through prescriptive rebate programs and less often through custom rebate programs.
- Utilities rely heavily on trade allies to promote their programs and high efficiency options. Community engagement, newsletters, and email are some other avenues for customer outreach.
- Controls are getting more attention and are being explored for inclusion in RTU measure offerings.
- It is common to see all types of buildings utilizing RTU savings measures. Office and retail were mentioned as particularly frequent participants but by a small margin compared to other sectors.
- For those programs and rebates that do not include an “X” in the above chart, most utilities will fulfill rebates for those technologies through their custom measures.

Differences

- Minnesota Power is the only utility to primarily deliver savings through custom measures. They rely on direct outreach and customer engagement by their account representatives to guide customers through their programs and help them save energy. Other utilities focus on prescriptive measures and tend to have more success there than with their custom programs.

Barriers Identified

Barriers to implementation discussed were lack of knowledge of retrofit technologies by the customer and contractors, the tendency to wait for RTU failure to replace with a new unit, supply chain complications and long delivery lead times, owner/tenant split-incentives for leased facilities, and a greater focus on minimizing first costs when building owners look to invest in RTUs.

Lack of Commercial HVAC System Awareness and Desire to Go Above Code

All utilities interviewed discussed a lack of HVAC system awareness as a major barrier. Several things can result from a lack of awareness of a building’s HVAC system, but the most common and troublesome is when it leads to only dealing with units once they have failed and need to be replaced immediately. When an RTU is not monitored near the end of its life, it is replaced on failure and in these scenarios supply chain issues can cause lower efficiency units to be installed rather than high efficiency units. This is because a high efficiency unit takes longer to get in most cases. Also, when a unit fails, customers usually choose the lowest bid. This may be because they did not plan funds for a high efficiency unit, or they do not want to or cannot pay for a high efficiency unit. According to Minnesota Power, they have helped mitigate the awareness issue by utilizing their customer outreach approach to engage customers about their plans for replacing their RTUs before they fail.

Leased Facilities

Cases where buildings are leased and not occupied by the building owner can also cause complications. The owner has an incentive to minimize the first cost of their investment and does not have an incentive to minimize the ongoing operating costs for the tenant because the tenant usually pays the utility bills. On the other hand, it is not common for tenants to want to invest in RTU upgrades or replacements because benefits will accrue at least partially to the building owner.

Retrofit

Lack of awareness is a particular problem for RTU retrofits. Utilities encounter contractors who are not aware of the available RTU retrofit rebates, the retrofit technologies themselves, or both. Unfamiliarity with the technologies, as well as skepticism about their benefits, also diminishes contractors' willingness to pursue RTU retrofits. Furthermore, the amount of time an RTU retrofit takes relative to the price contractors can charge discourages some contractors from recommending them. They may instead choose to focus on installing high quantities of baseline efficiency RTUs. Without contractor buy-in, utilities can struggle to actualize significant amounts of RTU retrofit savings. Utilities can address this issue by making the utility rebate process simpler. For example, SMMPA is looking to move some incentives away from custom (with a focus on controls at the moment) because the contractor and customer being able to see a prescriptive rebate amount and not have to pursue the complex custom rebate process is likely to increase participation.

National Utility Program Review

The purpose of interviewing utility programs outside Minnesota was to identify national best practices for programs with RTU measures that could be considered for inclusion within Minnesota utility portfolios. Utilities nationwide were first identified by internet search. A selection of those originally identified were interviewed based on the program managers who were willing to provide information about their programs. During this process, we attempted to contact utilities from as many regions of the country as possible.

As well as prescriptive and custom rebate programs, the utilities interviewed from outside Minnesota highlighted additional RTU-focused program types that they offered through their portfolios. Interviewees reported that low participation numbers motivated them to look for other avenues to engage with the RTU and RTU retrofit markets. Midstream programs were particularly common among all utilities outside Minnesota, and all utilities either offered midstream incentives or are currently looking to add them to their programs. The rest of the RTU program types were implemented by fewer utilities interviewed.

Table 8. Utilities outside Minnesota: RTU and RTU retrofit program

Program Type	Mass Save	ComEd	Southern California Edison	NJBPU*	Efficiency Works Colorado	BPA**
Direct Install	X			X		
RTU Tune-Up	X	X				
Early Retirement		X				
Midstream	X	X	X	X	X	X

*NJBPU - New Jersey Board of Public Utilities, **BPA - Bonneville Power Administration

Mass Save

Mass Save's commercial programs offer lighting, HVAC, and refrigeration savings. In addition to their prescriptive offerings, they have a direct install program where the primary savings come from lighting. However, building automation systems that control HVAC systems are currently being considered for inclusion in the program. Furthermore, RTU tune-ups are delivered through their Equipment & Systems Performance Optimization (ESPO) program. The Commercial and Industrial Electric HVAC and Heat Pumps program includes midstream incentives for heat pump systems, air-conditioning systems, VRF, ECM pumps, and HVAC controls.

Mass Save has not historically realized many savings from RTU measures. Their most successful programs for RTUs are ESPO and prescriptive controls. They found that over 90% of RTUs were replaced on failure and are looking to incentivize high efficiency levels at the distributor (midstream) level in order to increase the amount of high efficiency RTUs that are installed upon failure of the existing unit. They also highlighted the importance of contractors to increase program participation by making recommendations to customers and making it easier to take advantage of incentives through offerings such as midstream incentives.

Bonneville Power Administration

As a federal power marketing administration, it is BPA's utility customers that offer efficiency programs and incentives to end-use customers, but BPA helps coordinate and deliver the programs. Utility customers can opt in or out and can pick and choose incentives. BPA's focus with RTUs is their Advanced

Rooftop Unit Control (ARC) and ARC Lite programs. ARC provides incentives on a per-ton basis from several third-party companies who offer retrofit packages.* ARC is a successful program for them, with retail and office buildings being the most common participants.

Supply chain issues mainly prevent contractors from recommending RTU retrofits or high efficiency units. They often see that distributors have a low stock of high efficiency units, which can result in those units taking several months to get to a customer. Customers often need a unit quickly at a low cost if their current RTU has failed, resulting in purchasing a baseline efficiency replacement unit.

*Enerfit, Bes-Tech, Honeywell, Johnson Controls, Lennox, NexRev, Pelican Wireless Systems, Transformative Wave, Unitary Energy Solutions, Lennox, Turntide

NJBPU

For RTUs, prescriptive rebates and direct install programs are offered by NJBPU. In 2022, a midstream program is scheduled to launch but supply chain issues may result in the program launch being delayed. Recently their direct install program has shifted toward paying new construction buildings for how far above code they build. Their focus is on M.U.S.H. buildings (municipal, university, school, and hospital). NJBPU in general does not see a high volume of participation for their RTU measures. Most of their commercial and industrial savings come from lighting and custom projects.

The barrier they see to RTU program participation is motivation to install efficient equipment and education. Most building owners do not know much about energy efficient equipment or are not particularly interested in energy efficiency. In addition, NJBPU faces barriers from participants who provide feedback that the incentives are not high enough and that contractors do not want to take the time to fill out the paperwork.

Efficiency Works

Efficiency Works does not offer typical downstream rebates to customers or contractors. They focus on the distributor (midstream) level and have seen a significant increase in high efficiency units sold since 2016. For existing units, they have prescriptive rebates but very little activity on those measures. They are looking to move those prescriptive incentives to midstream and are also launching a building tune-up program.

In their experience, RTU replacements are typically emergency/replace-on-fail situations, but the midstream programs help make high efficiency RTU installs more common. This is because they result in distributors stocking more high efficiency RTUs and lowering the cost to the customer, making them more competitive with baseline efficiency units.

ComEd

The ComEd catalog has a variety of measures including lighting, HVAC, and refrigeration. They have a DX tune-up program, an early retirement program that offers higher rebates if an RTU is retired early, and a midstream HVAC program called "Instant Discounts."

Like some other utilities we interviewed, they typically get the most RTU-related savings from VFDs and controls. Tune-ups also produce some savings, but HVAC is only a small portion of the program. They have been looking into Turntide switched reluctance motors as a possible measure to add.

For customers participating in their early retirement program, RTUs are typically planned replacements. When looking at replacements within the RTU market, most are still replaced on failure.

Southern California Edison

Southern California Edison (SCE) has midstream and prescriptive-based incentives centered on RTUs. They previously had an RTU tune-up program, but it was discontinued due to their assessment that it was not cost-effective. A similar situation happened with an early retirement program that SCE used to offer. It was supplanted by a statewide midstream HVAC program, Comfortably CA, in California. All investor-owned utilities in California pay into the program, which is currently implemented by CLEAResult. Incentives are designed for distributors, and there is no requirement for the distributors to pass them on. This method has been successful in helping distributors overcome administration and stock burdens.

New technologies for potential additions to SCE's programs get reviewed by their emerging tech group, with engineering becoming involved with measures selected for implementation. Lately, VRF has attracted most of their interest for large buildings like hotels and campuses. For RTU tech, they have been researching heat pump RTU applications.

A pain point for SCE has been claiming savings for RTUs as federal efficiency standards increase. As the baselines increase, the incremental efficiency gains from installing high efficiency units may be lower, reducing the cost-effectiveness of their high efficiency RTU measures.

Local Market Interviews

Contractors

HVAC contractors have a very strong influence on system design and operation since they directly communicate with customers purchasing HVAC equipment. Generally, RTUs are replaced on failure and customers work with contractors to replace an RTU to get a unit up and running as quickly as possible. All the interviewees indicated that most customers rely heavily on contractor recommendations when purchasing new equipment or repairing existing equipment. Cost is a major factor at the time of replacement and customers are likely to choose the lowest cost option.

The interviewees gave a range of responses when asked whether they recommend high efficiency options at the time of replacement. Most provide options to the decision makers when making recommendations and generally push the higher efficiency equipment when the utility incentives can match the incremental cost from the standard to high efficiency option. One mentioned that high efficiency units are more difficult to get in stock, so they present the option but mostly recommend standard efficiency equipment.

All the interviewees were familiar with the advanced economizer controls that are being studied in this project (Honeywell JADE and Belimo ZIP) and presented this as what they feel has the most potential in terms of an energy efficiency upgrade to RTUs. They are generally recommended and installed when a technician comes across an economizer that has failed. None of the contractors would upgrade an economizer unless something was wrong with it, but since economizers are the most common failure on packaged RTUs, it is a common recommendation.

Only one of the contractors regularly recommends a retrofit solution not related to economizers that was summarized in the technology assessment. This technology is the Catalyst package, which includes a VFD on the evaporator fan and advanced economizer controls. The contractor finds that the technology is straightforward to install and offers significant savings, so recommends it to customers when applicable. Most were not familiar with the packages that included VFDs or smart motors on the evaporator fan or compressor. All expressed concerns about the technologies, cost, payback, and lack of available prescriptive utility incentives.

Manufacturers

Manufacturers of RTU retrofit technologies had significant input on barriers, utility incentives, contractor interaction, and ways to increase implementation. Five manufacturers for retrofit technologies of interest were interviewed: Turntide, Transformative Wave (Catalyst), Bes-Tech (Digi-RTU), Honeywell, and NexRev (DrivePak).

All the interviewees had varying forms of involvement with gas and electric utilities, both nationally and in Minnesota. Rebates are very important for retrofit technologies as they can reduce payback periods, which are the deciding factor when a customer is on the fence about a purchase. Custom rebates, while very open-ended and broad, tend to slow down projects and take considerable effort to apply for. Prescriptive rebates are generally preferred and offer a quick and easy way to get rebates to customers.

Contractor engagement and involvement is a crucial part of implementing RTU retrofit technologies. Multiple interviewees stated that contractor engagement has been a hurdle with their technologies. In general, contractors are unwilling to take on and sell technologies with which they are not familiar. Most manufacturers interviewed have found success reaching out to customers directly when possible. Each emphasized that businesses with multiple locations are ideal to target and implement their packages. National accounts can be lucrative because selling them on the product can lead to implementation across many RTUs and buildings. Manufacturers cited quick-serve restaurants as a target audience.

Distributors

Two large distributors that work in the Midwest were interviewed and both were mostly familiar with the various retrofit technologies in the project. The biggest takeaway from the interviews is that many RTUs they were selling come standard with either a two-stage VFD motor or an ECM direct drive motor. Many technologies studied include a way to vary the speed of the evaporator fan, which would not be necessary as a retrofit if variable speed motors already exist on RTUs. Both interviewees mentioned that higher efficiency units are becoming more popular as a replacement as rebates mostly offset the difference between them and a standard efficiency unit. Utility incentives play a large role in the RTU market and how distributors sell RTUs. One interviewee mentioned that prescriptive rebates are crucial, as many contractors they work with do not want to go through the time consuming and usually difficult process of processing a custom rebate.

Building Owners/Facility Managers

Payback period is the biggest factor for building owners when considering investing in RTU retrofits. Interviewees stated that any energy saving measure with a payback period longer than five years is not likely to be implemented. On the other hand, a payback period of two to three years is extremely likely to be implemented. System failure and callbacks are the biggest factors after payback period when considering an RTU retrofit. The interviewees stated that prior to purchasing it would be helpful to see case studies or talk to others who have had success with the same technology to increase confidence in the equipment.

Building owners are more likely to implement an RTU retrofit technology if there are prescriptive rebates available. Interviewees stated that custom rebates are difficult and time consuming, and prefer the ease of a prescriptive measure, which better display the information.

The relationship between mechanical contractors and those who own and manage buildings are extremely important for the HVAC market. Interviewees stated that most contractors rarely give options for what is available in the RTU market. Building owners are unaware of what technologies exist for RTU retrofits and generally rely on information only from the mechanical contractors who service their buildings.

Owner-occupied buildings, such as retail chains, offer the greatest opportunity to implement RTU retrofit technologies. Owners have full control of the equipment and are responsible for the utility bills, making efficiency and operating cost top priorities. That said, many buildings served by RTUs are occupied by tenants that are renting the space. In these situations, retrofits are difficult because the tenants do not own the equipment but are responsible for the utility bills. Building owners are not interested in making costly upgrades as their main priority is keeping occupants comfortable.

Minnesota Market Opportunities

RTU retrofits offer tremendous potential for existing RTUs in Minnesota. More education is needed to give mechanical contractors information on existing RTU retrofit technologies, and they can then use that information to provide more robust recommendations to their customers. Few contractors were aware of the retrofit technologies of interest, other than advanced economizer packages which they mainly install when an existing economizer has failed.

Interview takeaways:

- All interview groups favor prescriptive rebates over custom rebates due to simplicity.
- Contractor education and engagement is crucial for more technology implementation.
- Manufacturers have had success reaching out to customers directly.

- Owner-occupied buildings such as retail, restaurants, etc. offer the greatest potential for RTU retrofits.
- While many new RTUs have incorporated variable speed evaporator fans, there is still opportunity for various technologies, as well as retrofitting existing RTUs more than five years old.

Energy Savings Potential

The team analyzed annual energy savings, and performance of each field tested RTU was analyzed as described in the methodology on pages 20 to 25. Models were created to determine baseline (standard RTU operation before retrofit) energy use, which was compared to energy use after retrofit. The results from the analysis are summarized below.

Annual energy consumption for RTUs was calculated in two ways. For RTUs that were retrofitted with a solution to vary the speed of the evaporator fan (VFD or SRM), electricity consumption was calculated using power measurements taken to determine fan power and speed during all potential modes of operation. These power measurements were used to model the RTU's electricity use at each hour during the year (8,760 model) during a year of typical weather data in Minneapolis (TMY3 data). Electricity was the sole source of energy savings for the field-tested retrofit technologies, so that was the energy source analyzed for this project. Three technologies were tested that varied the speed of the evaporator fan as their main source of energy savings, Catalyst VFD, DrivePak VFD, and Turntide SRM. RTUs equipped with the Catalyst package saved an average 36% of annual electrical consumption (2,702 kWh per year), Turntide SRMs saved an average of 33% (3,556 kWh per year), and the DrivePak saved 43% (3,592 kWh per year). These values represent average values across all RTUs in the study.

RTUs retrofitted with advanced economizer packages were monitored for longer time periods, allowing for the team to establish and compare a pre and post regression. Data was gathered and analyzed during outside air temperatures that the project team expected to benefit from the economizer in free cooling mode, 45°F to 70°F. This data was normalized using a TMY3 data set to obtain annual usage data for the pre and post periods.

Table 9. Field site size and electricity savings

Technology	Average RTU Size (Tons)	Average RTU Annual Electricity Savings %	Average RTU Annual Electricity Savings (kWh)
Catalyst	6	36%	2,702
Turntide	9	33%	3,556
DrivePak	7	43%	3,592
Honeywell Jade	5	0%	-5
Belimo ZIP	7	3%	140

Figure 12. Electricity savings by site and retrofit technology

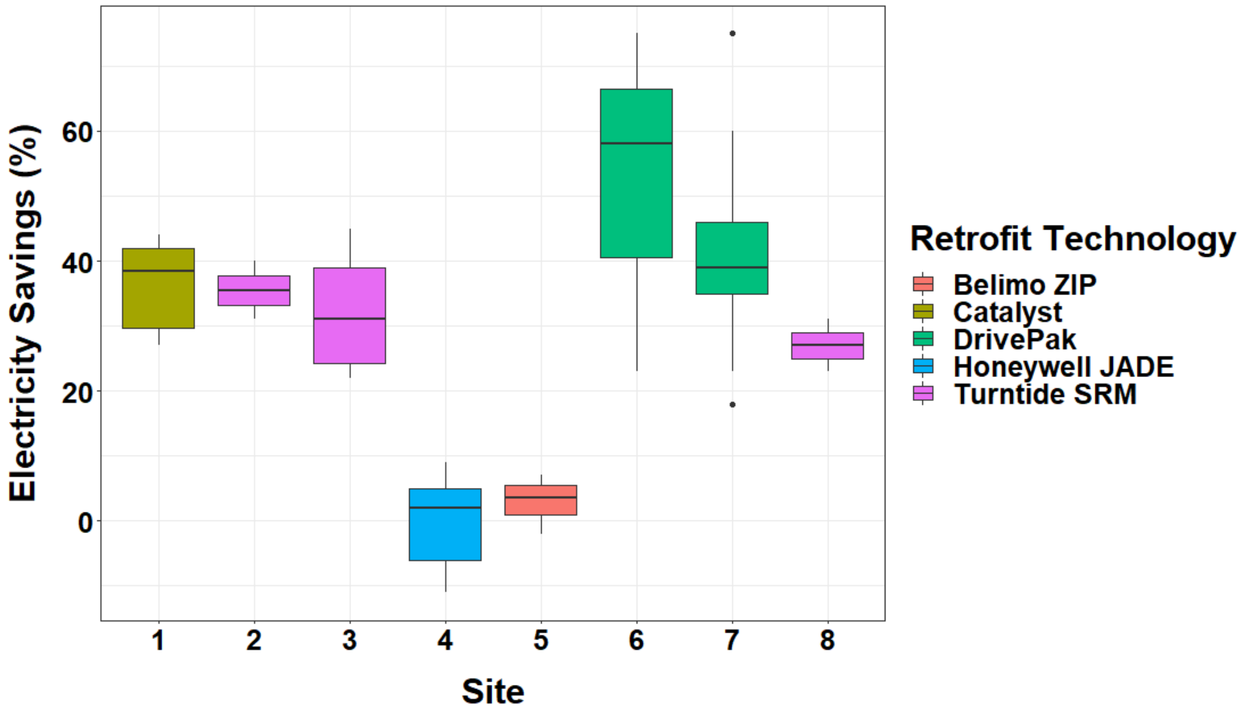
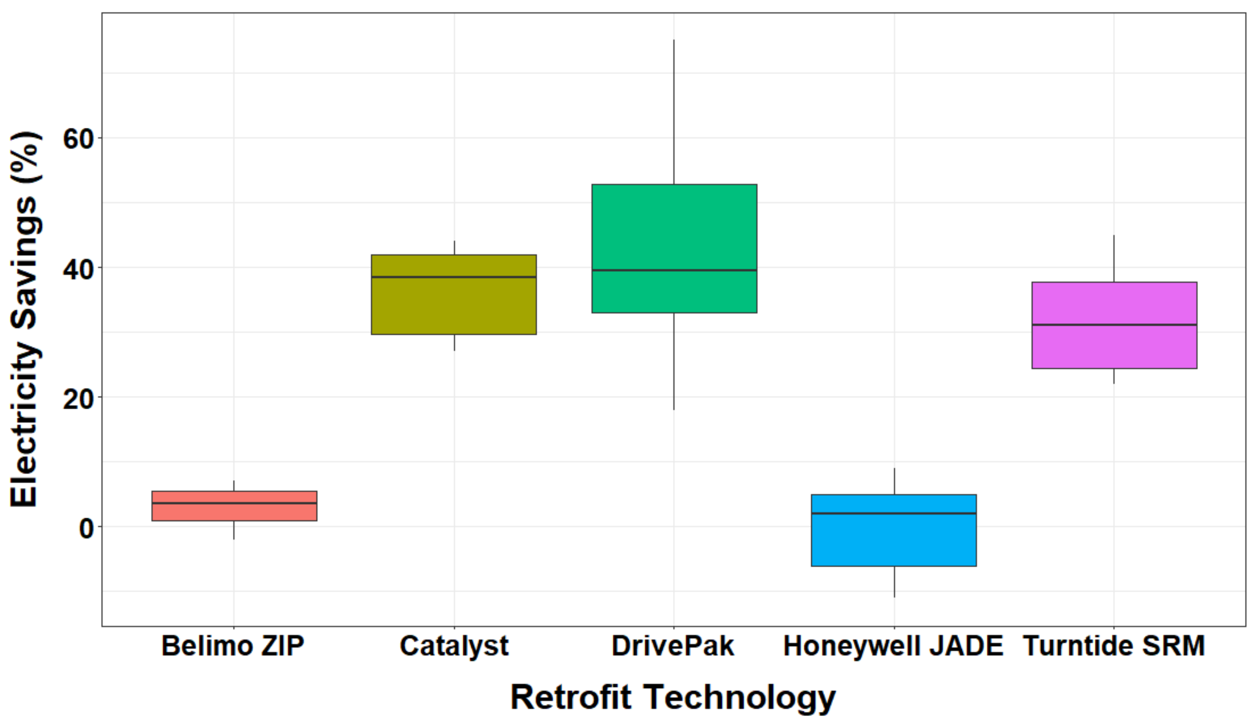


Figure 13. Electricity savings by retrofit technology

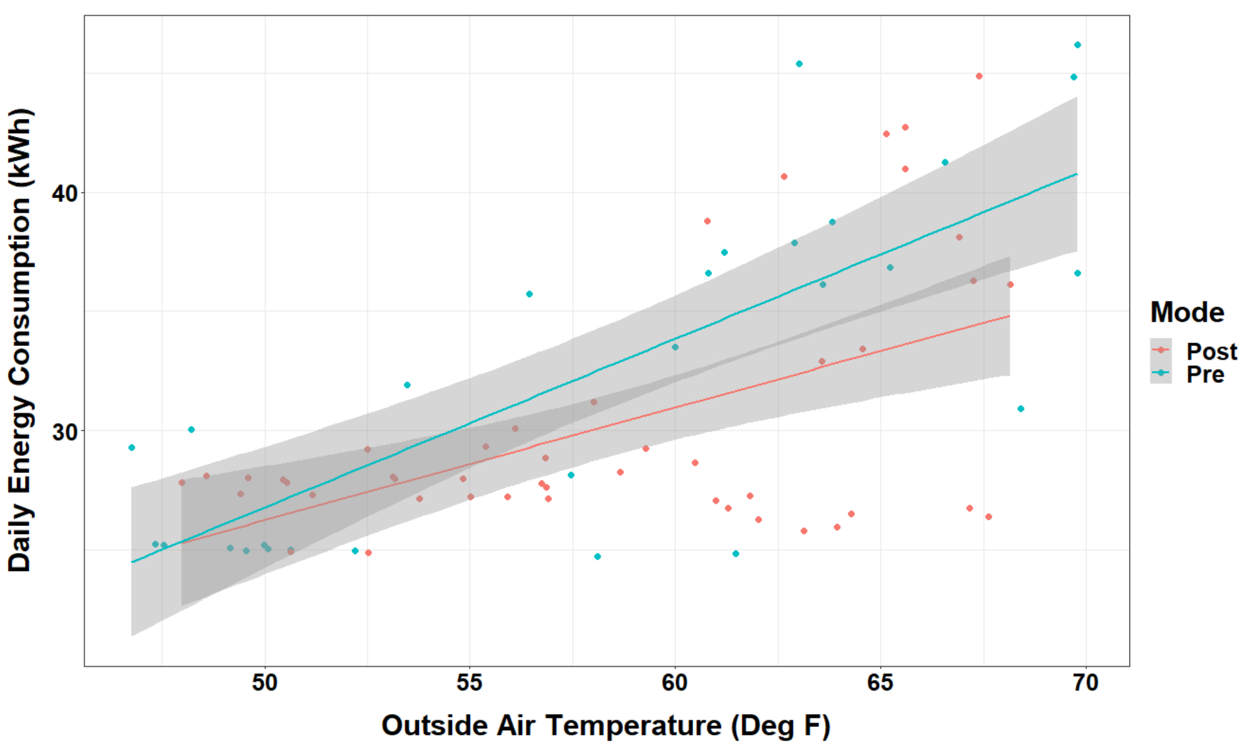


Advanced Economizer Package Savings Honeywell JADE and Belimo ZIP

Data was gathered and analyzed during outside air temperatures that the project team expected to benefit from the economizer in free cooling mode, 45°F to 70°F. Annual results varied across each RTU. Some showed negative savings, while most had positive savings. Most RTUs in this study did not cool a significant amount due to the building's configuration. RTU-5 and RTU-9 showed the most savings, as expected. Both serve perimeter offices and conference rooms, and are exposed to early sunlight that leads to warm morning temperatures and free cooling opportunities. This is a common free cooling scenario in Minnesota's climate. In shoulder seasons, thermostats are regularly set to automatically switch between heating and cooling due to large outside air temperature swings and potential for both heating and cooling operation in the same day.

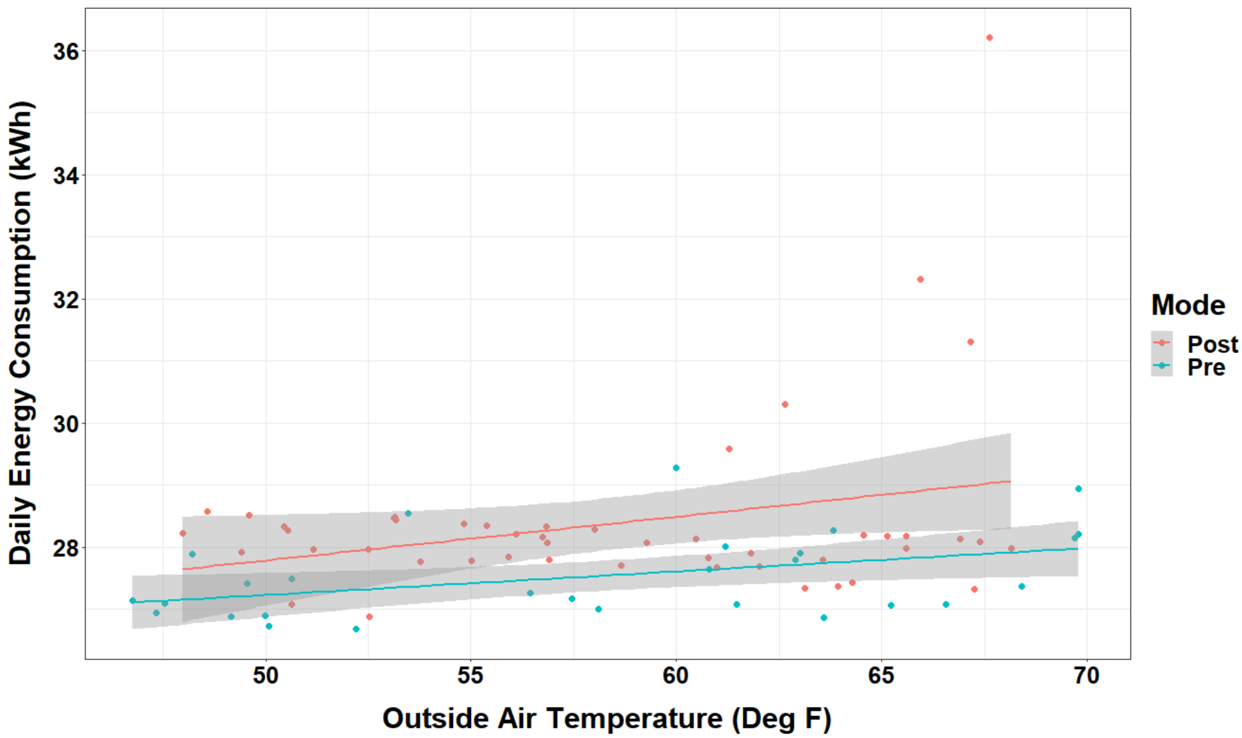
Cooling runtime is a significant factor in energy savings potential for an RTU equipped with an economizer or retrofitted with an advanced economizer package. The cooling operation of the RTUs at the test site equipped with the Honeywell JADE and Belimo ZIP economizer packages varied significantly, which had an impact on the individual RTU energy savings. Figure 14 represents daily energy consumption for RTU-5 and shows many days of cooling above 60 °F, represented by the steep positive slope.

Figure 14. Site 5, RTU-5 pre and post regression showing significant cooling runtime



The RTU depicted in Figure 15 experienced only a few cooling events during the test period. This situation is frequent in buildings where RTUs are responsible for conditioning shared areas. Fluctuating ambient conditions and thermostat setpoints, which may alter according to the comfort of the occupants, may cause RTUs to become overworked or underworked.

Figure 15. Site 5, RTU-7 pre and post regression with limited cooling runtime



Energy savings results did not meet expectations and resulted in very long payback periods. While some RTUs demonstrated a moderate energy savings of 2% to 9%, three RTUs experienced negative savings. In total, the annual energy savings for the site amounted to 535 kWh, which based on an assumed cost of $.13/kWh and a total site retrofit cost of $13,620, resulted in a site payback period of 196 years.

Table 10. Site 4 and site 5 Advanced economizer electricity savings

RTU	Pre Annual Use 45°F–70°F (kWh)	Post Annual Use 45°F–70°F (kWh)	Electricity Energy Savings (kWh)	% Savings
RTU-1	2237	2188	49	2%
RTU-2	2316	2116	200	9%
RTU-3	2066	2196	-130	-6%
RTU-4	3258	3618	-361	-11%
RTU-5	4136	3921	215	5%

RTU-6	2919	2724	195	7%
RTU-7	3505	3592	-87	-2%
RTU-8	3734	3672	62	2%
RTU-9	7455	7062	392	5%

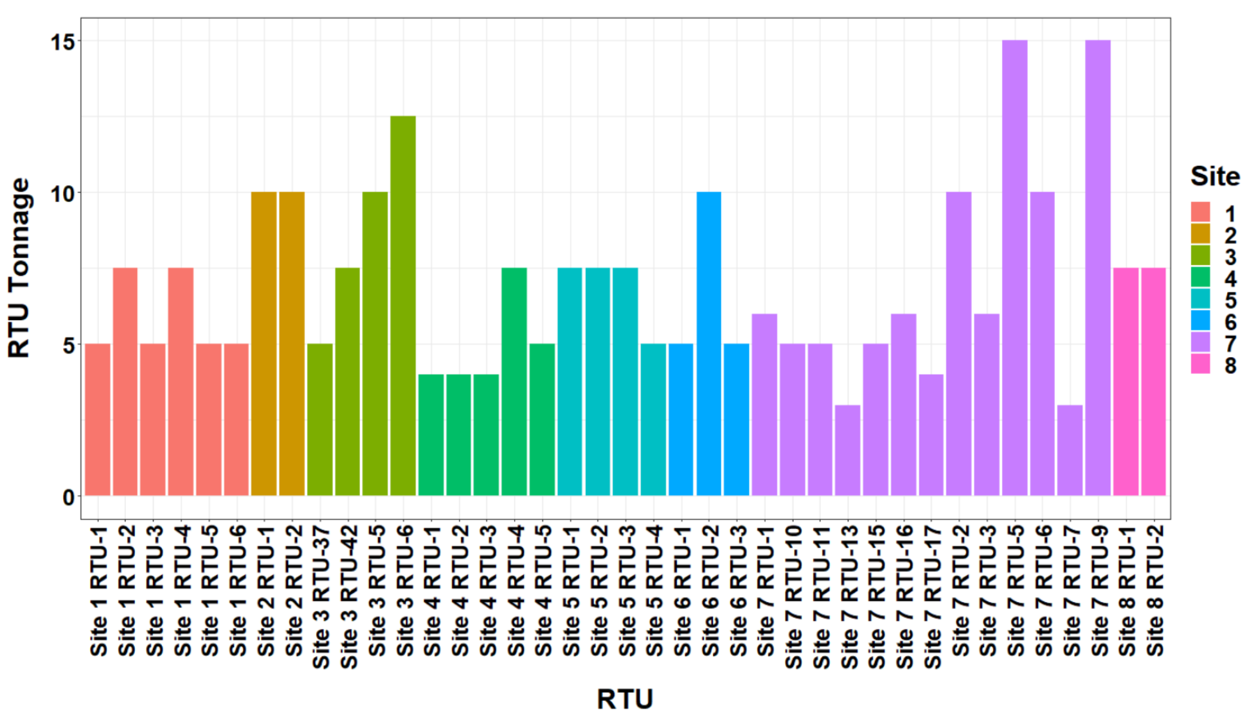
Optimal scenarios for achieving energy savings when retrofitting an RTU with an advanced economizer package in Minnesota include the following.

- Large RTU with high ratio of compressor to evaporator fan power
- High internal heating load such as industrial, manufacturing, or frequently used conference rooms
- Colder climate, such as Duluth/northern Minnesota, to provide a higher fraction of ideal outside conditions for free cooling

Impact of RTU and Motor Size

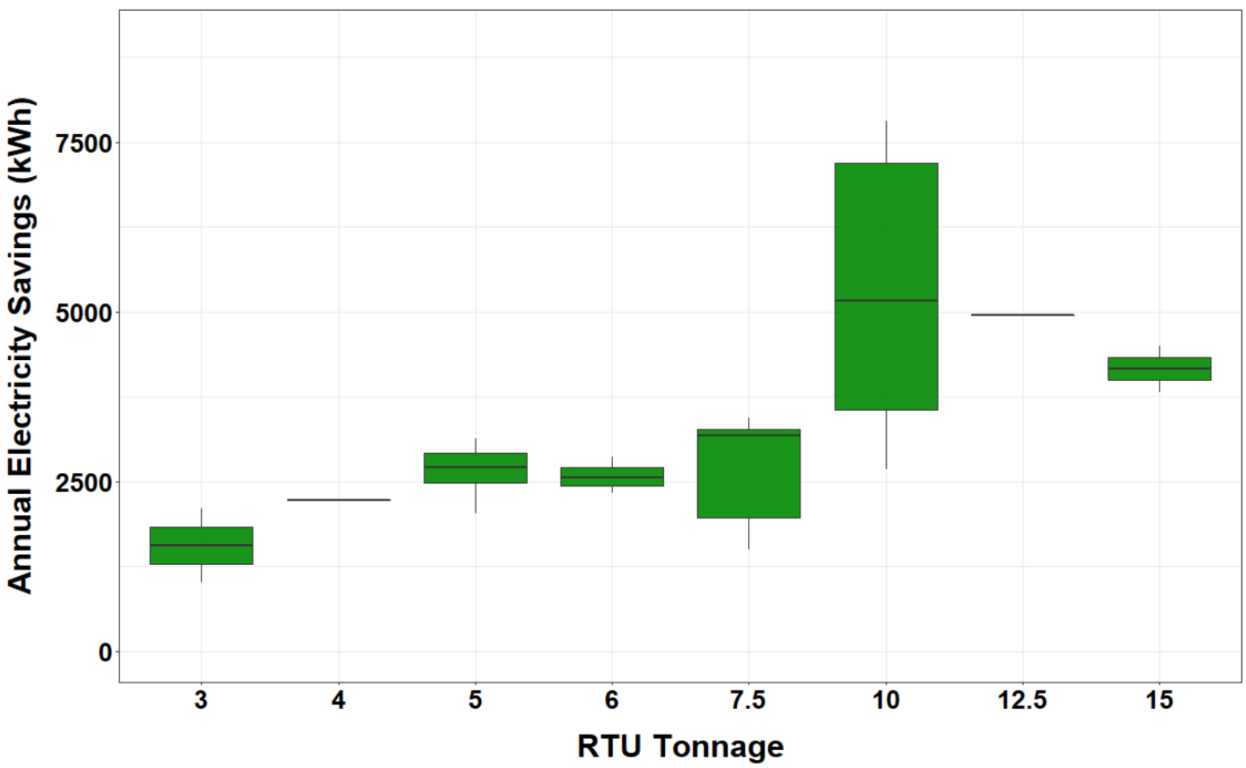
RTUs field tested in this project varied in size from 3 tons to 15 tons, with an average size of 6.9 tons. This is lower than the Minnesota average of 10.7 tons found by the CARD RTU Market Characterization study (Seventhwave, 2017), but a realistic representation of the RTU stock that serves Minnesota buildings. Size is a major factor when considering RTU retrofit, as RTU size (both heating and cooling capacity) and the various motor sizes can have a large impact on savings and overall cost-effectiveness. Figure 16 represents the sizes of the RTUs field tested in this project.

Figure 16. Tonnage of tested RTUs



As expected, annual electricity savings increased with RTU size, shown in Figure 17. Smaller sized RTUs are very common on Minnesota buildings, and while savings potential is limited, they can still offer reasonable payback periods if runtime hours are significant.

Figure 17. Electricity savings sorted by tonnage



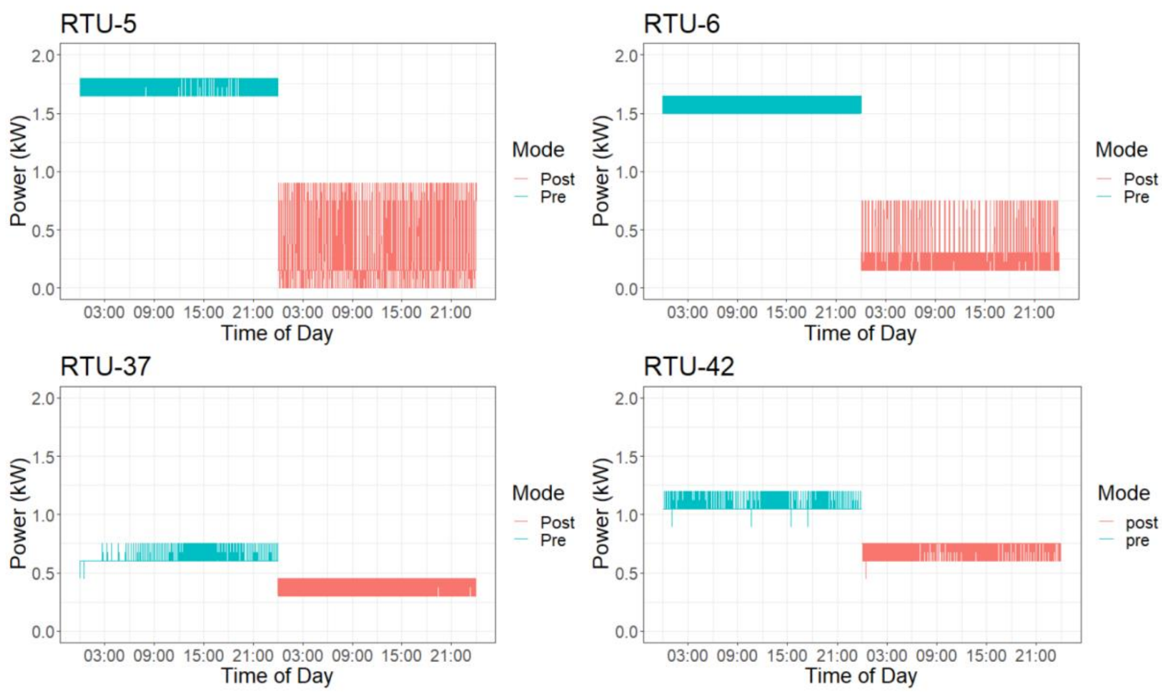
Performance

Fan Speed of Variable Speed Evaporator Fans

Fan speed operation was logged for each RTU retrofitted with a VFD or SRM and analyzed. Each retrofit option varies the speed of the supply fan to the necessary fan speed based on what the system needs, depending on the mode of operation. During fan-only mode, evaporator fan speed is decreased to provide the minimum amount of air for ventilation, 40–60% of the baseline speed. Because fan power is a cubic relationship to fan speed, any reduction of fan speed will result in significant electricity savings. Therefore, if a fan is reduced to 50% of the fan speed, the power will be reduced to around 13% of full load power.

Evaporator fan speed is increased for cooling and heating operation to ensure proper airflow across the evaporator coil or heat exchanger. During cooling mode, improper airflow can impact refrigerant pressure, delivered air temperature, and overall efficiency of the system. Heating mode is similar, and proper airflow is crucial for proper heat transfer and to provide adequate heat to the space. Calculated evaporator fan speeds (from power measurements) for RTUs measured for this project during heating and cooling ranged from 75–97%. RTUs with multiple stages (heating and cooling) varied fan speed between the first and second stage to allow for the additional capacity being provided. Figure 18 shows a typical day for each RTU at site 3 during the pre and post monitoring periods. Fan power during baseline operation remains steady and significantly decreases during the post period. Power fluctuation during the post period for RTU-5 and RTU-6 represent the fan speed variation for the first and second stage heating. Days were selected with similar outside air temperatures and operation to compare the modes.

Figure 18. Site 3 pre and post evaporator fan power



Fan Runtime Hours

Evaporator fan runtime hours greatly affect RTU electricity consumption patterns, ventilation rates, and overall potential savings by retrofitting the unit with a new motor or VFD. The fan configuration for site 2 varied across RTUs, space types throughout the building, and occupancy patterns. Measurements were made in the winter of 2021/2022, when COVID-19 restrictions were still in place and many employees were working from home. The site was sparsely occupied, and the site contact indicated that RTU fan configurations at the time of testing did not match the configurations when the building is fully occupied. Energy savings were calculated for three evaporator fan configurations, fan set to auto (the fan only runs during a call for heating and cooling), fan on for 14 hours on weekdays and 6 hours on weekends, and fan on 24/7.

Table 11. Site 3 RTU-5 fan configuration electricity use and savings comparison

RTU Component	Fan Auto		Fan On 14 Hours Weekday, 6 Hours Weekend		Fan On 24/7	
	Baseline	Retrofit	Baseline	Retrofit	Baseline	Retrofit
Total Electricity Use (kWh)	15,528	12,724	21,161	13,354	27,413	13,997
Evaporator Fan Use	23%	6%	44%	11%	58%	17%
Compressor Use	75%	92%	55%	87%	42%	82%
Condenser Fan Use	1%	2%	1%	2%	1%	2%
Total Electricity Savings (kWh)	18%		37%		49%	

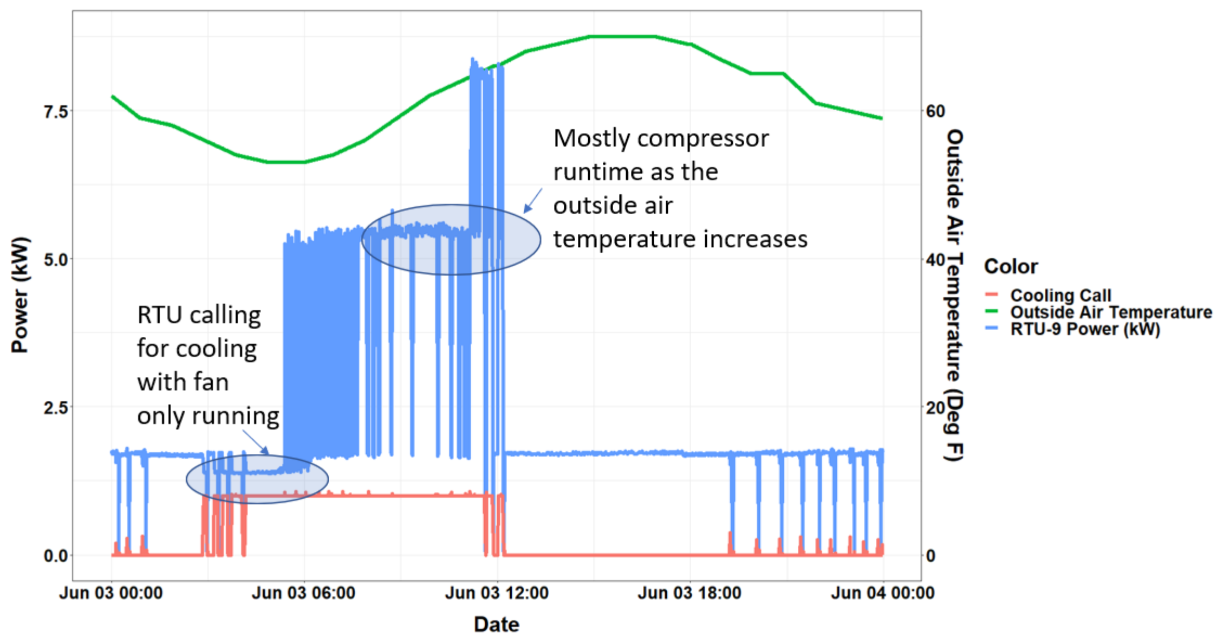
Many building operators and facility managers operate their RTUs with the fan in auto, which greatly decreases fan runtime hours and VFD savings potential, and should be a consideration when planning a retrofit. Fan auto configurations eliminate operation where only the evaporator fan runs without heating or cooling operation (except when economizing) and miss out on the extremely low fan power draws that can result in significant electricity savings.

Economizer Operation

Advanced economizer packages offer more robust and reliable controls and sensors, digital controllers that give the installer or technician more precision when setting parameters, and integration opportunities with other technologies. The Honeywell JADE and Belimo ZIP are the two most installed packages by mechanical contractors in Minnesota for economizer retrofit, and the technologies field tested in this project.

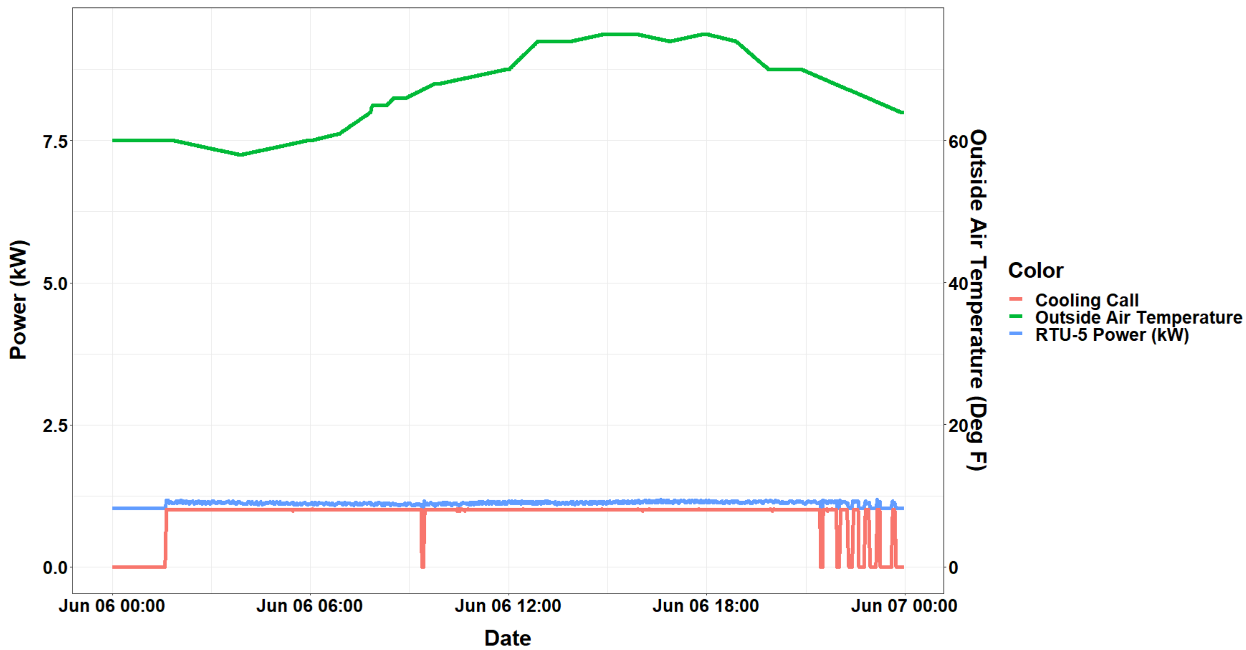
Figure 19 represents a day of operation for RTU-5 at site 5 after the economizer package was installed. This RTU has the highest potential for an economizer to operate in free cooling mode as it serves exterior offices that are exposed to sunlight in the morning. On a cool morning as the sun offers solar radiation to heat up the space, the thermostat warms and calls for cooling. Since the outside air conditions are in the threshold for economizer operation, the economizer is allowed to use the outside air to cool the building instead of turning on the compressor. The unit economizes until around 5 a.m., when the compressor starts to cycle on and off until the outside air temperature is high enough that the unit stops economizing and there is mostly compressor operation.

Figure 19. Site 5, RTU-5 typical day of operation



The advanced economizer packages have multiple advanced settings that control the operation of the RTU. While standard economizers generally use a simple outside air temperature sensor to judge when the system should use free cooling, the packages studied for this project employ multiple sensors and adjustable settings to maximize the economizer's benefits. In addition to outside air conditions, both economizer packages can measure return air temperature and mixed air temperature for more control. For example, the Honeywell JADE economizer package uses a setting that can economize when the outside air temperature is above the switchover temperature, if it is below the return air temperature (minus a deadband setting that the installer can adjust). In the test units that were studied, specific RTUs showed economizer operation when the unit called for cooling and above the switchover temperature of 60°F, as shown in Figure 20. The RTU maintains a cooling call from 2 a.m. until around 10 p.m. with only fan operation. The economizer control determined that the outside air would be adequate to cool the space and did not turn the compressor on.

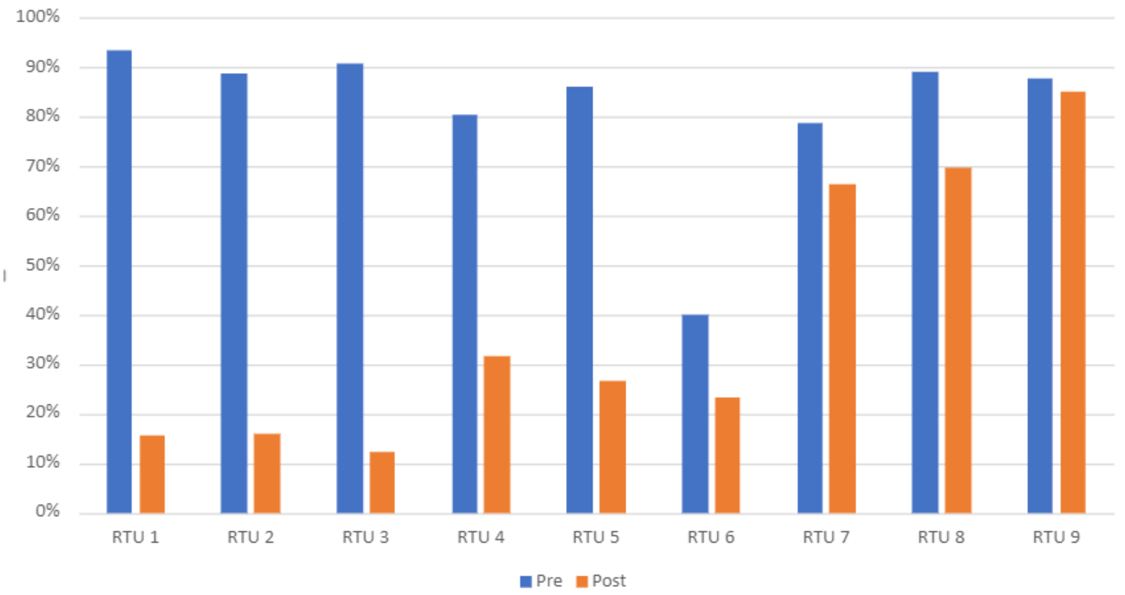
Figure 20. Site 5, RTU-5 economizing above switchover temperature



Both economizer packages were expected to cut down compressor runtime due to free cooling, which pulls in outside air to cool the space under certain outdoor air conditions. All the units studied showed a decrease in compressor runtime when comparing the post to the pre test period. Each RTU serves a different space type throughout the building and operates differently. Some units cool significantly, such as RTU-5 and RTU-9 which serve multiple offices along exterior walls. RTU-6 and RTU-7 showed very limited cooling calls, as they both serve an open space that is shared by multiple RTUs.

The figure below shows the decrease in compressor runtime between the pre and post test periods. Each bar represents the percentage of time that the compressor ran while the RTU called for cooling. If the compressor was not running during the cooling call, the unit was economizing. The outdoor air damper was open, and the evaporator fan pulled in outside air to cool the space.

Figure 21. Site 4 and site 5 pre and post compressor runtime to cooling call ratio



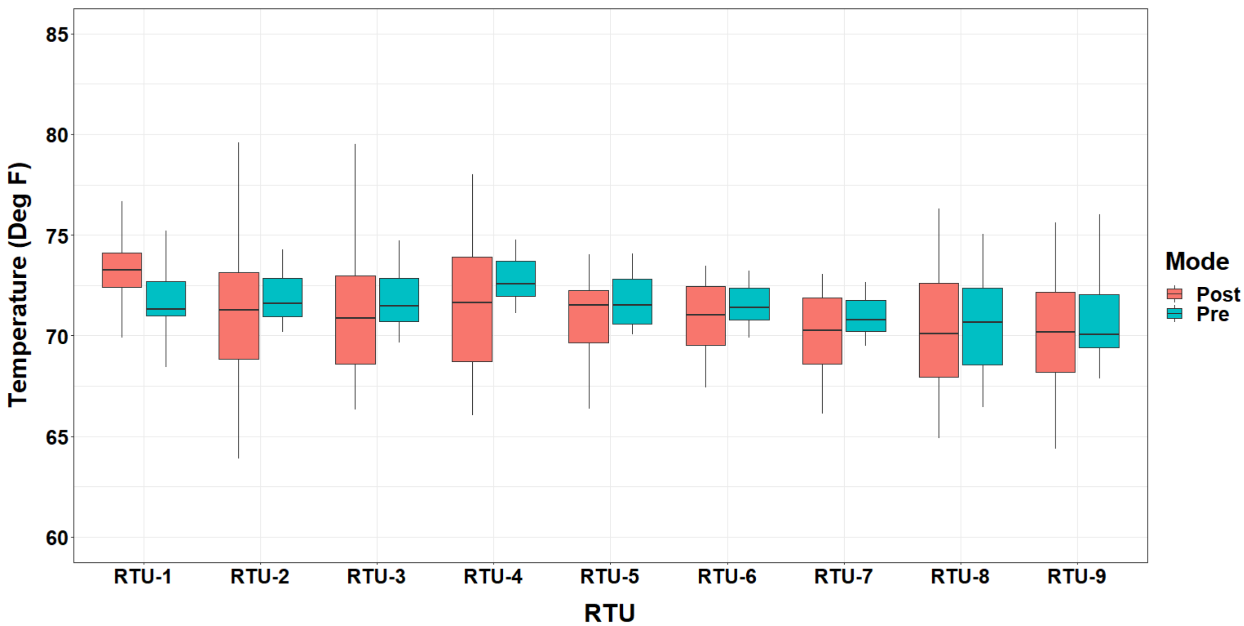
The amount of cooling varied across the RTUs and across the pre and post test periods. The main takeaway from the field RTUs equipped with advanced economizer packages is the reduction of compressor runtime after the economizer packages were installed.

Non-Energy Benefits and Space Conditions

In addition to energy savings, these technologies can provide non-energy benefits such as increased comfort, less noise, and building automation system integration for simple control. Space temperature and RH were monitored for sites 1, 3, 4, and 5 to compare space conditions during the pre and post test period. These conditions were assessed to verify that space conditions and comfort were not negatively affected by the RTU after the retrofit package was installed. Variable speed evaporator fans provide less air volume for all modes of operation, and an important factor in their operation is whether they can properly condition the space. Some of the packages researched employ sensors for supply air temperature (SAT), return air temperature (RAT), outside air temperature (OAT), and return air carbon dioxide to constantly monitor the system conditions and adjust the speed of the evaporator fan to maintain proper heating, cooling, or ventilation to the space. For RTUs retrofitted with economizer packages, free cooling opportunities use 100% outside air, which is usually higher than DX cooled air.

As illustrated in Figure 22, the space temperatures were not significantly impacted by the economizer retrofit packages.

Figure 22. Site 4 and site 5 pre and post space temperature



Cost-Effectiveness

Cost-effectiveness is a major factor for customers considering retrofitting an RTU. Generally, retrofits with payback periods over five years are not considered by building owners and decision makers. They prefer paybacks in the two to four year range. Payback periods for test sites were estimated by creating annual models and energy consumption and comparing use before and after retrofit. Results vary, but generally show that variable speed fan operation savings are significant and range from two to 10 years. The evaporator fan configuration is key to determine energy savings and payback period.

Figure 23. Payback period by technology

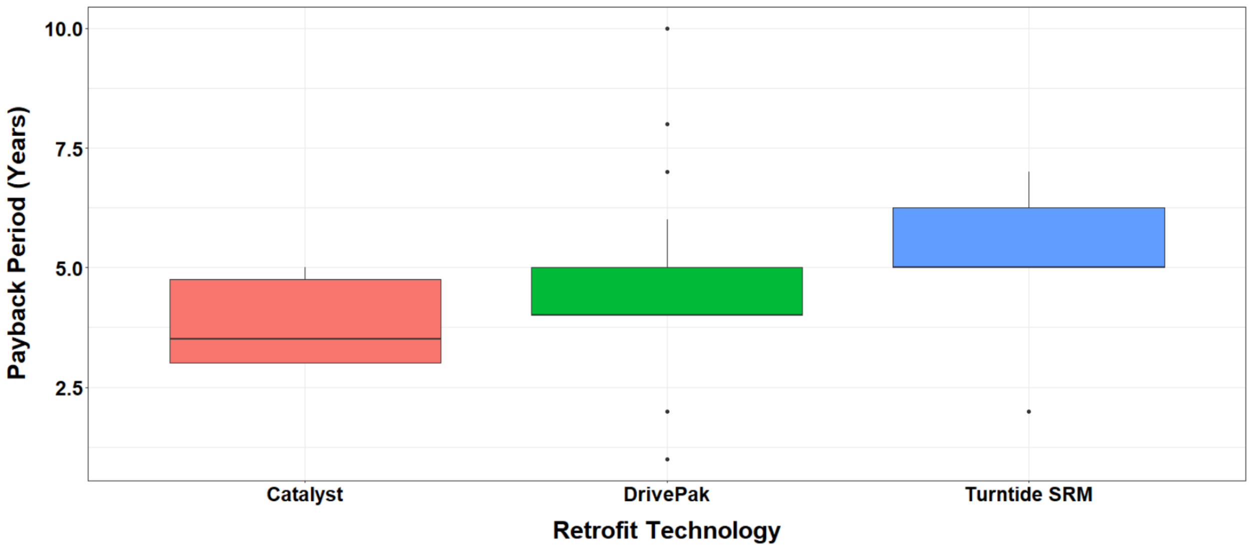


Table 12. Retrofit package cost per ton and typical cost for 10 ton RTU

Retrofit Package	Average Cost per Ton*	Typical cost for 10 Ton RTU**
Catalyst***	$222	$1,600
Turntide SRM	$244	$2,200
DrivePak*	$267	$1,900
Honeywell Jade	$334	$1,540
Belimo ZIP	$222	$1,480

*Average cost per Ton values is based on actual install cost information when available. DrivePak installation costs were not available, so generic VFD installation costs were used from the Minnesota TRM.
**Typical cost for a 10 ton RTU is based off cost information given by manufacturers at the beginning of the project.
***The cost for the Catalyst package is based on the Catalyst Lite pricing.

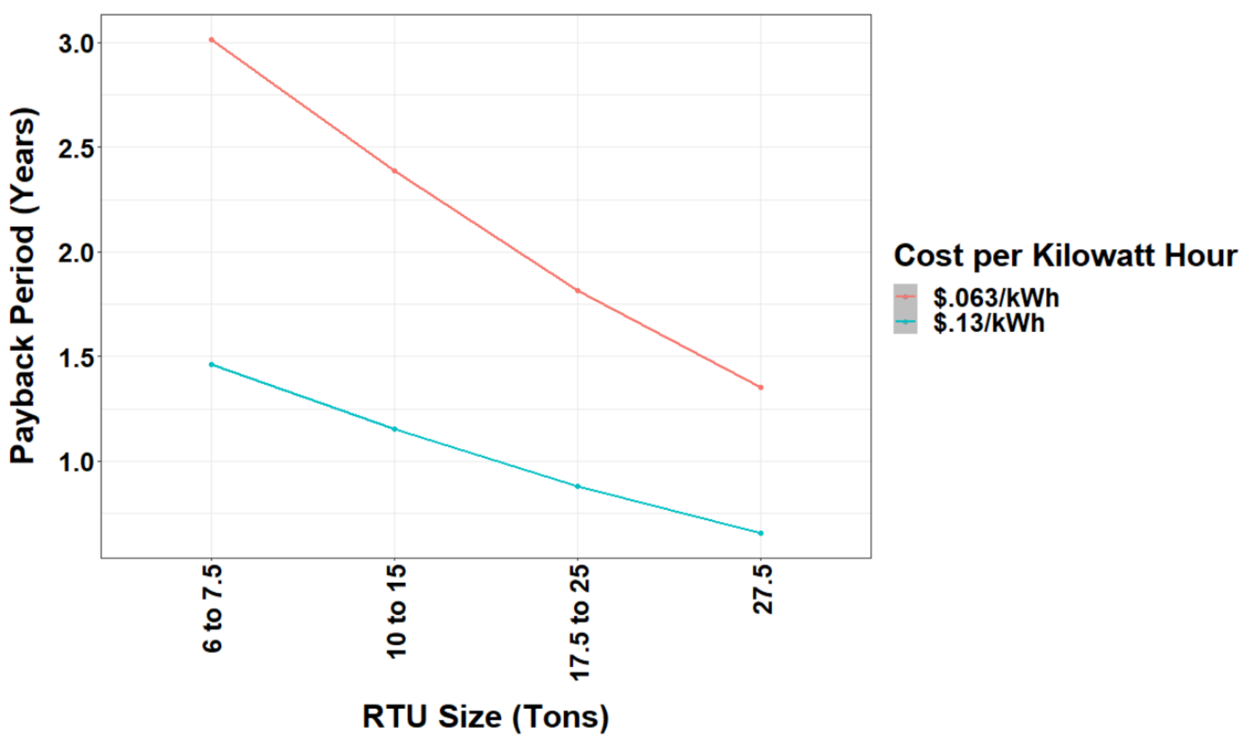
Because the RTUs field tested for this project are relatively small compared to the Minnesota market, the project team modeled savings and cost-effectiveness of RTUs sized from six to 27.5 tons to show the savings potential of larger RTUs. RTU information was determined for different Carrier Weathermaker RTUs to use as inputs in the energy savings calculator used for previous VFD savings. Savings and payback periods were calculated using the following assumptions.

- Reference city is Minneapolis
- Fan runtime of 60 hours per week (12 hours per weekday)
- 460-volt RTUs
- Heating balance point of 70°F
- RTU sizes of 6, 7.5, 10, 12.5, 15, 17.5, 20, 25, 27.5 tons

- Generic VFD pricing based on the Minnesota TRM (TRM, 2023)

Annual models were created for each RTU in baseline operation (no VFD) and operation with a VFD, then compared. Overall savings and payback periods vary based on size of the RTU, and show short payback periods, 0.5–1.5 years (assuming $.13/kWh) and 1.3–3 years (assuming $.063/kWh).

Figure 24. RTU payback period by tonnage



The payback periods in Figure 24 represent larger RTUs that have longer annual fan runtime than most RTUs field tested in this project. It shows that comparing larger RTUs with similar operations can lead to significantly more savings and shorter payback periods.

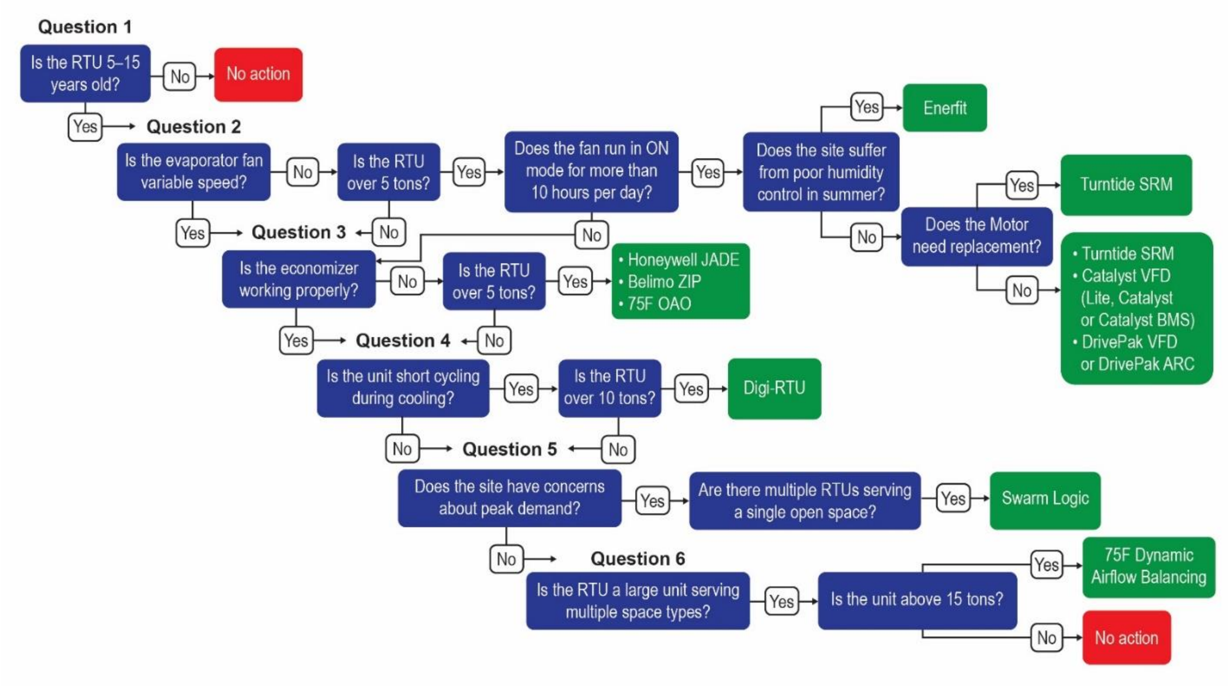
Decision Support Tools

Assessment of the overall market of retrofit options and results of the energy savings calculations were used to create decision support tools to help determine which options are most suitable for particular use cases in Minnesota. The tool is intended for building owners, contractors, CIP program administrators, and utility staff to summarize the findings from this study and inform decisions related to retrofitting packaged RTUs. Each tool is a condensed summary of the project (and can be found in appendix D), and comprises the following information:

- Recommendations for the most cost-effective, Minnesota-specific retrofit technologies for RTUs
- Decision tree to guide product choices for retrofit of an RTU

- Best practices for optimization packages
- Best markets and applications
- State of the current market
- Value proposition for installers to promote RTU efficiency upgrades including payback and additional non-energy upgrades

Figure 25. Decision tree for contractors when deciding to retrofit an RTU



Discussion of Results

Impact

Increasing the efficiency of RTUs shows tremendous potential due to the large penetration of low efficiency RTUs in the commercial, institutional, and industrial HVAC market. The total number of Minnesota RTUs was estimated using data collected from the 2017 RTU characterization project with growth extrapolated to 2023, for a total of 153,800 RTUs in Minnesota. The Minnesota TRM estimates that the useful life of an RTU is 20 years.

Variable speed evaporator fans offer the most potential energy savings on Minnesota RTUs. Overall, annual energy savings for every RTU that can benefit from the retrofits listed below are estimated to be 187 GWh and 3.7 million therms. The estimated savings were determined by refining the initial projected savings for RTU retrofits using data collected throughout the project, resulting in comparable savings. The following assumptions were used to calculate the Minnesota statewide energy savings.

- RTU retrofits to be installed on all Minnesota RTUs aged between 5 and 15 years old
- 60 hours of weekly evaporator fan runtime
- Each RTU will receive only one retrofit package (excluding AFDD and upgrades thermostats, as they are a common advanced feature with retrofit packages). While it is possible to combine retrofit technologies (e.g., a VFD and economizer), it is unlikely that building owners would purchase more than one.
- Electricity and gas savings were extrapolated from the results of the field-tested technologies for this project or estimated if they were not tested.
- Retrofit technologies:
    - Variable speed evaporator fan (VFD or SRM)
    - Variable capacity compressor and evaporator fan
    - Advanced economizer controls
    - Zone Controls
    - Upgraded thermostats
    - AFDD

CIP Implications

Current RTU Standards

Manufacturers of RTUs are now offering energy-saving options as a standard feature of RTUs installed in Minnesota. The 2020 Minnesota energy code (ICC, 2020) has implemented several regulations that affect retrofit technologies studied as part of this project, including variable speed evaporator fans. As per the code (which cites the 2016 ASHRAE 90.1 (ASHRAE, 2022)), direct expansion cooling systems must have at least two stages of evaporator fan control, with the low or minimum speed not exceeding 66%, and not consuming more than 40% of the fan power at maximum speed. Furthermore, air side economizer packages must have FDD to notify mechanical contractors and facility managers of sensor or damper failures, which are common in RTU economizers.

The Minnesota energy standard impacts newly installed RTUs, and RTUs installed in the last 2-3 years. In addition, high-efficiency equipment commonly comes equipped with variable speed or staged evaporator fans (more common on larger units) and upgrades such as more robust economizer controls, low-leakage dampers, etc. are becoming increasingly more prevalent. The potential for energy saving from the retrofit packages studied in this project is limited for new RTUs installed under the newer energy standards. However, there is significant potential for upgrades in RTUs installed prior to 2020. Assuming a 20-year lifetime, roughly 85% of RTUs operating in Minnesota pre-date the new energy standards.

Savings Variability

This project confirmed energy savings potential of multiple packages that vary the speed of an RTU evaporator fan (Catalyst, DrivePak, and Turntide SRM). Savings potential of these packages is highly variable, and depends on RTU evaporator fan operating mode (the most common options are continuously on and automatically controlled to only operate during active conditioning), building heating and cooling load, thermostat setpoint, building and specific space type, RTU size, maintenance and installation practices, and Minnesota climate (e.g., Minneapolis versus Duluth). While all of these are factors, the team found that varying the fan of the evaporator can provide significant savings for most RTUs, even when installation conditions are far from ideal.

The field testing of the advanced economizer packages conducted by this project did not meet the expected savings due to the limited cooling operation of the tested RTUs, which were smaller in size (5-7.5 tons). Although overall savings were limited, all the RTUs demonstrated a reduction in compressor runtime during the outside conditions measured in the monitoring period (45°F to 70°F) when outdoor conditions allowed for economizer operation. Advanced economizer packages may yield more significant energy savings for larger RTUs that serve spaces with high internal heat gains, such as those with high sun exposure or in restaurants, industrial, or manufacturing building types.

Stakeholder Outreach

Education and guidance of industry stakeholders is the main avenue for future RTU retrofit implementation found through this project. Mechanical contractors, manufacturers, and distributors are the key players in the market, with contractors having the largest pull with customers. Contractors service RTUs and provide recommendations to customers. While most of the interviewed contractors mentioned that they have a utility representative, they meet infrequently or only when they are applying for rebates. Consistent outreach and guidance throughout Minnesota offer tremendous potential for market saturation of RTU retrofit technologies.

Building owners often remain unaware of the efficiency upgrades available for RTUs unless their servicing contractor recommends them. To sell their products, many manufacturers have begun reaching out to customers directly and collaborating with contractors to represent their products.

Minnesota utilities can adopt this approach by proactively communicating with customers to consider RTU replacement before the end of its life or retrofit enhancements as recommended by this project. Although replacing RTUs only after their failure has been the standard approach, educating and guiding customers before their systems have outlived their usefulness can unlock significant savings potential.

Incentive Type

The most common barrier cited from interviews done with industry professionals was that custom rebates are more complicated and time consuming when compared to prescriptive rebates. Like all HVAC efficiency upgrades, retrofit implementation relies on incentives to offset the high initial cost. Manufacturers and contractors focus on building types, RTU types, and areas of the country with the highest and most straightforward available incentives. Currently, Minnesota utility programs employ a variety of incentive types for RTU upgrades, including both prescriptive and custom rebates. Introducing more prescriptive rebates and streamlining the custom rebate process could greatly facilitate the adoption of these technologies in Minnesota.

Midstream incentives are implemented by utilities through distributors to provide incentives for energy saving measures, and the impacts are typically passed to the contractor or customer. National programs have succeeded with this method and shifted the focus of their RTU programs to where they have seen limited success in downstream programs (providing incentives directly to customers). This method allows for more efficient equipment to be readily available for contractors and customers, which would incorporate many of the retrofit technologies studied as part of this project.

National Programs

The RTU retrofit program implemented by Bonneville Power Administration (BPA) was found to be the most effective among the programs analyzed in this study. Their Rooftop Unit Control (advanced rooftop controls (ARC)) and ARC Lite program has specific retrofit packages that are incentivized. The program utilizes a tiered approach and a value per ton, which offers higher incentives for larger units that install equipment with more energy saving features. For example, a 10 ton RTU retrofitted with a Catalyst Lite VFD or DrivePak (simple VFD) would receive a $1,000 incentive, while the same RTU retrofitted with the Catalyst with eiQ (VFD, BAS, DCV, advanced economizer control) would receive $2,000 at the time of retrofit.

This program provides a clear framework for Minnesota utilities to adopt for incentivizing RTU retrofits. There are two ways that this program promotes retrofit technologies. First, listing specific retrofit packages helps educate contractors and building owners on available options. Secondly, the tiered approach provides information on the multiple options available for specific retrofit packages.

Figure 26. BPA tiered RTU retrofit program (Administration, 2019)

Full ARC Retrofit

Manufacturer	Model	Product Website
Bes-Tech	Digi-RTU	http://www.bes-tech.net/digi-rtu/
Honeywell	LCBS with SmartVFD and LGW1000 Gateway	https://buildingcontrols.honeywell.com/Building-Automation-Systems/LCBS-Connect
Pelican	Pelican solution that includes:	http://www.pelicanwireless.com/
	• Pelican TS200 or TS250 Thermostat,	
	• Pelican zone controller Z8 or Z24, or PEARL Economizer,	
	• Pelican Extended Range Wireless Gateway, and	
Transformative Wave	CATALYST with eIQ	http://transformativewave.com/
Unity Energy Solutions	Unity solution that includes:	http://www.unityenergysolutionsgroup.com/unity/
	• USC Site Controller,	
	• SMT400 Thermostat or M-172 PLC Controller, and	
	•Site Support Package Subscription	

ARC-Lite Retrofit

Manufacturer	Model	Product Website
Bes-Tech	Digi-RTU	http://www.bes-tech.net/digi-rtu/
Honeywell	LCBS with SmartVFD	https://buildingcontrols.honeywell.com/Building-Automation-Systems/LCBS-Connect
Lennox	ARC -with DCV	http://www.lennoxcommercial.com/products/
NexRev	DrivePak	http://www.nexrev.com/products/drivepak/
Pelican	Pelican solution that includes:	http://www.pelicanwireless.com/
	• Pelican TS200 or TS250 Thermostat,	
	• Pelican PEARL Economizer,	
	• Pelican Extended Range Wireless Gateway, and	
Trane	ARC -with DCV	http://www.trane.com/
Transformative Wave	CATALYST Lite	http://transformativewave.com/
Unity Energy Solutions	Unity solution that includes:	http://www.unityenergysolutionsgroup.com/unity/
	• USC Site Controller and	
	• SMT400 Thermostat or M-172 PLC Controller	

Minnesota Technical Reference Manual (TRM)

There are multiple existing TRM measures related to packaged rooftop unit (RTU) retrofit. These include variable speed drives (VSDs), economizer addition, demand control ventilation (DCV), and high-efficiency motors. Calculations to determine savings for VSDs (VFDs and SRMs as part of this project), are based off an estimated duty cycle table, which uses estimated fan speeds and equipment runtime. To predict savings more accurately, actual evaporator fan percentages as found from field measurements through this project can be used in the calculations. In addition, providing guidance for accurately calculating runtime hours in each mode of RTU operation (heating, cooling, and fan only), as well as the fan speeds, will help determine estimated energy savings potential. Estimating energy savings for economizer packages is difficult, as runtime for RTUs on a building can vary significantly. When determining equivalent full load hours of cooling (EFLH) space type, other metrics such as balance point or an idea of runtime compared to other units can be used to adjust EFLH to estimate savings more accurately.

Conclusions and Recommendations

This project has identified energy saving enhancements for packaged RTUs for their ability to provide significant energy savings, reasonable payback periods (depending on the application), and non-energy benefits to Minnesota buildings. Manufacturers have continued to innovate the offerings and features of their retrofit packages. New innovations have increased add-on features for energy savings and manufacturers now offer more cost-effective options. In addition, new products have become available on the market. Table 13 depicts a tiered approach to differentiate the various retrofit options found through a market assessment.

Table 13. RTU retrofit summary

Retrofit	Manufacturer	Technology	Additional Features	Ideal application for maximum savings	Cost	Claimed electric savings %	Claimed payback period	Non energy benefits
Tier I								
Catalyst Lite	Prostar Energy Solutions	VFD-evaporator fan	Evaporator fan control	Large evaporator fan motor, fan ON	$	25-50	1-2 years	Increased comfort, less noise
DrivePak	NexRev	VFD-evaporator fan	Evaporator fan control	Large evaporator fan motor, fan ON	$	25-50	1-2 years	Increased comfort, less noise
JADE economizer	Honeywell	Advanced economizer control	DCV, FDD	Nonfunctioning economizer	$	30	Varies	Ventilation control, increased comfort
ZIP economizer	Belimo	Advanced economizer control	DCV, FDD	Nonfunctioning economizer	$	40	Varies	Ventilation control, increased comfort
Switched reluctance motor (SRM)	Turntide	Switched reluctance evaporator fan motor	Smart motor	Large motor, motor replacement, fan ON	$	60-70	1-4 years	Increased comfort, less noise
Tier II								
Catalyst	Prostar Energy Solutions	VFD-evaporator fan	Advanced economizer controls	Large evaporator fan motor, fan ON	$$	25-50	2 years	Increased comfort, less noise
Outdoor Air Optimization (OAO)	75F	Advanced economizer control	Cloud enabled system, DCV, FDD	Non functioning economizer	$$	30	Varies	Ventilation control, increased confort, cloud capabilities
Enerfit	Enerfit	VFD-evaporator fan	Space RH reduction, reduced compressor energy, optional	Large evaporator fan motor, fan ON	$$$	15-33	2-3 years	Increased comfort, less noise, better RH control

			economizer control					
Tier III								
Catalyst with EIQ	Prostar Energy Solutions	VFD-evaporator fan	BAS, scheduling and fault detection, advanced economizer control	Large evaporator fan motor, customer can benefit from BMS, fan ON	$$$$	25-50	2 years	BAS control, Increased comfort, less noise
DrivePak ARC	NexRev	VFD-evaporator fan	DCV, advanced economizer control	Large evaporator fan motor, fan ON	$$$$	25-50	1-2 years	Increased comfort, less noise, ventilation control
Dynamic Airflow Balancing	75F	Single RTU zoning	BAS, FDD, advanced economizer control	Large RTU serving multiple space types	$$$$	25-40	2-5 years	Advanced comfort control, BAS control
Digi-RTU	Bes-Tech	Compressor and evaporator fan VFD	DCV, FDD, BAS, advanced economizer control	Large RTU (>10 tons)	$$$$	60	2-4 years	Increased comfort, less noise, reduced compressor wear

RTU operation is highly variable, as evidenced by field measurements from this project and past research. This variability complicates field monitoring, modeling estimated energy savings, and predicting how a specific technology will perform when retrofitted on an existing RTU. Energy savings vary significantly for these systems and are ultimately driven by space type, RTU size, controls configuration, internal loads that impact heating and cooling runtime, and RTU interactions with one another (i.e., one RTU dominating the conditioning while the other rarely runs).

Thirty-four of the 43 RTUs tested as part of this project were equipped with energy savings technologies to vary the speed of the evaporator fan motor with a VFD or SRM (Catalyst, Turntide, and DrivePak). The RTUs achieved electricity savings of 18% to 75%, averaging 36% or 3,437 kWh per year. Payback periods ranged from one to ten years (assuming $.13/kWh) and 2 to 21 years (assuming $.063/kWh), without incorporating any incentives. Rebates for these projects would significantly reduce the payback period and make the installations far more cost-effective.

Nine of the 43 RTUs tested were equipped with advanced economizer packages. These were installed on RTUs that had nonfunctioning economizers, the most common scenario for an advanced economizer retrofit. Overall, the RTUs did not achieve significant electricity savings, which can be attributed to their small size and limited cooling runtime. Electricity savings ranged from -11% to 9%, with an average annual electricity savings of 59 kWh per RTU.

Larger RTUs that serve buildings in a colder region of Minnesota (such as Duluth) offer more electricity savings potential through advanced economizer optimization. In addition to energy savings, functioning economizers are crucial to provide the proper amount of fresh outside air to the space for ventilation, improving occupant comfort. These packages can also provide additional savings when an actuator has failed and the outside air damper gets stuck in an open position, and the RTU must over condition air that is either colder or hotter than the return air coming from the space. Advanced economizer packages offer more sensors and reliable control that can be easily adjusted by a facility manager or maintenance technician.

While five different retrofit packages were field tested and their energy savings potential were estimated as part of this project, the technology assessment uncovered other methods for achieving energy savings by retrofitting an RTU. Two of note are dynamic zone balancing, a way to introduce zones to an existing larger RTU that conditions multiple space types, and RTU coordinating controls, which sync multiple RTUs serving a single large space (e.g., a large open retail building). DCV and AFDD are energy savings measures available for RTU retrofit, but are generally add-on features of the packages studied and often not the primary technology installed. Advanced thermostats options were found as potential retrofit options, but not field tested. These offer various energy savings options, more control, and potential integration with other retrofit options.

Mechanical contractors and manufacturers are the most influential industry professionals in the RTU retrofit market. Decision makers rely on contractors' expertise to provide recommendations on HVAC equipment, and the conclusion of the project is that while contractors are familiar with the technologies (VFDs, economizers, etc.), many are unaware of the various options outlined by this project. Only one of the interviewed contractors actively represents and installs a VFD option — most were familiar with economizer options as this is a common failure for RTUs. Manufacturers of retrofit technologies have had success reaching out directly to customers, focusing on owner-occupied buildings, quick-serve restaurants, and retail chains. These offer the most potential, as they tend to have similar RTU configurations across many buildings.

Future Work

RTUs present significant research opportunities due to their various configurations and sizes, as well as their abundance in the Minnesota commercial market. This project researched multiple types of retrofit packages, which are continuing to evolve and offer various options and features for increasing efficiency. Future research could focus on packages that offer energy savings potential in cold climates and were not field tested as part of this project. The packages studied as part of this project produced electricity savings, thus technologies that focus on gas savings would be beneficial. Technologies of interest for future research include dynamic zone balancing on large RTUs that serve multiple space types and multi-unit RTU coordination of multiple RTUs serving a large open space.

CIP Recommendations

- The custom rebate process was overwhelmingly cited as the main barrier behind high-efficiency RTUs and retrofit technology implementation. Contractors do not want to take on the additional hassle of a tedious and time-consuming custom rebate application and will avoid this process when possible. For RTU retrofits, a custom rebate may be required depending on the application. In these situations, making the process as simple and quick as possible should be a priority.

- Industry stakeholder outreach is crucial for market adoption of RTU retrofit technologies. Study findings indicate that building owners and mechanical contractors, key influencers in this market, were not familiar with available options. To effectively promote these systems, it is critical that these industry contacts have a strong relationship with program implementers, so they are fully informed of the available energy upgrades.
- Midstream incentives were offered by most of the utilities outside Minnesota that were interviewed and has proven effective for implementation. Providing incentives at the distributor level is an effective way to bypass barriers seen with downstream incentives with contractors and customers.
- The Bonneville Power administration has successfully managed a program that uses a tiered approach (ARC and ARC lite) to incentivize customers on a per-ton basis, effectively promoting the adoption of RTU retrofit technologies. This program serves as a successful model for Minnesota utilities to implement a similar approach.

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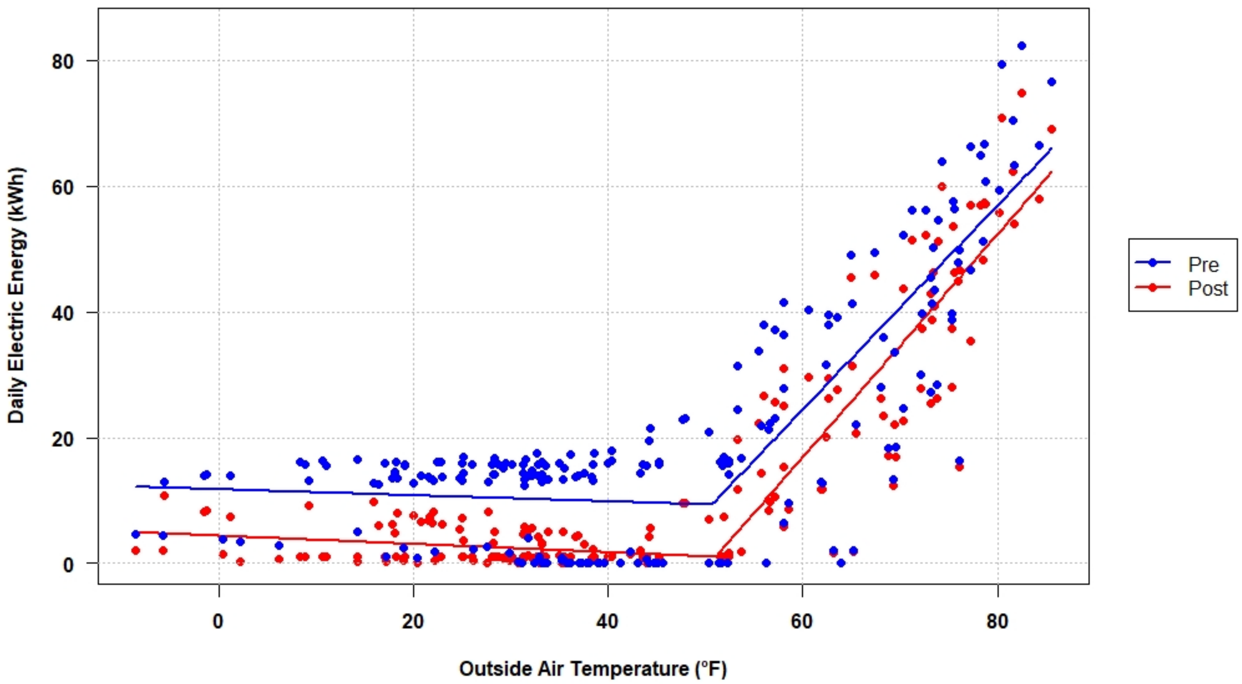
Appendix A: Approach for Weather Normalizing of Data

TMY3 normalizing approach

Normalizing energy use data is necessary to characterize HVAC system performance during a typical meteorological year. This accounts for atypical weather during a field monitoring project and allows for more accurate energy use forecasting. Data collected during the field assessment of this project was collected for the test period, summed to determine daily electricity use, and normalized using the TMY3 data set for Minneapolis. The analysis approach for data normalization for this project is as follows.

1. Convert RTU power value from kW to kWh and sum for total daily electricity consumption for pre and post monitoring periods.
2. Using NOAA weather data, compute daily average dry bulb temperature for each day in the monitoring period.
3. Plot electricity consumption versus outside air temperature (OAT) to create regressions of the test data. For data captured during both heating and cooling operation, a changepoint model is required to characterize data during each mode of operation.
4. Determine the balance point where the RTU switches from heating to cooling. For heating or cooling only analysis, this is the temperature at which the regression line meets the x-axis. For changepoint analysis, regression lines do not cross the x-axis, so the balance point is the point at which regression lines with different slopes meet.
5. Determine the TMY3 data below (heating) or above (cooling) the balance point. Count the number of days of this data set.
6. Determine the mean temperature of the TMY3 data found in step 5.
7. Use the regression equations found in step 3 and the mean temperature in step 6 to calculate the average daily energy use at the mean TMY3 temperature for both the pre and post test monitoring periods.
8. Multiply the values in step 7 by the number of days found in step 5 to determine annual energy use. This needs to be done twice for changepoint models, before and after the balance point.

Figure 27. Changepoint regression pre and post for site7, RTU-1



Appendix B: Survey Instruments

Base questions (All groups - Excluding contractors)

Questions in blue should be completed prior to interview

1. Interview Date
2. Interviewee(s) Name
3. Interviewee(s) Company
4. Interviewee(s) Title
5. Interviewee(s) Email Address
6. Interviewee(s) Phone Number
7. Have you participated in or implemented any efficiency focused projects that you have found effective? If so, what are the specifics?
8. In what capacity do you work with packaged rooftop units (RTUs)?
9. How many buildings and/or RTUs do you deal with annually?
10. What is the general age and size range of the RTUs that you work with?
11. Are you familiar with retrofit technologies for RTUs? (VFDs, economizer controls, DCV, etc.)
12. What are your general thoughts behind retrofitting an existing rooftop unit?
13. In your opinion, what are the biggest opportunities for RTU retrofits?
14. What do you see as the main barriers behind implementing RTU retrofits?
15. Of these barriers, what do you think is the best way to overcome them?
16. What support have utilities and incentive programs provided that has been helpful?
17. What support do you desire that utility programs are not currently providing?
18. Are there any new technologies for energy savings specific to RTUs that you are interested in learning more about, or are currently investigating?
19. What have you found to be effective channels for educating decision-makers about RTU retrofit options? What about efficient ongoing operations?
20. Who do you work with in MN that would be good for us to talk to?
21. Are there any RTU retrofits that you are aware of that we could take a closer look at to better understand the technology?
22. Are you aware of any buildings that have RTUs that would be willing to participate in a short electronic survey?

Contractor questions

Questions in blue should be completed prior to interview if possible

1. Interview Date
2. Interviewee(s) Name
3. Interviewee(s) Company
4. Interviewee(s) Title
5. Interviewee(s) Email Address
6. Interviewee(s) Phone Number
7. What technologies related to energy efficiency upgrades do you offer?
8. At what age do you typically recommend replacing an RTU?

9. When an RTU needs replacement, how much weight would you say your recommendation has with the customer?
10. Are higher efficiency options typically recommended?
11. Which distributor(s) do you work with?
12. Do you install a specific manufacturer or system for packaged RTUs?
13. What are your reasons for choosing the manufacturer(s) or systems?
14. Does the manufacturer(s) you chose offer something specific that made you choose them?
15. Do you currently offer or recommend any retrofit technologies for existing packaged RTUs?
16. If so, how often do you recommend them to customers?
17. Is there a specific RTU size, age, or space type that you are more willing to recommend a retrofit technology versus replacement of the RTU?
18. How often do you receive callbacks on retrofit technologies?
19. If so, what are they?
20. Are there any retrofit technologies that you no longer sell due to callbacks?
21. How often do you come across RTUs that have been retrofitted?
22. Are there situations where you would not consider retrofitting an RTU?
23. What concerns do you have with RTU retrofit technologies?
24. What do you see as the biggest opportunity for savings when it comes to RTU retrofits?
25. What size RTUs do you typically work with?
26. What do you see as the barriers behind retrofit technologies?
27. Have utility program representatives reached out to you about their programs?
28. Have there been times that a utility program caused a customer to ask for something that you would not have recommended? Was this a positive or negative experience?
29. What utility incentives are you aware of regarding RTU retrofits?
30. Do you feel like your utility provides sufficient incentives for retrofit technologies?
31. Regarding specific measures (technologies), how often do you install/service systems that include (please give an estimated percent):
    a. VFDs on evaporator fans or variable speed fan control
    b. Variable capacity systems (cooling)
    c. DCV
    d. Advanced economizer controls
        1. How often do you run into economizers that are not functioning properly?
        2. Do you ever perform functionality testing on economizers?
    e. Programmable thermostats
    f. Smart/Wi-Fi enabled thermostats
    g. BAS systems
    h. Condensing RTUs
    i. Heat pump RTUs
    j. Other technologies?

What proportion of various technologies do you see used in existing systems? New systems?

We would like to recruit buildings for both:

a. Field sites if you have buildings with known retrofits. This involves access to their roof and RTUs to take some field measurements which should not interfere with the RTU operation.
b. Buildings known to have RTUs to do a quick electronic survey to gain a better understanding of the adoption of RTU retrofit technologies.

Manufacturer questions

1. What products do you offer for RTU Retrofits?
2. What market/building type do you have the most success in?
3. What market/building type do you have the least success in?
4. What areas of the country do you have the most success in?
5. What areas of the country do you have the least success in?
6. Who installs your products? Do you work with specific contractors?
7. Once a system is installed, do you offer any warranty to the customer if something were to go wrong? If so, what is the warranty? Does is vary for type of retrofit?
8. What do you think is the biggest barrier when it comes to selling your products?
9. What have you done to try to overcome this?
10. What do you see as the biggest factor in getting RTU retrofit products more widely adopted?
11. Our next step is to take field measurements on existing installs. Ideally we will be able to do a pre/post measurement. Are you aware of MN installations that we could monitor for a short period of time?

Distributor questions

1. Is there a specific part of the state/country you work in?
2. Do you work with specific contractors in MN?
    1. Which ones?
3. Do you currently participate in any midstream incentive programs?
4. What percentage of new equipment you offer has the following built in to a packaged RTU:
    1. VFD on supply fan or compressor (or variable speed motor)
    2. DCV
    3. Smart or Wi-Fi enabled thermostats
    4. Condensing or high efficiency RTUs
    5. Heat pump RTUs
5. Can you give a rough percentage of the equipment you sell that is standard efficiency (or in your mind could potentially have a retrofit upgrade)?

Building owner questions

1. How many buildings do you own or manage?
2. Have you recently replaced any RTUs on buildings you manage?
3. What was the reason for replacement?
4. What do you consider when replacing an RTU?
5. Do you use the same contractor for all your buildings?
6. What is the name of the contractor(s)?
7. Do you do routine maintenance/checkups for the RTUs at your buildings? How often does this happen?

8. Have any mechanical contractors recommended RTU retrofit technologies to your RTUs? If so, what were the recommendations? Did you implement any of those technologies? Why or why not did you decide to install or not install?
9. Is there anything that would make it more likely for you to upgrade the efficiency of your existing RTUs or purchase higher efficiency RTUs when your current ones are at the end of their life? (e.g., help comparing options, financial incentives, etc.)

Interview groups

- Minnesota Utilities/Program Managers
- National Utilities/Program Managers

Interview questions

*Questions in blue font should be populated to the extent possible prior to conducting the interview, so most will not need to be asked during the interview.

1. Interview Date
2. Utility
3. Name of Program
4. Website URLs specific to program (including marketing landing/signup pages)
5. Interviewee(s) Name
6. Interviewee(s) Company (if different from utility)
7. Interviewee(s) Title
8. Interviewee(s) Email Address
9. Interviewee(s) Phone Number
10. First, could you briefly describe your program offerings that are geared towards new Rooftop Units (RTUs) and Rooftop Unit retrofit measures?
11. Is the program RTU specific or does it incorporate other HVAC technologies or non-HVAC end uses?
12. What measure types are included in the program?
13. Do your HVAC programs incorporate any of the following delivery models?
    1. Direct install
    2. RTU tune-ups
    3. Early retirement programs for roof-top units
    4. Mid-stream
14. If yes to any part of the previous question: Who delivers the measures and can you describe the process for how they work?
15. What is your process for deciding what measures to include in your program?
16. Are there any RTU measures you can recall that you decided not to offer through the program? Why?
17. Are there any retrofit or RTU efficiency measures that you are considering adding to the program in the future?
18. Are there measures that customers and/or trade allies have asked about that are not currently eligible for incentives through your program?
19. What measures do you get the most savings from through the program?
20. Do you have a third-party program administrator that implements the program? Which program administrator do you use?
21. What types/sizes of customers are eligible for your program?

22. How do you recruit participants?
23. What recruitment methods are most successful?
24. Would you be able to share any key marketing materials that you have found to be effective?
25. What types of businesses are the most common participants?
26. Is the program open to any contractor to participate or do you have a closed contractor network? If the program is open to any contractors to participate, do you have a list of contractors that you recommend?
27. How do you recruit contractors to participate in the program?
28. About how many contractors actively participate in the program?
29. Do you do any contractor training as part of this program? If so, what does that look like?
30. What kind of feedback do you receive from contractors and trade allies about their experiences with your program? Anything in particular that they like or dislike?
31. What are the processes to verify measure installation and determine savings?
32. What is the process for recipients to receive incentives for their participation in the program?
33. Who is responsible for completing the paperwork?
34. How long does it take to provide an incentive to a customer once the rebate application is submitted?
35. What kind of process do you have for program performance review? Does it include a formal program evaluation?
36. What kind of feedback do you receive from customers about their experiences with the program? Anything in particular that they like or dislike?
37. Overall, what do you see as the main barriers for you to get more traction in the RTU retrofit technology market (both with customers and contractors)?
38. Would you be ok with us reaching out to you with follow-up questions in the future?
39. *If the interviewee answers yes to the previous question:* For RTU installation and retrofit measures, would you be able to share measure level program participation data for 2020?

Appendix C: Field Sites

Site 1

Table 14. Site 1 RTU and building characteristics

RTU #	Manufacturer	Space Type	Tonnage	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Trane	Lunchroom	5	On	YHC060E4RMA0YD2A1C1B100A3	72	74
2	Trane	Office, interior	7.5	On	YHC092E4RMA0AD0A1C1B100A3	74	76
3	Trane	Office, exterior	5	On	YHC060E4RMA0YD2A1C1B100A3	72	74
4	Trane	Office, interior	7.5	On	YHC092E4RMA0AD0A1C1B100A3	74	76
5	Trane	Reception	5	On	YHC060E4RMA0YD2A1C1B100A3	74	76
6	Trane	Office, Interior	5	On	YHC060E4RMA0YD2A1C1B100A3	74	76

Site 1 is a 45,000 square foot office building conditioned by 6 RTUs. Site 1 includes office spaces, conference rooms, reception/lobby, and a warehouse. The RTUs that serve the building are 5 to 7.5 tons, and each has been retrofitted with a Catalyst retrofit package.

Figure 28. Site 1 aerial view of RTUs

Site 2

Table 15. Site 2 RTU and building characteristics

RTU #	Manufacturer	Space Type	Tonnage	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Carrier	Retail Store	10	Auto	48HCDD12B2M5A5A3C0	67	73
2	Carrier	Retail Store	10	Auto	48HCDD12B2M5A5A3C0	67	73

Site 2 is a 7,550 square foot retail building conditioned by 2 RTUs. Site 2 includes office spaces, retail area and a small warehouse. The RTUs that serve the building are both tons, and each has been retrofitted with a Turntide retrofit package.

Figure 29. Site 2 aerial view of RTUs

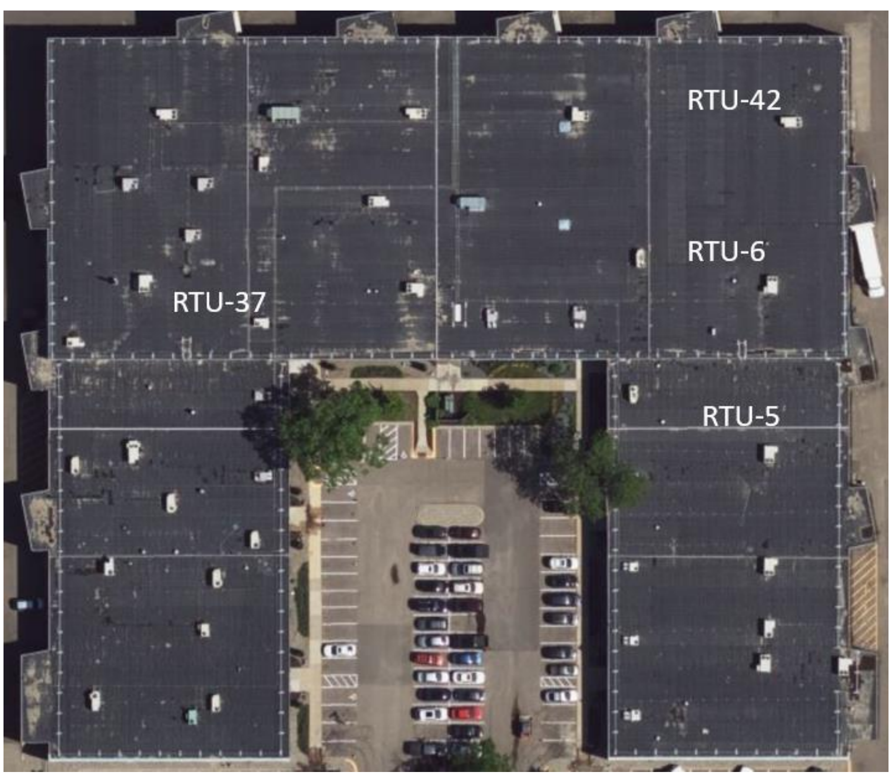
Site 3

Table 16. Site 3 RTU and building characteristics

RTU #	Manufacturer	Space Type	Tonnage	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Lennox	Cubicle area	10	On	LGA120SH1Y	72	80
2	Lennox	Break room, cubicle area, private office area	12.5	On	LGA150SH2Y	72	80
3	Lennox	Center cubicle area	5	On	LGC060S2BH1Y	72	75
4	Lennox	Warehouse	7.5	On	LGH092H4BH1Y	70	72

Site 3 is a 112,000 square foot office and warehouse building conditioned by 38 RTUs. We monitored 4 of the 38 RTUs and incorporated a mix of space types over the 4 monitored RTUs. Site 3 includes private office spaces, open office/cubicle areas, break rooms, and warehouse space. Of the RTUs we monitored, the size ranged from 5 to 12.5 tons, and each has been retrofitted with a Turntide retrofit package.

Figure 30. Site 3 aerial view of RTUs



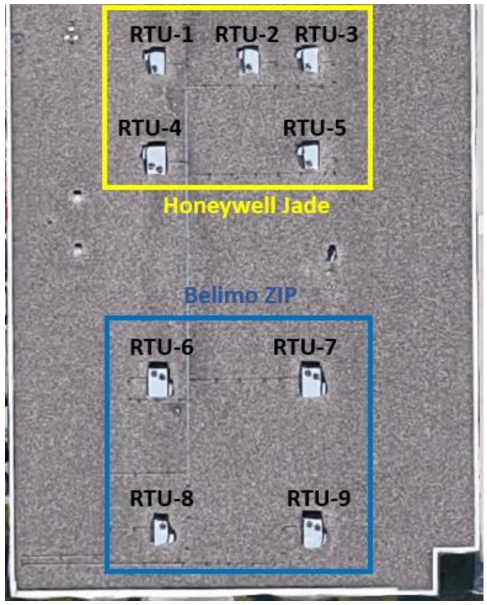
Site 4 and Site 5

Table 17. Site 4 and site 5 RTU and building characteristics

RTU #	Manufacturer	Space Type	Tonnage	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Carrier	Conference	4	On	48HJE005---651--	68	72
2	Carrier	Conference	4	On	48HJE005---661--	68	72
3	Carrier	Conference	4	On	48HJE005---651--	68	72
4	Carrier	Hallway, Break room	7.5	On	48TME008-A-601--	68	72
5	Carrier	Reception area	5	On	48HJE006---641--	68	72
6	Carrier	Open office/cubicles	7.5	On	48TME008-A-601--	68	72
7	Carrier	Open office/cubicles	7.5	On	48TME008-A-601--	68	72
8	Carrier	Open office/cubicles	7.5	On	48TME008-A-601--	68	72
9	Carrier	Exterior Private Offices	5	On	48HJE006---641--	68	72

Site 4 and 5 is a 21,801 square foot office building conditioned by 9 RTUs. This building has a wall which divides the two office areas in a way that they appear as two separate sites sharing a common wall. We monitored all 9 RTUs and split each side into two sites. Site 4 is 5 RTUs that we retrofitted with a Honeywell Jade Economizer and Site 5 is 4 RTUs retrofitted with Belimo ZIP Economizers. Site 4 includes three conference rooms, a break room, and the reception area. Site 5 includes Open office/cubicle space, and exterior private offices. For 9 total RTUs we monitored, the size ranged from 5 to 7.5 tons.

Figure 31. Site 4 and site 5 aerial view of RTUs



Site-6

Table 18. Site 6 RTU and building characteristics

RTU #	Manufacturer	Space Type	Tonnage	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Carrier	Restaurant	5	On	48TFE006---511--	68	72
2	Carrier	Kitchen	10	On	48TFE012---511--	68	72
3	Carrier	Restaurant	5	On	48HJE006---351--	68	72

Site 6 is a 4,500 square foot restaurant conditioned by 3 RTUs. Site 6 includes kitchen space and restaurant areas. The RTUs we monitored ranged from 5 to 10 tons, and the DrivePak retrofit package was modeled for RTUs at this site.

Figure 32. Site 6 aerial view of RTUs

Site-7

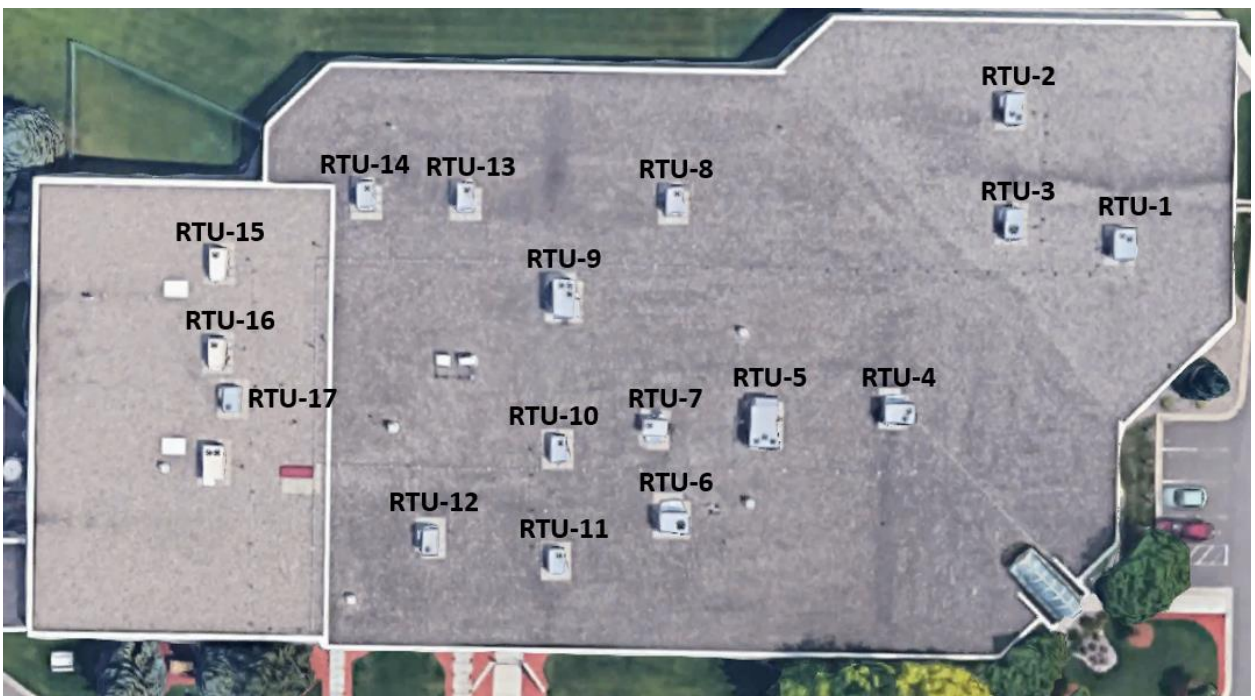
Table 19. Site 7 RTU and building characteristics

RTU #	Manufacturer	Space Type	Size in Tons	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Carrier	Office	6	On	48TFE007---611--	72	75
2	Carrier	Office	10	On	48TFE012---611--	72	75
3	Carrier	Office	6	On	48TFE007---611--	72	75
4	Trane	Office	N/A	On	N/A	72	75
5	Trane	Office	15	On	YC0180B4LGCA	72	75
6	Trane	Office	10	On	YC0120B4LGCA	72	75
7	Carrier	Office	3	On	48HCEA04A2A6A0A0A0	72	75
8	Trane	Office	N/A	On	N/A	72	75
9	Carrier	Office	15	On	48TCED16A2A6A0A0A0	72	75

10	Carrier	Office	5	On	48TFE006---611--	72	75
11	Carrier	Office	5	On	48TFE006---611--	72	75
12	Trane	Office	N/A	On	N/A	72	75
13	Carrier	Office	3	On	48HCEA04A2A6A0A0A0	72	75
14	Trane	Office	N/A	On	N/A	72	75
15	Lennox	Office	5	On	LGH060H4EH1G	72	75
16	Lennox	Office	6	On	LGH072H4BH1G	72	75
17	Carrier	Office	4	On	48TFE005---611--	72	75

Site 7 is a 48,200 square foot office building conditioned by 18 RTUs and monitored 17 of them. Site 7 is primarily office space. The RTUs that serve the building are 3 to 15 tons, and the DrivePak retrofit package was modeled for RTUs at this site.

Figure 33. Site 7 aerial view of RTUs



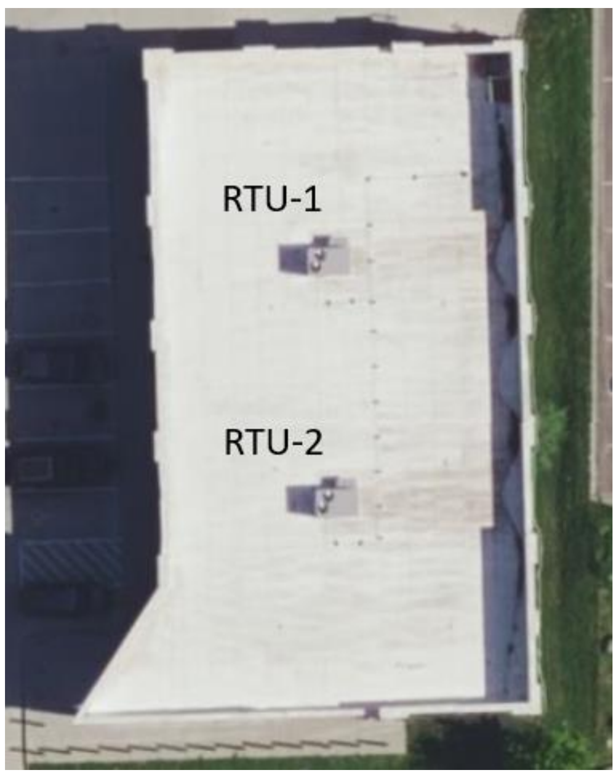
Site-8

Table 20. Site 8 RTU and building characteristics

RTU #	Manufacturer	Space Type	Tonnage	Fan Setting When Occupied	Model #	Heat Setpoint	Cool Setpoint
1	Carrier	Retail Store	7.5	Auto	48HCDD08B2M5A5A3C0	67	73
2	Carrier	Retail Store	7.5	Auto	48HCDD08B2M5A5A3C0	67	73

Site 8 is a 7,550 square foot retail store conditioned by 2 RTUs. Site 8 is primarily retail space with small office and warehouse space. The RTUs are 7.5 tons, and each has been retrofitted with a Turntide retrofit package.

Figure 34. Site 8 aerial view of RTUs

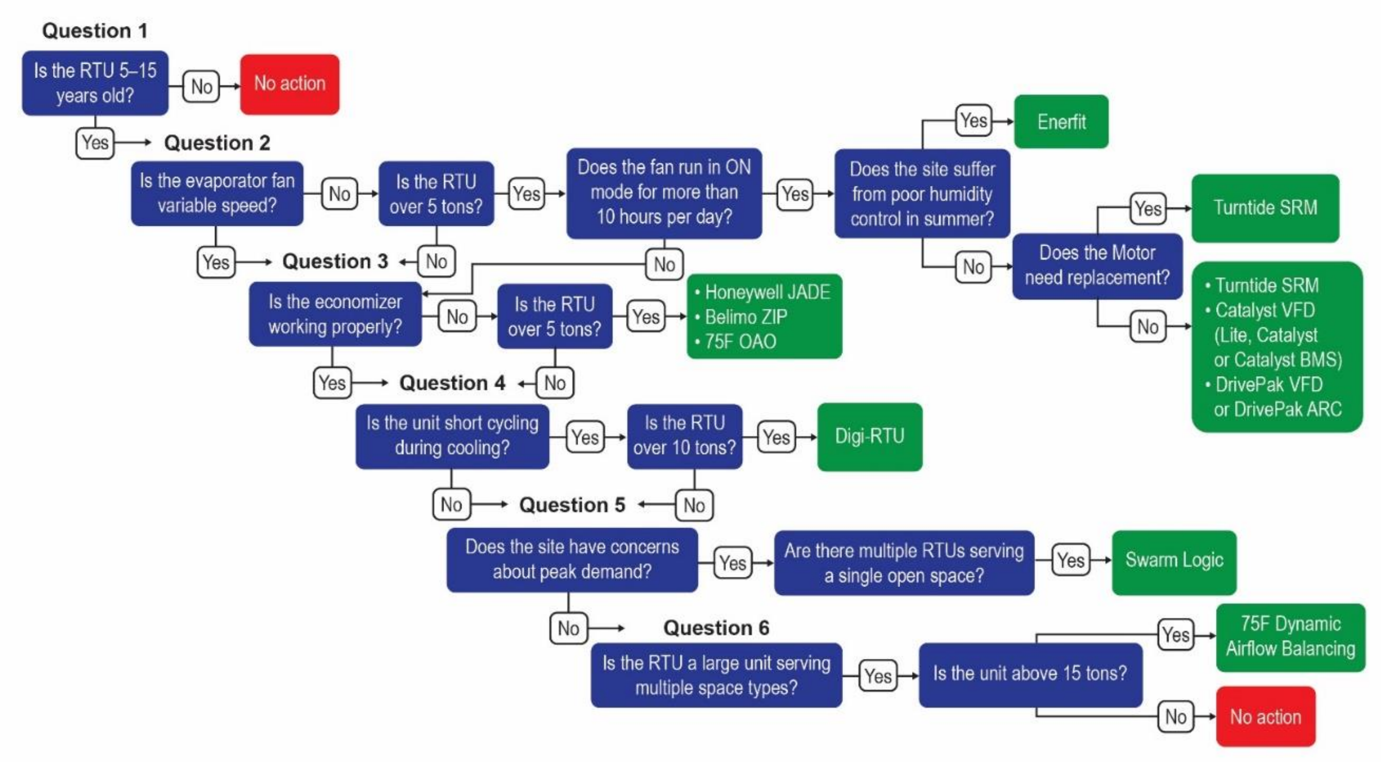


Appendix D: Decision Support Tools

HVAC Contractor RTU Retrofit Decision Support Tool

This comprehensive guide is meant for HVAC contractors and offers results and recommendations from a Minnesota state-funded research study, which was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program. The study aimed to assess the market barriers for packaged RTU retrofit technologies and suggest ways to overcome them. Multiple technologies were assessed, characterized, and field tested as part of this study. Stakeholders such as mechanical contractors, distributors, manufacturers, and utility representatives were interviewed for their assessments of barriers that exist in the market. The results from these tasks have been compiled to provide guided recommendations based on this research.

Figure 35. Contractor decision support tool



Variable frequency drives (VFDs), switched reluctance motors, and advanced economizer controls are the most frequently installed retrofits for RTUs and the technologies field tested as part of this project. Overall, field measurements and calculated annual energy savings met the manufacturer claimed savings with the exception of the economizer retrofits. Savings vary significantly across all technologies and depend on RTU size, motor size, the space type they serve, evaporator fan configuration (on versus

AUTO), system runtime (heating, cooling, and evaporator fan), heating and cooling balance point, and customer needs and comforts.

The following decision tree guides the assessment of an RTU for possible retrofits. The tree poses a series of questions that focus on existing characteristics about the RTU and the space it serves. Recommended packages are based on the ideal application, energy savings, and cost.

Table 21. Tiered RTU retrofit packages

Retrofit	Manufacturer	Technology	Additional Features	Ideal application for maximum savings	Cost	Claimed electric savings %	Claimed payback period	Non energy benefits
Tier I								
Catalyst Lite	Prostar Energy Solutions	VFD-evaporator fan	Evaporator fan control	Large evaporator fan motor, fan ON	$	25-50	1-2 years	Increased comfort, less noise
DrivePak	NexRev	VFD-evaporator fan	Evaporator fan control	Large evaporator fan motor, fan ON	$	25-50	1-2 years	Increased comfort, less noise
JADE economizer	Honeywell	Advanced economizer control	DCV, FDD	Nonfunctioning economizer	$	30	Varies	Ventilation control, increased comfort
ZIP economizer	Belimo	Advanced economizer control	DCV, FDD	Nonfunctioning economizer	$	40	Varies	Ventilation control, increased comfort
Switched reluctance motor (SRM)	Turntide	Switched reluctance evaporator fan motor	Smart motor	Large motor, motor replacement, fan ON	$	60-70	1-4 years	Increased comfort, less noise
Tier II								
Catalyst	Prostar Energy Solutions	VFD-evaporator fan	Advanced economizer controls	Large evaporator fan motor, fan ON	$$	25-50	2 years	Increased comfort, less noise
Outdoor Air Optimization (OAO)	75F	Advanced economizer control	Cloud enabled system, DCV, FDD	Nonfunctioning economizer	$$	30	Varies	Ventilation control, increased confort, cloud capabilities
Enerfit	Enerfit	VFD-evaporator fan	Space RH reduction, reduced compressor energy, optional economizer control	Large evaporator fan motor, fan ON	$$$	15-33	2-3 years	Increased comfort, less noise, better RH control
Tier III								
Catalyst with EIQ	Prostar Energy Solutions	VFD-evaporator fan	BAS, scheduling and fault detection, advanced economizer control	Large evaporator fan motor, customer can benefit from BMS, fan ON	$$$$	25-50	2 years	BAS control, Increased comfort, less noise
DrivePak ARC	NexRev	VFD-evaporator fan	DCV, advanced economizer control	Large evaporator fan motor, fan ON	$$$$	25-50	1-2 years	Increased comfort, less noise, ventilation control

Dynamic Airflow Balancing	75F	Single RTU zoning	BAS, FDD, advanced economizer control	Large RTU serving multiple space types	$$$$	25-40	2-5 years	Advanced comfort control, BAS control
Digi-RTU	Bes-Tech	Compressor and evaporator fan VFD	DCV, FDD, BAS, advanced economizer control	Large RTU (>10 tons)	$$$$	60	2-4 years	Increased comfort, less noise, reduced compressor wear

Utility and Program Administrator Decision Support Tool

This support tool is meant for utility and program administrators and offers results and recommendations from a Minnesota state-funded research study, which was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program. The study aimed to assess the market barriers for packaged RTU retrofit technologies and suggest ways to overcome them. Multiple technologies were assessed, characterized, and field tested as part of this study. Stakeholders such as mechanical contractors, distributors, manufacturers, and utility representatives were interviewed for their feedback regarding barriers that exist in the market. The results from these tasks have been compiled to provide guided recommendations.

Variable frequency drives (VFDs), switched reluctance motors, and advanced economizer controls are the most commonly installed retrofits for packaged RTUs and the technologies field tested as part of this project. Field studies were conducted on RTUs retrofit with five different packages with short-term pre-/post-monitoring periods. Energy consumption, space conditions, and overall performance of each RTU were tested and data were analyzed to provide annual estimated energy use and savings. Overall, energy savings generally matched claimed manufacturer savings. The economizer packages were the exception, with all RTUs showing less savings than expected. The most important takeaway from the field measurements is that savings vary significantly based on unit size, configuration, building space type, runtime, controls, and overall operation. These are extremely important considerations when determining if or when to retrofit an RTU.

State of the Market

The key drivers for building owners and facility managers are cost and payback, comfort/reliability concerns, and recommendations from mechanical contractors. Contractors play a large role in the process, as buildings rely on their expertise to maintain their equipment and offer upgrade and replacement recommendations. Many contractors interviewed were familiar with the types of technologies, and recommend and install advanced economizer packages on failed economizers, but were not aware of the specific packages available and summarized for this project. Contractor engagement and education is crucial for the future of these technologies. Many retrofit manufacturers work directly with customers, focusing on owner-occupied businesses, such as retail chains, as they tend to have many locations, the same or similar equipment at each building, and full control over RTU maintenance and replacement. The most cited barrier to retrofit technologies is the lack of prescriptive rebates available. All interviewees stated that custom rebates are time consuming and tend to steer contractors and building owners away from pursuing these technologies.

National Utilities

Representatives from six national utilities were interviewed to identify best practices for programs outside of Minnesota for potential inclusion in Minnesota utility portfolios. Utilities reported low participation in the existing RTU retrofit market, which motivated them to pursue other avenues for market penetration and retrofit implementation. Midstream incentives for high-efficiency RTUs and retrofits were common across all utilities interviewed and were cited as the most successful. Bonneville Power Administration has taken a unique approach specific to RTU retrofit technologies: a tiered system for rooftop unit control (ARC) and ARC Lite programs and incentives are offered on a per-ton basis.

The following table summarizes the retrofit technologies recommended as an outcome of this project. CEE has interviewed manufacturer representatives from each package and conducted field measurements on Turntide SRMs, Catalyst, JADE economizer, ZIP economizer, and Digi-RTU (from a previous study) to verify performance and energy savings potential.

Table 22. Retrofit packages summary

	Manufacturer									
	Prostar Energy Solutions	Bes-Tech	75F	NexRev	Enerfit	Prostar Energy Solutions	Swarm Logic	Turntide	Honeywell	Belimo
	Controller									
	Catalyst w/ eIQ	Digi-RTU	Dynamic Airflow Balancing/ Outdoor Air Optimization	Drivepak ARC	Enerfit	Catalyst	Swarm Logic	Switched Reluctance Motor	JADE Economizer	ZIP Economizer
Main Features										
Evaporator Fan Control	x	x		x	x	x		x	x	x
Demand Controlled Ventilation (DCV)	x	x	x	x	x	x			x	x
Advanced Economizer Controls	x	x	x	x	x	x			x	x
Fault Detection and Diagnostics (FDD)	x	x	x	x	x		x		x	x
Compressor Control		x								
Additional Features										
Advanced Thermostat Control	x	x	x					x		
Setpoint and Schedule Control	x	x	x					x		
DR Capability	x	x					x			
Web User Interface	x	x	x				x	x		
BAS Integration	x	x			x	x	x	x		x
Stand Alone BAS	x	x	x							
Zone Control			x							

Multi-Unit Coordination	x						x			
Claimed Savings	25%-50%	60%	25%-40%	25%-50%	50%	25%-50%	15%-30%	60%-70%	30%	40%
Claimed Payback Period	2 years	2-4 years	2-5 years	1.5-2 years	3 years	2 years	1 year	1-4 years	Varies	Varies
Ideal Application	Large evaporator fan motor, fan ON	Large RTU (>10 tons)	Large RTU serving multiple space types	Large evaporator fan motor, fan ON	Large evaporator fan motor, fan ON	Large evaporator fan motor, fan ON	Many RTUs serving single open space	Large evaporator fan motor, fan ON	Nonfunctioning Economizer, above 5 tons	Nonfunctioning Economizer, above 5 tons
Price	$$$$	$$$$	$$$$	$$$$	$$$	$$	$$	$	$	$

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Appendix E: Case Studies

Overcoming the Market Barriers for RTU Retrofit Enhancements – Switched Reluctance Motors

Background

This project was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program. The goal of this project is to develop strategies to overcome the market barriers to proven energy efficiency improvements of existing rooftop units (RTUs). Eight sites were selected for a field evaluation of different RTU retrofit technologies. Field sites included RTUs that had previously undergone retrofit improvements and sites that were retrofit with energy saving technologies as part of this project. All sites included a baseline and demonstration monitoring period to compare baseline RTU operation more accurately to the operation under optimization. RTUs that had already been retrofitted had the ability to switch the technology on and off to capture both modes of operation.

Switched reluctance motors (SRMs) are an RTU retrofit measure designed to improve the evaporator fan's performance. The SRM is a more energy efficient motor than the motors traditionally used by the RTU's evaporator fan. In this study, four RTUs were retrofitted with a Turntide SRM. These RTUs were monitored to determine energy savings compared to the existing induction motor.

Site Characteristics

- 38 packaged RTUs, four RTUs were monitored
- Located in Minnetonka, Minnesota
- Mix of office, laboratory, and warehouse spaces
- Each RTU was controlled by an individual programmable thermostat

Field study

The project team installed monitoring equipment to accurately assess the energy savings performance of the SRMs. Data was gathered at 30-second resolution and downloaded remotely via a cellular modem connection. A power meter was installed on each RTU to determine the total electrical energy use of the evaporator fan, for both the existing induction motor and the SRM. In addition to energy consumption, a current transformer was installed on each gas valve to determine when each RTU was in heating mode. Space temperature and relative humidity were also monitored to assess space conditions and occupant comfort.

Installation

Four Turntide SRMs were installed to replace existing evaporator fan motors on RTUs. The motors varied from two to five horsepower, and RTU sizes varied from 5 to 12.5 tons. The installation included a premium efficiency SRM, programmable variable speed drive, and a cloud-based management and monitoring platform. The systems were installed by the mechanical contractor who services the building.

Table 1. RTU specifications

RTU	Manufacturer	Tonnage	Age	Model #	Motor Horsepower	Heating Input (Btu/h)
RTU-5	Lennox	10	2001	LGA120SH1Y	3	235,000
RTU-6	Lennox	12.5	2001	LGA150SH2Y	5	235,000
RTU-37	Lennox	5	2008	LGC060S2BH1Y	1.5	125,000
RTU-42	Lennox	7.5	2011	LGH092H4BH1Y	2	230,000

Figure 1. Existing motor

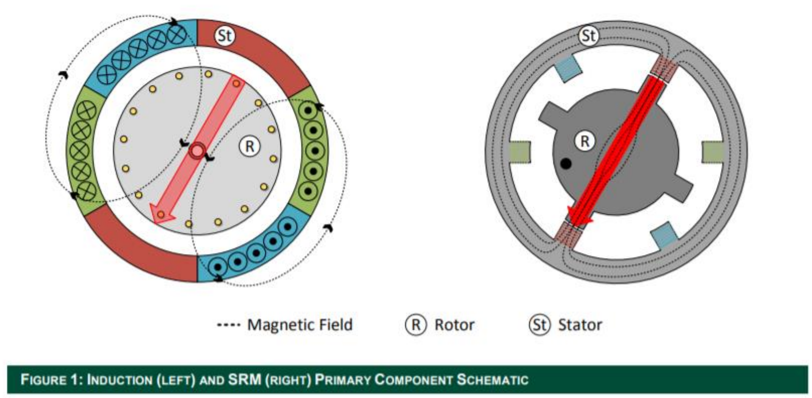
Figure 2. SRM retrofit

Technology

Induction motors are the most common motor type for most HVAC systems, including packaged RTUs. RTUs utilize multiple motors for their operation and the evaporator fan motor is the largest and uses a significant amount of energy. Most evaporator fan motors operate at a single speed and run at 100% when called to run.

Switched reluctance motor technology has been around since the 1850s and the technology's potential has recently been realized. An induction motor utilizes stators, rotors, and wire winding that creates a rotating magnetic field by supplying current to the windings in the stator, which causes the rotor to turn. An SRM provides individual current signals to various coils along the stator to create electromagnets with which the rotor continuously tries to align. This current is switched on and off at the various coils thousands of times per second and can be varied to meet the fan speed requirements, thus the variable speed motor.

Figure 3. Induction versus SRM motor diagram



Turntide's patented Smart Motor System includes motor electronics, networking, and IoT platform capabilities. The motor is a High Rotor Pole Switched Reluctance Motor (HRSRM), which offers higher efficiencies than a standard induction motor, and is inherently variable speed. The controller communicates with a cloud-based manager to monitor motor operation and to optimize efficiency at any fan speed. The Drive can also utilize sensors (temperature, pressure, CO_2, etc.) or control inputs (e.g., cooling or heating status, 0-10V, 0-20mA, resistive, etc.) to control motor speed, direction, start/stop, and external outputs (for controlling dampers, turning on/off compressors, etc.).

Findings

Data was measured during the following time-period.

Pre: 12/16/21–12/26/21

Post: 12/27/21–1/13/22

The thermostats for each RTU were set to ON during the entire monitoring period to simulate operation when the building is fully occupied, as well as to get maximum runtime of the supply fans to characterize the operation of the motors. The thermostat fan settings directly before the monitoring period were mostly set to AUTO due to lower-than-average occupancy since most of the employees were working from home during the pandemic. The on-site contact indicated that normal operation (when fully occupied) is to run the fan in ON during occupied times, and in AUTO during unoccupied times, but this varied from unit to unit. Since fan runtimes varied across RTUs, analysis was completed for multiple scenarios to characterize different thermostat configurations.

1. Fan on 24/7
2. Fan on 14 hours Monday through Friday and 6 hours on Saturday and Sunday during occupied periods. Fan in AUTO during unoccupied periods.
3. Fan in AUTO

Data analysis was performed using an 8760-hour calculator to summarize the annual performance. The calculator uses various RTU inputs to predict energy savings. Inputs include parameters from heating, cooling, economizer operation, thermostat setpoint and schedules, and supply and evaporator fan characteristics. The measured fan power values were used as inputs to calculate the annual results more accurately.

Motor Operation

Motor operation was logged for each motor and characterized. The existing induction motor ran at a constant speed during each mode of RTU operation. The SRM motor is designed to vary the speed of the evaporator fan during different modes of operation. Since this field study was conducted during winter, heating and fan-only operation were the two modes that were observed. Each RTU was placed in cooling mode a single time to measure fan speeds to estimate energy savings.

The SRM motor significantly reduced the power of the evaporator fan during all modes of operation. The pre/post comparison shows the impact of the SRM versus the baseline operation. Baseline power values remain steady throughout all modes of operation. SRM operation fluctuates based on the mode of the RTU. Fan only runs at around 50% speed, while the fan speed increases when the unit is heating. Larger units heat in stages and the SRM ramps up fan speed to meet the additional heating capacity as needed.

Table 2. Fan power measurements

RTU	Baseline Fan Power (kW)	SRM Fan Only Power (kW)	SRM Heating Fan Power (kW)	SRM Cooling Fan Power (kW)
5	1.8	0.19	0.75	0.03
6	1.5	0.22	0.68	1.36
37	0.8	0.07	0.45	0.64
42	1.05	0.15	0.75	0.96

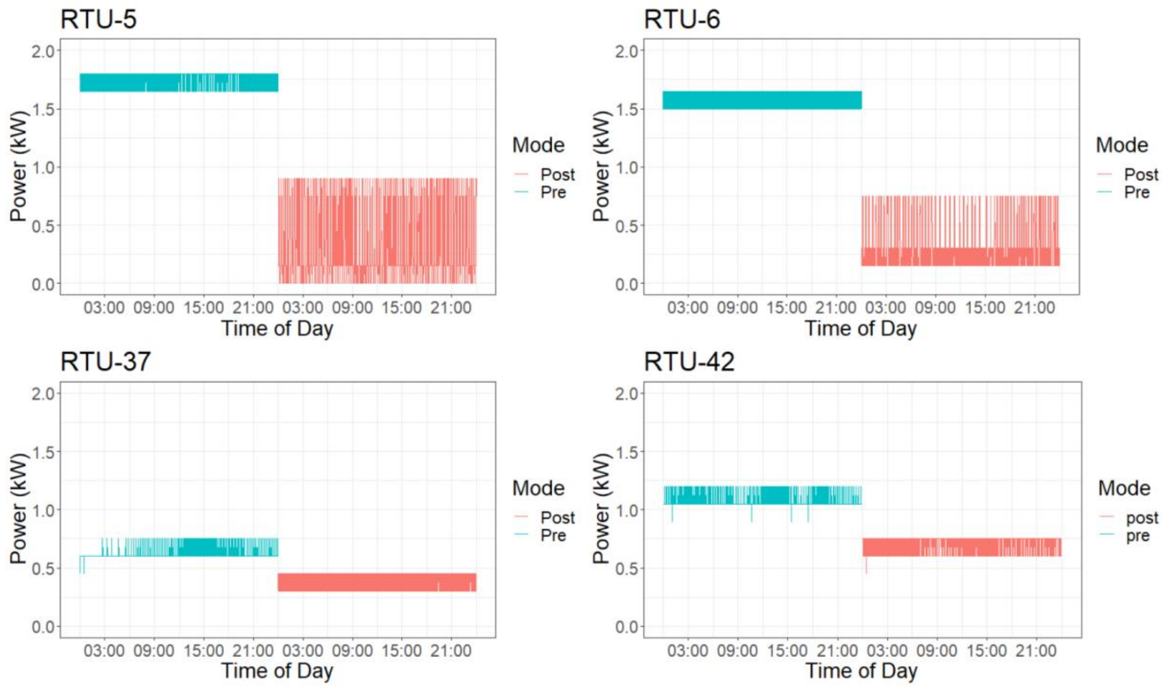
The RTUs showed varying levels of heating runtime, which is common with RTUs especially in larger buildings that are conditioned by many units. Heating runtime hours can vary by thermostat setpoint and location, space type, building type, RTU size, etc. These factors can significantly influence RTU operation in situations where multiple units serve a single open space, cubicles, or open offices, for example.

RTUs 37 and 42 spent most of the monitoring period in heating mode. RTU 37 is small and acts as the only unit in a large open office setting, and RTU 42 serves as the only unit in a large warehouse, which contributed to the long heating events. The plot below shows a typical day of operation, with units 5 and 6 heating the entire day. This contributes to the higher power values in the post period.

RTUs 5 and 6 varied operation throughout the test period. Most days include three to seven hours of heating, and the rest was fan-only operation. This is evident in the large power fluctuations as the fan ramped up and down for each mode and heating stage during the post period.

Figure 4 shows a typical day for each unit during the pre and post monitoring period. Days were selected with similar outside air temperatures and operation to compare the modes.

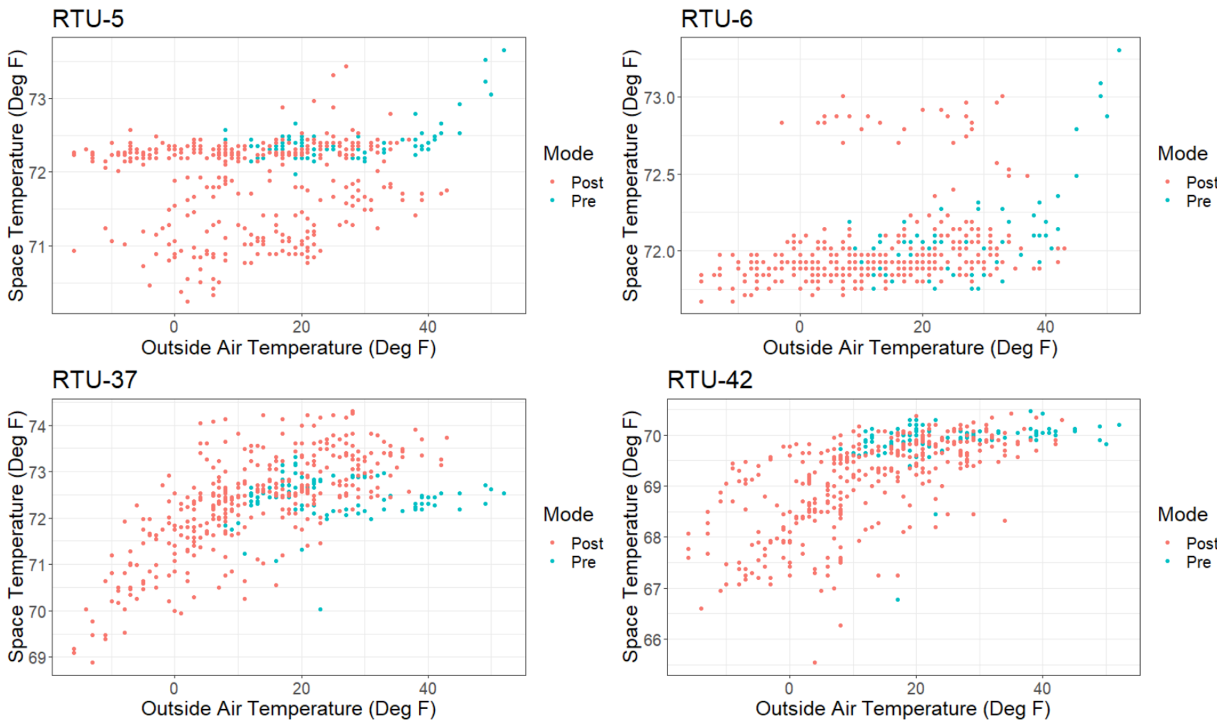
Figure 4. Pre/post average day power comparison



Space Conditions

Space temperature and relative humidity were monitored with a data logger that was located near each thermostat. These conditions were not expected to change considerably during the post period compared to the pre period. Overall, conditions were comparable between both periods. The pre period did not include outside air temperatures below 10°F, so no data was captured for comparison. The drop in space temperature in the post period at lower outside air temperatures for units 37 and 42 can be attributed to extreme conditions and undersized units that struggled to keep up with the heating load.

Figure 5. Space temperatures



Results

The performance of each motor was characterized by comparing the pre versus post (existing induction motor versus the SRM) total RTU electricity use, supply fan electricity use, and operating costs. Three modes of operation were analyzed for various fan runtimes for each unit. Fan settings vary based on different building and space types, occupant comfort levels, and requirements for ventilation.

The motors showed significant energy savings over the existing induction motors. The fan energy savings for the fan ON configuration ranged from 69% to 85%, with most of the savings resulting from the supply fan running at significantly lower speeds (44% to 53%) when the unit is not heating or cooling.

Table 3. SRM motor performance

RTU	Fan Mode	Baseline Total Energy Use (kWh)	Baseline Fan Energy Use (kWh)	Post Total Energy Use (kWh)	Post Fan Energy Use (kWh)	Total Annual Savings ($.13/kWh)	Total Electric Savings	Total Fan Savings
5	ON	27,413	15,768	13,997	2,340	$1,746	49%	85%
5	14/6	21,161	9,325	13,354	1,517	$1,015	37%	84%
5	AUTO	15,528	3,602	12,724	797	$365	18%	78%
6	ON	27,643	13,140	18,245	3,742	$1,222	34%	72%
6	14/6	22,538	7,796	17,594	2,852	$643	22%	63%
6	AUTO	17,902	3,048	16,919	2,065	$128	5%	32%
37	ON	9,369	7,008	3,897	1,499	$716	58%	79%
37	14/6	6,494	4,098	3,576	1,179	$379	45%	71%
37	AUTO	3,806	1,436	3,264	894	$70	14%	38%
42	ON	16,634	9,145	10,330	2,840	$820	38%	69%
42	14/6	12,938	5,410	9,764	2,236	$413	25%	59%
42	AUTO	9,589	2,098	9,192	1,701	$52	4%	19%

Conclusions

SRMs were tested in a field demonstration to compare against existing single-stage induction motors that controlled evaporator fans on four RTUs of various sizes. A pre/post monitoring strategy was used to gather data for both motor types and characterized to calculate energy savings. The findings are summarized in the following.

- Fan speeds of the SRMs during fan-only operation were 45%–55% of the baseline operation.

- Fan energy savings were reduced 69%–85% during fan on 24/7 simulations.
- Total RTU electrical savings were reduced 38%–58% during fan on 24/7 simulations.
- Total annual savings ranged from $716–$1,746 (assuming $.13/kWh and 24/7 operation).
- Payback periods ranged from one to three years for RTUs that were configured for fan ON operation.
- No significant reduction in space temperature or occupant comfort was observed.

Overcoming the Market Barriers for RTU Retrofit Enhancements – Advanced Economizer Controls

Background

This project was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program. The goal of this project is to develop strategies to overcome the market barriers to proven energy efficiency improvements of existing rooftop units (RTUs). Eight sites were selected for a field evaluation of different RTU retrofit technologies. Field sites included RTUs that had previously undergone retrofit improvements and sites that were retrofit with energy saving technologies as part of this project. All sites included a baseline and demonstration monitoring period to accurately compare baseline RTU operation to the operation under optimization. RTUs that had already been retrofitted had the ability to switch the technology on and off to capture both modes of operation.

Air-side economizers are common on packaged RTUs and provide outside air as a means of ventilation and free cooling under the proper outside conditions. Free cooling refers to the act of using outside air as a means of cooling under favorable outside air conditions, instead of turning on the compressor. They offer significant energy savings potential since free cooling reduces overall compressor runtime. Stock economizer systems often fail due to malfunctioning sensors and controllers, which can leave a damper stuck closed or open, rendering the economizer useless. These failures can cause a significant energy penalty or comfort issues, as an outside air damper that has failed to open will allow continuous flow of outdoor air resulting in overheating or overcooling, and a failed closed or partially closed damper offers limited or no ventilation to the conditioned space.

Existing economizers are typically only replaced on failure. Therefore, advanced economizers are only considered at the time of replacement due to failure. Predictably, the most common opportunity to upgrade will be when an economizer has failed — as such, this scenario is represented by the field site chosen for this project. The test site included nine RTUs, all of which had failed economizers and were bypassed with the damper set to the minimum position to only allow a fraction of outside air during operation. All nine economizers were replaced with an advanced economizer package as part of this project.

Site Characteristics

- 9 packaged RTUs
- Located in St. Paul, Minnesota
- Office building
- Each RTU was controlled by an individual programmable thermostat

Field study

The project team installed monitoring equipment to accurately assess the performance of the RTU economizer before and after retrofit. Data was gathered at one-minute resolution and downloaded manually throughout the test period. A current transformer was installed on each RTU to determine the total electrical current of the RTU and correlated to power to calculate total energy. In addition to energy consumption, a logger was placed on the RTU control board to measure the cooling signal from the thermostat. Space temperature and relative humidity were also monitored to assess space conditions and occupant comfort.

Installation

Nine RTUs were retrofitted with advanced economizer packages, five with the Honeywell JADE economizers, and four with the Belimo ZIP economizers. Each economizer package included a new controller, a mixed air temperature sensor, an enthalpy sensor, and used the existing economizer motor.

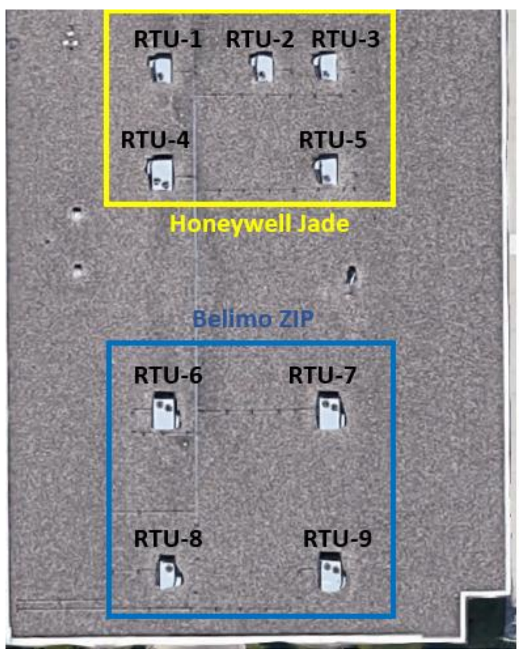
Table 4. RTU specifications

RTU	Economizer Retrofit Package	Space Type	Manufacturer	Tonnage	Model #	Heating Input (Btu/h)
RTU-1	Honeywell JADE	Conference	Carrier	4	48HJE005---651--	82,000
RTU-2	Honeywell JADE	Conference	Carrier	4	48HJE005---661--	82,000
RTU-3	Honeywell JADE	Conference	Carrier	4	48HJE005---651--	82,000
RTU-4	Honeywell JADE	Hallway, break room	Carrier	7.5	48TME008-A-601--	120,000
RTU-5	Honeywell JADE	Reception area	Carrier	5	48HJE006---641--	82,000

RTU-6	Belimo ZIP	Open office, cubicles	Carrier	7.5	48TME008-A-601--	120,000
RTU-7	Belimo ZIP	Open office, cubicles	Carrier	7.5	48TME008-A-601--	120,000
RTU-8	Belimo ZIP	Open office, cubicles	Carrier	7.5	48TME008-A-601--	120,000
RTU-9	Belimo ZIP	Exterior office	Carrier	5	48HJE006---641--	82,000

The test sites are part of a single office building and split by a divider into two separate spaces. The space served by RTUs 1–5 is a mix of large conference rooms (RTUs 1–3), a reception area, and the lunchroom and kitchen (RTUs 4–5). RTUs 6–7 serve a mixture of cubicle farms, storage areas, and perimeter offices. RTUs 8–9 serve perimeter offices and cubicles.

Figure 1. Roof view of RTUs



Technology

Advanced economizer packages offer more robust and reliable controls and sensors, digital controllers that give the installer or technician more precision when setting parameters, and integration opportunities with other technologies. The Honeywell JADE and Belimo ZIP are the two most installed packages by mechanical contractors in Minnesota for economizer retrofit.

The Honeywell JADE allows multiple sensor inputs, including mixed air temperature (MAT), outdoor air temperature (OAT), outdoor air enthalpy, and CO_2. In addition to economizer controls, additional technologies can be incorporated in Honeywell's advanced RTU retrofit solution. This includes variable frequency drives (VFD), demand-controlled ventilation (DCV), web-enabled thermostats, fault detection and diagnostics (FDD), and building automation system (BAS) integration.

Figure 2. Honeywell JADE economizer

Figure 3. Belimo ZIP economizer

Findings

Data was measured during the following time period.

Pre: 3/25/2022–5/25/2022

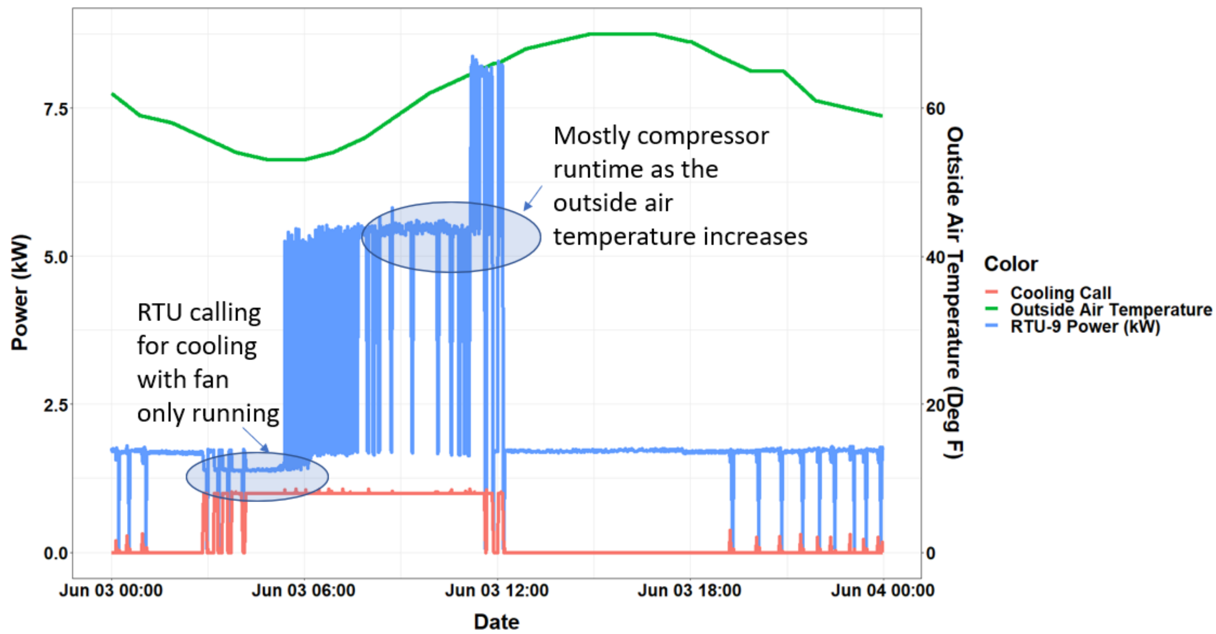
Post: 5/25/2022–11/11/2022

Data was gathered for a full spring and fall season to capture potential economizing conditions. Each unit was operated as-is for the baseline period, with a bypassed non-functioning economizer. Under this operation, an RTU will run the compressor for every cooling call regardless of the outdoor conditions. It has no ability to use outdoor air for cooling, and the damper is locked at the minimum position desired by the contractor to provide a fraction of outdoor air anytime the evaporator fan runs.

Economizer Operation

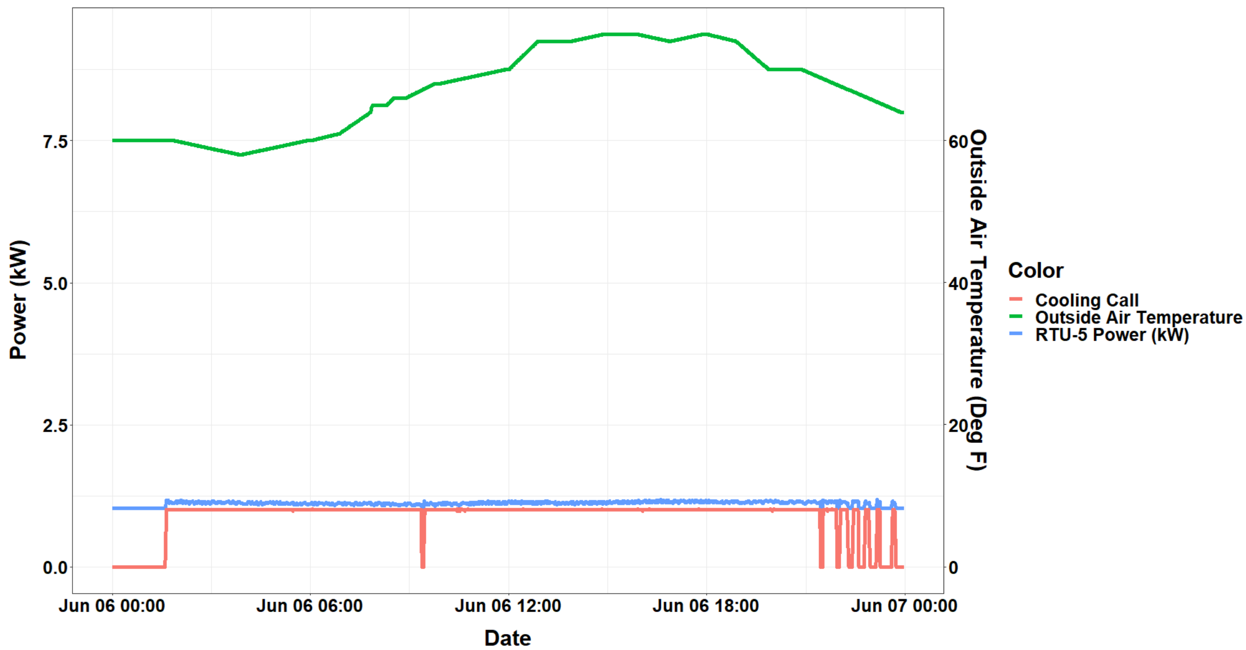
Figure 4 represents a day of operation for RTU-5 after the economizer package was installed. This RTU has the highest potential for an economizer to operate in free cooling mode as it serves exterior offices that are exposed to sunlight in the morning. On a cool morning as the sun offers solar radiation to heat up the space, the thermostat warms and calls for cooling. Since the outside air conditions are in the threshold for economizer operation, the economizer is allowed to use the outside air to cool the building instead of turning on the compressor. The unit economizes until around 5 a.m., when the compressor starts to cycle on and off until the outside air temperature is high enough that the unit stops economizing and there is mostly compressor operation.

Figure 4. Typical day of operation – RTU-5



The advanced economizer packages have multiple advanced settings that control the operation of the RTU. While standard economizers generally use a simple outside air temperature sensor to judge when the system should use free cooling, the packages studied with this project employ multiple sensors and adjustable settings to maximize the economizer's benefits. In addition to outside air conditions, both economizer packages can measure return air temperature and mixed air temperature for more control. For example, the Honeywell JADE economizer package uses a setting that can economize when the outside air temperature is above the switchover temperature, if it is below the return air temperature (minus a deadband setting that the installer can adjust). In the test units that were studied, specific RTUs showed economizer operation when the unit was calling for cooling and above the switchover temperature of 60°F, as shown in Figure 5. The RTU maintains a cooling call from 2 a.m. until around 10 p.m. with only fan operation. The economizer control determined that the outside air would be adequate to cool the space and did not turn the compressor on.

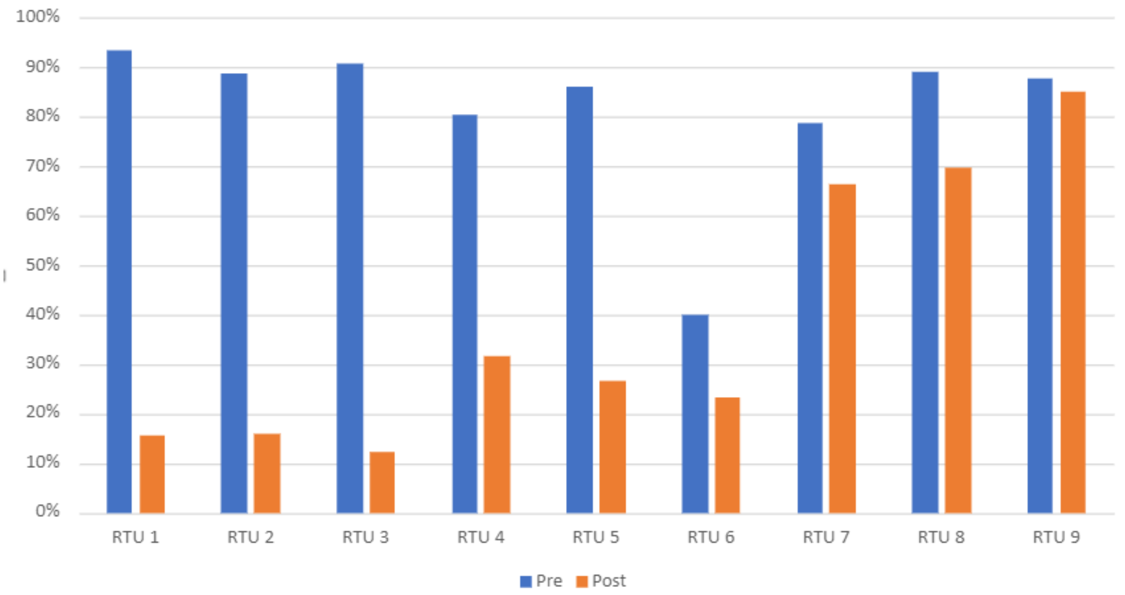
Figure 5. Economizing above switchover temperature – RTU-5



Both economizer packages were expected to cut down compressor runtime due to free cooling, which pulls in outside air to cool the space under certain outdoor air conditions. All the units studied showed a decrease in compressor runtime when comparing the post to the pre test period. Each RTU serves a different space type throughout the building and operates differently. Some units cool significantly, such as RTU-5 and RTU-9 which serve multiple offices along exterior walls. RTU-6 and RTU-7 showed very limited cooling calls, as they both serve an open space that is shared by multiple RTUs.

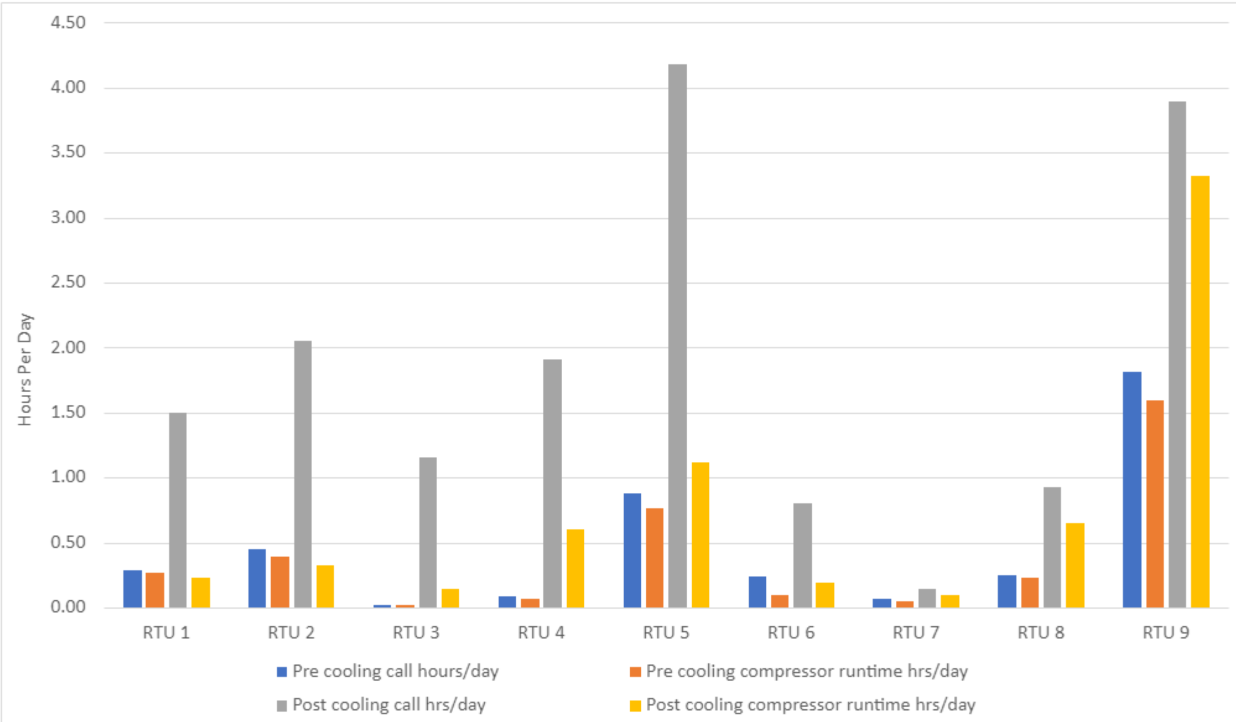
The figure below shows the decrease in compressor runtime between the pre and post test periods. Each bar represents the percentage of time that the compressor was running while the RTU was calling for cooling. If the compressor was not running during the cooling call, the unit was economizing. The outdoor air damper was open, and the evaporator fan was pulling in outside air to cool the space.

Figure 6. Compressor runtime percentage during cooling call



The amount of cooling varied across the RTUs and across the pre and post test periods. The main takeaway from the field study is the reduction of compressor runtime after the economizer packages were installed. The following figure represents the hours per day that the RTU calls for cooling and, of those hours, the amount the compressor ran. This shows the variance in the amount that each RTU cools, as RTU-5 and RTU-9 cool significantly more than any other unit.

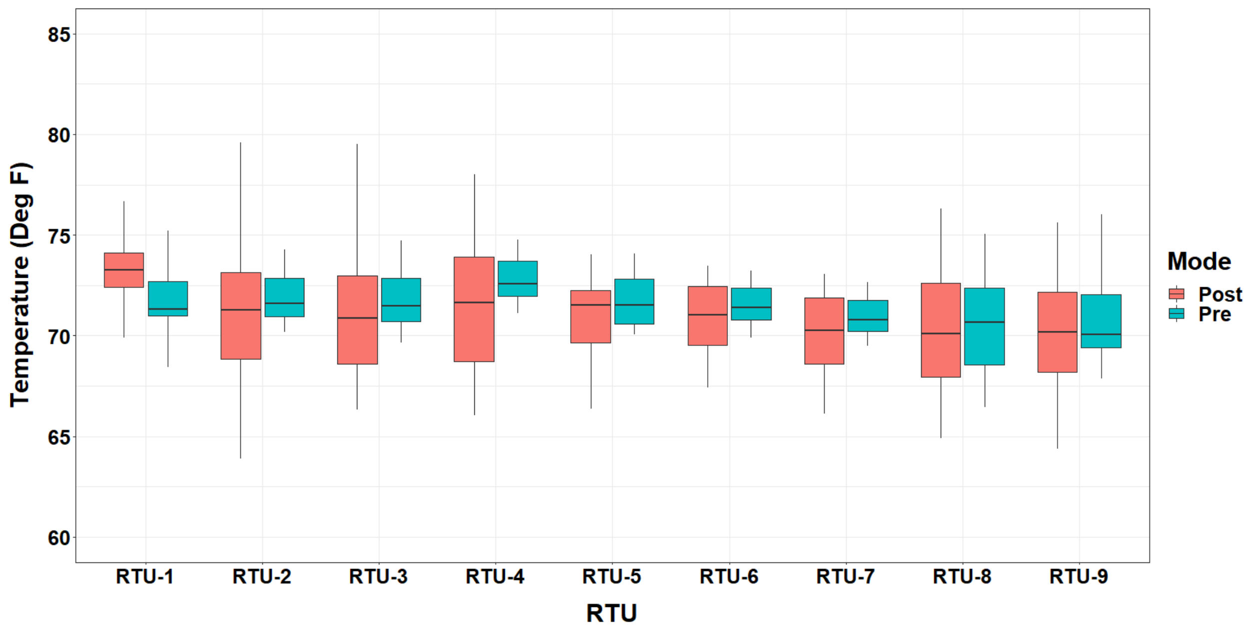
Figure 7. Compressor runtime and cooling call hours per day



Space Conditions

Space temperature and relative humidity were monitored for each RTU by a data logger located at each thermostat for both test periods. Temperatures were generally held between 68°F and 74°F as temperature setpoints throughout the building tended to match each other well. The post test period included a wider range of outside air temperatures, which explains the larger variation. Occupants were asked about comfort at the end of the test period and no complaints were reported.

Figure 8. Space temperatures

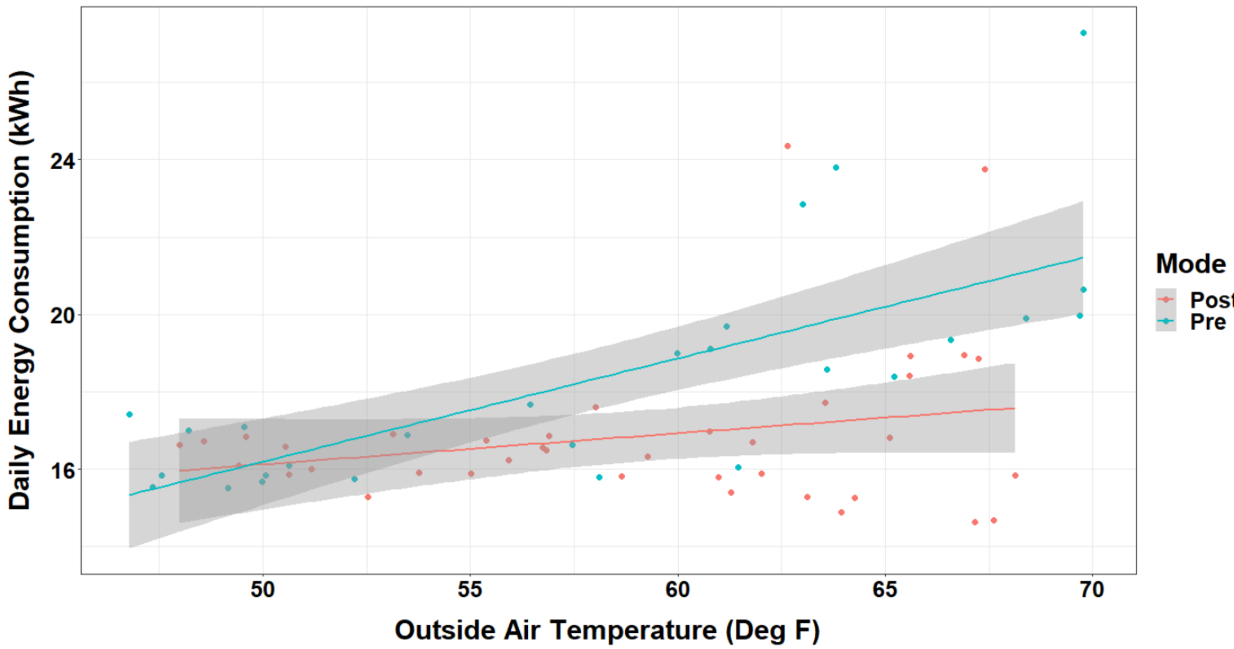


Results

Data was analyzed for a pre (baseline RTU operation) and post (after economizer package retrofit) and compared. Analysis was completed by summing daily energy consumption for each RTU and creating regressions versus outside air temperature. Data was gathered and analyzed during outside air temperatures that the project team expected to benefit from the economizer in free cooling mode, 45°F to 70°F. This data was normalized using a TMY3 data set to obtain annual usage data for the pre and post periods.

A sample of a pre versus post regression is shown in Figure 9 for RTU-2.

Figure 9. Pre versus post regression



Annual results varied across each RTU. Some showed negative savings, while most had positive savings. RTU-5 and RTU-9 showed the most kWh savings, as they had the most time spent calling for cooling. Three RTUs showed negative savings, but most of the RTUs saved 2% to 9%.

Table 5. Results

RTU	Pre Annual Use 45°F-70°F (kWh)	Post Annual Use 45°F-70 °F (kWh)	Electric Energy Savings (kWh)	% Savings
RTU-1	2237	2188	49	2%
RTU-2	2316	2116	200	9%
RTU-3	2066	2196	-130	-6%
RTU-4	3258	3618	-361	-11%
RTU-5	4136	3921	215	5%
RTU-6	2919	2724	195	7%
RTU-7	3505	3592	-87	-2%
RTU-8	3734	3672	62	2%
RTU-9	7455	7062	392	5%

Conclusions

Advanced economizer packages were field tested on nine packaged RTUs on an office building in Minnesota. A pre period consisted of the RTUs with non-functioning economizers, and 5 Honeywell JADE and 4 Belimo ZIP economizer packages were installed and monitored for the end of spring and the following fall. The two test periods were compared and the results are summarized as follows.

- Compressor runtime was reduced from 85% to 45% during calls for cooling across all RTUs.
- Negative savings are not indicative of the economizer packages working incorrectly. Setpoint changes and occupancy changes can drastically alter RTU operation in zones and building areas that are served by multiple units and lead to a change in RTU runtime patterns.
- Most of the RTUs in this study did not cool a significant amount due to the building's configuration. RTU-5 and RTU-9 showed the most savings, as expected. Both serve perimeter offices and conference rooms and are exposed to early sunlight that leads to warm morning temperatures and free cooling opportunities.
- The project showed an overall RTU electrical energy savings of 2% in the 45°F to 70°F outside air temperature range.
- The size of the RTUs studied were relatively small (4 to 7.5 tons). Larger RTUs that cool significantly would yield higher savings.