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# Efficient Rooftop Unit Field Study

## Baseline and Tier 2 Efficient Rooftop Unit Draft Report – 2023/2024 Heating Season

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# Efficient Rooftop Unit Field Study Final Report

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# 1. Table of Contents



# 2. Table of Figures

# 3. Executive Summary

## 4.1 Introduction

Packaged rooftop unit (RTUs) are used in over approximately 60% of all air-conditioned commercial floor space, with about 60% of these units using natural gas for heating, including over 400,000 units in the Northwest. With such a high market saturation, implementing efficiency in RTUs would generate significant energy savings.

In its pursuit of increased gas RTU efficiency, NEEA first examined condensing gas rooftop units, but found technical and financial challenges to scaling the market for these condensing units. NEEA then examined non-burner efficiency improvements, namely increased insulation, reduced damper leakage, and heat recovery. To date prior to this report, NEEA had analyzed these efficiency measures through lab testing and modeling.

NEEA has developed a two-tier specification for efficient RTUs (eRTUs). Tier 1 requires cabinet insulation, reduced damper leakage, and a minimum thermal efficiency of 81 percent. Tier 2 requires the unit to meet Tier 1 and either achieve a condensing level of efficiency or be equipped with a heat or energy recovery ventilation (ERV) system.

In order to gain an understanding of real-world performance, cost, and constructability, NEEA commissioned Energy 350 to conduct a field study looking at the performance of eRTUs. This report summarizes that study, the results, and the lessons learned through the experience.

## 4.2 Overview of Field Study

This project involved installing two new RTUs on a small existing commercial building in Portland, OR. The building was previously served by three (3) RTUs, two (2) of which were replaced (the third original RTU remained in place). The new units installed were:

- **Unit A:** a high efficiency unit with increased insulation, low leakage dampers, and a built in ERV. This unit was similar to a Tier 2 unit, but had an insulation value of R-7, rather than R-12.
- **Unit B:** a baseline efficiency unit with a bolt-on ERV.

In addition to installing the RTUs, we installed monitoring data to better understand real world performance. Data was collected in 1 -minute intervals between Nov 2023 and June 2024.

The project research objectives included:

- Field validating the savings of a near-Tier 2 eRTU compared to a baseline unit.
- Measuring whether overall savings in the field align with lab research.
- Measuring how savings in the field break down between insulation, damper, and ERV performance and how these align with lab research.
- Measuring whether a bolt-on ERV has the same performance as an integrated ERV.
- Gaining a real world understanding of the cost, equipment availability, engineering, permitting, weight and associated structural challenges, startup, etc.

## 4.3 Results

Overall, the study found significant energy savings driven both by the features of the eRTUs and reduced duct leakage. Compared to the baseline period, the weather-normalized whole building gas savings were 64 percent. These savings are significant and likely represent a variety of factors, including:

- Ductwork improvements leading to reduced leakage and wasted heat.
- Unit operational efficiency improvements. Even though the units had similar rated efficiencies to the ones they replaced, it is likely that the old units were not continuing to perform at their rated efficiencies.
- ERVs: the ERVs reduced heating load significantly, which contributed to these savings.
- Reduced unit infiltration and improved insulation. These were a smaller component of overall load reductions, but still impacted overall savings, as discussed below.
- Other operational factors not captured in the analysis, such as shifting operations or internal loads.[1]

The savings corresponding to ERV performance and increased insulation are in line with those expected based on previous field and lab research. While savings from damper performance were not able to be quantified, performance data showed qualitatively that the improved dampers in Unit A significantly reduced outside air infiltration. Overall, this leads to the conclusion that eRTUs can achieve significant energy savings in the field, with ERVs being the highest contributor to energy savings.

In terms of how savings broke down between the various eRTU components, the study found the following:

- **Heating efficiency:** Both units had an average measured heating efficiency of 78 percent, slightly lower than their rated efficiencies of 81 percent, which is to be expected in a field trial.
- **ERV effectiveness:** The field measured ERV effectiveness of the two units was 82 and 80 percent, showing roughly equivalent performance between the integrated and bolt-on units. This resulted in 19% and 23% heating load reduction for Unit A and B respectively.
- **Insulation performance:** The increased insulation in Unit A reduced heating energy use by 3.1 percent compared to a baseline unit with typical insulation. This is in line with the expected performance of increased insulation.
- **Low leakage damper performance:** Damper leakage results in extremely low velocities of infiltration and exfiltration through the RTU and ductwork that are too low for field measurement. However, we can look at rate of change of temperature in the RTUs and ductwork after the units cycle off to qualitatively understand impact of low leakage dampers. This review clearly demonstrates the effectiveness of low leakage dampers in preventing infiltration and exfiltration as compared to standard dampers.

[1] While there were no specific changes that we are aware of, these could have contributed to total savings.

## 4.4 Learnings

Field tests such as this provide invaluable real-world lessons far beyond installed efficiency and performance. For example, the field study illuminated the effects of weight increases and consequent structural engineering analysis and potential upgrades needed. When the contractor saw the weight of the high efficiency unit, they advised the project team to select a much lighter unit to avoid that barrier. While in this case, the weight only resulted in $4,628 in structural engineering costs and a minor delay, this would dissuade owners from installing heavier custom units. While the bolt-on ERV added less weight than the high efficiency unit, structural analysis was still required to ensure that the unit could be accommodated (in this case, the structural analysis for the high efficiency unit was sufficient to show that the bolt-on ERV could also be supported). If structural analysis triggered the need for upgrades, this would likely be a deal breaker for most real-world projects.

Another important real world data point is cost. Costs are documented in detail in Appendix A. While the costs for this project were driven by the particular units available (they were reused from a laboratory study), they still provide insight into potential real-world challenges in program implementation. Notably Unit A was over four times the cost of Unit B (without the bolt-on ERV). For Unit B, the bolt-on ERV more than doubled the cost of the unit. The major driver of such a large incremental cost for Unit A is the fact that the high efficiency unit was custom.

# 4. Introduction

## 4.1 Overview

Packaged rooftop unit (RTUs) are used in over approximately 60% of all air-conditioned commercial floor space, with about 60% of these units using natural gas for heating, including over 400,000 units in the Northwest. With such a high market saturation, implementing efficiency in RTUs would generate significant energy savings. The Northwest Energy Efficiency Alliance (NEEA) is a nonprofit that works to catalyze market transformation towards energy efficient products and practices in the Northwest. NEEA's Efficient Rooftop Unit (ERTU) program seeks to improve rooftop unit efficiency through product differentiation and ultimately federal standards. In its pursuit of increased gas RTU efficiency, NEEA first examined condensing gas rooftop units, but found technical and financial challenges to scaling the market for these condensing units. NEEA then examined non-burner efficiency improvements, namely increased insulation, reduced damper leakage, and heat recovery. To date, NEEA has analyzed these efficiency measures through lab testing and modeling. One of NEEA's strategies is supporting emerging technologies through field-performance testing to demonstrate energy savings potential and to identify market barriers. This report seeks to validate the achievable energy savings from these non-burner energy efficiency measures in the field and to learn about the design and installation, reliability, and field application of these units.

## 4.2 NEEA Specification

NEEA has developed a two-tier specification for ERTUs, as shown in Figure 1 and Figure 2. Tier 1 requires cabinet insulation, reduced damper leakage, and a minimum thermal efficiency of 81 percent. Tier 2 requires the unit to meet Tier 1 and either achieve a condensing level of efficiency or be equipped with a heat or energy recovery ventilation (ERV) system. NEEA's specification also includes a performance path that allows for qualification based on Total Heating Season Coefficient of Performance ($TCOP_{HS}$). Schematic diagrams for Tier 1 and Tier 2 units are shown in Figure 3 and Figure 4, respectively.

| Tier 1: Prescriptive Path Requirements | |
|---|---|
| *Thermal Efficiency* | >= 81% Thermal Efficiency[6] |
| *Insulation* | Cabinet shall be thermally insulated:<br>• All panels (Door liners, top panels, divider panels, and mullions) adjacent to conditioned air, including the base, shall be fully insulated with a minimum of R-12<br>• Insulation exposed to supply air must either be cleanable foil-faced with sealed edges or be sealed within double-wall cabinet to ensure no insulation fibers enter the airstream |
| *Outdoor and Return-Air Mixing Dampers* | Damper leakage rate shall be no greater than the rate described in ASHRAE/IESNA 90.1-2019 Table 6.4.3.4.3 |

FIGURE 1: NEEA'S ERTU SPECIFICATION TIER 1 REQUIREMENTS[2]

| Tier 2: Prescriptive Path Requirements (in addition to Tier 1 Requirements) | |
|---|---|
| *Condensing Furnace Requirements* | |
| Thermal Efficiency | >=90% Thermal Efficiency[7] (condensing heat exchanger) |
| *Heat or Energy Recovery Requirements* | |
| Heat or Energy Recovery | The unit must be equipped with a heat or energy ventilator that that allows for energy recovery (sensible or total) between the exhaust and ventilation air steams |

FIGURE 2: NEEA'S ERTU SPECIFICATION ADDITIONAL TIER 2 REQUIREMENTS[3]

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[2] NEEA, Efficient Gas Rooftop Units for Commercial Buildings: System Requirements and Compliant Equipment, August 1, 2023.
[3] Ibid.

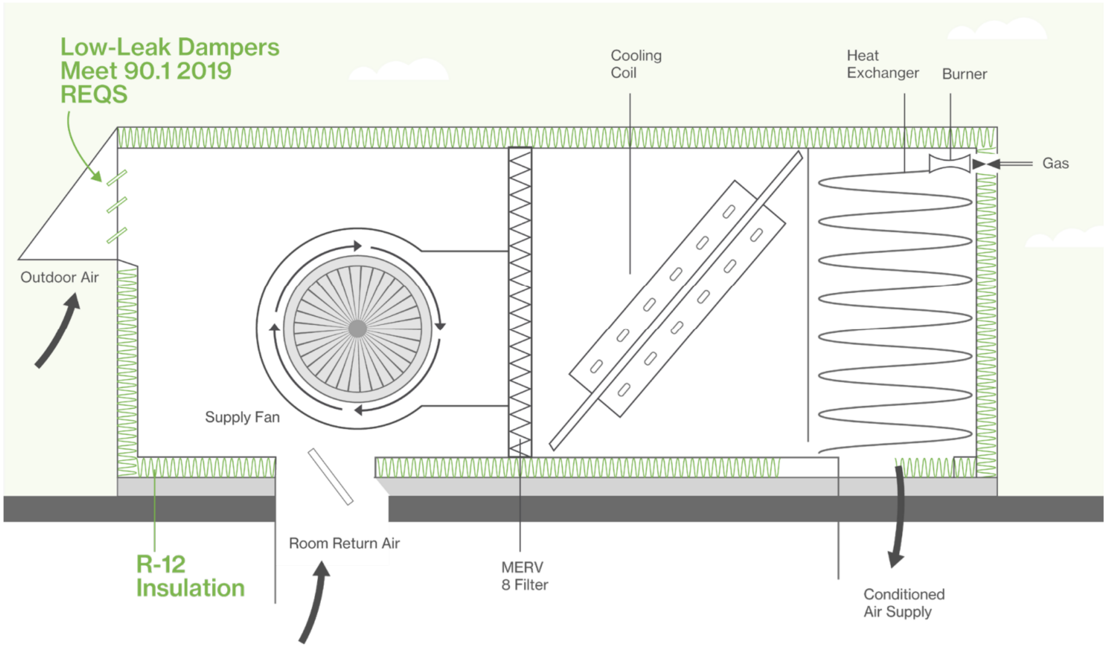


FIGURE 3: TIER 1 ERTU SCHEMATIC DIAGRAM[4]

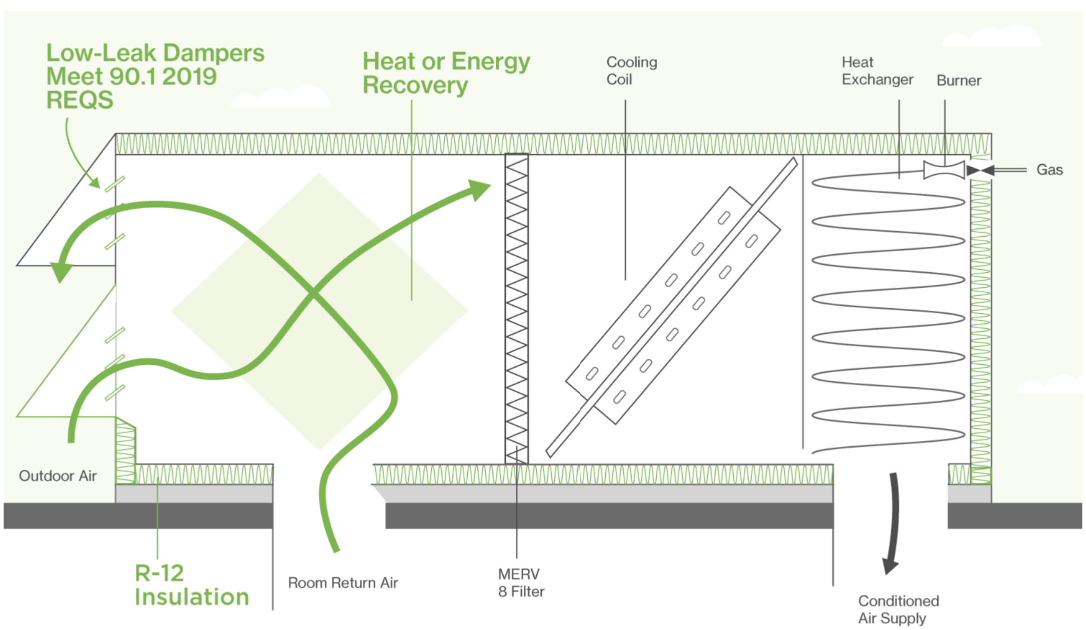


FIGURE 4: TIER 2 ERTU SCHEMATIC DIAGRAM[5]

[4] Better Bricks, *The Better and best efficiency in gas rooftop units.* 2024. Available at: https://betterbricks.com/uploads/resources/ERTU-Tiers-Article.pdf
[5] Ibid.

## 4.3 Previous Research

NEEA and other stakeholders have conducted a series of energy modeling analyses and laboratory tests over the last 5 years to determine the savings achievable from different RTU efficiency measures, including condensing technology, reduced-leakage dampers, increased insulation, heat/energy recovery ventilation, and cooling efficiency improvements.[6]

Most recently, Cadeo conducted an energy modeling analysis looking at the effect of different RTU efficiency technologies across 4 building prototypes in five climate zones.[7] The examined building prototypes were grocery, strip mall, retail, and medium office. The climate zones are summarized in Figure 5. The Cadeo report looked at five energy efficiency measures and five different combinations of measures, as summarized in Figure 6.

| Locations | Climate Zone | HDD[3] | CDD |
|---|---|---|---|
| Seattle, WA | 4C | 2627 | 1130 |
| Rockford, IL | 5A | 3719 | 1635 |
| Bend, OR | 5B | 3633 | 959 |
| Spokane, WA | 5B | 3715 | 1182 |
| Great Falls, MT | 6B | 4200 | 1061 |

FIGURE 5: CLIMATE ZONES ANALYZED IN CADEO REPORT

| Measure | Measure abbreviation | Measure Description |
|---|---|---|
| Condensing Gas Furnace | CGF | Add condensing gas heat exchanger to RTU furnace |
| Energy Recovery Ventilation | ERV | Add sensible and latent heat exchanger between exhaust and ventilation air streams |
| Reduced Damper Leakage | RDL | Update RTU dampers to low leakage type dampers |
| Increased Enclosure Insulation | IEI | Add additional insulation to RTU enclosure |
| Efficient Cooling | EC | Increase the cooling compressor total and part load efficiencies |

[6] These include:
Cadeo, Energy Modeling of Commercial Gas Rooftop Units in a Representative Canadian Climate, July 18, 2019
Natural Gas Technology Center, *Gas-Fired Rooftop Unit Efficiency Testing*, January 21, 2022
NEEA, Report #E22-330, Energy Savings from Efficient Rooftop Units in Heating Dominated Climates, April 20, 2022.

[7] NEEA, Report #E22-330, Energy Savings from Efficient Rooftop Units in Heating Dominated Climates, April 20, 2022

| Package | Measures included |
| --- | --- |
| Tier 1 | 1. Reduced Damper Leakage<br>2. Increased Enclosure Insulation |
| Tier1 + Efficient Cooling | 1. Reduced Damper Leakage<br>2. Increased Enclosure Insulation<br>3. Efficient Cooling |
| Tier2A | 1. Reduced Damper Leakage<br>2. Increased Enclosure Insulation<br>3. Condensing Gas Furnace |
| Tier 2B | 1. Reduced Damper Leakage<br>2. Increased Enclosure Insulation<br>3. Energy Recovery |
| Tier 2B + Efficient Cooling | 1. Reduced Damper Leakage<br>2. Increased Enclosure Insulation<br>3. Energy Recovery<br>4. Efficient Cooling |

FIGURE 6: MEASURES AND PACKAGES ANALYZED IN CADEO REPORT

The range and average savings found by EEM and EEM combinations across all prototypes and climate zones is summarized in Figure 7. Relevant to this pilot, the most similar prototype and climate zone combination to the building studied in this project was the medium office in Seattle, WA. For this prototype and location, the expected HVAC energy use intensity (EUI) reductions by measure were as follows: reduced damper leakage 2%, increased enclosure insulation 1.5%, and energy recovery 11.4%. One of the objectives of this field study was to determine if similar HVAC EUI reductions can be achieved in the field.

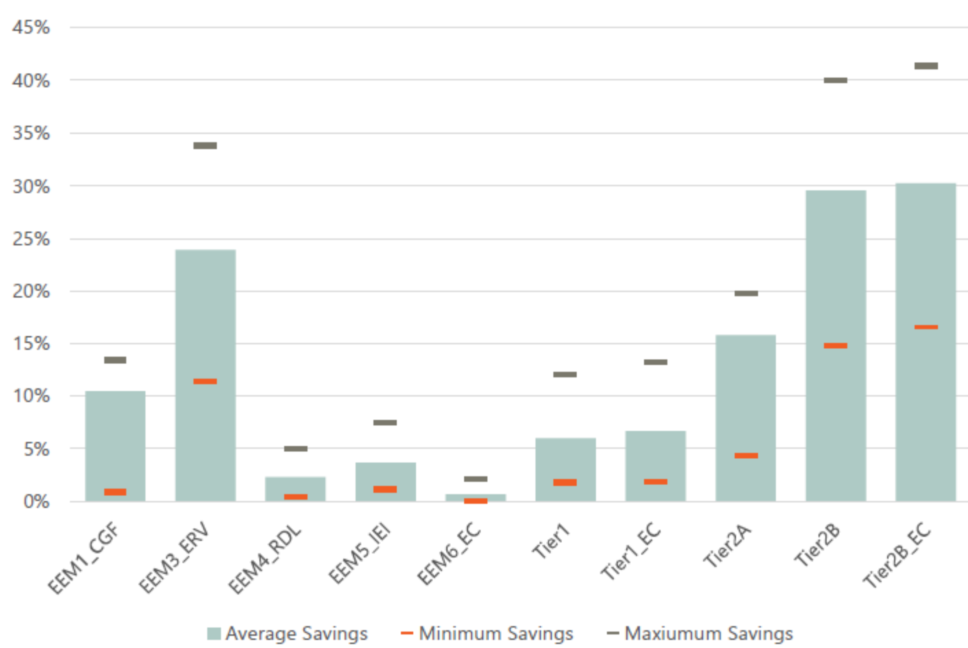


FIGURE 7: AVERAGE, MINIMUM, AND MAXIMUM HVAC EUI SAVINGS ACROSS BUILDING TYPES AND CLIMATE ZONE FROM CADEO REPORT

## 4.4 Project Description

This project involved installing two new RTUs on a small existing commercial building in Portland, OR. The building was previously served by three (3) RTUs, two (2) of which were replaced (the third original RTU remained in place). The new units installed were:

- **Unit A:** a high efficiency unit with increased insulation, low leakage dampers, and a built in ERV. This unit was similar to a Tier 2 unit, but had an insulation value of R-7, rather than R-12.
- **Unit B:** a baseline efficiency unit with a bolt-on ERV.

The units were installed in November 2023 and monitored through June 2024.

## 4.5 Research Objectives

The project research objectives included:

- Field validating the savings of a near-Tier 2 eRTU compared to a baseline unit.
- Measuring whether overall savings in the field align with lab research.
- Measuring how savings in the field break down between insulation, damper, and ERV performance and how these align with lab research.
- Measuring whether a bolt-on ERV has the same performance as an integrated ERV.
- Gaining a real world understanding of the cost, equipment availability, engineering, permitting, weight and associated structural challenges, startup, etc.

## 5. Site Description and Equipment Installation

### 5.1 Site Configuration

The project site was the KBOO radio station building located in Portland, Oregon. The building is a single-story, 5,000 square foot building that operates 24/7. Space types consist of production rooms, recording studios, storage areas, and office spaces. The building is served by three (3) packaged rooftop units, which each serve a single zone, as shown in Figure 8.

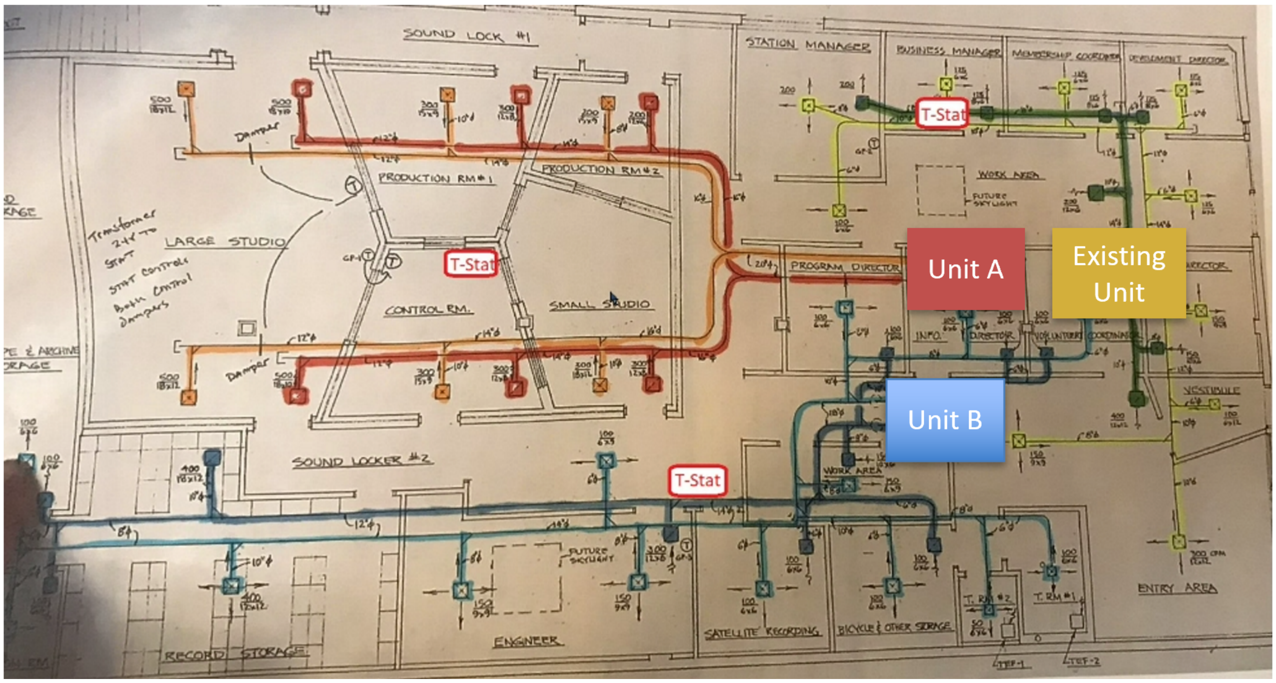


FIGURE 8: KBOO HVAC SYSTEM LAYOUT

### 5.2 Baseline Equipment

The baseline RTUs were aging Rheem units that were still functional, but certainly approaching end of life. Below is a summary of the baseline units.

**South Unit (replaced by unit A):**

- 5-ton Rheem manufactured in 2000 (model# RKKA-A060JK10E)
- 100,000 Btu/hr input, 81,000 Btu/hr output
- Single stage, non-modulating burner
- Single zone
- Single speed fan
- Gas heating, DX cooling
- 81% Thermal efficiency
- 573 lbs

**North Unit (replaced by Unit B):**

- 4-ton Rheem manufactured in 2001 (model# RKKA-A048CK10E)
- 100,000 Btu/hr input, 81,000 Btu/hr output

- Single stage, non-modulating burner
- Single zone
- Single speed fan
- Gas heating, DX cooling
- 81% Thermal efficiency
- 573 lbs

**West Unit (not replaced):**

- 3-ton Rheem manufactured in 2000 (model# RKKA-A036CK08E)
- 80,000 Btu/hr input, 64,500 Btu/hr output
- Single stage, non-modulating burner
- Single zone
- Single speed fan
- Gas heating, DX cooling
- 81% Thermal efficiency
- 513 lbs

## 5.3 Installed Equipment

### 5.3.1 Unit A – High Efficiency Unit

Unit A replaced the south unit and is a modern unit intended to represent an efficient RTU. Below is a summary of unit A.

- 5 tons cooling with gas pack heating
- Modulating gas burner with 5:1 turndown
- 160,000 Btu/hr input, 130,000 Btu/hr output
- 81% thermal efficiency
- Outside air economizer
- OEM Energy Recovery Ventilator (ERV)
  - 78% sensible effectiveness
  - 0.46 IWC pressure drop across wheel
  - 0.13 IWC pressure drop across ERV outside air filter
- Double walled construction with R7 insulation between the walls
- Variable speed, EC motor fan
- Controlled as a single-zone variable air volume unit
- Inverter driven scroll compressor
- Low leakage dampers
- 2020 equipment only purchase price of $30,580
- 1,662 lbs

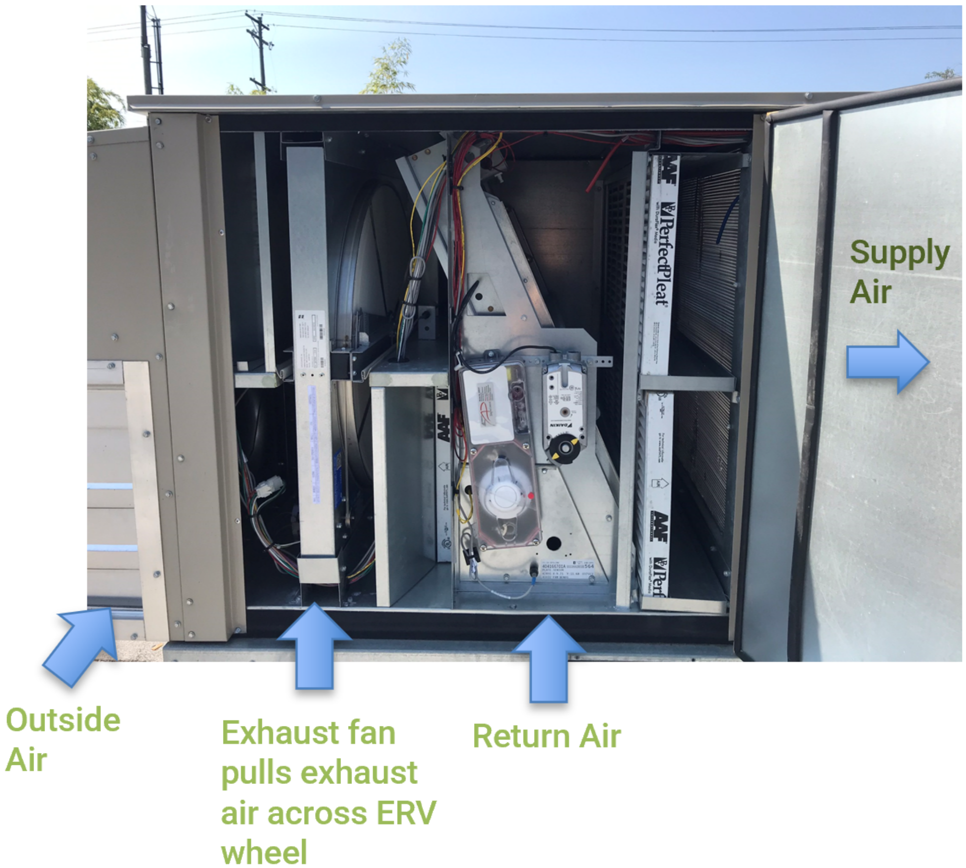


FIGURE 9: UNIT A ERV AND AIRFLOW PATH

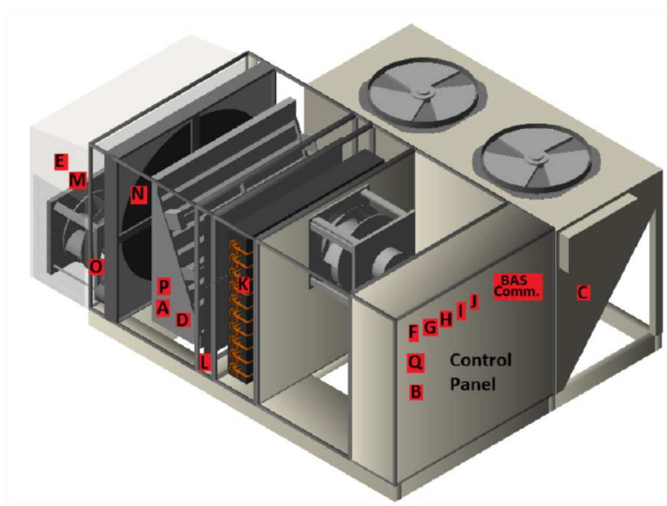


FIGURE 10: UNIT A SCHEMATIC

### 5.3.2 Unit B – Baseline Unit with Bolt-on ERV

Unit B replaced the north unit and is intended to represent a baseline unit with an aftermarket ERV retrofit. Below is a summary of unit B.

- 5 tons cooling with gas pack heating
- Two stage, non-modulating burner
- 150,000 Btu/hr input, 121,000 Btu/hr output
- 81% thermal efficiency
- Outside air economizer
- Single walled construction with ½” insulation
- 1.5 hp fan motor, direct drive with VFD
- Controlled as a single-zone variable air volume unit
- Constant speed, single stage scroll compressor
- Standard dampers
- 529 lbs
- 2020 equipment only purchase price of $7,150
- We added a retrofit ERV with the following specifications:
    - SEMCO ERV SP-700
    - Equipment price of $6,250
    - 76% sensible effectiveness
    - 0.3 IWC pressure drop across wheel
    - 350 lbs

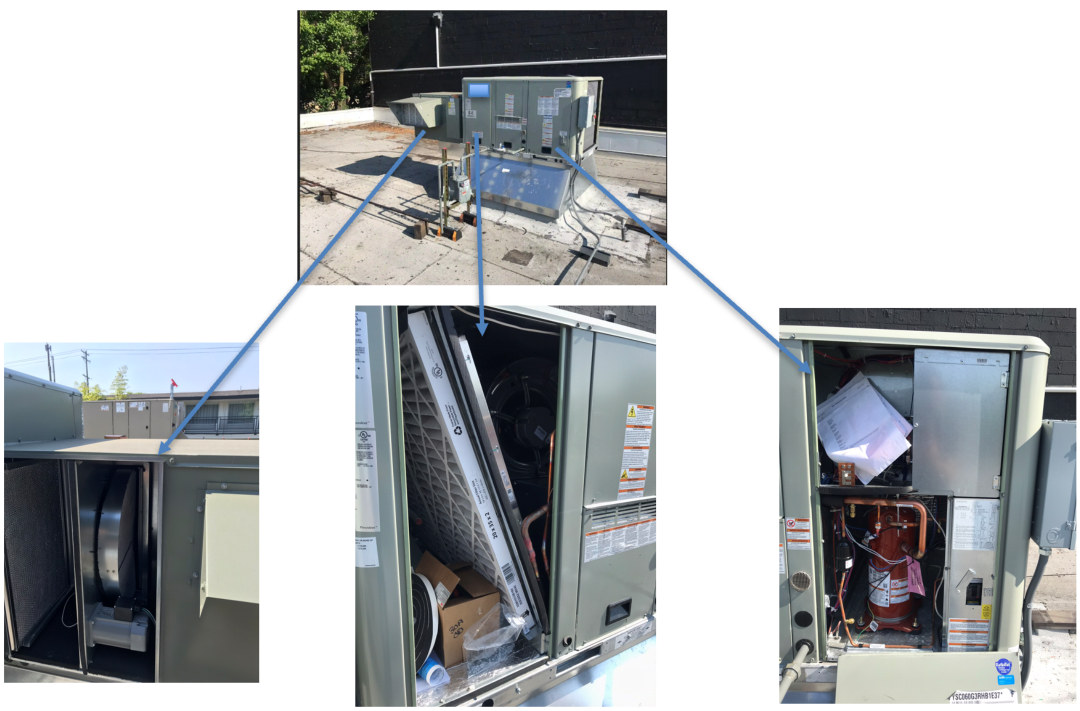

FIGURE 11: UNIT B CONFIGURATION INCLUDING BOLT-ON ERV

## 5.4 Site Considerations

### 5.4.1 Weight/Structural

Weight is a major factor in RTU selection. If the weight of the new unit is more than 10% heavier than the existing unit, this triggers the need for structural engineering. Both units (when including the bolt-on ERV for Unit B) exceeded this threshold. Initially, a contractor estimated that the project would need approximately $50,000 in structural upgrades to accommodate the increased weight of the RTUs. However, a structural analysis was conducted and found that upgrades were not necessary. For this project, this added $4,268 in engineering costs to conduct a structural analysis and resulted in project delays. Fortunately, the analysis did not result in any needed structural upgrades, however it is our experience that structural upgrades are often required to accommodate heavier RTUs. While the bolt-on ERV added significantly less weight than the high efficiency unit, this structural analysis was still needed to demonstrate that it could be safely installed.

Some efficient features of RTUs can add weight, which is a major barrier for the replacement market. The high efficiency unit (unit A) was triple the weight of the unit that it replaced. The two major contributors to increased weight include the ERV and the fact that unit A was a custom unit. Custom units tend to be heavier-duty construction. Additionally, to achieve the high R-value, unit A is double walled construction with insulation between the walls. We don't know of any units that achieve high R values without double walled construction and the significant weight associated with that.

The bolt-on ERV added to unit B allows us to isolate the weight of the ERV. In this case, it increased the weight of the unit by 66%. This indicates that we must plan on ERVs always triggering the need for structural engineering, which often triggers the need for structural upgrades.

The added weight of double walled construction and ERVs present a major barrier to adoption of these efficiency measures, since it adds complexity and cost in evaluating the need for upgrades and, if needed, the cost of the upgrades can be significant.

### 5.4.2 Ductwork

When removing the old units, we found significantly damaged ductwork that was leaking a meaningful amount of supply air into the attic of the building. An example of the damage found is shown in Figure 12. As can be seen in this figure, there were significant gaps in the ductwork causing conditioned air to be delivered to unintended places, as well as causing overlap in areas served between the units.

We paused and collected a quote to replace ductwork. At a cost of $54,489, this was very cost prohibitive. Rather than a full replacement, we repaired what we reasonably could and proceeded with the installation of the new RTUs. We can see from the utility data that the energy savings exceeds what we would expect from an RTU replacement, even with the efficient features included. We believe the dramatic energy savings to be a result of the ductwork repairs.

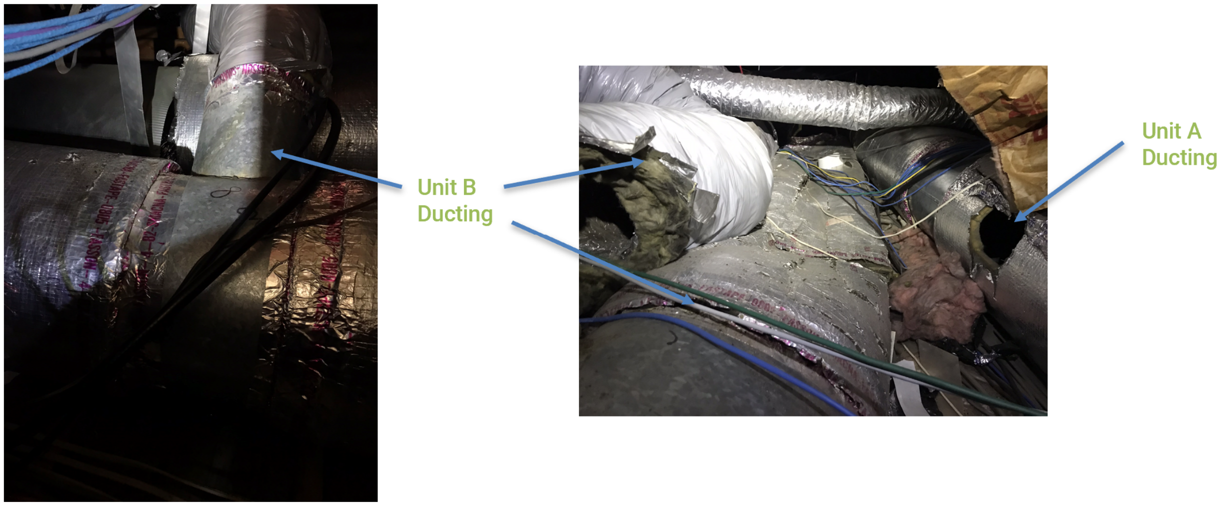


FIGURE 12: DUCTWORK PHOTOGRAPHS SHOWING LEAKING/DISCONNECTED DUCTWORK

While the supply ductwork is still somewhat damaged, we're not overly concerned with it impacting our results. Some leakage may increase the heating and cooling load on the RTU's and contributes to the interaction between the units (which was reflected in the data), but should not impact the measurement of key elements such as case losses, ERV effectiveness, etc.

## 5.5 Metering Configuration

Data was collected in 1-minute intervals from November 2023 through June 2024.

### 5.5.1 Data Points

Figure 13 outlines the collected metering points, indicated by red.

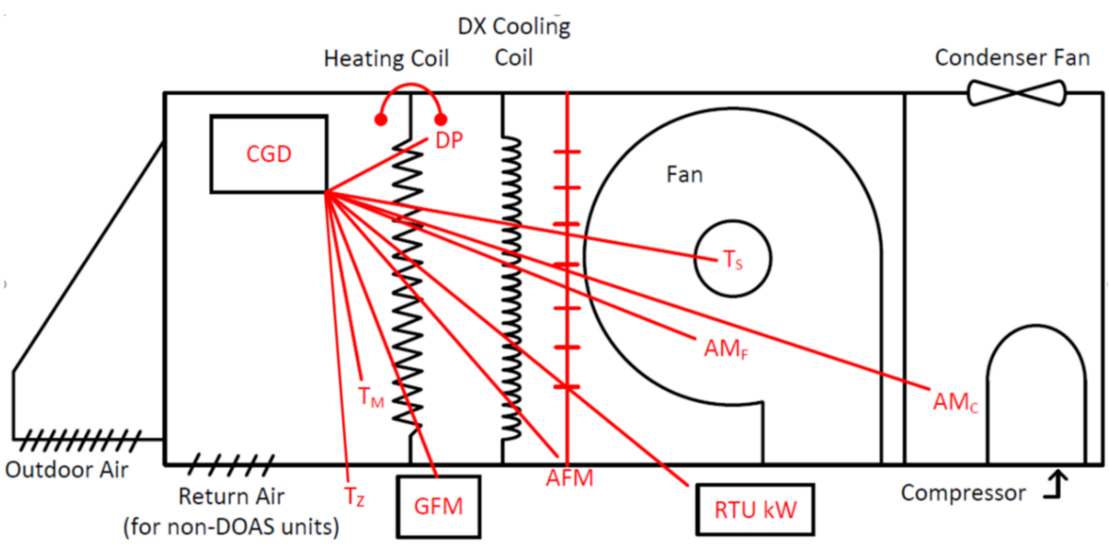


FIGURE 13: RTU METERING SCHEMATIC

**CGD** – Cellular Gateway Device – This served as a hub to collect data from all of the sensors and transmit it to the web for safe keeping and easy remote access. Data was measured real time, intervals stored every minute and uploaded to the cloud every 4 hours.

**$T_M$** – Mixed Air Temperature – This was an averaging temperature sensor to capture true inlet temperature to the coil, despite the large temperature gradient across the cross section of airflow.

**$T_S$** – Supply Air Temperature – This was the air temperature exiting the heating and cooling coil, captured at the inlet of the fan to eliminate fan heat from the measurement and ensure air is well mixed for an accurate measurement.

**$T_Z$** – Zone Air Temperature – This was the air temperature of the zones conditioned by the RTUs, as shown in Figure 14.

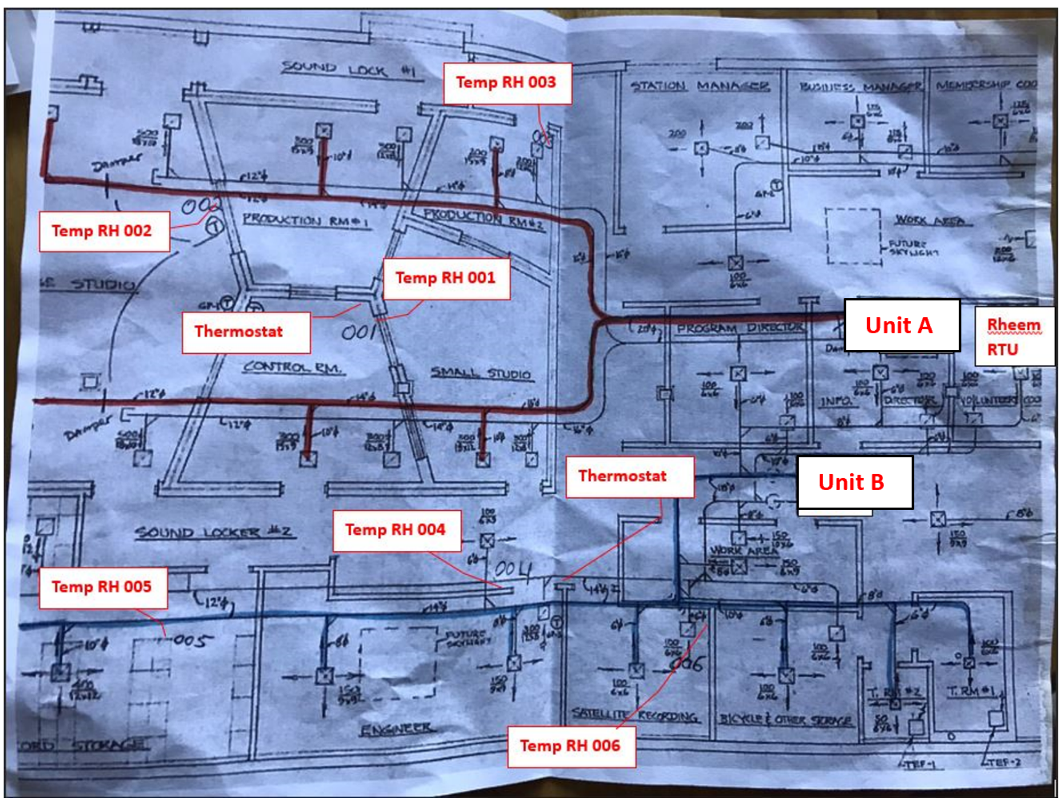


FIGURE 14: ZONE AIR TEMPERATURE SENSOR LAYOUT

**AFM** – Air Flow Monitoring Station – This collected airflow measurements and was necessary for an accurate energy balance as filters dirtied and conditions changed. Of particular importance, this allowed us to get accurate measurements of work performed even while using two speed or variable speed fans.

**GFM** – Gas Flow Meter – This was a diaphragm gas meter with pulse output to accurately measure energy into the two new units.

**$AM_C$** – Compressor Amp Meter –While this study was not focused on cooling performance, this meter allowed us to be sure that the compressor was not running during any of our heating performance calculations.

**$AM_F$** – Fan Amp Meter – This provided critical insight on fan speed to allow us to analyze impacts that fan speed and types (2-speed, variable) may have on other aspects of performance.

**RTU kW** – We monitored real power of the entire RTU. This aided in the quantification of the parasitic controls energy (non-fan or compressor) as well as provided additional insight into overall RTU operation.

**$T_O$** – Outdoor Air Temperature – This was the air temperature of the ambient air at the inlet of the economizer. This sensor was installed in a manner so as not to be impacted by solar gain.

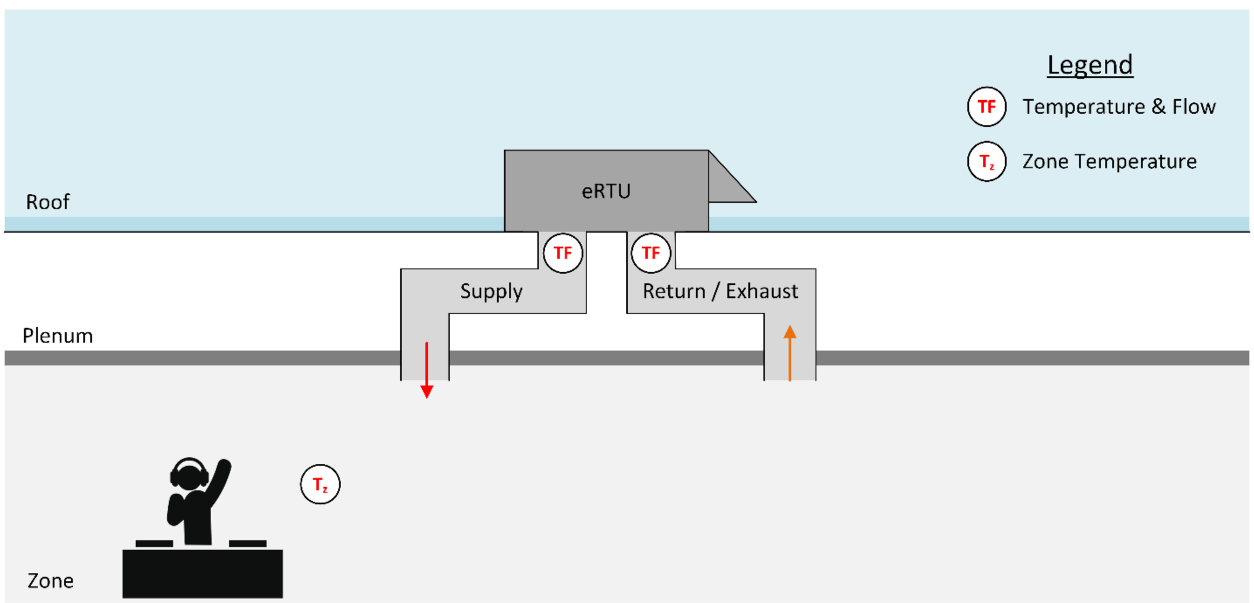


FIGURE 15: ZONE, SUPPLY, AND RETURN TEMPERATURE METERING SCHEMATIC

### 5.5.2 Metering Architecture

All data points were logged using the Hobo RX3000 cellular data logging station. This allowed 24/7 access to all data via a secure web browser and instant alarm notifications in case of sensor or RTU component failure. This minimized the risk of lost data during this monitoring period. All sensors had accuracies ±2% or better. Figure 16 lists the sensors for all monitoring points along with the proposed pulse adapters and modules to allow all data to be accessed in real-time on the Hobolink web browser interface.

| Monitoring Point | Sensor Manufacturer | Sensor Model/Name | Adapter/Module | Accuracy |
|---|---|---|---|---|
| Zone Air Temperature | Onset | RXW-THC-B-900 | RXMOD-RXW-900 | ± 0.36°F |
| Outdoor Air Temp<br>Mixed Air Temp<br>Supply Air Temp | Onset | S-TMP-M002 12-Bit Temp Sensor | None required | ±0.36°F |
| Airflow | Provided by RTU Manufacturer | | Onset RXMOD-A1 Analog Module | TBD |
| Gross Fuel Input | Measurement Control Systems | AL425 Natural Gas Flow Meter | Onset S-UCC-M006 | Not stated |
| Fan Power<br>RTU Power | AccuEnergy | AcuCT-075-100 Split-Core CT | WattNode WNB-3D-240-P Real Power Meter | ±0.5% from 10 to 120% Rated Current |
| Duct Temperature and Flow | DegreeC | F350 | Onset RXMOD-A1 Analog Module | ± 1.0°C<br>1% CFM |

FIGURE 16: SENSOR LIST

# 6. Methodology

The goal of this report was to field validate the potential energy savings from a near Tier 2 eRTU—including the performance of the ERV, low-leakage dampers, and improved insulation—and to determine if the bolt-on ERV had the equivalent performance of an integrated ERV. This section describes the methodology used to examine energy savings and ERV performance.

## 6.1 Total Energy Savings

High level energy savings were examined by looking at total year over year gas consumption using utility bill data. The baseline period used was July 2022 through June 2023 and the study period was October 2023 through May 2024. Using this data, an algorithm was developed to predict monthly gas use in therms based on average monthly temperature from whole building utility bill data during both the baseline period of the previous year and the study period. These algorithms were used to determine weather-normalized total year over year savings using TMY3 data. Figure 17 shows the total building monthly gas use based on utility bill data compared to average monthly temperatures.

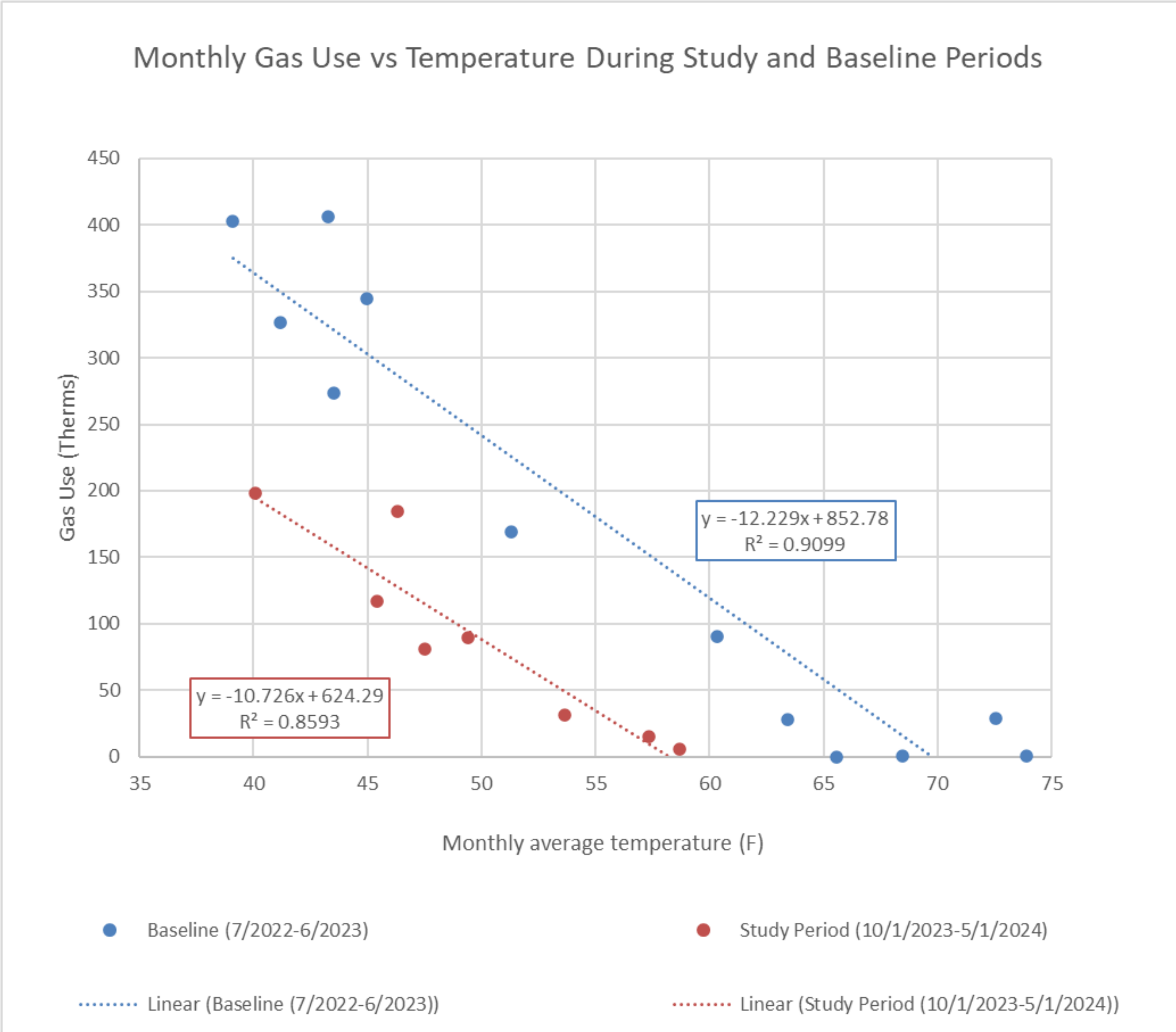


FIGURE 17: MONTHLY GAS USE COMPARED TO AVERAGE MONTHLY TEMPERATURE IN THE BASELINE AND STUDY PERIODS

## 6.2 Heating Efficiency

On mode heating load and efficiency for both units were determined using airflow and temperature data from the supply air sensor and mixed air temperature. The equation used to determine heating load is show in equation 1 and total unit heating efficiency is show in equation 2.

$$[eq. 1]\ Q\ = 1.08 * CFM * \Delta T$$

where:

Q = heating load (Btu/hr)
CFM = supply airflow in cubic feet per minute
ΔT = difference in air temperature between the supply air temperature and mixed air temperature (degrees Fahrenheit)

$$[eq.2]\ Efficiency = \frac{Q}{Gas\ input}$$

where:

Efficiency = heating operational efficiency when in heating mode
Q = heating load (Btu/hr)
Gas input = total gas input rate (Btu/hr)

## 6.3 ERV Effectiveness

The ERV effectiveness was determined as the ratio of mixed and return air temperature to outside air temperature as shown in equation 3.

$$[eq.3]\ ERV\ effectiveness = \frac{Mixed\ air\ temperature - Outside\ air\ temperature}{Return\ air\ temperature - Outside\ air\ temperature}$$

For Unit B, the mixed air temperature was not functioning until it was replaced on 2/13/2024 and so only dates after this were used to determine ERV effectiveness for Unit B. This average ERV effectiveness was then used to calculate mixed air temperature for dates prior to 2/13/2024 and used to calculate load, which is dependent on mixed air temperature.

## 6.4 Insulation Performance

To determine the effect of increased insulation in unit A, equation 4 was used to determine enclosure losses for both units.

$$[eq.4]\ Q = U * A * \Delta T$$

where:

Q = heat loss (BTU/hr)

U = U-value (Btu/ft$^2$ /°F/hr)

A = exposed surface area of the RTU (ft$^2$)

ΔT = difference in air temperature between the average of mixed air and supply air temperature (to approximate average unit temperature) and outside air temperature (°F)

A baseline U-value of 0.43 was used (corresponding to an R-value of 2.3)[8] and a U-value of 0.14 was used for unit A (corresponding to an R-value of 7).[9] The baseline value was used to both determine the losses for Unit B and to determine the losses for Unit A compared to a theoretical

[8] Cadeo, Energy Modeling of Commercial Gas Rooftop Units in a Representative Canadian Climate, July 18, 2019
[9] Unit A product literature

unit of the same size with minimal insulation. The surface area of unit A and B were 111 $ft^2$ and 86 $ft^2$, respectively.[10]

## 6.5 Damper Performance

Damper performance was examined by looking at the decay in unit temperatures over a 24-hour period following a heating mode period for both units during cold weather. While this did not lead to a precise measurement of damper effectiveness it does provide insight into the effects of low-leakage dampers.

# 7. Performance Results

## 7.1 Total Energy Savings

Compared to the baseline period, the weather-normalized whole building gas savings were 64 percent. These savings are significant and likely represent a variety of factors, including:

- Ductwork improvements leading to reduced leakage and wasted heat.
- Unit operational efficiency improvements. Even though the units had similar rated efficiencies to the ones they replaced, it is likely that the old units were not continuing to perform at their rated efficiencies.
- ERVs: as discussed in Section 8.3, the ERVs reduced heating load significantly, which contributed to these savings.
- Reduced unit infiltration and improved insulation. These were a smaller component of overall load reductions, but still impacted overall savings, as discussed below.
- Other operational factors not captured in the analysis, such as shifting operations or internal loads.[11]

## 7.2 Heating Efficiency

Both units had an average measured heating efficiency of 78 percent, slightly lower than their rated efficiencies of 81 percent, which is to be expected in a field trial. These heating efficiencies do not represent savings from the eRTU measures, as heating efficiency is a thermal efficiency metric representing the effectiveness at using natural gas to meet delivered load. All of the eRTU measures examined (ERV, increased insulation, and high-performance dampers) effectively reduce load, leading to annual savings, but do not affect heating efficiency. Average hourly heating efficiency is shown in Figure 18 and Figure 19.

[10] Unit A and B product literature
[11] While there were no specific changes that we are aware of, these could have contributed to total savings.

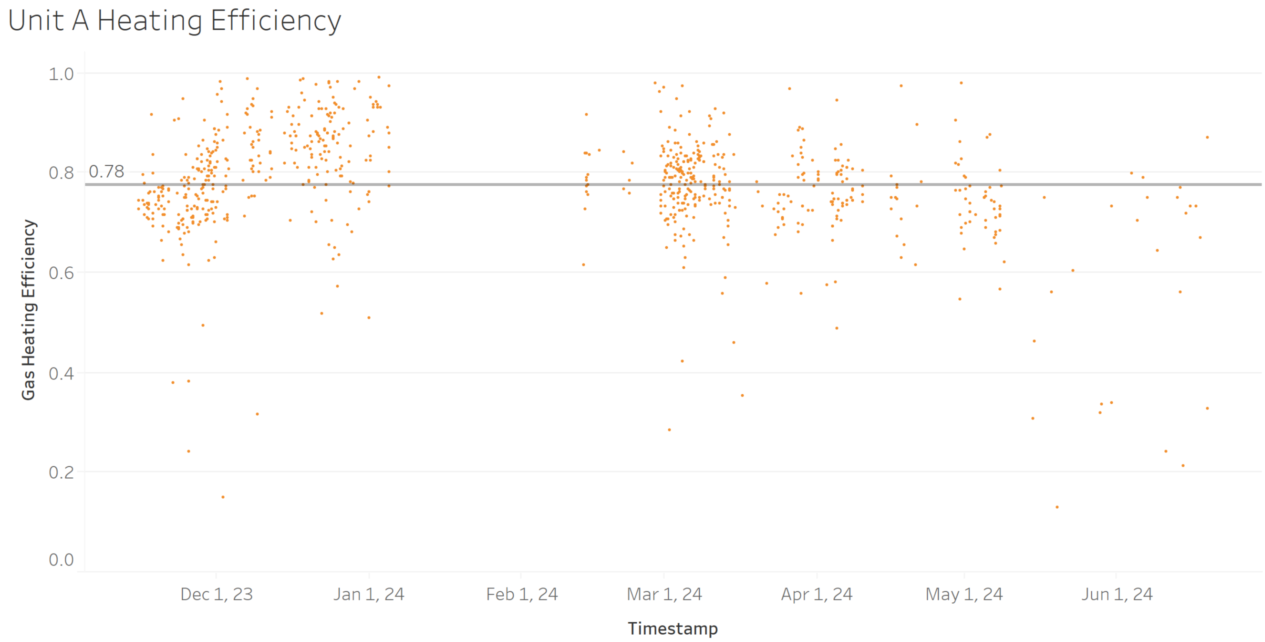


FIGURE 18: UNIT A AVERAGE HOURLY HEATING EFFICIENCY

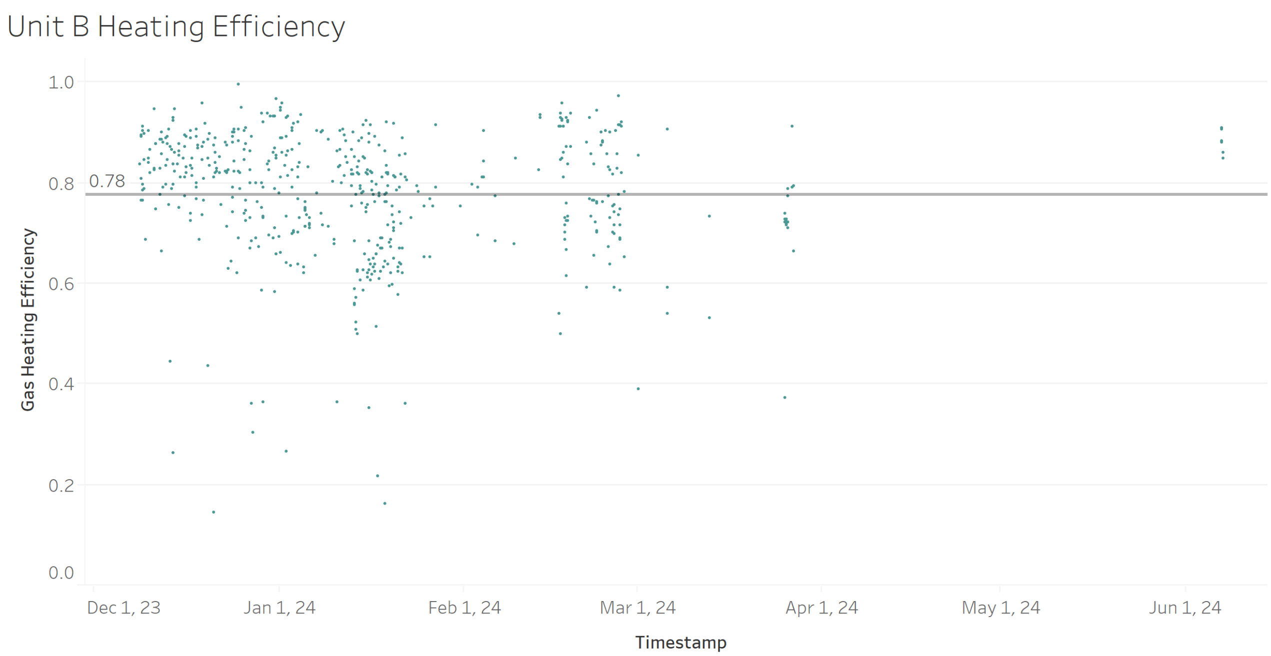


FIGURE 19: UNIT B AVERAGE HOURLY HEATING EFFICIENCY

## 7.3 ERV Effectiveness

Figure 20 and Figure 21 show calculated ERV effectiveness for Unit A (integrated ERV unit) and Unit B (bolt-on ERV unit), respectively, for the same time period (2/13/2024 – 3/23/2024) during which time both units were running regularly. The data below shows average hourly-level ERV effectiveness and are filtered for times when the supply fan was running. Based on this data, both ERVs were effective at recovering heat, with the integrated ERV having a higher average efficiency of 78 percent and the bolt-on ERV having an effectiveness of 64 percent. This is compared to rated sensible efficiency of 78 and 76 percent, respectively. However, these average efficiencies include many data points at much lower effectiveness in the 20 to 50 percent range. These low values are likely caused by interaction between the units when both units are on. Specifically, when the exhaust fan from one unit cycles on it likely starves the other unit of exhaust air, creating an imbalance between exhaust and outside air, which reduces effectiveness. It is logical that this would affect Unit B more, since that unit does not have the low-leakage dampers and insulation of Unit A, leading to the lower calculated effectiveness values for Unit B. To account for this, the data was filtered to screen out effectiveness values lower than 70 percent. These filtered effectiveness values are shown in Figure 22 and Figure 23, and were 82 and 80 percent, effectively, showing roughly equivalent performance between the integrated and bolt-on units.

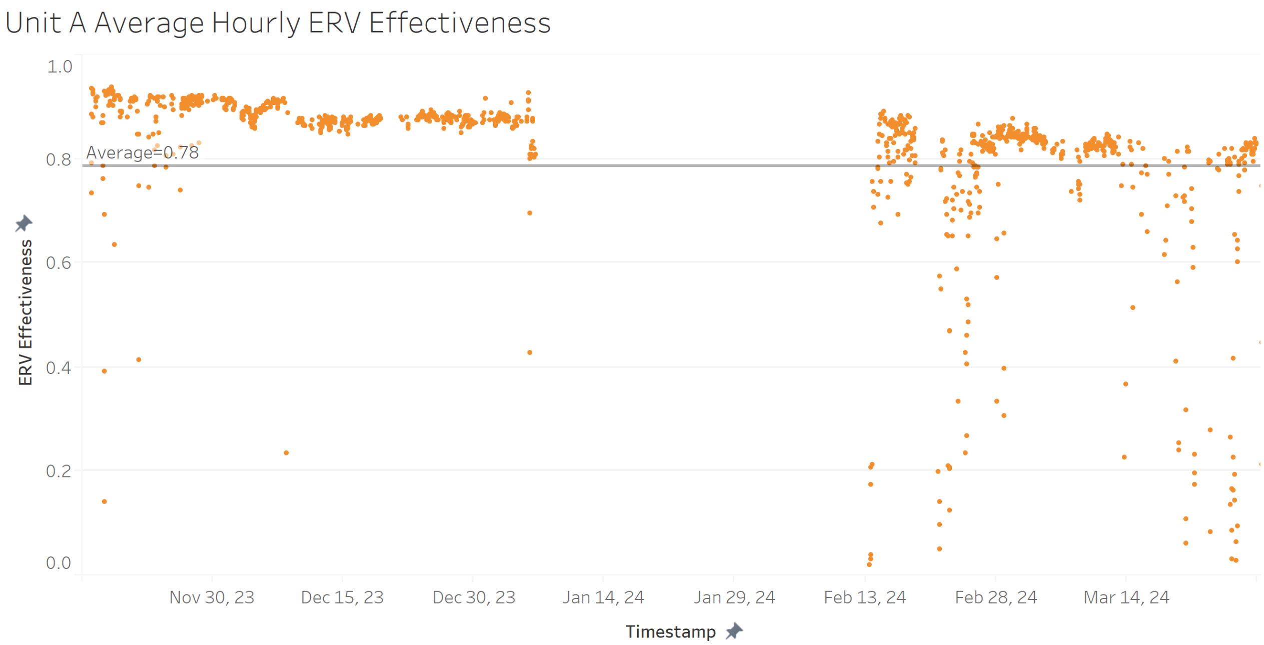


FIGURE 20: UNIT A (INTEGRATED ERV) AVERAGE HOURLY EFFECTIVENESS (UNFILTERED)

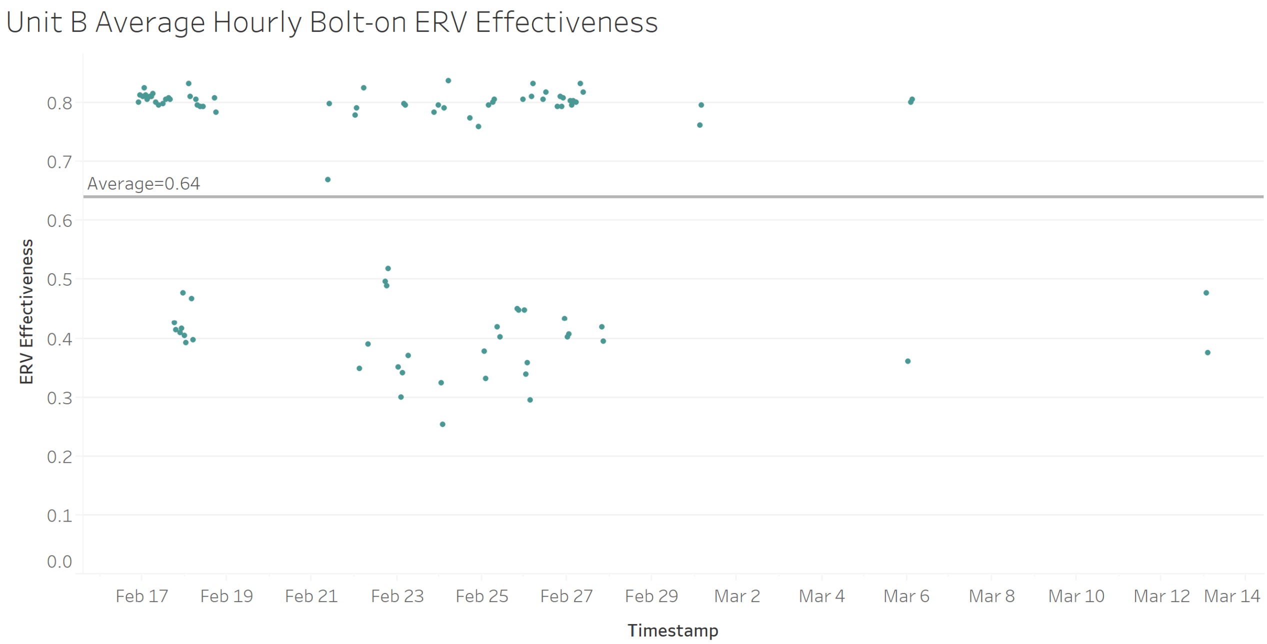


FIGURE 21: UNIT B (BOLT-ON ERV) AVERAGE HOURLY EFFECTIVENESS (UNFILTERED)

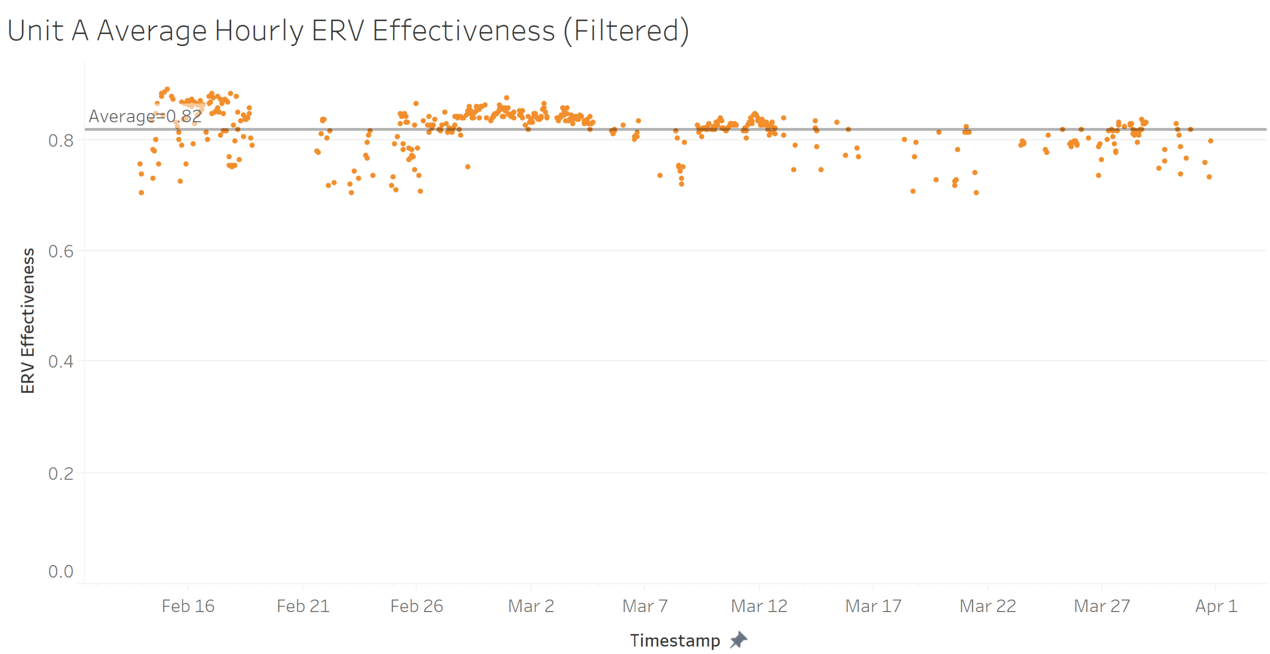


FIGURE 22: UNIT A (INTEGRATED ERV) AVERAGE HOURLY EFFECTIVENESS (FILTERED OUT <70%)

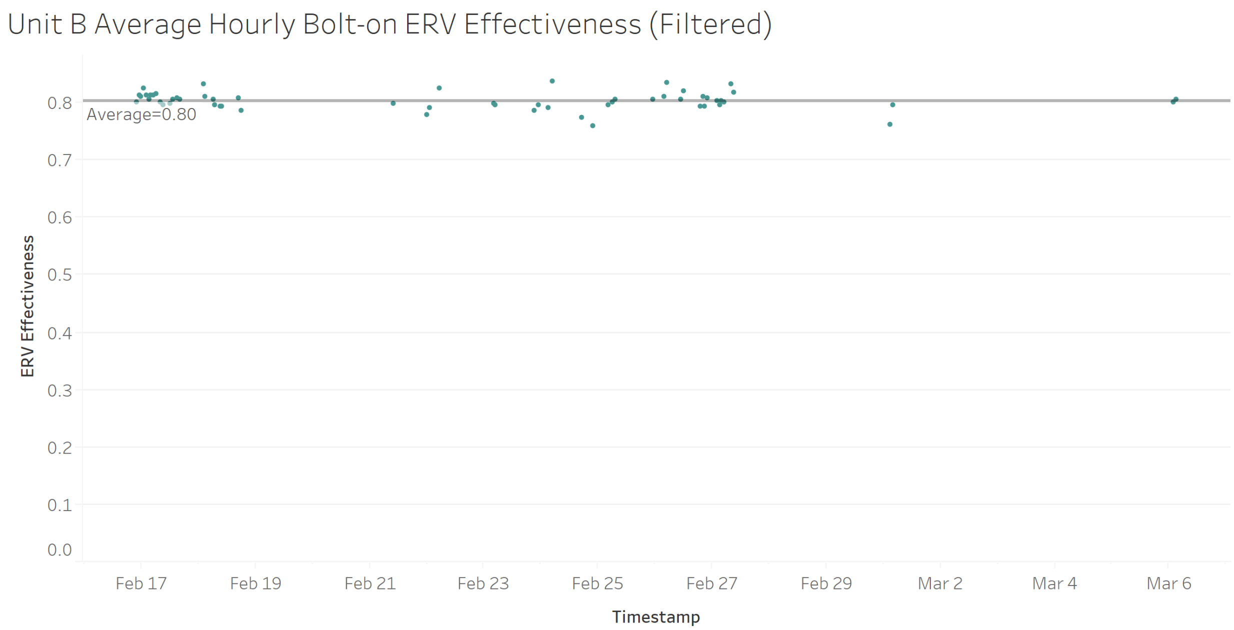


FIGURE 23: UNIT B (BOLT-ON ERV) AVERAGE HOURLY EFFECTIVENESS (FILTERED OUT <70%)

This ERV effectiveness led to significant overall energy savings:

- Unit A delivered 8,443 kBTU of heat over the course of the field study. During this time, the ERV recovered 1,943 kBTU from the exhaust air stream, resulting in savings on 19 percent, as shown in Figure 24.
- Unit B delivered 21,073 kBTU of heat over the course of the field study. During this time, the ERV recovered 6,163 kBTU from the exhaust air stream, resulting in a savings of 23 percent, as shown in Figure 25.

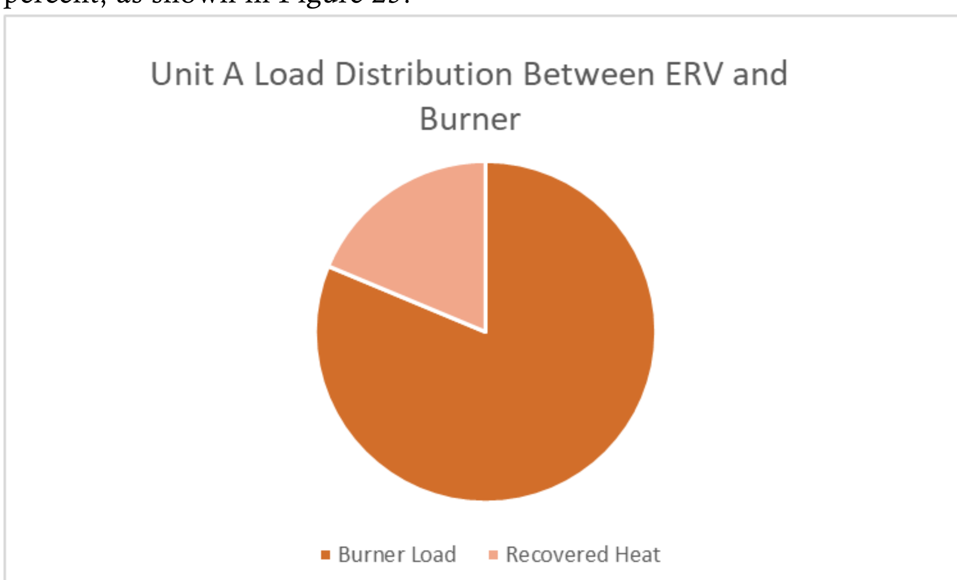


FIGURE 24: UNIT A LOAD DISTRIBUTION

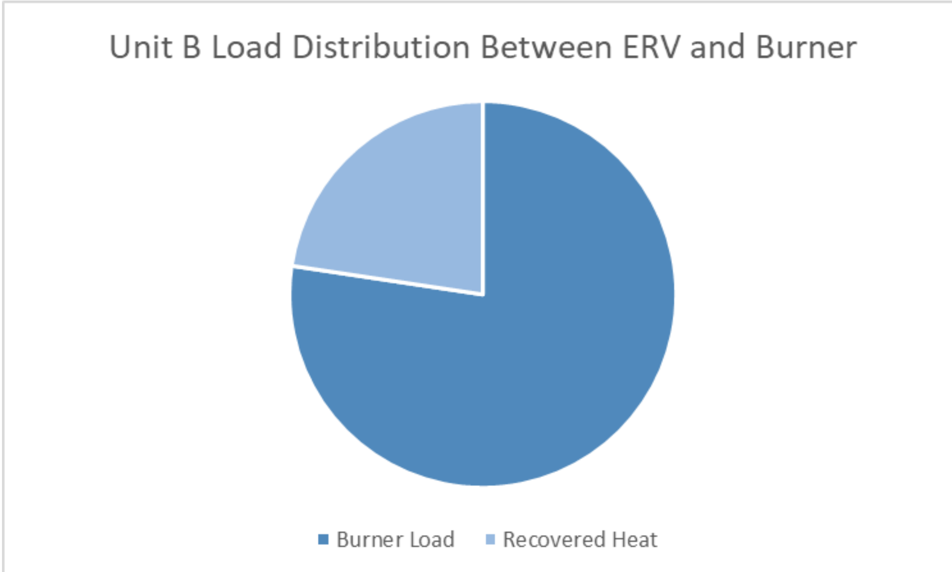


FIGURE 25: UNIT B LOAD DISTRIBUTION

The difference in delivered and recovered hourly load is shown in Figure 26 and Figure 27.

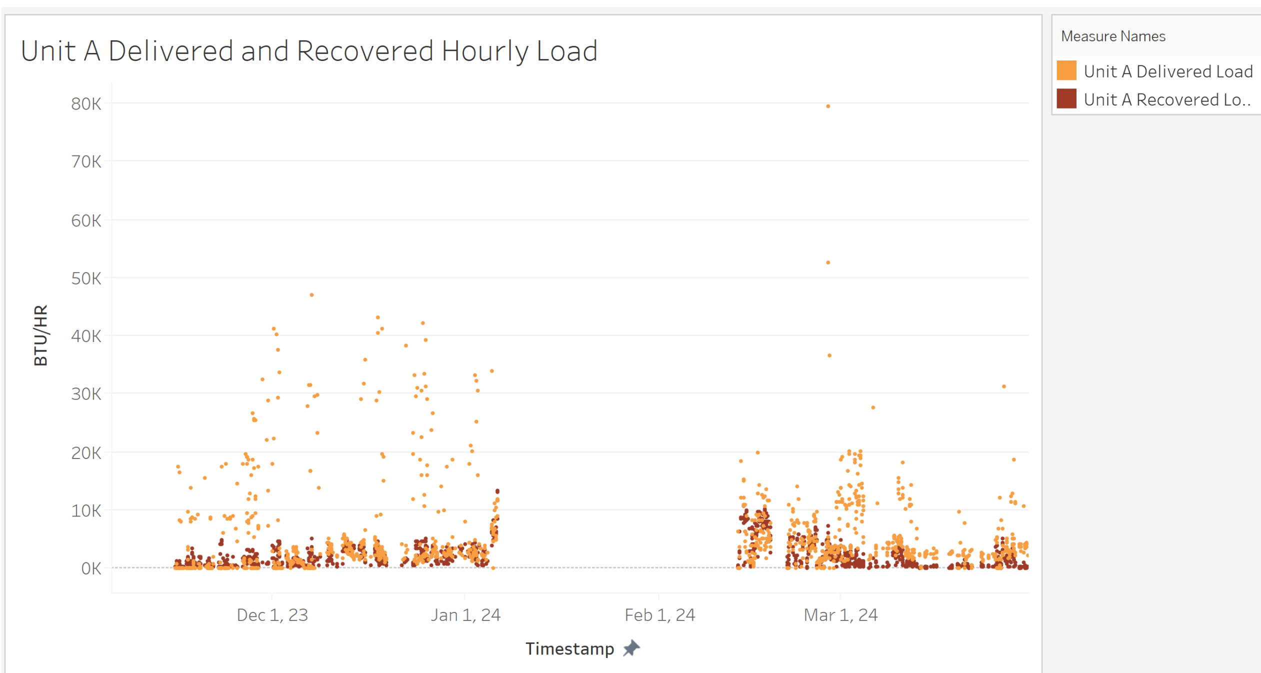


FIGURE 26: UNIT A DELIVERED AND RECOVERED HOURLY LOAD

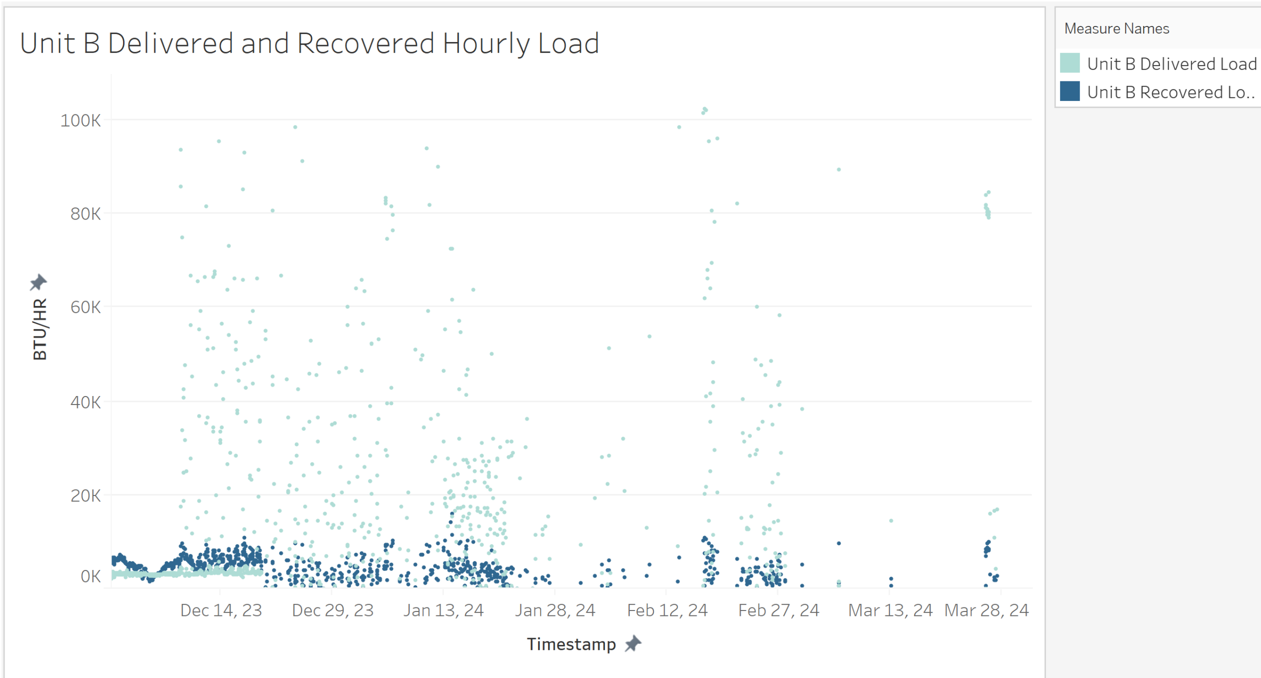


FIGURE 27: UNIT B DELIVERED AND RECOVERED HOURLY LOAD

## 7.4 Insulation Performance

Overall, the increased insulation in Unit A reduced heating energy use by 3.1 percent compared to a theoretical baseline unit with typical insulation as described in Section 6.4. This is in line with the expected performance of increased insulation. To show how this increased insulation led to a difference in losses across the two units, Figure 28, shows the average hourly cabinet losses for each unit.

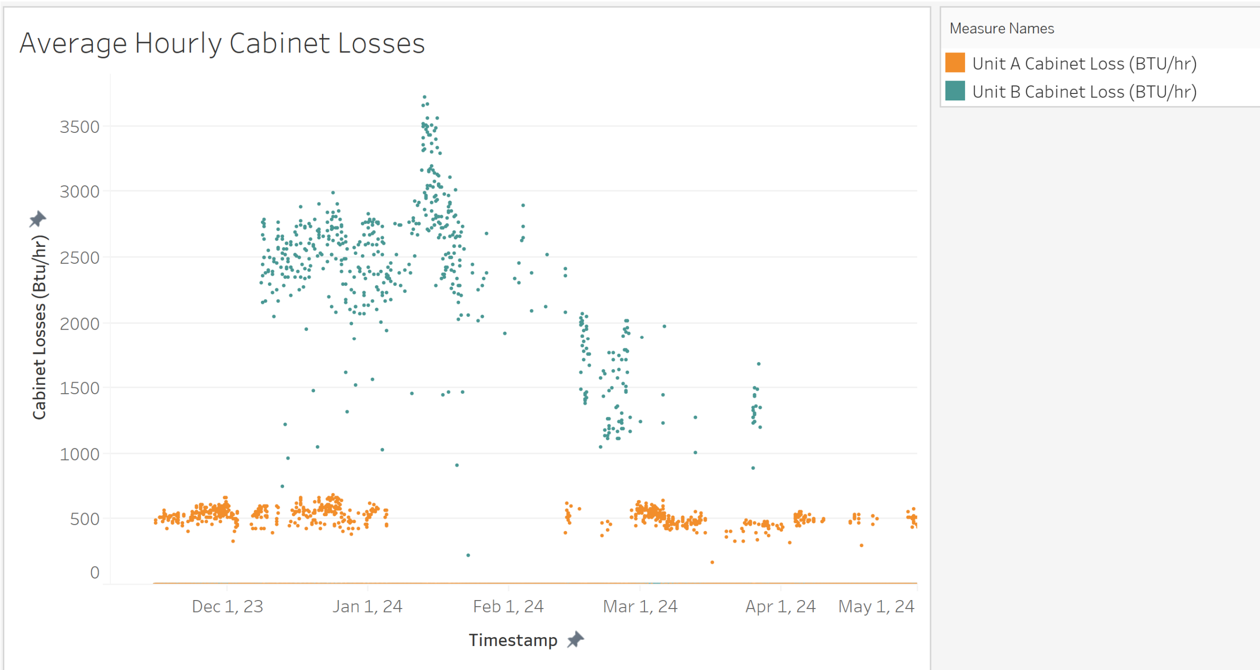


FIGURE 28: AVERAGE HOURLY CABINET LOSSES IN UNITS A AND B

## 7.5 Damper Performance

To examine damper performance, the change in unit return and supply air temperatures after a period of operation for both units was analyzed. Figure 29 shows such a period on January 6, 2024. In this graph, Unit B was operating in heating mode and Unit A was operating in ventilation mode until 2:57 AM. As can be seen in the graph, the supply and return air temperatures quickly drop for Unit B below those of Unit A, showing the increased infiltration in that unit. Most notable is the dramatic reduction in return air temperature of unit B in the hours following the unit shutting off. This indicates a meaningful amount of outside air infiltration through the outside air dampers and into the building. Also, during this time, the supply air temperature of unit B hovers around 70°F, indicating likely exfiltration from the building. In contrast, unit A, with low leakage dampers, shows quite stable temperatures, indicating minimal infiltration and exfiltration.

In cases where some RTUs are on and others aren’t, this creates slight pressure differences between building static pressure and outdoor air pressure. This can be seen starting at around 7 AM, when the Rheem unit turns on, Unit B return and supply air temperatures start to climb and eventually cross around 10 AM, with return starting to exceed supply, indicating air migration through the outside air dampers into the return duct and ultimately, the building.

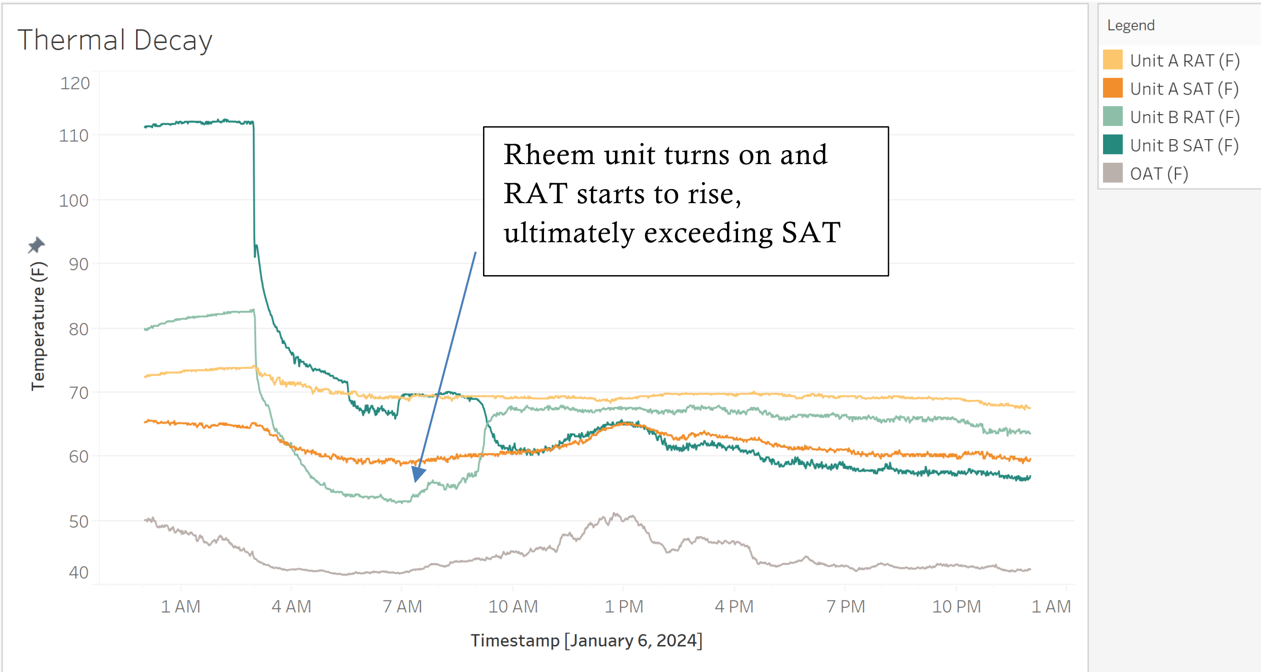


FIGURE 29: THERMAL DECAY OF SUPPLY AND RETURN AIR TEMPERATURES IN BOTH UNITS

# 8. Conclusions and Lessons Learned

Overall, the study found significant energy savings driven both by the features of the eRTUs and reduced duct leakage. The savings corresponding to ERV performance and increased insulation are in line with those expected based on previous field and lab research.[12] While savings from damper performance were not able to be quantified, performance data showed qualitatively that the improved dampers in Unit A significantly reduced outside air infiltration. Overall, this leads to the conclusion that eRTUs can achieve significant energy savings in the field, with ERVs being the highest contributor to energy savings.

Field tests such as this provide invaluable real-world lessons far beyond installed efficiency and performance. For example, the field study illuminated the effects of weight increases and consequent structural engineering analysis and potential upgrades needed. When the contractor saw the weight of the high efficiency unit, they advised the project team to select a much lighter unit to avoid that barrier. While in this case, the weight only resulted in $4,628 in structural engineering costs and minor delay, this would dissuade many potential projects from installing heavier custom units. While the bolt-on unit added less weight than the high-efficiency unit, it also exceeded the threshold for structural analysis. However, the lower weight could enable projects to determine that the existing structure is sufficient (in this case, the existing structure was sufficient for both units). If structural analysis triggered the need for upgrades, this would likely be a deal breaker for most real-world projects.

[12] Note that savings are not directly comparable to previous lab research and modeling because they are in terms of reduced heating energy rather than total HVAC energy use intensity.

Another important real world data point is cost. While the costs for this field study are not fully reflective of the market, since they were based on existing units available from a laboratory study, they still provide a data point. Costs are documented in detail in Appendix A. Notably, Unit A was over four times the cost of Unit B (without the bolt-on ERV). For Unit B, the bolt-on ERV more than doubled the cost of the unit. The major driver of such a large incremental cost for Unit A is the fact that the high efficiency unit was custom. To bring down costs long-term, high efficiency features need to be integrated into mass market units. Alternatively, modifying the specification to include the more efficient range of mass manufactured units would dramatically reduce incremental cost but would also reduce energy savings.

The RTU market is very different when considering replacements versus new construction. We would expect very limited adoption of custom units in the replacement market. However, the new construction market has several conditions that make it a much more attractive market for custom units.

- Custom units require an MEP design, as do all new construction buildings. Most RTU replacements skip a formal design process.
- New construction can afford the long lead times associated with custom units.
- New construction can design structurally for heavier rooftop units, avoiding the need for separate engineering and often structural upgrades.

# Appendix A – Equipment Cost

### 8.1.1 Unit A

Invoice Number: 0100427-IN
Invoice Date: 12/15/2020
Order Number: 0112772
Ship Date 12/11/2020
Salesperson: KT
Customer Number: NWEEA INC
Job Number: P00642

**Sold To:**

NW ENERGY EFFICIENCY ALLIANCE
421 SW SIXTH AVE, SUITE 600
Portland, OR 97204

**Ship To:**

Natural Gas Technologies Ctr
1350, Nobel Street, Office 150
Boucherville, Quebec J4B 5H3
PO #51650
QUEBEC,

**Confirm To:**
AMC NEEA RTU

**Job:**
NEEA RTU

| Customer P.O. | Ship VIA | F.O.B. | Terms |
|---|---|---|---|
| 51650 | BEST WAY | FACTORY | NET 30 |

| Item Number | Unit | Ordered | Shipped | Back Ordered | Price | Amount |
|---|---|---|---|---|---|---|
| [illegible] | EACH | 1.000 | 1.000 | 0.000 | 30,580.000 | 30,580.00 |
| [illegible] | EACH | 1.000 | 1.000 | 0.000 | 0.000 | 0.00 |

Need W-9 and EFT form - emailed CO 1/4tld
Rec'd & entered

**REVIEWED**
*By Roger Monette at 4:57 pm, Dec 30, 2020*

| | |
|---|---|
| Net Invoice: | 30,580.00 |
| Less Discount: | 0.00 |
| Freight: | 0.00 |
| Sales Tax: | 0.00 |
| Invoice Total: | 30,580.00 |

### 8.1.2 Unit B

Page 1 of 1

# Invoice

| | |
|---|---|
| Invoice Number | 311242456 |
| Invoice Date | 29-OCT-2020 |
| Customer No. | 833800 |
| Reference No. | CF13027 |
| Internal Account | 4189367 |
| Payment Terms | .5%10 NET30 |
| Payment Due Date | 28-Nov-2020 |
| Discount Date | 08-Nov-2020 |
| Customer Tax ID | |

Remit To [illegible]

**Bill To**

NORTHWEST ENERGY EFFICIENCY
ALLIANCE 421 SW 6TH AVE STE 600
PORTLAND, OR 97204
UNITED STATES

51649

| | |
|---|---|
| Inco Terms | FCA |
| Supply Location | Montreal SO, QC |
| Shipping Method | MWLK |
| Tracking No. | |
| Freight Terms | FA-PPD |
| Bill of Lading | |

**Sold To**
NORTHWEST ENERGY EFFICIENCY
ALLIANCE 421 SW 6TH AVE STE 60
PORTLAND, OR 97204
UNITED STATES

**Ship To**
ATT: NEEA
1350 NOBEL #150
BOUCHERVILLE, QC J4B 5H3

**CERTifyTax** - for submittal of tax exemptions certificates.
**iReceivables** - access invoice copies, account balances & make payments.

| | | | |
|---|---|---|---|
| GST ID: 10556 5931 RT0003<br>PST/QST ID: 1002896776 TQ0005 | GST: 399.53 5.00% | PST: 797.06 9.98%<br>BOUCHERVILLE | HST: 0.00 0.00% |

| Currency | Subtotal | Special Charges | Tax | Freight | Total |
|---|---|---|---|---|---|
| CAD | 7990.62 | 0.00 | 1196.59 | 0.00 | 9187.21 |

| Special Instructions | 5 Ton Gas RTU |
|---|---|

| Sales Order | Order Date | Ship Date | Purchase Order |
|---|---|---|---|
| CFB027 | | 28-OCT-2020 | 51649 |

| Line | Description | Quantity | UOM | Unit Price | Extended Price |
|---|---|---|---|---|---|
| 1 | Line Note: 00000000000:3-10 Ton R-410A PKGD Unitary Gas/Electri<br>Line Note: [illegible]<br>Model Number: [illegible]<br>Tag Number: [illegible] | 1 | EA | | |
| 2 | [illegible] st Year<br>Line Note: Labor warranty<br>Model Number: [illegible] | 1 | EA | | |

- Country of Origin: USA
- HTS Code: 8415.82.0115
- Receiver: Energy 350
  Fed Tax ID: 27-4038699 1033 SE Main St, Suite 1,
  Portland, OR 97214
  971-544-7211
- Add'l Note, unit was shipped to Canada for testing, now being moved to USA for final installation.

$9,187.21 CAD is $7,150.41 USD as of 12.21.2020
used Bank of Canada conversion tool

***REVIEWED***
***By TL Douglas at 8:44 am, Dec 15, 2020***

$7,150.41 USD

### 8.1.3 Engineering and Structural Costs

**Energy 350, Inc.**
1033 SE Main St. Ste 1
Portland, OR 97214
(971) 544-7211
chris@energy350.com

## Purchase Order

| VENDOR | SHIP TO | |
|---|---|---|
| McKinstry Co LLC<br>PO Box 3895<br>Seattle, WA 98124<br>United States | Energy 350, Inc.<br>1033 SE Main St. Ste 1<br>Portland, OR 97214 | **P.O. NO.** 1041<br>**DATE** 12/07/2021 |

| ACTIVITY | QTY | RATE | AMOUNT |
|---|---|---|---|
| Engineering and Structural for KBOO RTU Replacement | | | 4,268.00 |
| | TOTAL | | $4,268.00 |

Approved By

Date 12/7/21

#### 8.1.4 Unit Installation

**Energy 350, Inc.**
1033 SE Main St. Ste 1
Portland, OR 97214
(971) 544-7211
chris@energy350.com

ENERGY350

## Purchase Order

**VENDOR**
McKinstry Co LLC
PO Box 3895
Seattle, WA 98124
United States

**SHIP TO**
Energy 350, Inc.
1033 SE Main St. Ste 1
Portland, OR 97214

**P.O. NO.** 1042
**DATE** 04/08/2022

| ACTIVITY | QTY | RATE | AMOUNT |
|---|---|---|---|
| KBOO RTU Replacements | | | 55,632.00 |
| | **TOTAL** | | $55,632.00 |

Approved By

Date 4/8/22

### 8.1.5 Bolt on ERV

## *Proposal*

Proposal is valid for 15 days.

Customer must obtain credit approval and release order to production within 60 days of proposal date.

***Prepared For:***
All Bidders

***Date:*** December 30, 2022

***Proposal Number:*** Y2-97167-3639-1

***Job Name:***
Energy 350 ERV

***Delivery Terms:***
Freight Allowed and Prepaid - F.O.B. Factory

***Payment Terms:***
Net 30 Days

[illegible] pleased to provide the following proposal for your review and approval.

**Tag Data - Semco ERV (Qty: 1)**

| Item | Tag(s) | Qty |
|---|---|---|
| A1 | ERV-1 | 1 |

**Product Data - Semco ERV**
**Item: A1 Qty: 1 Tag(s): ERV-1**

Semco ERV SP-700
SEMCO standard panels of 20 gauge galvanized steel including armaflex insulation.
Enthalpy wheel with 3A molecular sieve, acid-resistant face coating, and drive motor.
Premium Efficiency, ODP supply and exhaust fan motors on dwdi type fans
29" wide x 31" tall x 70" long - weight 450 lbs
Outdoor construction including a weatherproof roof and weather hoods for outdoor intake and exhaust discharge openings
Pleated MERV 8 filters included
Pleated MERV 8 Filtration on the building exhaust side of the wheel
H Configuration Unit will be oriented to include Horizontal duct connections
Exterior finish is painted
A 30 Amp disconnect is shipped loose for installation by others
Outdoor damper is included with 2 position actuator
Stop/Jog Economizer Wheel Control
Rotation Detector with Alarm Relay
Pedestal Support
(208/3/60) Power

**Excludes:** Less (or by others): controls, seismic calculations/restraints/stamps, installation, installation of (fld) items, storage, rigging, start-up & labor warranty, commissioning, balancing, owner training, any item not specifically mentioned above.

Total Net Price *(Excluding Sales Tax)* ........................................ $ 6,250

**From:** Lindsey Bozich
**To:** Scott Jasinski
**Cc:** Chris Smith
**Subject:** RE: New project inquiry
**Date:** Friday, August 18, 2023 9:06:15 AM

Hi Scott,

As a rough estimate our tech's feel it would have taken 2 of them a full day.
Assuming electric is a wiring harness and plugging into existing, the cost would run approximately $2,800.00

I hope this helps.

Lindsey Bozich
Apollo Mechanical Contractors, Facility Services