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Condensing Rooftop Unit Field Study: Baseline and Final Report – 2018/2019 Heating Season

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) is a nonprofit working to increase awareness and adoption of energy-efficient technologies for a sustainable future in the Northwest. One of NEEA's market transformation strategies is support of emerging technologies through field-performance testing to demonstrate energy savings potential and to identify market barriers. NEEA has identified condensing rooftop units (C-RTUs) as an efficient natural gas technology with energy savings potential. C-RTU technology faces several challenges in becoming a widespread technology, including higher upfront cost, added complexity managing condensate, contractor unfamiliarity with technology, and limited manufacturer offerings.

To better understand these challenges and to evaluate field performance, user acceptance, reliability, and energy savings in the Northwest, NEEA hired Energy 350 to install and monitor four custom C-RTUs. This report summarizes the field study results from those four units over the 2018/2019 heating season. Section 0 describes the site locations, building characteristics, and existing RTU equipment that was replaced with custom C-RTUs.

Summary of Key Findings
The key findings from the C-RTU field study are as follows:

- C-RTUs provide consistent gas savings (11.0-11.5%, 438-717 therms/year at the four sites) relative to a standard efficiency RTU (81-82% efficient).
- Condensate disposal is the most significant barrier to reaching acceptable paybacks and may significantly reduce the number of feasible replacement RTU applications.
    - Added cost and complexity of condensate treatment and disposal is significant when following best practices and manufacturer recommendations ($3,724 on average).
    - This cost varied significantly in previous field studies (Nicor 2013, NEEA 2017A) depending on how local contractors and Authority Having Jurisdiction (AHJ) interpreted building codes; whether condensate was discharged into the closest storm drain or sanitary sewer; and whether neutralization was required ($429-$4,480).
    - Installing contractors will experience efficiencies as they become more familiar, but the cost and effort will remain a barrier for many RTU replacements.
- When all costs are considered (upfront equipment premium and installation, as well as added annual maintenance costs and fan electric penalty), paybacks are high (11.3-57.4 years).
    - Among these costs, fan penalty and maintenance costs are minor.
    - Equipment cost premiums will decrease, especially if more manufacturers of packaged RTUs enter the C-RTU market.

Performance and Energy Savings
All four C-RTUs performed above the manufacturer-stated efficiency (>91%) and saved 11.4% natural gas on average relative to a new standard efficiency RTU from the same manufacturer (baseline unit). The total gas savings are heavily dependent on the annual equivalent full load hours (EFLH) of the existing unit, which is driven primarily by percentage of outside air, annual hours of operation, and discharge air temperature setpoint. Table 1 summarizes the performance and energy savings results which are annualized and normalized for a typical weather year.

TABLE 1 – PERFORMANCE AND ENERGY SAVINGS (ANNUALIZED)

	Site A	Site B	Site C	Site D
Operation	100% OA	100% OA	30% OA	100% OA
Annual HDD_65	6,541	6,875	4,405	4,505
Annual EFLHs	1,798	1,235	1,665	2,659
Baseline unit nominal efficiency	82%	81%	82%	81%
Baseline unit annual gas consumption (therms)	5,386	4,163	6,499	3,742
Condensing RTU				
C-RTU field measured efficiency (annualized)	92.7%	91.5%	92.2%	91.7%
Annual gas savings (therms/yr)	622	476	717	438
Gas savings (%)	11.5%	11.4%	11.0%	11.7%

Notes: OA = outside air; HDD = heating degree days

Condensing RTU Replacement Economics

The replacement C-RTUs engendered annualized gas savings ranging from $186 to $557 ($333 on average) per year compared to the gas costs for new standard efficiency RTUs from the same manufacturer. Condensing equipment premiums averaged $3,035 and the additional condensate installation costs averaged $3,724. The site-specific simple paybacks (including a small fan electric penalty and annual maintenance costs) range from 11.3 to 57.4 years, as summarized in Table 2. See Section 4.2 for more detail on the incremental economics.

TABLE 2 – C-RTU INCREMENTAL ENERGY SAVINGS AND PAYBACKS (ANNUALIZED)

	Site A	Site B	Site C	Site D
C-RTU Manufacturer	ICEW	EngAir	ICEW	EngAir
Heating capacity output (MBH)	246	273	320	114
Annual EFLHs	1,798	1,235	1,665	2,659
Annual gas savings ($/yr)	$376	$186	$557	$214
Equipment premium	$3,000	$3,446	$3,000	$2,694
Added condensate installation cost	$4,480	$4,155	$2,704	$3,558
Fan penalty and maintenance ($/yr)	-$60	-$54	-$52	-$53
Simple payback (years)	23.7	57.4	11.3	39.0

Notes: ICEW = ICE Western; EngAir = Engineered Air

Condensate Management

The most significant potential barrier to widespread adoption of C-RTU technology is condensate management. The acidic condensate liquid produced by all high efficiency condensing gas technologies must be removed and often treated before disposal into the sanitary sewage system (not into stormwater runoff). The process is costly and requires additional planning and coordination from the installing contractor. The contractor did experience some efficiencies as the crew gained familiarity with the C-RTU. After the first installation, the contractor did most of the condensate planning and drainage installation before the actual unit arrived to avoid delays on the day of installation. The total labor required did trend downward with each installation, but not significantly. Additionally, constructability challenges with the condensate management system may also limit the number of existing RTUs suitable for replacement with condensing technology.

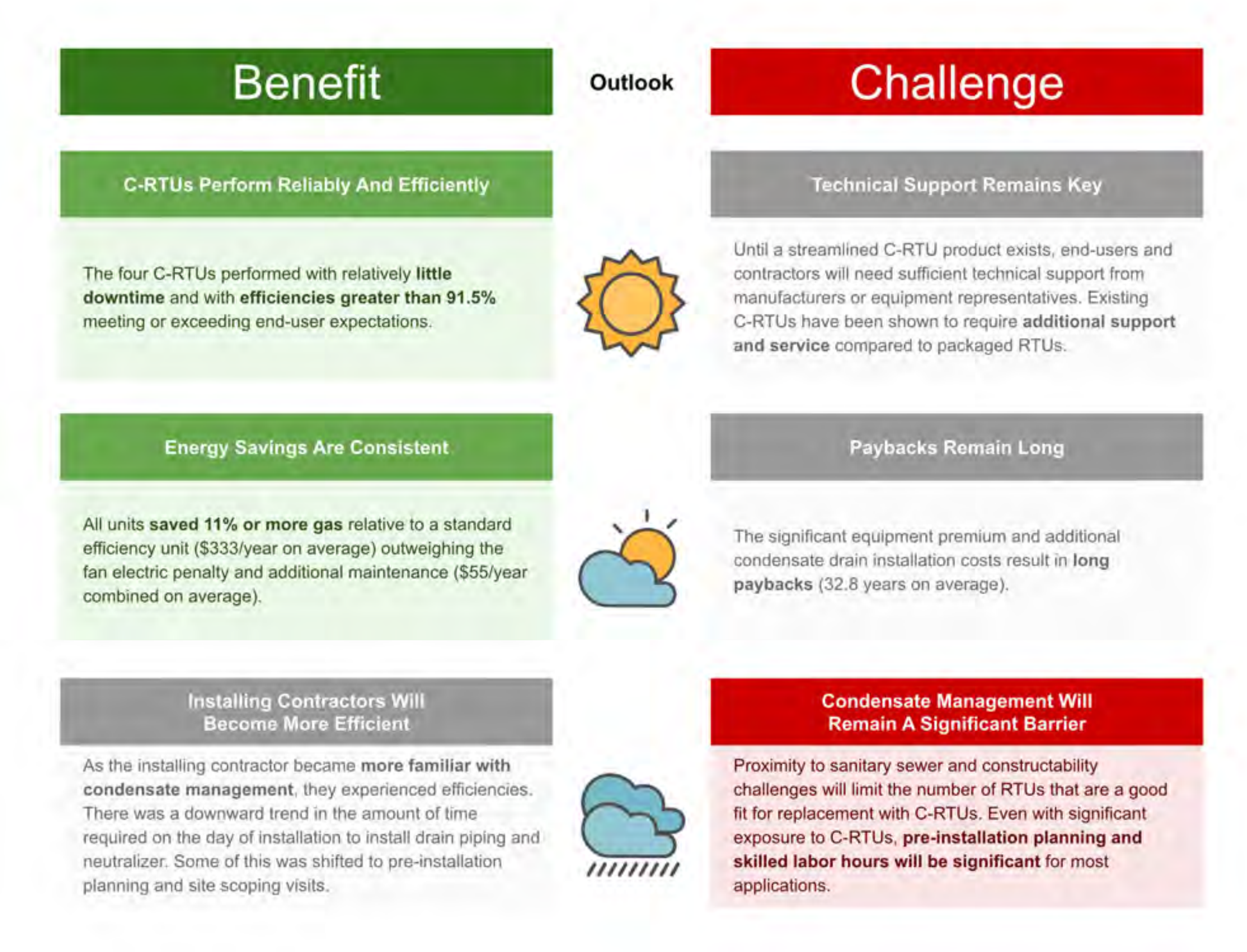
Reliability

The four C-RTUs performed satisfactorily over the 2018/2019 heating season and according to the site facilities managers, the equipment has performed at or above their expectations for a new standard efficiency RTU. However, all four units experienced downtime ranging from one to six days resulting from issues including burner alarms, controller errors, temperature sensor failures, and a fan belt failure. Most of these issues were not related to the condensing technology and were resolved quickly and with minimal impact to occupant comfort. However, multiple facilities managers expressed frustration working with their applicable C-RTU manufacturers' technical support in diagnosing issues during the field trial.

C-RTU Outlook

This field study provided important real-world experience in testing the viability of condensing RTUs in the Northwest market. Figure 1 summarizes some of the primary benefits and challenges based on our experience managing the design and installation of four C-RTUs, monitoring their performance over a nine-month monitoring period, and working closely with contractors, end users, and the manufacturers.

FIGURE 1 – PRIMARY C-RTU BENEFITS AND CHALLENGES



The performance of the C-RTUs in this field study is promising, and we are optimistic that installers and end users will become more confident in the technology as their familiarity increases and more manufacturers develop reliable equipment. Our outlook is also positive that equipment costs will continue to come down to help improve the incremental economics of upgrading to a C-RTU relative to a standard efficiency RTU. However, we are far less optimistic about the condensate management barrier, both in its impact on project economics and in the number of viable applications for C-RTU replacements.

1. Introduction

1.1 Background

The Northwest Energy Efficiency Alliance (NEEA) is a nonprofit working to mobilize the Northwest to become increasingly energy-efficient for a sustainable future. One of NEEA's market transformation strategies is supporting emerging technologies through field-performance testing to demonstrate energy savings potential and to identify market barriers. NEEA has identified condensing rooftop units (C-RTUs) as an efficient natural gas technology with energy savings potential. While condensing appliances with 90-97% efficiency are not new technologies in the boiler and water heater sectors, RTUs equipped with condensing burners that deliver ventilation air at greater that 90% are an emerging product.

The primary challenges C-RTU technology has faced in becoming widely adopted in the Northwest[1] are as follows:

- Upfront C-RTU equipment costs are higher than those of standard efficiency RTUs.
- Managing condensate liquid adds installation cost and complexity as well as introducing new design challenges and building-/application-specific barriers.
- Installing contractors and end users are unfamiliar with condensing RTU technology.
- A limited number of manufacturers offer condensing options on packaged RTUs.

To assess the magnitude of these challenges as well as to determine the field performance, user acceptance, reliability, energy savings, and simple paybacks of C-RTU technologies, NEEA selected Energy 350 to manage the installation and commissioning, as well as monitoring the operation of four high efficiency units across the Northwest. This report summarizes the field test results of these four units over the 2018/2019 heating season. Installation of the four RTUs took place in summer and fall of 2018; this report includes the results from five to nine months of field monitoring data (August 2018 through May 2019).

1.2 Objective and Scope

The primary objective of this field study was to assess the energy savings potential, reliability, and simple paybacks of two condensing RTU technologies in the Northwest. Additionally, we attempted to identify and understand the magnitude of several market barriers that condensing RTUs face to increasing uptake.

[1] These challenges are not unique to the Northwest RTU market nor to emerging energy-efficient technologies in general. The project economics are particularly challenging in the Northwest, however, with relatively inexpensive natural gas rates and mild winters (western Oregon and Washington).

For this field study, we performed the following actions:

- Screened and selected four locations suitable for new C-RTU installations:
  - Site A – Restaurant kitchen in Bend, OR (Cascade Natural Gas)
  - Site B – School faculty offices in Post Falls, ID (Avista)
  - Site C – School gymnasium in Gladstone, OR (Northwest Natural)
  - Site D – Retirement community residences in Renton, WA (Puget Sound Energy)
- Measured existing unit combustion efficiency and fan power with spot measurements
- Monitored the gas consumption of the existing units for a period of two to four months
- Selected and managed a traveling installation team to install the four C-RTUs[2]
- Installed metering equipment to monitor and quantify the performance of the C-RTUs

[2] Local electricians and sheet metal journeymen were utilized for two of the remote (to Portland) locations, but the same project manager and pipe fitter who were most involved with condensate management installation were used across the four installations to provide consistency.

2. Site Selection and Baseline Equipment

The four sites for the C-RTU installations were selected based on the following criteria:

- One in each service area for the four gas utilities: Avista, Cascade, Northwest Natural, and Puget Sound Energy
- Minimum of 30% outside air
- Preferred airflow of 4,000 cfm or less

Additionally, sites were screened based on the structural capacity of the roof to support the much heavier custom units (typically more than 2-3 times the weight of the packaged units being replaced) and access to a nearby drain to dispose of the liquid condensate. Over 15 sites were actively recruited, and many screened out mostly due to structural limitations. A few potential sites were also screened out due to limited access to a nearby floor drain for discharging condensate. The four selected sites are located across three states and two climate zones, and the building types and applications are all unique. Key site characteristics, as well as existing RTU descriptors, are summarized in Table 3 and photos of the baseline RTUs are shown in Figure 2.

TABLE 3 – SITE AND EXISTING EQUIPMENT SUMMARY

	Site A	Site B	Site C	Site D
General				
Location	Bend, OR	Post Falls, ID	Gladstone, OR	Renton, WA
IECC Climate zone	5B	5B	4C	4C
Annual HDD_65	6,541	6,875	4,232	4,505
Gas Utility	Cascade	Avista	Northwest Natural	Puget Sound Energy
Application	Restaurant Kitchen	School Offices	School Gymnasium	Retirement Housing
Building constructed	1988	1999	1996	2006
Area RTU serves (sq. ft.)	1,500	13,500	7,500	6,000
Existing RTU				
Year installed	2001	1999	1996	2006
Heating capacity (btu/hr)	275,000	273,000	320,000	89,000
Nominal airflow (cfm)	3,250	4,150	12,000	1,670
Outside air percentage	100%	100%	30%	100%
Nominal efficiency	~100% (Direct Fired)	80%	80%	80%
Measured efficiency (spot)	N/A	72.9%	70.8%	73.1%

FIGURE 2 – EXISTING RTUS

SITE A SITE B

SITE C SITE D

2.1 Site A – Restaurant kitchen makeup air unit in Bend, OR

The Site A baseline RTU provided 100% outside air to a restaurant kitchen to make up the range exhaust hood air extracted from the space. The CaptiveAire unit had nominal capacity of 275,000 btu/hr, rated airflow of 3,250 cfm, and was a direct-fired unit with combustion taking place directly in the supply air.[3] Heating was provided to temper makeup air to approximately 65°F during the winter based on a discharge air temperature setpoint, and the unit also contained an evaporative cooler that provided air-conditioning during the summer. The kitchen is approximately 1,500 ft^2 in area and is occupied from 7am to midnight seven days per week. The RTU ran 24/7 year-round and consumed approximately 4,417 therms and 15,418 kWh annually.

2.2 Site B – School office ventilation RTU in Post Falls, ID

The Site B existing unit was a 100% outside air RTU that provided tempered ventilation air (heating only) to 13,500 ft^2 of faculty offices and break rooms. The space heating and cooling for these spaces are provided by 11 water source heat pumps (WSHP). The RTU had nominal capacity of 273,000 btu/hr and rated airflow of 4,150 cfm and was an 80% nominally efficient indirect-fired unit. The unit was controlled to a discharge air temperature setpoint (adjustable) typically set between 55-75°F

[3] Direct-fired units are common practice in kitchen applications with 100% outside air (no recirculation) and high air changes. This unit provided over 13 air changes per hour.

depending on ambient conditions and on the ability of the WSHPs to maintain space temperature. The unit typically operated between 6am and 4pm in mild conditions, but the facilities manager will often start the building RTUs at 4am or 2am in colder weather to pre-heat the offices for early-arriving faculty. In the coldest conditions, the units ran 24 hours per day to assist the WSHPs in maintaining space temperature. The unit typically did not run on weekends or during the summer, expect for occasional events (staff in-service, conferences, etc.). We calculated a typical annual energy consumption of 4,627 therms and 7,829 kWh.

2.3 Site C – School gymnasium RTU in Gladstone, OR

The existing unit at Site C was a 12,000 cfm RTU that delivered ventilation and heating to a 7,500 ft^2 school gymnasium. The unit provided 30% minimum outside air to make up for two large exhaust fans, and a maximum of 83% outside air when economizing. The unit provided 320,000 btu/hr of capacity (heating only), with a nominal efficiency of 80%. The unit was controlled based on a discharge air temperature setpoint, typically 68°F, and operated 4am to 6pm seven days a week. The gym is used for community and school events most weekends and the unit was shut off over school holidays and most of the summer. The calculated annual energy consumption of the baseline unit was 7,465 therms and 50,534 kWh.

2.4 Site D – Retirement community ventilation RTU in Renton, WA

Site D is a retirement community located in Renton, WA and the existing unit was a 100% outside air RTU serving four floors of residences. The unit provided 1,670 cfm of heating and ventilation air to approximately 6,000 ft^2 of conditioned space with 89,000 btu/hr of capacity at 80% nominal efficiency. The residences have individual air-conditioners for the summer and the RTU was typically shut down from May through September. The unit was controlled based on a discharge air temperature setpoint (typically 75-85°F) and operated 24/7 the other seven months of the year. The calculated typical weather year annual energy consumption was 4,145 therms and 4,806 kWh.

3. Methodology

This section describes the methodology we used to calculate the annual energy savings and simple paybacks of the four C-RTUs relative to a new standard efficiency RTU as well as to the existing RTU that was replaced.

3.1 Existing RTU Measurements and Metering

For each of the four existing units we measured the instantaneous combustion efficiency, supply fan power, and overall RTU power using the equipment listed in Table 4. We used these spot measurements to calculate the annual energy consumption of the existing, non-condensing RTUs based on the weather-correlated run time and heating loads measured on the C-RTUs during the 2018/2019 heating season.

TABLE 4 – EQUIPMENT FOR SPOT MEASUREMENTS

Measurement	Equipment Manufacturer	Model	Accuracy
Combustion Efficiency	Bacharach	PCA3	±2%
Fan Power	Flir	CM82	±2%
Overall RTU Power	Flir	CM82	±2%

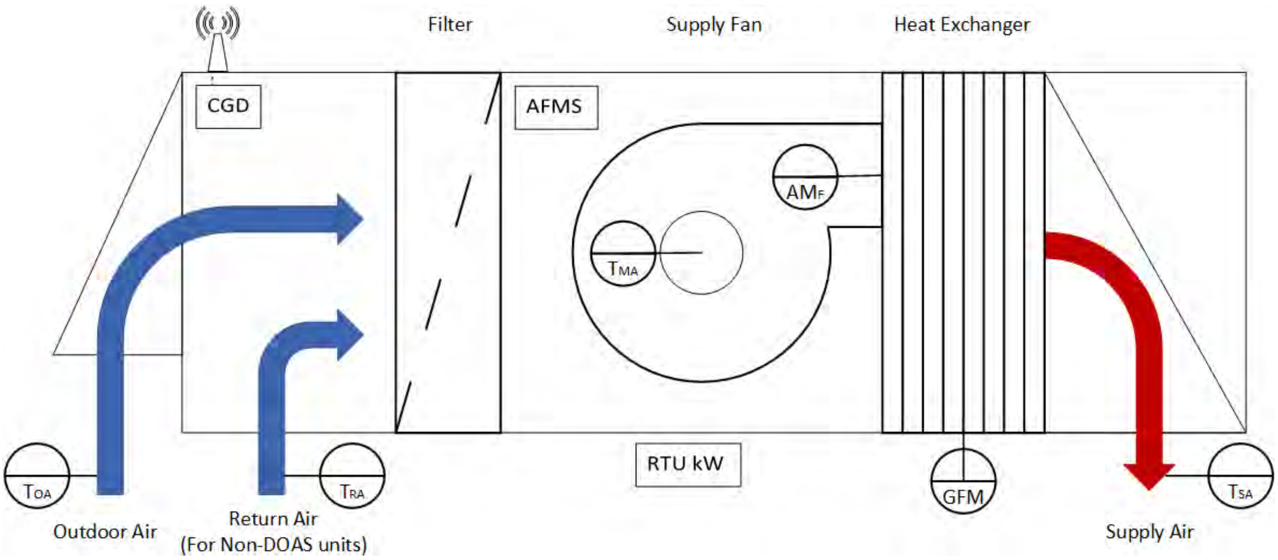
In addition to spot measurements, we installed temperature-corrected gas flow meters on each of the four existing RTUs to measure input gas energy. However, other than Site D, these data proved to be of limited usefulness because the C-RTUs at Sites A, B, and C were installed in late summer and early fall and we therefore collected very little gas consumption data.

3.2 C-RTU Metering Equipment and Data Acquisition

To calculate the efficiency and delivered heating load of the four C-RTUs, we installed long-term metering equipment to monitor the gas energy input, airflow, heating section temperature difference, RTU electrical power, and supply fan power. Figure 3 shows the typical data points we monitored[4] and Section 3.3 describes the energy balance calculations in detail.

[4] Only Site C has return air, and Site A contains an evaporative cooling section, so each unit's metering points differ slightly. However, Figure 3 encapsulates the important metering points and is simplified for clarity.

FIGURE 3 – DATA METERING POINTS



CGD – Cellular Gateway Device – This device acts as the hub to receive, interpret, and scale the signals from all sensors, and to transmit the data to a web interface for safekeeping and easy remote access. Data are measured real-time, in one- to five-minute intervals, and uploaded to a secure web-based platform every four hours. The device has over one month of on-board data storage.

T_{OA} – Outside Air Temperature – This sensor was either installed within the outside air stream under the weather hood to avoid direct solar exposure or at the intake of the supply fan on the 100% outside air units (Sites A, B & D). For these sites, this value was used to calculate the gross temperature difference across the heat exchanger. For Site C, which is a 30% outside air unit, outside air temperature is used primarily for calibrating the air temperature increase from fan heat and for calculating the percentage of outside air being delivered.

T_M – Mixed Air Temperature – For 100% outside air units, this is the same as outside air temperature. For Site C, which recirculates 70% return air, this sensor is located at the fan inlet to better capture the mixed air inlet temperature to the heating coil.

T_S – Supply Air Temperature – This sensor measures the air temperature exiting the heating section of the C-RTU. To ensure accuracy, we installed this sensor between 5 and 10 feet after the heat exchanger and not in direct line of sight to avoid radiant errors and to ensure air is well-mixed.

T_{RA} – Return Air Temperature – While not used in performance calculations, this data point allows us to calculate percentage of outside air; it also serves as a proxy for space temperature.

AFMS – Air Flow Monitoring Station – Airflow metering, rather than spot measurements, is necessary to calculate heating delivered as filters become dirty and conditions change.

GFM – Gas Flow Meter – We installed temperature-corrected diaphragm gas meters with pulse output to accurately measure energy into each unit. Monitoring gas valve status would have been easier and cheaper, but would not provide sufficient accuracy to calculate efficiency, particularly for modulating gas units.

AM_F – Fan Amp Meter – The data point collected by this device provides critical insight into fan operation and allows us to accurately calculate the fan energy penalty associated with C-RTU technology.

RTU kW – We monitor real power of the entire RTU to aid in quantification of the fan energy penalty as well as to provide additional insight into overall RTU operation.

T_{CD} – Cooler Discharge Temperature – Site A included an evaporative cooler to provide some air conditioning to the kitchen during the summer. The sensor is omitted from Figure 3 as it was specific to Site A and not critical to performance calculations.

We logged all data points using the Hobo RX3000 cellular data logging station. This data acquisition system allowed 24/7 access to all data points via a secure web browser and instant alarm notifications in case of sensor or RTU component failures, which helped mitigate the risk of lost data during the monitoring period. All sensors have accuracies of ±2% or better. Table 5 lists the sensors, meters, adapters, and modules used to monitor the performance of the four C-RTUs.

TABLE 5 - MONITORING EQUIPMENT SCHEDULE

Monitoring Point	Sensor/Meter	Model	Adapter/Module	Accuracy
Outside Air Temp Return Air Temp Mixed Air Temp[5] Supply Air Temp	Onset	S-TMP-M002 12-Bit Temp Sensor	None required	±0.36°F
Airflow	Comefri model 99998035 (ICEW) or Greystone LP3 (EngAir)		Onset RXMOD-A1 Analog Module (0-10Vdc signal)	Not stated
Gross Fuel Input	Honeywell	AC250 Natural Gas Flow Meter	Onset S-UCC-M006	Not stated
Fan Power RTU Power	Continental Control Systems	CTML--0350-20 Split-Core CTs	WattNode WNB-3D-240-P Real Power Meter	CTs: ±1% from 10 to 100% Rated Current Meter: ±0.5%

Notes: ICEW = ICE Western; EngAir = Engineered Air

[5] Sites A, B, and D are 100% outside air units and required only two temperature sensors (OAT and SAT).

Figure 4 through Figure 8 show example sensors and meters installed in the field.

FIGURE 4 – DISCHARGE AIR TEMPERATURE PROBE INSTALLED AT MIDPOINT OF SUPPLY AIR DUCT

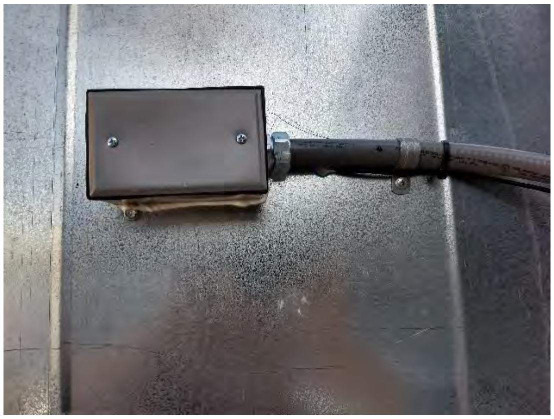


FIGURE 5 – MANUFACTURER-INSTALLED AIRFLOW METER W/ PULSE OUTPUT

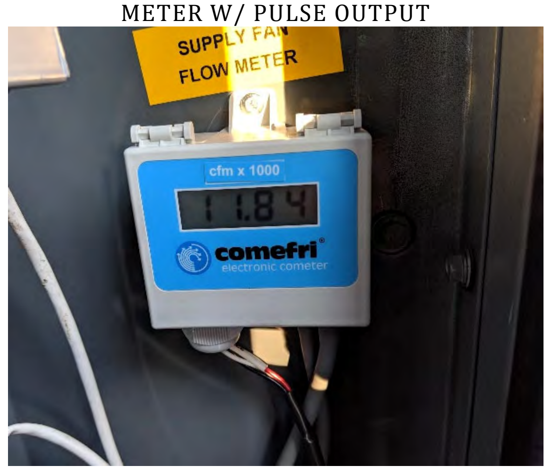


FIGURE 6 – GAS FLOW METER

FIGURE 7 – REAL POWER METER

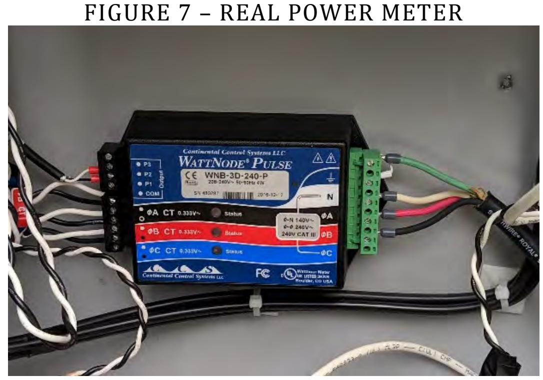
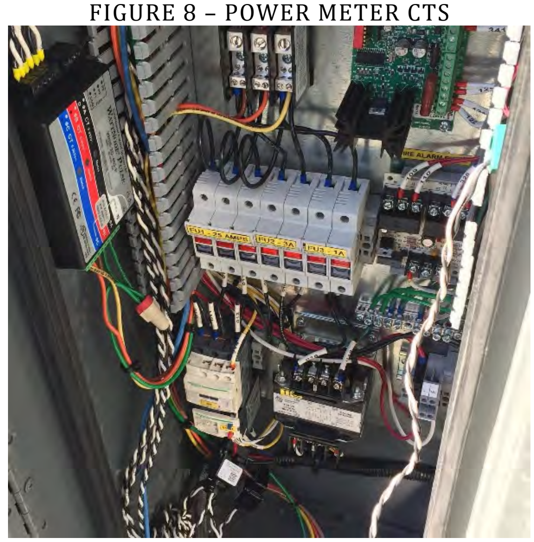


FIGURE 8 – POWER METER CTS



3.3 C-RTU Performance and Energy Savings Calculations

We define the term *Annual Field Measured Efficiency* (AFME) as the site-specific expected annual efficiency based on measured performance over the 2018/2019 heating season and applied to a typical weather year.[6]

$$[Eq\ 3.1]\quad Annual\ Field\ Measured\ Efficiency = \frac{\sum Annual\ heat\ output\ (btu)}{\sum Annual\ gas\ energy\ input\ (btu)}$$

We calculate AFME using the following methodology:

1. Calculate C-RTU heat output energy over a five-minute interval based on airflow, temperature, and humidity data net of supply fan heat (see equations 4.1 and 4.2).
2. Calculate C-RTU gas input energy based on temperature-corrected natural gas flow meter and utility-provided gas heat contents (higher heating values provided daily or monthly depending on utility).
3. Sum heat output, gas heat energy input, and heating degree days to daily totals.
4. Calculate daily efficiency using the ratio of net heat output to gas input.
5. Calculate relationships of daily heating load and daily efficiency compared to daily heating degree days (HDDs) (i.e., BTUs vs. HDD_65, Efficiency vs. HDD_65°F, base depending on site's balance point[7]).
6. Apply heating load relationship to the total daily heating degree days for each of the 365 days in a typical weather year (TMY3, Wilcox 2008) for the nearest weather station to calculate daily heat output.
7. Apply efficiency relationship to total daily heating degree days for each of the 365 days in a typical weather year for C-RTU (utilize nominal efficiency for new standard efficiency unit and field combustion efficiency spot measurement for existing baseline unit).
8. Divide daily heating load by daily efficiency to calculate daily input gas energy.
9. Calculate daily fan energy relationship to daily heating degree days for C-RTU (use manufacturer-provided pressure drops to calculate fan reduction for non-condensing new baseline unit, and unit power spot measurement for existing baseline unit).
10. Sum the 365 days of heating output and gas energy input; calculate ratio of output to input to obtain AFME.

[6] TMY3 or "typical meteorological year" comes from the National Solar Radiation Database (NSRDB) and provides a type of average annual weather based on data from 1991-2005.
[7] Balance point is an imaginary temperature at which no heating is required to maintain space temperature due to internal loads. We select the appropriate HDD base depending on which value gives an approximate daily heating output of zero when there are zero HDDs (y-intercept is approximately zero).

3.3.1 Heat Output

The heat output rate was calculated net of supply fan heat on a five-minute time interval during the 2018/2019 heating season for each of the four sites by using the difference in the C-RTU burner intake and discharge air enthalpies. The unit supply air mass flow is calculated based on volumetric airflow measurements from a temperature-corrected airflow meter provided and installed by the C-RTU manufacturer and adjusted based on ambient air density as shown in Equations 4.2 and 4.3.

$$[Eq\ 4.2]\quad \dot{Q}_{output} = \dot{m}_{intake\ air} \times \left(h_{supply\ air} - h_{intake\ air}\right) - \dot{q}_{supply\ fan}$$

where:

$\dot{Q}_{output}$ = heating output rate, net of supply fan energy $\left(\frac{btu}{hr}\right)$

$\dot{m}_{intake\ air}$ = massflow of intake air $\left(\frac{lbs}{hr}\right)$

$h_{supply\ air}$ = enthalpy of supply air based on air temperature and absolute humidity $\left(\frac{btu}{lb}\right)$

$h_{intake\ air}$ = enthalpy of air entering heating section [outside air for 100% OA units, mixed air for others] $\left(\frac{btu}{lb}\right)$

$\dot{q}_{supply\ fan}$ = supply fan heat deducted from heat output calculation[1] $\left(\frac{btu}{hr}\right)$

$$[Eq\ 4.3]\quad \dot{m}_{intake\ air} = \dot{V}_{intake\ air} \times \rho_{intake\ air}$$

where:

$\dot{V}_{intake\ air}$ = volumetric flow of intake air, temperature-corrected $\left(\frac{ft^3}{hr}\right)$

$\rho_{intake\ air}$ = density of intake air based on air temperature and humidity $\left(\frac{lb}{ft^3}\right)$

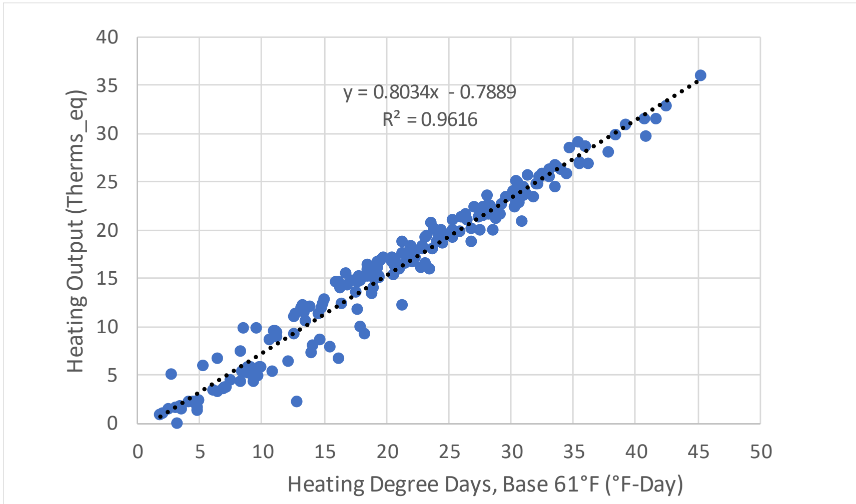
3.3.2 Gas Energy Input

We installed temperature-corrected diaphragm gas meters to monitor the volumetric gas flow (cubic foot pulses) into the C-RTUs on a five-minute interval. All meters used are temperature-compensated and equipped with electronic pulse output. We use the gas energy content values (higher heating values) provided by the site utilities and adjust for line pressure to account for the difference in pressure between utility meters (typically 2 psig) and our gas meters (typically 0.25-0.5 psig).

3.3.3 Heating Load-Weather Relationships

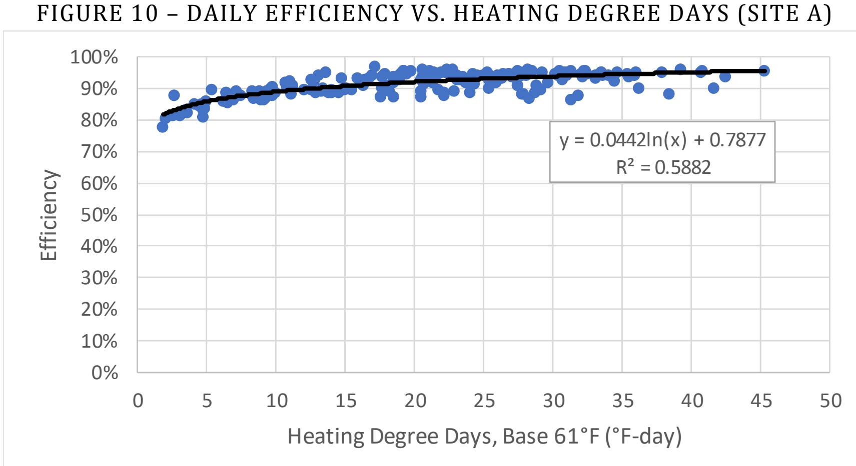
To smooth out shorter time intervals with partial operation while still capturing total performance, we sum five-minute interval heating load to daily totals and compare to the daily heating degree days. Heating degree days quantify the heating demand of a building based on the duration and magnitude that the outside air temperature is below a reference temperature. Figure 9 gives an example relationship by showing the daily heating load in therms equivalent (100,000 BTUs) relative to the daily heating degree days, base 61°F (HDD_61) for Site A. Site D operates 24/7 during the winter and is controlled to a fixed discharge air temperature setpoint and therefore shows a highly correlated relationship.

FIGURE 9 – DAILY HEATING OUTPUT VS. HEATING DEGREE DAYS (SITE A)



Similarly, we calculate the daily efficiency relationship to heating degree days. Figure 10 shows an example relationship plotting Site A's daily heating efficiency compared to the daily HDD_61. Efficiency is relatively flat at this site except for the warmer days (lower HDDs). On these warmer days, the burner has very few run-hours and cycles more often than on colder days despite the C-RTU's high turndown (35:1). The higher cycle rate results in some inefficiencies as the burner goes through a purge sequence before running the burner. However, this inefficiency has very little effect on the annual performance as a majority of the heating load occurs on higher HDD days and the annual performance is significantly weighted toward these higher efficiency days.

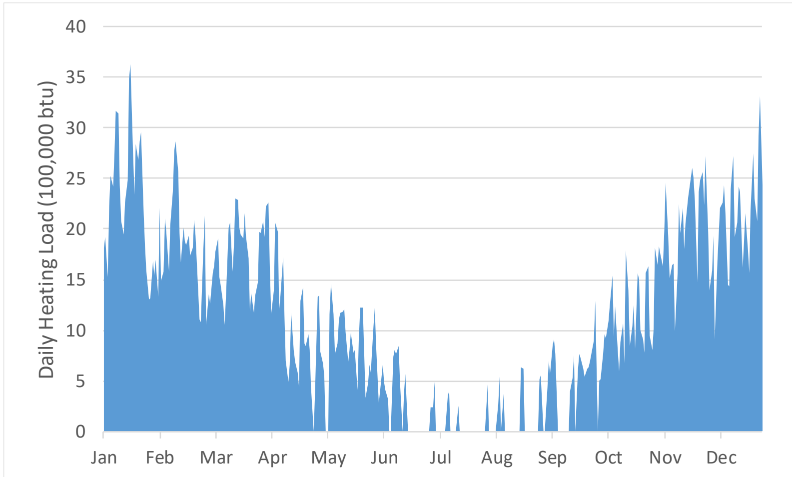
FIGURE 10 – DAILY EFFICIENCY VS. HEATING DEGREE DAYS (SITE A)



3.3.4 Annual Energy Calculations

We use the daily heating load and efficiency regression equations to calculate an annual load profile and C-RTU performance profile based on TMY3 data for the nearest weather station. Figure 11 shows the annual heating load profile for Site A and displays the daily heating load required for a typical weather year in delivered equivalent therms per day.

FIGURE 11 – ANNUAL HEATING LOAD PROFILE (SITE A)

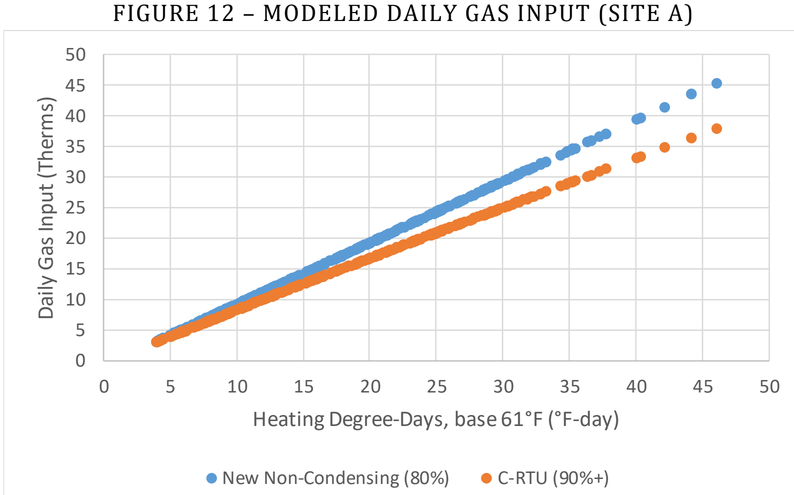


We then calculate the daily C-RTU gas energy consumption by dividing the daily heating load (shown in Figure 11) by the daily efficiency (determined by the daily total HDD and daily efficiency regression equation shown in Figure 10). Equation 4.4 provides the general equation we used to determine gas input.

$$[Eq\ 4.4]\ \ Gas\ input\ (therms) = \frac{Heating\ load\ (therm_{eq})}{Efficiency_{C-RTU,Daily}}$$

For the existing RTU, we use a field measured combustion efficiency[8] and for the new non-condensing baseline RTUs we used the manufacturer-stated nominal efficiency for a similar RTU from the same provider (80% for all sites). Figure 12 shows the Site A modeled daily gas input compared to heating degree days for both the standard non-condensing unit and the C-RTU.

FIGURE 12 – MODELED DAILY GAS INPUT (SITE A)



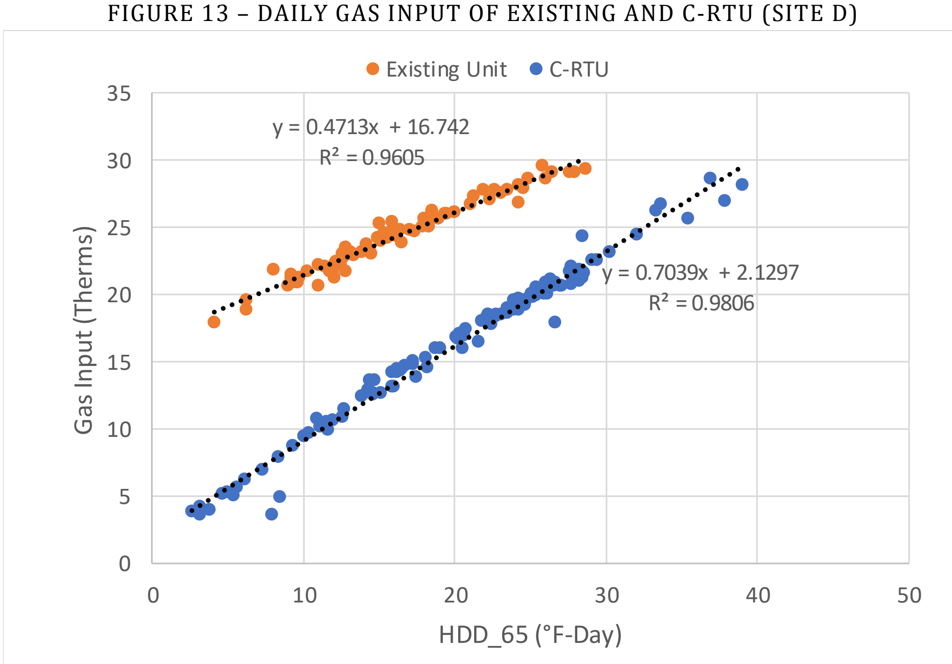
[8] Combustion efficiency spot measurement adjusted for skin losses.

We elected to use the method described in this section rather than a direct comparison method for multiple reasons:

- We selected all sites during the summer of 2018 and installed three of the four C-RTUs before the weather cooled. Therefore, we collected a limited amount of baseline data.
- Holding all variables constant relevant to heating load from the baseline to C-RTU phases proved to be difficult. For example, site managers changed discharge air temperature setpoints by as much as 20°F depending on the weather; operational schedules for multiple sites changed; and while we specified identical unit performance, airflow and output capacity were not always held constant.

The one site for which we were able to collect significant cold weather data for the baseline unit was Site D. Figure 13 compares the daily RTU gas input for the existing unit from 10/2/2018 through 12/18/2018 and the replacement C-RTU from 12/21/2018 through 3/31/2019. While this figure clearly shows the gas savings between the two units on similar weather days, using these results to compare savings would not be a fair comparison. The baseline unit provided roughly 1,550 cfm of outside air at 85°F (unit originally designed at 1,670 cfm and 68°F). The new C-RTU now delivers 1,833 cfm on average and the maintenance manager elected to change the discharge air temperature setpoint to 75°F based on recent feedback from residents. These differences in pre- and post-replacement are typical across the four sites; for this reason, we calculate the energy savings based on holding the delivered heating load measured during the post-installation period constant as described in this section rather than making a direct comparison. In addition, since we selected and installed two of the sites during the summer of 2018, we have little gas consumption data on the existing Site A and B units.

FIGURE 13 – DAILY GAS INPUT OF EXISTING AND C-RTU (SITE D)



4. Performance Results

In this section, we present the performance and energy savings results from three analysis methods:

1. **2018/2019 heating season savings**: the actual C-RTU gas consumption and efficiency compared to a new non-condensing unit (81-82% nominal efficiency)
2. **Annualized incremental savings**: normalizing 2018/2019 gas consumption to a typical weather year (TMY3) and comparing C-RTU to a new non-condensing unit (81-82% nominal efficiency)
3. **Annualized replacement savings**: normalizing 2018/2019 gas consumption to a typical weather year (TMY3) and comparing C-RTU to the existing unit (71-73% measured efficiencies)

4.1 2018/2019 Heating Season Savings

Table 6 summarizes the energy performance and savings of the four C-RTUs relative to an equivalent non-condensing RTU for the 2018/2019 heating season through 5/31/2019. These results are not annualized and represent the energy consumption of the C-RTUs only from the date the unit was started up through 5/31/2019. While all units ran through 5/31/2019, each was started up on a different date.

TABLE 6 – 2018/2019 HEATING SEASON ENERGY RESULTS (THROUGH 5/31/2019) (NOT ANNUALIZED)

	Site A	Site B	Site C	Site D
Condensing RTU				
C-RTU manufacturer	**ICEW**	**EngAir**	**ICEW**	**EngAir**
Length of performance data	9.2 months	8.9 months	7.2 months	5.3 months
Runhours	6,417	2,596	2,878	3,083
Heating degree days (base 61, 57, 61, 65)	4,810	4,832	2,939	2,253
Gas consumed (therms)	4,038	3,501	5,036	1,810
Heat output (therm_eq)	3,748	3,217	4,559	1,663
2018/2019 seasonal efficiency	92.8%	91.9%	90.5%	91.9%
C-RTU electric consumption (kWh)	14,202	6,653	28,412	3,420
Non-condensing RTU				
Nominal efficiency	82%	81%	81%	81%
Calculated gas consumption (therms)	4,570	3,972	5,629	2,054
Calculated electric consumption (kWh)	14,010	6,553	28,326	3,358
Energy savings				
Gas savings (therms)	532	472	593	244
Gas savings ($)	$322	$185	$460	$119
Electric penalty (kWh)	-191	-100	-86	-62
Electric penalty ($)	-$14	-$6	-$6	-$4
Net seasonal savings (as of 5/31/19)	$308	$178	$454	$115

4.2 Annualized Incremental Savings

The following results are based on five to nine months of field monitoring data, as well as weekly and seasonal operational schedules, typical annual local weather data (TMY3), and utility incremental energy rates to calculate the expected annual energy consumption (gas and electric) and costs of the four C-RTUs. We compare the annual energy and added maintenance costs with the upfront equipment and installation costs of these units to an equivalent non-condensing RTU (81%-82% nominal efficiency) from the same manufacturer to calculate a simple payback which ranged from 11.3 to 57.4 years for the four sites. We also include a gross simple payback which excludes the fan energy penalty and added maintenance costs associated with the high efficiency technology, which ranges from 10.2 to 40.8 years. Table 7 summarizes these performance and savings results.

TABLE 7 – INCREMENTAL ENERGY SAVINGS AND PERFORMANCE (ANNUALIZED)

	Site A	Site B	Site C	Site D
Baseline New Non-Condensing RTU				
Manufacturer	ICEW	EngAir	ICEW	EngAir
Heating capacity output (MBH)	246	273	320	114
New standard equipment cost	$21,999	$27,004	$25,572	$22,680
Operation	100% OA	100% OA	30% OA	100% OA
Annual EFLHs	1,798	1,235	1,665	2,659
Nominal efficiency	82%	81%	82%	81%
Annual gas consumption (therms)	5,386	4,163	6,499	3,742
Condensing RTU				
Manufacturer	ICEW	EngAir	ICEW	EngAir
Equipment premium	$3,000	$3,446	$3,000	$2,694
Equipment premium ($/MBH)	$12.21	$12.62	$9.38	$23.63
Added condensate installation cost	$4,480	$4,155	$2,704	$3,558
Condensate installation labor hours	38.25	42.75	29.25	33.00
Total condensing premium	$7,480	$7,601	$5,704	$6,252
Nominal efficiency	91%	90%	91%	90%
Annual field-measured efficiency	92.7%	91.5%	92.2%	91.7%
Annual gas consumption (therms/yr)	4,764	3,687	5,781	3,304
Annual gas savings (therms/yr)	622	476	717	438
Site marginal gas rate ($/therm)	$0.6045	$0.3913	$0.7760	$0.4883
Annual gas savings ($/yr)	$376	$186	$557	$214
Gross simple payback (years)	19.9	40.8	10.2	29.3
Including fan maintenance/fan penalty				
Additional annual maintenance ($/yr)	-$41	-$46.00	-$41	-$46
Simple payback w/ maintenance (years)	22.3	$54	11.1	37.3
Fan penalty (kWh/yr)	-261	-126	-160	-108
Fan penalty ($/yr)	-$19	-$8	-$11	-$7
Simple payback (years)	23.7	57.4	11.3	39.0 [9]

[9] The annual gas savings ($) are based on the site-specific marginal gas rate ($/therm). These rates are low relative to the Department of Energy (DOE) Energy Information Administration (EIA) state average gas rates of $0.83/th (Oregon), $0.73/th (WA), and $0.56/th (ID) over the same period (October 2018 through April 2019).

4.3 Annualized Replacement Savings

In addition to considering the incremental economics of a high efficiency C-RTU relative to a standard efficiency non-condensing unit, we analyzed the economics of an early replacement. From this perspective, we consider the energy costs of continuing to operate the existing units and the total cost to replace the units with new condensing units. The paybacks from this perspective are not as favorable due to the high upfront costs of the new units in relation to the relatively small energy savings. It is important to note that we chose to replace the existing packaged RTUs with custom-built RTUs that are 3-5 times the cost of a new packaged RTU regardless of whether the new unit is condensing. Additionally, the existing Site A unit was a direct-fired unit that doesn't have the same stack losses that indirect-fired units do. For this reason, there is no payback and the primary reason for replacement was increased air quality in the kitchen. Table 8 summarizes the performance results from the early replacement perspective where payback ranges from 26 to 286 years and likely exceeds the useful life of the equipment.

TABLE 8 – REPLACEMENT PERFORMANCE AND SAVINGS SUMMARY

	Site A	Site B	Site C	Site D
Existing RTU				
Manufacturer	CaptiveAire	Reznor	Reznor	Greenheck
Nominal efficiency	Direct Fired	80%	80%	80%
Measured spot efficiency	N/A	72.9%	71.4%	73.1%
Annual gas consumption (therms)	4,417	4,627	7,465	4,145
Condensing RTU				
Manufacturer	ICEW	EngAir	ICEW	EngAir
New equipment cost	$24,999	$30,450	$28,572	$25,374
Installation cost	$45,391*	$25,878	$22,450	$26,720
Total cost	$70,390	$56,328	$51,022	$52,094
Nominal efficiency	91%	90%	91%	90%
Annual field measured efficiency	92.7%	91.5%	92.2%	91.7%
Annual gas consumption (therms)	4,764	3,687	5,781	3,304
Annual gas savings (therms/yr)	-348	940	1,684	841
Site marginal gas rate ($/therm)	$0.6045	$0.3913	$0.7760	$0.4883
Annual gas savings ($/yr)	-$210	$368	$1,307	$411
Gross simple payback (years)	N/A	153.2	39.0	126.9
Including fan penalty/maintenance				
Fan savings (+), penalty (-) (kWh/yr)	-4,076	-551	10,183	-2,729
Fan penalty ($/yr)	-$304	-$35	$728	-$182
Simple payback w/ fan pen. (years)	N/A	169.1	25.1	228.0
Additional annual maintenance ($/yr)	-$41	-$46	-$41	-$46
Simple payback (years)	N/A	196.2	25.6	285.5 [10, 11]

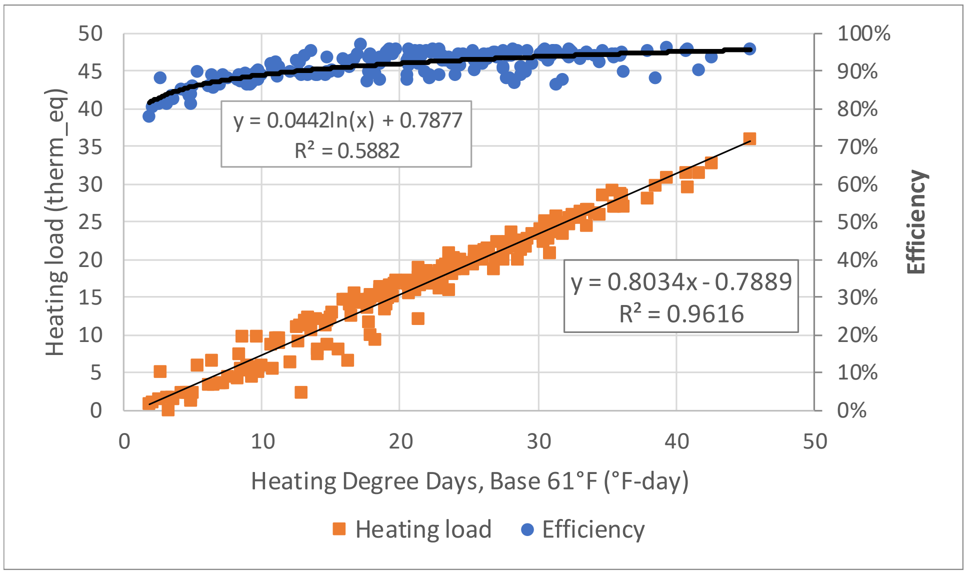
[10] The Site A installation cost is abnormally high due to the significant structural engineering and modifications required to support the new custom C-RTU, which weighed more than double the existing RTU.

[11] The annual gas savings ($) are based on the site-specific marginal gas rate ($/therm). These rates are low relative to the Department of Energy (DOE) Energy Information Administration (EIA) state average gas rates of $0.83/th (Oregon), $0.73/th (WA), and $0.56/th (ID) over the same period (October 2018 through April 2019).

4.4 Site Weather Regressions

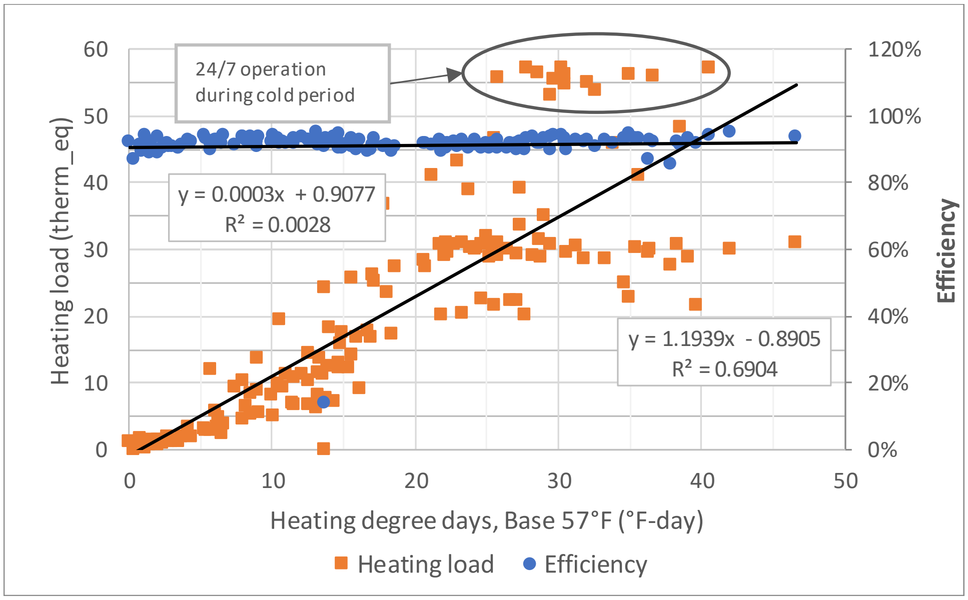
To calculate the expected annual energy consumption of the baseline and condensing units, we compared the daily heating load and unit efficiency to the daily heating degree days (HDD). The HDD base was selected independently for each site to account for the different heating requirements. For example, we selected a 61°F HDD base for Site A as that is the system's approximate balance point (where there is no gas consumption on days that remain above 61°F outside). Figure 14 shows the daily heating load and efficiency of the Site A C-RTU compared to daily HDD_61. These two regression equations are used to calculate the annual gas consumption. The heating load shows a strong linear relationship with HDD which is expected since this unit runs 24/7 and is controlled to a discharge air temperature setpoint rather than to space temperature. The daily efficiency is mostly flat except on the warmest days (fewest HDDs) where the heating was cycled off most of the day and the cooling section was turned on.

FIGURE 14 – SITE A DAILY HEATING LOAD & EFFICIENCY



The heating load regression is not nearly as strongly correlated with HDD for Site B as for the other sites due to varying operational schedules. The facility manager is quite active and often changes the HVAC equipment schedule depending on weather and school events. For example, the outliers highlighted in Figure 15 all occur during two of the coldest weeks in the winter of 2018/2019 when the C-RTU ran 24 hours per day to ensure the faculty offices were sufficiently conditioned.

FIGURE 15 – SITE B DAILY HEATING LOAD & EFFICIENCY



The Site C unit experienced issues with low inlet gas pressure and an out-of-tune burner from December 2018 through January 2019 (see Section 5.2 for more information). Due to these issues, we only include the heating load and efficiency weather regressions after 2/14/2019 in our annual performance calculations, which is the date Energy 350 and the site facilities manager tuned the burner. Figure 16 shows the equations used to annualize the gas consumption for Site C.

FIGURE 16 – SITE C DAILY HEATING LOAD & EFFICIENCY (2/14/19 – 5/31/19)

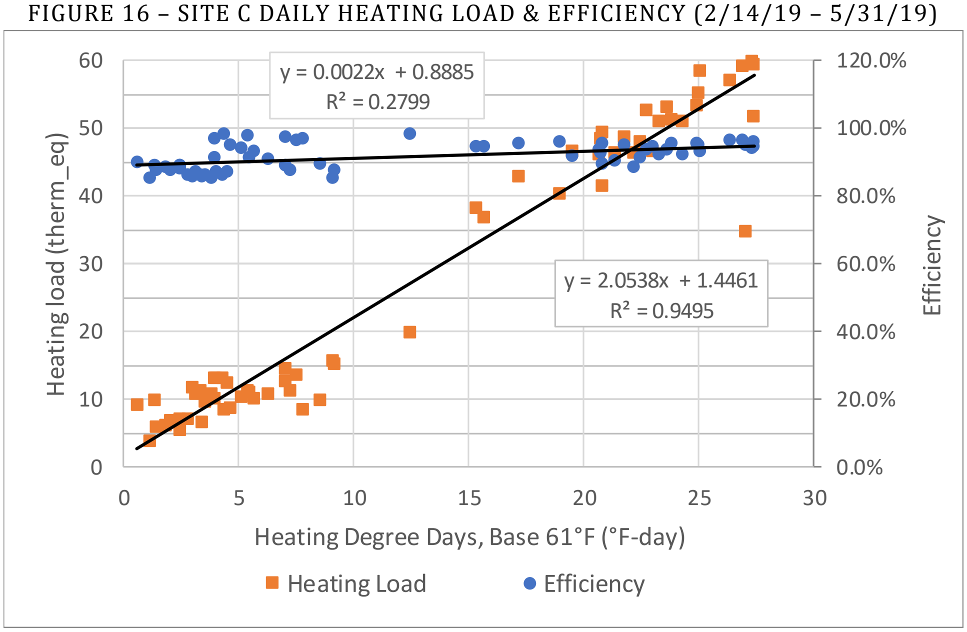
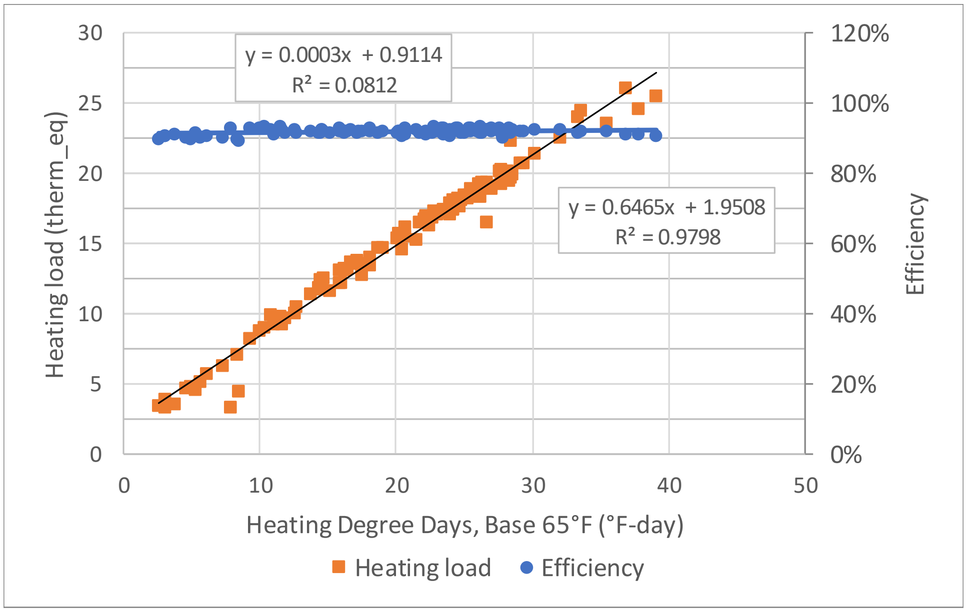


Figure 17 shows the heating load and efficiency relationships with HDD for Site D. This unit operated consistently 24/7 throughout the 2018/2019 heating season at a constant discharge air temperature setpoint. As a result, the heating load and efficiency relationships with HDD are tightly correlated.

FIGURE 17 – SITE D DAILY HEATING LOAD & EFFICIENCY



5. Reliability

In general, the four C-RTUs performed reliably over the 2018/2019 heating season, although each had varying issues that resulted in at least 24 hours of downtime. Table 9 summarizes the incidents each site experienced as well as the total unit run hours and downtime. The length of downtime is not necessarily indicative of the severity of the incident or the responsiveness of the manufacturer. For example, most of the 28 days of downtime for Site D were due to time constraints of the maintenance staff coinciding with warm April weather. The unit's fan belt broke in April during a warm stretch when most of the building residents had their windows open for ventilation, and there were no comfort or air quality issues to create urgency in resolving the issue. In addition, it took multiple calls with the manufacturer to diagnose the subsequent low-limit alarm issue.

TABLE 9 – SUMMARY OF ISSUES RESULTING IN UNIT DOWNTIME

	Site A	Site B	Site C	Site D
Operation				
C-RTU manufacturer	**ICEW**	**EngAir**	**ICEW**	**EngAir**
Start-up date	8/18/2018	8/27/2018	10/17/2018	12/21/2018
Length of operation to date	9.2 months	8.9 months	7.2 months	5.3 months
Runhours to date	6,417	2,596	2,878	3,083
Unit down time (# incidents)	6 days (3 incidents)	3 days (2 incidents)	1 day (1 incident)	4 days (2 incidents)
Reasons for downtime	PLC tripped	Temp sensor fail	Burner alarm	Fan belt failure
	Undiag. burner alarm	Fan speed sensor		Low limit alarm
	Flue condensate leak			

5.1 General Issues

One issue that arose to varying degrees at all four sites was low gas pressure at the units. This did not result in any downtime but did result in low heating capacity. Site B experienced low heating output and we noticed lower efficiency at Site C on the coldest days. We tested the gas pressure at the inlet of these two units on cold mornings, and both were receiving well below the manufacturer-recommended gas pressure. In both cases the manufacturer recommended dedicated gas piping installed at the unit with a pressure regulator located near the unit for optimum performance. Dedicated piping and regulators were installed at both sites at a cost of just over $3,100 per site. These upgrades helped with the capacity issues but did not fully resolve the low efficiency issue at Site C until the burner was retuned. This is described in more detail in Section 0.

Both Sites A and D experienced less significant and more sporadic fluctuations in heating capacity on cold days. It was noted that gas pressure was close to the minimum recommended values on startup, so it is assumed that these units were also being partially starved during periods of high gas demand. While low gas pressure is out of the control of the C-RTU manufacturers, we believe inlet gas pressure is an important consideration when replacing RTUs with high efficiency gas technology that requires fairly constant gas pressure to perform as expected.

It is common for gas-fired units on existing commercial buildings to be supplied gas by shared piping. We believe that the low gas pressure issues experienced in this field trial were only identified due to the level of detail at which the C-RTUs were being monitored. It is likely that both the existing RTUs replaced and new non-condensing RTUs would experience issues similar to those of the C-RTUs.

5.2 ICE Western Specific Issues

Three issues arose on both of the ICE Western (ICEW) units during the field study:

1. Condensate leaking from the lower right corner of the flue box
2. Burner needed additional tuning after startup, which required shipping a unique human-machine interface (HMI) tool
3. Combustion smells reported in building on very cold, calm mornings

5.2.1 Leaking Flue Box

During a morning equipment inspection, the Site A facility manager noticed a small pool of liquid developing inside the flue cabinet below the flue exhaust. Upon close inspection, he discovered a slow leak from the lower right corner of the box where combustion gases exit the heat exchanger before being exhausted through the flue, as shown in Figure 18. A small amount of this condensate was also leaking around the condensate drain stub (pictured in Figure 19). After consulting ICE Western, Energy 350 removed the flue box to identify the issue and discovered a small gap in the welding joint (Figure 20). The facilities manager had his/her shop repair the weld, and we reattached the flue box and sealed all joints with high temperature sealant. No further issues have been discovered.

We also later discovered a smaller leak in the same location on the Site C unit. Figure 21 shows the underside of the flue box and is annotated to show the location of the leak and dried condensate.

FIGURE 18 – SITE A FLUE BOX LEAK

FIGURE 19 – SITE A LEAK INTO ATTIC SPACE

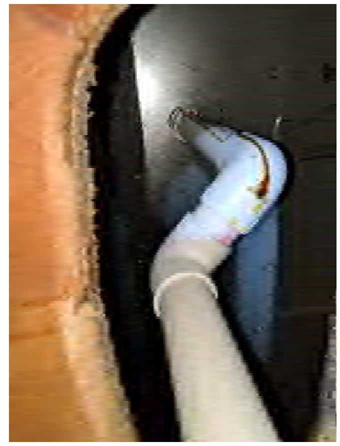
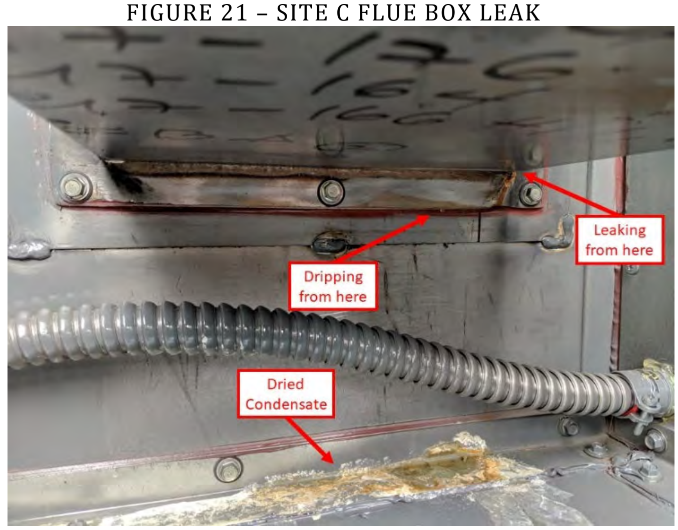


FIGURE 20 – SITE A FLUE BOX WELDING GAP & ORIGIN OF LEAK

FIGURE 21 – SITE C FLUE BOX LEAK



5.2.2 Burner Tuning

Both ICE Western units required additional burner tuning after startup, which was only possible with a special HMI tool (Figure 22) that had to be shipped from the manufacturer. We were unaware of the need for this tool for the installation of the first ICE Western unit (Site A), and we elected not to have ICE Western send a technician from Calgary as the HMI tool was not included with the unit and was quite expensive. However, after the installing contractor's burner technician was sent to Site A to tune the burner, and was unable to do so with the tool, we hired an ICE Western technician to fly down with the HMI tool and tune the burner.

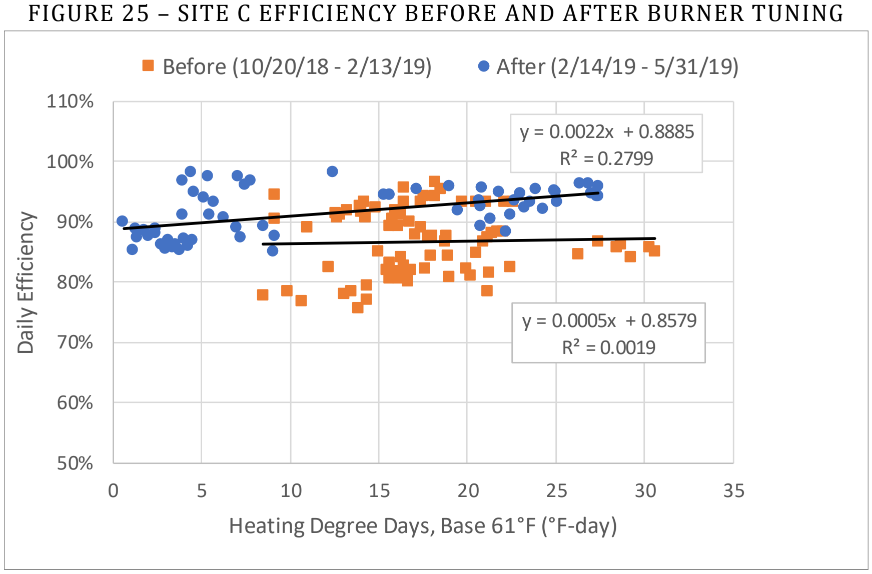
FIGURE 22 – HMI TOOL

FIGURE 24 – COMBUSTION ANALYZER

FIGURE 23 – SITE C BURNER TUNING

For the second ICE Western installation (Site C), we elected up front to bring down their technician to start up the unit; however, they failed to send the HMI tool with the technician. He was still able to make adjustments manually, and the unit seemed to perform well. After a couple months of operation, we noticed that the efficiency of the unit was starting to fall lower than expected (<85%). We made several visits to the site, taking measurements and making small adjustments, but the efficiency remained lower than expected and we discovered that the combustion fan would shake every time the burner was between 40-50% capacity. After several requests, ICE Western sent the HMI tool and we thoroughly tuned the burner on 2/14/2019. Figure 25 shows the Site C daily efficiency before and after this burner tuning.

FIGURE 25 – SITE C EFFICIENCY BEFORE AND AFTER BURNER TUNING



The total unit efficiency before the tuning was just under 88%; after tuning, the efficiency rose above 94%, as shown in Table 10.

TABLE 10 – PRE- AND POST-TUNING EFFICIENCIES

Period	Date Range	Efficiency
Before Burner Tuning	10/20 - 2/13	87.5%
After Burner Tuning	2/14 - 5/31	94.2%
Total Period	10/20 - 5/31	90.5%

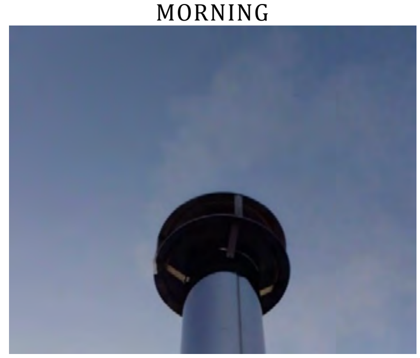
5.2.3 Recirculated Combustion Gas

Both ICE Western units (Site A and Site C) reported that the building occupants complained of combustion gas smells in the spaces served by the C-RTU on very cold, calm days. The condensing technology extracts most of the heat from the combustion products and exhausts relatively cool flue gases (typically less than 80°F), which contribute to the high efficiencies. Standard efficiency gas RTUs typically exhaust combustion products well above 130°F. We believe that on these cold, calm days the combustion gases quickly cooled, sank from a lack of buoyancy, pooled on the roof, and were delivered into the building through the outside air intake. This issue was easily remedied in both cases by installing the manufacturer-provided flue extension (picture in Figure 27) which releases the combustion products at a higher elevation. The installing contractor and site contacts for both Sites A and C elected not to install the flue extension originally because the standard flue rose more than three feet above the mechanical screen and met local code requirements. This does not appear to be a serious issue; it is just worth noting that high efficiency C-RTUs may require additional consideration of flue height selection and installation.

FIGURE 26 – FLUE BEFORE EXTENSION INSTALLED

FIGURE 27 – SITE C NEW GAS PIPING & FLUE EXTENSION

FIGURE 28 – COMBUSTION GASES ON A COLD MORNING



5.3 Engineered Air Specific Issues

A few issues specific to the Engineered Air C-RTUs arose during the field study:

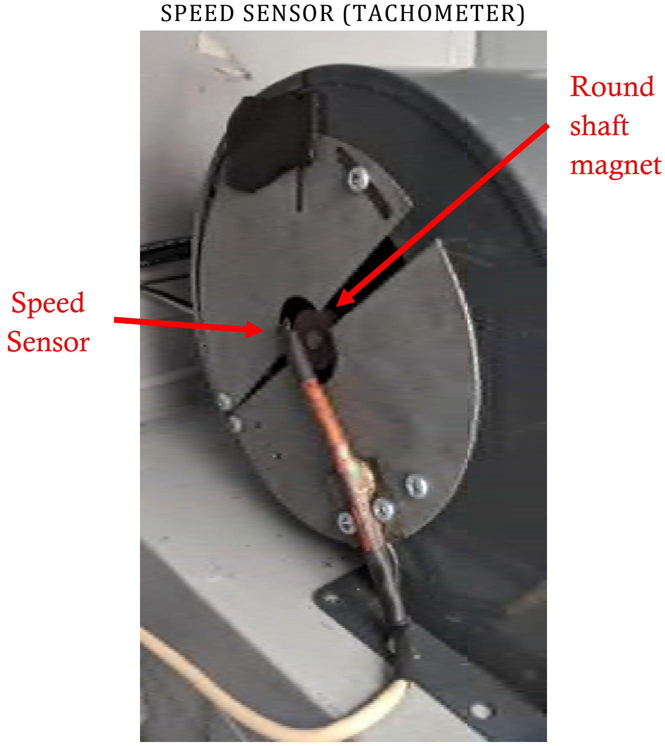
- Combustion fan speed sensors required adjustment
- Undiagnosed burner alarms
- Fan belt failure

Both Engineered Air units experienced two minor issues: a problem with the combustion fan speed sensor and burner alarms that required manual resetting.

5.3.1 Combustion Fan Speed Sensor

Figure 29 shows the combustion fan speed sensor that caused the burner not to fire for both Site B and Site D. In both cases, the fix was relatively simple and required flipping the orientation of the magnet located on the fan shaft. This issue occurred during startup for Site D and resulted in no unit downtime. However, at Site B the speed sensor alarm did not occur until a month after installation, and the burner was down for two days due to the time it took to schedule a technician onsite and diagnose the issue with Engineered Air.

FIGURE 29 – SITE D COMBUSTION FAN SPEED SENSOR (TACHOMETER)



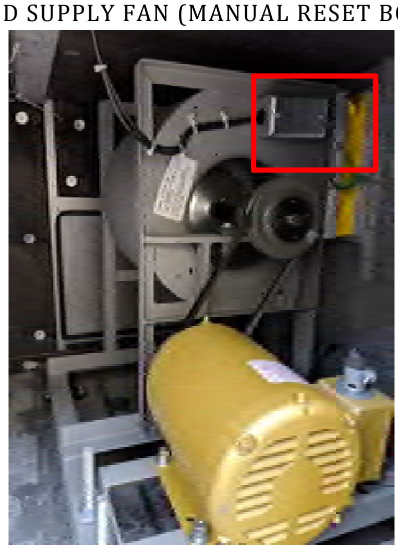
5.3.2 Burner Alarms

The Engineered Air units both experienced undiagnosed burner alarms or low-limit alarms within the first month of operation. The alarms caused the heat to be locked out and required manually resetting the alarms. These issues were quickly diagnosed at both Site B and Site D and have not recurred since early in the monitoring period.

5.3.3 Fan Belt Failure

Site D also experienced a failed fan belt after only 3.4 months (2,515 hours) that required replacing. Shortly after replacement, a "low-limit" alarm appeared which required multiple rounds of troubleshooting with Engineered Air technical support. Eventually they diagnosed the issue as a failed Condensate Water Pump (CWP) controller, which they replaced under warranty; however, replacing this component did not resolve the issue. The site brought in its preferred HVAC service contractor who worked with Engineered Air over the phone; Engineered Air eventually recommended a manual reset switch near the supply fan located inside the air stream (see Figure 30). It is unclear why this was not recommended to Energy 350 or the site contact during the previous rounds of troubleshooting. According to the Site D contact, he was unable to find mention of this reset switch in the O&M manual.

FIGURE 30 – SITE D SUPPLY FAN (MANUAL RESET BOX HIGHLIGHTED)



5.4 Manufacturer Recommendations

As several components of C-RTUs are new to facilities and maintenance managers (advanced burner controls, combustion fans, condensate drain sensors), adopting the technologies will necessitate a learning curve. It is important that this group is supported by either manufacturers or equipment reps to diagnose the many small issues that arise with C-RTUs. Our experience from this field trial and in general is that facilities and maintenance managers are quite capable and expect to perform a majority of the required maintenance and repairs on RTUs. They typically bring in HVAC service contractors only for larger repairs or due to time constraints. Additionally, our exit interviews suggest this group has significant influence in the type of equipment selected when replacing RTUs, and ease of maintenance and service is one of the primary factors influencing their decisions.

6. Installations

This section describes highlights from the four C-RTU installations that occurred from August to December of 2018 as a part of this field trial.

6.1 Site A Installation

The Site A installation took place over three days from August 15^{th} to August 17^{th}. Much of the installation time and cost was due to adding structural members to support the added weight of the new custom unit. The existing packaged RTU weighed 1,100 lbs while the new C-RTU weighed 3,200 lbs. The added weight was primarily due to the construction of the custom unit (double-walled sheet metal, 2” insulation, custom components) rather than to the added heat exchanger material of the C-RTU.[12] The structural upgrades would have been required whether installing a standard efficiency ICEW RTU (~3,050 lbs) or the ICEW C-RTU that was installed. Figure 31 shows photos from the installation.

FIGURE 31 – SITE A INSTALLATION PHOTOS

ADDITIONAL STRUCTURAL ENGINEERING, SUPPORT AND ROOFING SIGNIFICANTLY ADDED TO INSTALLATION COSTS

NEW CUSTOM-BUILT ROOF CURB

C-RTU CRANE PICK

C-RTU INSTALLED

[12] According to the manufacturer ICEW, the added weight of upgrading from their standard efficiency unit (82% efficiency) to their C-RTU (91% efficiency) in this size range is less than 150 lbs. The added weight comes from additional heat exchanger material and some additional corrosion-resistant condensate piping.

The condensate drainage system for Site A ran through the roof curb into the attic space above the restaurant dining area. The installing contractor used 1 ¼” PVC pipe and field-installed a 6” p-trap directly below the unit in the attic. The piping runs about 12 feet into the kitchen space then down a column before being reduced to 1” from which it runs into a condensate neutralizer tank (Axiom NT25 NeutraPro) before being discharged into an open floor drain to sanitary sewer. The kitchen staff requested that the neutralizer tank be installed above the floor to allow for cleaning, and a stainless-steel platform was fabricated by the site. The kitchen staff also did not want work being performed during operating hours (6am-12am), so all work within the kitchen had to be completed in the early morning. The installing contractor followed NEEA’s *Condensate Management Best Practices* (NEEA, 2017B) and all manufacturer recommendations. Figure 32 shows photos of the different sections of the condensate drainage system installed. Overall, the condensate drainage system required 38.25 labor hours totaling $4,225 and an additional $255 in materials. This did not include the cost of the neutralizer tank that was included with the unit.[13]

FIGURE 32 – SITE A CONDENSATE DRAIN INSTALLATION PHOTOS

DRAIN PENETRATION & P-TRAP BELOW UNIT

DRAIN ENTERING KITCHEN

CONDENSATE NEUTRALIZER TANK

CONDENSATE DRAIN TERMINATION

[13] The NT25 NeutraPro condensate neutralizer tank retails for $266.

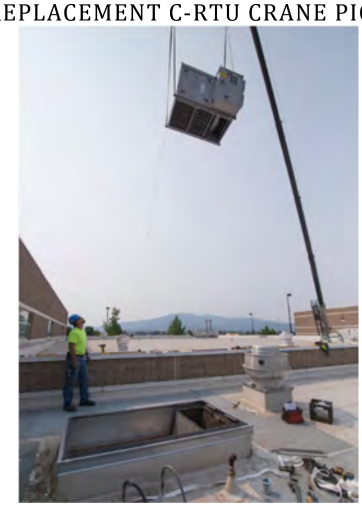
6.2 Site B Installation

We installed the Site B C-RTU over August 25th and 26th of 2018. To avoid construction during school hours, we completed all major work on a weekend with no faculty or students in the building. With a short window to complete construction, the installing contractor ran most of the condensate drain piping two days before the major installation took place. The installation crew completed all the mechanical work on the first day: removing the existing unit, preparing the curb and condensate drain penetration, placing the new C-RTU, and completing the condensate drainage system installation. The electrician and site facilities manager completed the controls wiring and BMS integration the following day. Figure 33 shows photos from the first day of installation.

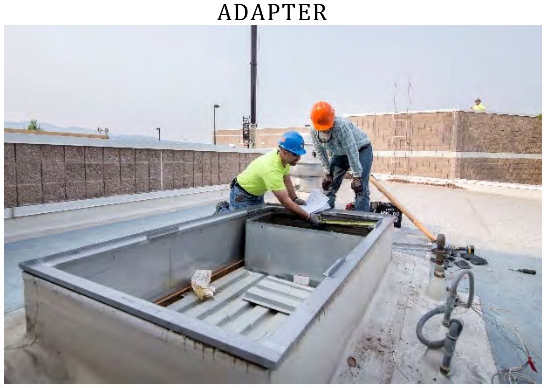
FIGURE 33 – SITE B INSTALLATION PHOTOS

EXISTING UNIT BEING REMOVED

REPLACEMENT C-RTU CRANE PICK



UTILIZING EXISTING ROOF CURB WITH CURB ADAPTER



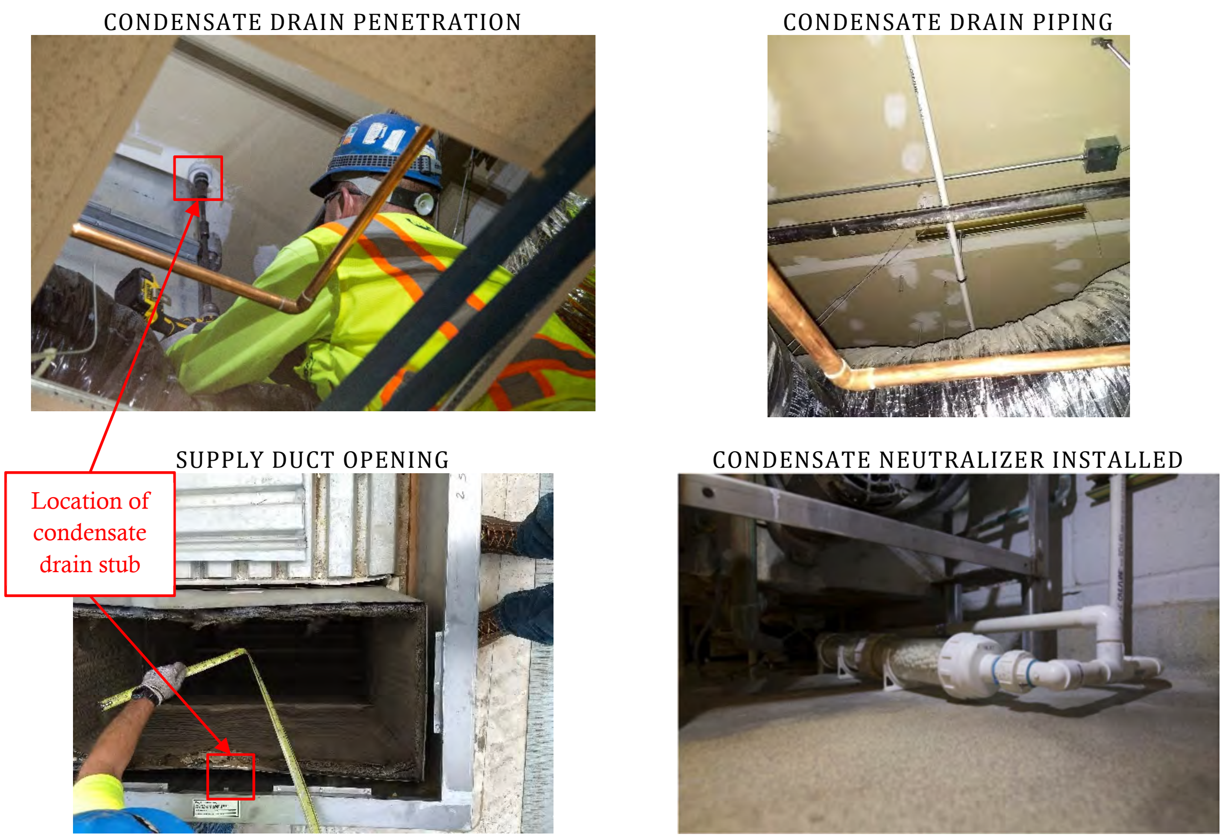
C-RTU INSTALLED

The condensate drain installation for Site B proved to be one of the most challenging and labor-intensive tasks among the four installations. The closest approved plumbing drain was located in a cafeteria kitchen about 50 feet horizontally from the C-RTU. This piping is located above a corridor with 4-foot-high space concealed by t bar ceiling, yet it required nearly 20 hours of labor. However,

> "THIS WHOLE DANG INSTALLATION HINGES ON THIS TINY CONDENSATE STUB."
>
> -PIPE FITTER DURING SITE B INSTALLATION

the condensate stub was located between the downward discharge supply duct and the inside edge of the roof curb. As shown in the top and bottom left photos of Figure 34, there was very little clearance between the duct and curb because of where the condensate fluid comes out of the bottom of the C-RTU. This tricky installation led the installing contractor's head pipe fitter, who was responsible for the condensate system in all four installations, to express his concern regarding the impact of the condensate drain on the overall installation. He also expressed concern about where the condensate stub would be located on the remaining two C-RTUs to be installed and what structural or plumbing obstructions might be located under the units. It is important to understand that mechanical contractors are not used to dealing with condensate drains on RTU installations where they are often expected to remove the existing unit and install the new unit in the same location without having visited the site beforehand. Overall the condensate drainage system required 42.75 labor hours totaling $3,982 and an additional $173 in materials. This did not include the cost of the neutralizer tank that was included with the unit.[14]

FIGURE 34 – SITE B CONDENSATE DRAIN INSTALLATION PHOTOS



6.3 Site C Installation

We removed the existing RTU and installed the new C-RTU at Site C on October 15th, 2018. As with Site B, the installing contractor chose to run most of the condensate drainage system before the day of the install to avoid delaying the timeline in the event of challenges in the field. This C-RTU installation

[14] The NC-2 NeutraPal condensate neutralizer kit retails for $97.

went smoothly and was started up the following day. Figure 35 shows photos from the day of the installation.

FIGURE 35 – SITE C INSTALLATION PHOTOS

PREPARING EXISTING UNIT FOR REMOVAL

REPLACMENT C-RTU CRANE PICK

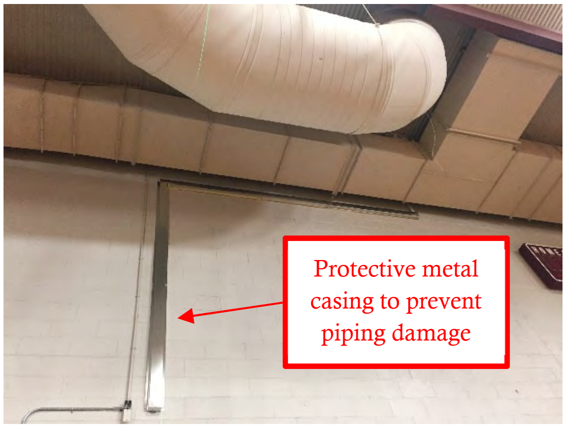
NEW UNIT INSTALLATION

NEW C-RTU

The installing contractor elected to run most of the condensate drain three days before the installation day. The C-RTU is located on the roof of a gymnasium and a scissor lift was required to access the 30-foot ceiling where the drain piping penetrates the roof. The contractor ran 1 ¼" PVC pipe down the gym wall and into a storage room where a small air compressor and floor drain are located. A protective casing was installed over the PVC pipe to prevent damage to the drain piping from gym activities, as shown in Figure 36. Despite the height of the space, this condensate installation was the most straightforward of the four sites and required the fewest labor hours and lowest overall cost to install. In total, the condensate drainage and neutralization system required 29.25 labor hours, $2,556 in labor costs, and $148 in materials.

FIGURE 36 – SITE C CONDENSATE DRAIN INSTALLATION PHOTOS

DRAIN PIPING WITH PROTECTIVE CASING



CONDENSATE NEUTRALIZER INSTALLED

6.4 Site D Installation

We installed the Site D condensate system on December 18th and the new C-RTU on December 19th, 2018. The unit was commissioned and started up by the manufacturer on December 20th. Figure 37 shows photos from the installation.

FIGURE 37 – SITE D INSTALLATION PHOTOS

EXISTING UNIT

REPLACEMENT C-RTU PLACEMENT

NEW C-RTU INSTALLED

C-RTU INSTALLED

The Site D condensate drain system was the fourth system installed by the installing contractor. The pipe fitters were very familiar with the equipment, best practices, and manufacturer recommendations and the system was installed with few surprises or major challenges. Even so, the pipe fitters required 33 hours of labor to complete the installation of the system and surrounding activities. The installer routed the drain pipe directly below the unit into the conditioned 5th floor above a t bar ceiling. They routed the piping about 30 feet to a laundry room floor sink. Between the t bar ceiling and the laundry room is a corridor transition space with hard-top ceilings and fire rated wall. The firewall had to be penetrated and resealed, and in order to maintain the required slope on the drain piping above the hard ceiling, the installers cut four ~1 square foot access panels that the site maintenance staff preferred to repair themselves.

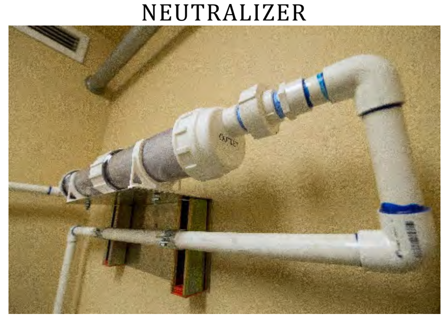
FIGURE 38 – SITE D CONDENSATE DRAIN INSTALLATION PHOTOS

DRAIN PENETRATION & P-TRAP

CONDENSATE NEUTRALIZER INSTALLED

CONDENSATE DRAIN PIPING

NEUTRALIZER



6.5 Equipment and Installation Costs Summary

The average C-RTU equipment cost of the four sites was $27,349 with an average incremental cost above an equivalent non-condensing unit of $3,035. The average installation cost, excluding Site A[15] was $25,016 and the average incremental installation cost for the condensate management system was $3,724, including all sites (while the total installation cost of Site A was an outlier, the incremental cost was not). This added installation cost was primarily attributable to skilled labor, as installing the condensate management system took an average of 36 labor hours. A key finding of this field trial is that the incremental installation cost of the four C-RTUs was more than the incremental equipment cost for three of the four sites. While the installing contractor did get more proficient as they became more familiar with the process, they do not expect the labor cost to significantly decrease even after many installations. Table 11 summarizes the equipment and installation costs of the four C-RTUs and their standard efficiency equivalent baseline units.

TABLE 11 – EQUIPMENT AND INSTALLATION COSTS

	Site A	Site B	Site C	Site D
Non-condensing equipment				
New non-condensing	ICEW HTDM400-82	EngAir DJS40	ICEW HTDM400-82	EngAir DJS20
Capacity (MBH)	246	273	320	114
Nominal Efficiency	82%	81%	82%	81%
Base equipment cost	$21,999	$21,804	$25,572	$17,180
Freight	Included/None	$5,200	Included/None	$5,500
Total base equipment cost	$21,999	$27,004	$25,572	$22,680
Condensing equipment				
New condensing	ICEW HTDM400-91	EngAir DJX40	ICEW HTDM400-91	EngAir DJX20
Nominal Efficiency	91%	90%	91%	90%
Condensing incremental cost	$3,000	$3,446	$3,000	$2,694
C-RTU equipment cost	$24,999	$30,450	$28,572	$25,374
Installation				
Non-condensing install cost	$40,911	$21,723	$19,746	$23,162
Condensate labor hours	38.25	42.75	29.25	33
Condensate labor cost	$4,225	$3,982	$2,556	$3,450
Condensate material cost	$255	$173	$148	$108
Condensing incremental cost	$4,480	$4,155	$2,704	$3,558
Condensing total install cost	$45,391	$25,878	$22,450	$26,720
Structural/roofing costs				
Added structural design cost	$6,627	$3,778	$4,131	$3,813
Added roofing/structural cost	$16,281	--	--	-- [16]

[15] Site A installation cost included significant structural upgrades to support the heavier custom C-RTU, which also resulted in significant roofing costs. These upgrades were not a result of the condensing technology, as the same upgrades would have been required with a non-condensing custom unit, since the ICEW HTDM 400 91+ unit weighed nearly three times as much as the RTU that was replaced.

[16] For consistency, sales tax is removed from the equipment cost for Sites B and D (Idaho – 6% and Washington 10%).

Both manufacturers, ICE Western and Engineered Air, make high-quality, fully-customizable RTUs, which explains the high cost of the C-RTUs and non-condensing baseline equipment. The four units that were replaced were significantly less expensive packaged RTUs.

7. Condensate Management

Potentially the most significant barrier to widespread adoption of C-RTU technology is condensate management. High efficiency condensing gas technologies produce acidic condensate liquid, typically between 2.9 and 4.0 pH (similar to vinegar), during the combustion process. Unlike boilers and water heaters, RTUs are by nature often located in remote locations across a building's roof. It can be challenging and costly to install a condensate management system that transports and neutralizes this liquid, especially if there is not a nearby and easily accessible sanitary sewer drain or plumbing fixture. Additionally, if routing piping directly through the roof curb is not an option, an additional challenge of freeze protection is introduced. These factors not only add cost but require additional planning by the installing contractor and coordination among trades (pre-installation communication among pipe-fitter, project manager/engineer, sheet-metal foreman, facilities manager, and local authority having jurisdiction (AHJ) was necessary for these four projects).

Condensate management is certainly a costly and significant barrier to C-RTU adoption in many applications. There is some ambiguity in the local codes dealing with condensate management, and the interpretation can vary significantly depending on the installing contractor and AHJ. However, this field study showed that when the installing contractor follows condensate management best practices by neutralizing and transporting condensate liquid to a sanitary sewer, the cost to install condensate system is similar, if not more than the C-RTU equipment premiums.

7.1 Condensate Management Best Practices

As part of this field trial, we asked the installing contractor to be familiar with and adhere to the recommendations in NEEA's *High Efficiency Gas RTU Condensate Management Best Practices* (NEEA 2017B) and the manufacturer's installation manuals. The result was that the condensate fluid from all four C-RTUs passed through the roof curb directly into conditioned space via approved piping material and was terminated in an approved sanitary sewer drain after passing through a neutralization system. This required significant planning, labor, and materials; the additional costs ranged from $2,704 to $4,480, costlier than the equipment premiums for three out of four sites. Condensate management is certainly a costly and significant barrier to C-RTU adoption in many applications.[17]

According to the installing contractor, the Condensate Management Best Practices document (CMBP) is useful, clear, and aligns well with the manufacturer's recommendations and best practices in his experience. In addition, the primary cost and effort associated with the condensate drain system was due to the long piping runs.

7.2 Building Codes

There is some ambiguity in both the local codes dealing with condensate from fuel-burning appliances and in the local Authority Having Jurisdiction (AHJ) The International Fuel Gas Code (IFGC) and Uniform Plumbing Code (UPC) refer to manufacturer's instructions and indicate that liquid combustion byproducts be transported via approved materials and discharged into an

[17] The four C-RTU locations were screened for access to a nearby sanitary sewer location and three or four other sites with more challenging condensate installations were excluded in part for this reason.

approved plumbing fixture or disposal area. Both Engineered Air and ICE Western installation manuals recommend condensate neutralizers in accordance with local codes and AHJs, and both manufacturers shipped neutralizers with the units at no additional cost.

The Seattle Fuel Gas Code, which has amended the base International Fuel Gas Code (IFGC), explicitly calls for liquid combustion products from fuel-burning appliances to “be collected, pH-neutralized and discharged to an approved plumbing fixture or disposal area in accordance with the manufacturer’s instructions.” (Seattle, 2015) Neither the Uniform Plumbing Code (UPC) nor the International Mechanical Code (IMC) explicitly requires neutralizers or specifies drainage location; this means that in Oregon, Idaho, Montana, and Washington (outside of areas adopting Seattle’s code), it appears condensate management is greatly up to the installing contractor and the approval of the local AHJ. However, any strict interpretation of the code and manufacturer’s recommendations aligns well with NEEA’s CMBP guidelines.

7.3 Manufacturer Instructions

While the building codes may not explicitly require neutralization and discharge of condensate liquid to sanitary sewer, there is no ambiguity in the ICE Western instructions, which state the following:

- Discharge location: “Both indoor and outdoor units **must** have the heat exchanger condensate piped to sanitary sewer drain.” (emphasis included in original text)
- Neutralization: “Connection to the appliance and neutralization kit must be installed to ensure that no condensate backflow into the appliance can occur.”
- Maintenance: “Monitor the level of the neutralization media in the capsule periodically. Check the pH level at the outlet of the neutralizing kit annually…neutralizing media should be replaced when the pH level drops below the minimum level of the local water authority.” (ICE Western, 2018)

The Engineered Air installation instructions are less direct and defer to local codes:

- Discharge location: “Finish piping the condensate drain to the building sanitary sewer in accordance with local codes.”
- Neutralization: “This may include installation of an optional neutralizer tank…Install a neutralizing tank if required by local codes.” (Engineered Air, 2016)

However, both Engineered Air units were shipped with neutralizer tanks, and all piping installation diagrams depict a neutralizer installed before discharge to a sanitary drain. (Refer to Appendix C for excerpts from the two installation manuals.)

8. Lessons Learned from Two C-RTU Field Studies

NEEA commissioned a similar field trial of four C-RTUs over the 2015/2016 and 2016/2017 heating seasons (NEEA, 2017). This section draws lessons learned from both trials.

- Condensate management system installations can vary significantly based on the installing contractor and AHJ's interpretation of local building codes.
  - With or without neutralization
  - Rooftop storm drain or sanitary drain
  - Strict or loose interpretation of mechanical and plumbing codes by different AHJs
  - Cost as low as $429 in Reznor demonstration and as high as $4,480 in the first installation of this study (Site A)
- Installing contractors experience efficiencies as they become more familiar with condensate management system processes.
  - In the 2018/2019 field study, the same project manager and pipe fitter were utilized for all four installs; they became more experienced with condensate installation as they went on.
  - While the number of labor hours remained high, they shifted primarily to days before the unit arrived on site to avoid delays.
- RTUs often require significant maintenance and many small repairs.
  - All (8) units across the two field studies experienced downtime within the first heating season.
  - Very few of these issues were related to the condensate system.
  - Most facility managers and end users from the two field studies believe that the C-RTUs performed as well as standard RTUs and that the issues were typical.
- End users and HVAC contractors will need technical support as long as C-RTUs are an emerging technology.
  - One maintenance manager from Reznor study referred to C-RTU as "our high efficiency unit with special needs."
  - All four end users from this field study expressed a desire for better technical support from manufacturers due to some of the nuances of their C-RTU technologies.
- Fan energy penalty differs based on manufacturer design but is often minor.
  - ICE Western claims no additional pressure drop across heat exchanger between standard and C-RTU, but uses a slightly larger combustion fan for C-RTU.
  - Engineered Air provided pressure drop tables for standard and C-RTU burners, which resulted in minor energy penalties (62-100 kWh for Sites B and D).
  - The Reznor study calculated fan energy penalties of 400-1,600 kWh/year.

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Appendix A – Issues Log

The following issues log describes the issues that arose throughout the scoping and monitoring phases.

TABLE 12 – ISSUES LOG

Issue ID	Date	Site	Manu-facturer	Issue/Challenge	Details	Solution	Status	Unit Down Time	Specific to C-RTUs?
A1	5/18/2018	Site A (Bend Kitchen)	ICEW	Unit Weight (Structural)	- New unit weighs 2,400 lbs more than existing unit - Load must be transferred to primary beams	Add tube steel to transfer load to primary beams	Resolved	N/A	No
A2	8/15/2018	Site A (Bend Kitchen)	ICEW	Crane Location	- Best location for crane was parking owned by bank; bank would not allow crane in spots during business hours	Early morning start (5am - 9am) and 1 hour concession from bank	Resolved	N/A	No
A3	8/15/2018	Site A (Bend Kitchen)	ICEW	Condensate Drain Roof Penetration	- Unable to know what (if any) obstructions would be under the condensate drain stub coming out of RTU. Installers were concerned about structural members, other piping/wiring, and clearances.	After removing unit, path under unit was mostly clear. Drain pipe was routed to kitchen successfully.	Resolved	N/A	Yes
A4	8/16/2018	Site A (Bend Kitchen)	ICEW	Condensate Drain Path	- The best location for drain termination was in the kitchen; the head cook was very concerned about large amounts of fluid being discharged into drain. - Site A cook also did not want neutralizer to be in the way of kitchen operation or to be located on floor due to concerns with cleaning and sanitation.	- We explained that peak flow would be <2 gallons/hour. - Built stainless steel grate to raise neutralizer off the floor for cleaning access.	Resolved	N/A	Yes
A5	8/17/2018	Site A (Bend Kitchen)	ICEW	Evaporative Cooler Components	- Upon startup of the evaporative cooler, the float valve was cracked and sprayed inside unit. - Cooler water header PVC piping above evaporative media was not glued and was spraying outside of water sump.	- Replaced float valve - Glued header PVC piping	Resolved	N/A	No
A6	8/21/2018	Site A (Bend Kitchen)	ICEW	Supply Fan Cycling	- Supply fan was found off; when unit was reset fan would run then cycle off	- Distech controller was tripping contact; ICEW sent replacement controller under warranty	Resolved	None, during commissioning	No
A7	8/24/2018	Site A (Bend Kitchen)	ICEW	Simultaneous Heating/Cooling	- Unit was found to be calling for heating and cooling simultaneously; issue diagnosed as a programming error incorrectly converting °C to °F twice causing space temperature reading at controller to be 150°F causing constant call for cooling	- ICEW technician replaced Dischtech controller with new correctly programmed one	Resolved	None	No

Issue ID	Date	Site	Manu-facturer	Issue/Challenge	Details	Solution	Status	Unit Down Time	Specific to C-RTUs?
A8	8/27/2018	Site A (Bend Kitchen)	ICEW	Burner Combustion Tuning	- Combustion analysis showed CO levels as high as 100 ppm - Due to high cost of flying technician from Calgary, we originally did not plan on having ICEW start-up unit, but rather use local HVAC technician - We learned via phone tech support that tuning the burner on ICEW units require proprietary HMI tool which is not included with unit and must be rented	- ICEW shipped HMI tool for adjusting combustion overnight, and sent tech to site on 8/29/2018 - ICEW tech tuned burner but did not see the same high CO levels as installing contractor tech and questioned testing methods	Resolved	None	No
A9	9/23/2018	Site A (Bend Kitchen)	ICEW	Burner Alarm	- Burner did not fire the morning of 9/23/18 even though OAT was <40F - Burner alarm eventually caused unit to shut off at 3am on 9/24/18 - Site A reset burner alarm at 8am on 9/24 and unit and burner came back on	- After resetting alarm, unit has continued to run with no issues	Resolved	5.3 Hours	No
A10	10/21/2018	Site A (Bend Kitchen)	ICEW	120V Outlet	- Fuses on 120V outlet have blown multiple times - No power to 120V GFCI outlet - ICEW diagnosed that 2A fuses were undersized for loads	- ICEW sent new 10A fuses to Site A - Site A replaced fuses	Resolved	None	No
A11	11/15/2018	Site A (Bend Kitchen)	ICEW	Combustion Smell Reported in Kitchen	- Site A employees reported combustion smells in the kitchen	- Site A added 5-foot flue extension and have had no further reports of smells	Resolved	None	Possibly due to colder flue gases (less natural buoyancy)
A12	12/4/2018	Site A (Bend Kitchen)	ICEW	Condensate Leak in Flue Box	- Site A site contact noticed condensate leaking into the flue box cabinet. - We discovered a small leak in the flange connecting the flue box at the base of the flue chimney to the heat exchanger. This was due to small welding imperfection. - A small amount of condensate also leaked around the condensate stub out the bottom of the unit which leaked into the attic but caused no damage.	- Energy 350 removed the flue box to diagnose the issue; Site A enforced the weld in their shop, and Energy 350 re-sealed both the flue box connection and the condensate stub penetration from below.	Resolved	None	Yes
A13	1/18/2019	Site A (Bend Kitchen)	ICEW	Unit Down (PLC in Programming Mode)	- Unit shut down unexpectedly at 7:20pm on 1/18/2019 - Primary site contact out of country, so diagnosing was delayed - Diagnosed as Allen Bradley PLC being in "Programming Mode" - ICEW says this has happened before but rarely and resetting controller typically fixes the issue for good	Site A electrician reset the PLC using Allen Bradley software on a laptop.	Resolved	4 days	No

Issue ID	Date	Site	Manu-facturer	Issue/Challenge	Details	Solution	Status	Unit Down Time	Specific to C-RTUs?
B1	4/24/2018	Site B (Post Falls School)	EngAir	Unit Weight (Structural)	- New unit weighs 900 lbs more than existing unit (custom unit, more sheet metal)	Existing structural sufficient	Resolved	N/A	No
B2	4/26/2018	Site B (Post Falls School)	EngAir	Condensate Drain Termination	- Long run (>30 ft) between downward supply plenum and nearest sanitary sewer drain - Duct runs through fire corridor, may need to penetrate fire wall and/or ceiling	- Plumber found kitchen drain closer (50') - Repaired fire wall penetration on 8/27/18	Resolved	N/A	Yes
B3	8/25/2018	Site B (Post Falls School)	EngAir	Duct Transition	- Typical challenges with replacing a downward discharge RTU; difficult to set unit to match up with downward ducts - Downward duct had an offset that was unknown before removing existing unit	Adjustments and small modifications in ductwork to form tight seal	Resolved	N/A	No
B4	8/25/2018	Site B (Post Falls School)	EngAir	Condensate Drain Location, Clearance, and roof penetration	- Condensate drain stub on bottom of unit was designed to be between the Supply Air Discharge and the downward duct leaving very tight clearance; when existing MAU was taken off roof, we discovered that the downward duct angled toward the front curb, leaving less than 3" for condensate drain. - EngAir unit requires a straight factory drain pipe making it challenging for any field modifications	Installing contractor was able to make penetration in roof and connect drain after a few hours of work.	Resolved	N/A	Yes
B5	8/25/2018	Site B (Post Falls School)	EngAir	Electrical Wiring	- Fuse tripped and controls transformer failed when unit was powered up; grounded circuit was likely cause	- Replaced fuse and transformer on 8/27/2018	Resolved	N/A	No
B6	10/3/2018	Site B (Post Falls School)	EngAir	Burner Error (flipped combustion fan speed sensor)	- Burner has not been running the past few days, despite cool weather - Site B Maintenance Manager went through the manual troubleshooting checklist - After calling EngAir tech support, it was recommended to adjust the magnet on the end of the combustion fan motor shaft	- Adjusting combustion fan shaft magnet resolved the issue	Resolved	No unit down time, but 2 days with burner down	No
B7	12/4/2018	Site B (Post Falls School)	EngAir	Discharge Air Sensor Fail	- The unit supply fan shut down due to a low discharge air alarm - The issue was diagnosed by Engineered Air as a failed discharge air temperature sensor	- EngAir sent Site B a new sensor -Temp fix: E350 had an extra sensor already in box, site contact switched wiring	Resolved	5 hours (12/4, 4am-9am)	No
B8	1/8/2019	Site B (Post Falls School)	EngAir	Cold Morning Start-up Controls Issue	-On cold mornings (OAT <28°F) at start-up, the Site B DDC system would send Occupied signal to EngAir unit. EngAir unit would be in low discharge air alarm due to unit not running all night. DDC needs a supply fan on proof to enable heat. EngAir controller will not start supply fan without burner on if low discharge air alarm is active so as not to bring cold air into building.	- Enable heat in DDC system to avoid conflicting signals on cold mornings. - This was a controls conflict and not an issue with the unit.	Resolved	14 hours total (7 hours each on 1/8 and 1/14 from 2am-9am)	No

Issue ID	Date	Site	Manu-facturer	Issue/Challenge	Details	Solution	Status	Unit Down Time	Specific to C-RTUs?
B9	1/15/2019	Site B (Post Falls School)	EngAir	Discharge Air Temperature Drop	- At 4am on 1/15, 1/16, 1/17, and 1/22 we have been noticing a precipitous drop in discharge air temperature from 84°F (current setpoint) down to 65-70°F - While not a comfort issue since zones are served by water-source heat pumps, we are investigating the cause	- A dedicated gas piping line was installed on 3/21/2019 - We have yet to have cold enough weather to determine conclusively if the issue is resolved, but the unit now has a 2psig dedicated line and has been delivering the required air temperature	Resolved	None (only drop in discharge air temp)	TBD
C1	8/1/2018	Site C (Gladstone Gym)	ICEW	Access/Clearance	- ICEW design has bumpout for controls & burner sections on same side as electrical/gas connections - Bumpout causes clearance concerns for accessing filters, controls, etc.	Flipped access to other side of unit and re-routed utilities to other side	Resolved	N/A	No
C2	8/1/2018	Site C (Gladstone Gym)	ICEW	Condensate Path	- Unit is on gymnasium roof; running condensate drain will be a challenge at 35'+ height	Large scissor lift brought in and routed drain into mech room	Resolved	N/A	Yes
C3	10/17/2018	Site C (Gladstone Gym)	ICEW	OA Damper Control Signal	- The outside air damper was tuned on a 0-10 Vdc signal, but the Distech controller was programmed to send a 2-10Vdc signal.	- Temp fix: set OA % to 44% which equals desired 30% position - Energy 350 installed re-programmed controller and set to 30%	Resolved	None	No
C4	10/17/2018	Site C (Gladstone Gym)	ICEW	Gas Line Pressure Regulator	- The school's gas line serving the MAU had a pressure regulator that was failing - We read 15" w.c. one minute and then 4.5" the next - Unit requires 7"-14" w.c.	- We adjusted regulator to 11.5" to be within unit spec - Site C has replaced regulator and set to 11.5"	Resolved	None	No
C5	10/18/2018	Site C (Gladstone Gym)	ICEW	Bad Flowmeter	- The piezo airflow meter for the energy study was faulty - This does not affect unit operation, only the energy study	- Comefri shipped new flow meter and Energy 350 installed	Resolved	None	No
C6	11/13/2018	Site C (Gladstone Gym)	ICEW	Combustion Smell Reported in Gym	- Occupants reported smells of combustion product in gym at 8am - This occurred after a 3-day weekend with the unit down, and a very cold gym, 32F outside air temperature, with unit running full out for about an hour - A very cold, windless morning, may have led to combustion products pooling on roof near unit and being drawn back into the building	- We added a 5-foot flue extension to increase height of combustion discharge and no further complaints have taken place	Resolved	None	Possibly due to colder flue gases (less natural buoyancy)

Issue ID	Date	Site	Manu-facturer	Issue/Challenge	Details	Solution	Status	Unit Down Time	Specific to C-RTUs?
C7	12/7/2018	Site C (Gladstone Gym)	ICEW	Fire Alarm Tripped	- The C-RTU duct fire alarm was tripped when contractor was checking the screws securing the roof curb to the roof for structural compliance. They were unable to reset the alarm and the unit remained off until the following morning. This issue had nothing to do with the unit itself, but rather the building's fire alarm.	- Reset fire alarm	Resolved	24 hours	No
C8	12/11/2018	Site C (Gladstone Gym)	ICEW	Burner Alarm	- After the unit was down for 24 hours, the unit needed to run for high fire for an extended period of time, the Site C staff noticed burner alarms and vibrations in the combustion fan. - Energy 350 performed combustion analyses at different fire rates, and discovered that at or above 45% fire, the burner runs rich (not enough oxygen) - ICEW believed this was due to low gas pressure at the unit because the pressure regulator valve is 50 feet from the unit	- We added a dedicated gas piping line with new pressure regulator and retuned the burner using ICEW's HMI tool - The unit's combustion is now within spec at all fire rates	Resolved	None	No
C9	12/12/2018	Site C (Gladstone Gym)	ICEW	Condensate Leak in Flue Box	- Similar to Site A, we discovered a small condensate leak from the flue box into the flue cabinet. A very small amount of condensate was leaking through a welding imperfection on the flange where the flue box connects to the wall of the unit.	Weld sealed with high-temperature sealant	Resolved	None	Yes
D1	5/16/2018	Site D (Renton Residences)	EngAir	Condensate Drain Termination	- Very long run to an accessible sanitary sewer drain - Participant does not want to penetrate apartment unit walls or cabinets where closer drain pipes are located	Switched to MU-2 which has much shorter run to laundry room	Resolved	N/A	Yes
D2	12/20/2018	Site D (Renton Residences)	EngAir	Burner Fan Sensor	- An hour after start-up the burner shut off - Energy 350 called EngAir technician who had just left and diagnosed the error light as a combustion fan speed sensor error	We flipped the magnet on the end of the combustion fan shaft (same issue as Site B unit)	Resolved	15 minutes	No

Issue ID	Date	Site	Manu-facturer	Issue/Challenge	Details	Solution	Status	Unit Down Time	Specific to C-RTUs?
D3[18]	4/4/2019	Site D (Renton Residences)	EngAir	Fan Belt Failure	- At 7:50am on 4/4/2019 the unit fan belt snapped - The fan motor continued to run unloaded and our temperature sensors remained within normal range so we did not catch the issue for a few days - We had just had some connectivity issues with our cellular data monitoring device a couple days prior and when we did identify the issue assume our monitoring system had failed - Site D site contact was not aware of the issue and received no comfort complaints	Site D maintenance staff replaced fan belt on 4/12/2019; needed to use belt two sizes larger than the one originally installed.	Resolved	8 days (2 days from detection)	No
D4	4/12/2019	Site D (Renton Residences)	EngAir	Low-Limit Alarm	- After the fan belt was replaced, the heat would not come back on, although the fan continued to run; warmer weather, so no issues bringing in untempered outside air - After a few rounds of troubleshooting with EngAir tech support, we diagnosed the issue as a failed "CWP Controller" that disables heat when a conductivity sensor in the condensate drain senses moisture; this feature prevents the unit from heating in the event the condensate drain is blocked - However, replacing the CWP Controller did not resolve the issue, and after hiring an HVAC technician who ran through the same troubleshooting, EngAir tech support recommended a supply fan manual reset button that was hidden near the motor, which resolved the issue	- EngAir shipped a replacement controller under warranty as soon as the issue was diagnosed - Actual solution to alarm was resetting the alarm manually with a switch located within the fan/motor area -Slow response time due to warm weather and no comfort complaints (busy time for maintenance)	Resolved	12 days without air (20 days without heat)	Yes
--	5/8/2018	Abandoned University Site	--	Unit Weight (Structural)	- Heavier unit requires 20' 2x12" added structural members to existing beams - Poor access to joists supporting roof --> Project abandoned	Site Abandoned	Abandoned		No
--	7/6/2018	Abandoned School Site	--	Unit Weight (Structural)	- New unit added >1,000 lbs and existing trusses were designed with very little additional capacity - Upgrading structural was not practical	Site Abandoned	Abandoned		No

[18] The downtime from issues D3 and D4 is limited to 4 days in Table 9 when reporting the total downtime. The majority of the actual downtime was due to a lack of urgency and impact on occupant comfort. When the fan belt broke on the Site D unit in April, the outside air temperature was quite warm and the site's facility manager had multiple construction projects in development. Since there were no complaints from the building occupants, it took multiple weeks to coordinate with Energy 350 and the manufacturer to resolve the issue. If this issue would have occurred during the Winter, it would have likely been resolved within a few days.

Appendix B – Previous Condensing RTU Demonstration Lookback

Summary

This document details the findings from revisiting the four Reznor condensing roof top units that were installed as a part of NEEA's Condensing Gas Heating Rooftop Unit Demonstration prepared by Gas Technology Institute and Washington State University over the 2015/2016 and 2016/2017 heating seasons. Given some of the unit issues during the demonstration project, NEEA contracted Energy 350 to check on the current state of the rooftop units and their reliability and operation over the last two years from the perspective of the building owners and maintenance staff.

The four demonstration sites were visited in February and March of 2019. During the visits, spot measurements of combustion efficiency and unit electrical power were taken, the unit and condensate drain systems were inspected, and informal surveys with the business owners, managers, facilities maintenance staff, employees, and mechanical service contractors were conducted.

Three of the four units were running and have been somewhat reliable since the demonstration ended almost two years ago, although two of these have been adjusted to provide less outside air than originally intended. The fourth site was shut down by the owner due to challenges maintaining space temperature, although this appears to have been a controls issue rather than unit performance or reliability problem. The following table summarizes the findings from the lookback.

TABLE 13 – LOOKBACK SUMMARY

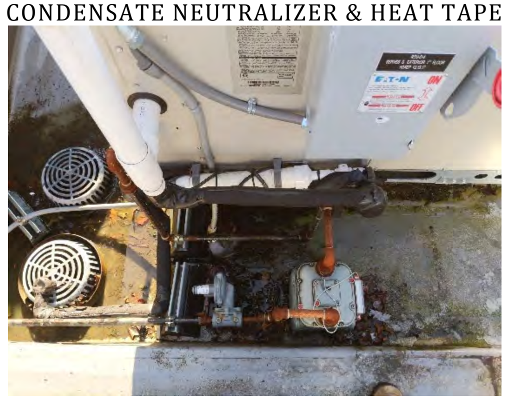
Site	Location (Utility)	Current Condition	Reliability Over Past 2 Years	Owner Satisfaction	Combustion Efficiency
Site A: Retirement Community	Lake Oswego, OR (NW Natural)	Running w/ 100% Return Air (Economizer failed)	Fair, maintenance has had few issues until recently	Fair, maintenance sees as "higher maintenance"	97.4% (high fire)
Site B: Retail Carpet Showroom	Chehalis, WA (Puget Sound Energy)	Running @ ~ 90% Return Air (Outside Air Damper closed)	Great, no issues reported by owner or HVAC service contractor	Great	99% (low fire)
Site C: Restaurant Kitchen	Union Gap, WA (Cascade Natural)	Turned off	Was shut down at end of demonstration due to control challenges	Indifferent, owner saw demonstration as interesting research; has backup heat (sort of)	N/A (off)
Site D: Bar & Grill Kitchen	Spokane, WA (Avista)	Running @ 100% Outside Air	Fair, Shuts down any cold stretch due to condensate line freezing	Fair, Owner loves high efficiency unit; kitchen staff doesn't like cold mornings 2-3 times/year	98.5% (High Fire)

Site A: Lake Oswego Retirement Community (NW Natural)

- Background:
  - Retirement Community in Lake Oswego, OR
  - 1/28/2016 Installed
  - 12/4/2016 Supply Blower motor/board failed
  - 2/16/2017 Supply Blower failed again
  - 2/23/2017 Supply Blower replaced, main control board failed
  - 3/3/2017 Control board replaced, economizer failed
  - 3/7/2017 Economizer board replaced, Economizer left @ 0% instead of 30% at conclusion of monitoring period
- Site Visit, 2/21/2019
  - Unit was off, although maintenance staff indicated that it must have gone offline within the last 24-48 hours as indicated by the 65°F zone temperature and cold outside air temperatures
  - Maintenance Manager called Hunter Davisson (HVAC service provider) to schedule service call
- Site Visit #2, 3/22/2019
  - Maintenance staff was busy, and it was very difficult to reschedule second visit
  - Hunter Davisson is site's preferred mechanical service contractor
  - HD replaced induction fan pressure switch, did not resolve the issue
  - After quite a bit of troubleshooting they learned that a capacitor in the induction fan motor had failed and fan was not pulling enough static pressure to trigger pressure switch
  - After replacing capacitor, unit has been running well for past couple weeks
  - Combustion analysis spot check resulted in 97.4% Combustion Efficiency
  - Honeywell economizer had failed, and outside air dampers were at 0%
  - 100% Return air led to short cycle times, 5 minutes on, 10 minutes off while on site
  - Economizer is standard part, which site had on order and would replace within the week

SITE A C-RTU

CONDENSATE NEUTRALIZER & HEAT TAPE



COMBUSTION RESULTS

GAS METER

Site B: Chehalis Retail Carpet Showroom (Puget Sound Energy)

- Background
  - Retail Carpet Showroom in Chehalis, WA
  - 1/28/2016 - Installed
  - 4/28/16 – Faulty Gas ignitor/flame sensor
  - Leaking Condensate
  - 9/1/2016 – control board failure
- Notes
  - Chehalis Sheet Metal – installing contractor and current service provider
    - Operating Well as far as he knows
    - Tricky metal roof access (wait till good weather)
    - Chehalis Sheet Metal has no records of any repairs or failures since 9/2016 (only filter changes and annual service inspections which included typical RTU checks but no major work)
- Site Visit 2/18/2019
  - Running well, 99% efficient combustion spot check
  - Condensate out inducer fan outlet onto roof, although no signs of damage to roof
  - Outside air damper fully closed, bringing in 10% outside air or less from small gap where air leaks by (mostly just recirculating air)
    - While on site, the unit burner would cycle on for 5-10 minute and then off for 10 minutes to maintain space temperature (very little ventilation load)
  - No neutralizer, condensate drain piped directly into bathroom vent piping
  - Owner has had no issues with unit and is very happy with the operation of the new unit
  - Overall very good experience with Reznor unit and pilot project
  - Gas meter spot check: 1.9 cfm ~ 118,000 btu/hr (96,000 btu/hr nameplate)
  - Unit power spot check: 0.22 kW (supply fan on, combustion fan off)

SITE B CONDENSING UNIT

COMBUSTION EXHAUST OUTLET

OUTSIDE AIR DAMPER CLOSED

COMBUSTION ANALYSIS RESULTS

BACHARACH

BACHARACH, INC.
PCA 3
SN: QX1056

Time: 01:34:47 PM
Date: 02/18/19

Fuel
NGAS

O_2	10.4 %
CO	5 ppm
Eff	99.0 %
CO_2	5.9 %
T-Stk	82 °F
T-Air	66.4 °F
EA	87.9 %
CO(0)	9 ppm
NO	*** ppm

CONDENSATE DRAIN RUN IN ATTIC

UNNEUTRALIZED CONDENSATE PENETRATION IN TOILET VENT PIPE

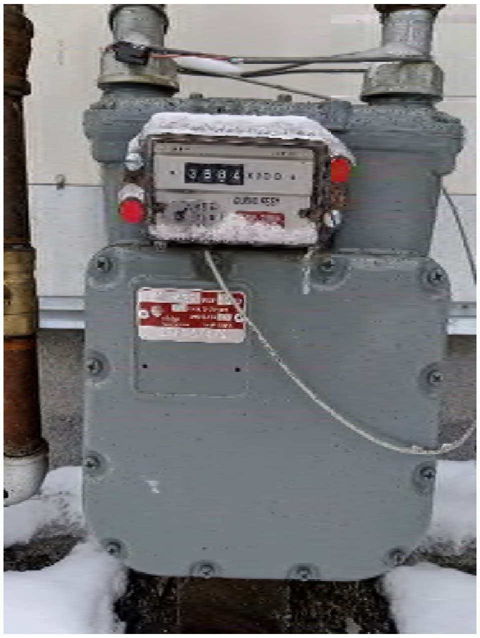
Site C: Union Gap Restaurant (Cascade Natural Gas)

- Background
  - Restaurant Kitchen in Union Gap, WA
  - 9/1/2016 – Failed combustion fan and control board
  - 12/10/2016 – Modulating inducer fan and speed control board failures (replaced)
- Notes
  - Owner believed that unit had not run since end of field trial (Spring 2017)
- Site Visit 3/7/2019
  - Unit supply fan was not running, but appeared to be in good shape physically
  - Gas valve was closed, unit controls indicated unoccupied mode
  - Steve remembers that after a few problems initially, the unit ran fairly well through Winter 2016/2017, however, the kitchen was always too hot
  - As detailed in the GTI report, while the baseline unit was controlled to a thermostat setpoint in the kitchen, the Condensing RTU was controlled to a supply air temperature
  - A few adjustments were made through the field trial
  - Owner believes that they shut the unit down in the Spring and the end of the trial and never turned it back on due to comfort concerns
  - The staff rarely complain now, as they just leave the kitchen door open which experiences significant transfer air from the restaurant (effectively transferring load to the (5) or so other RTUs on the roof
  - The kitchen has a separate A/C only unit that runs during the summer to provide makeup air to the kitchen
  - I recommended that they have their mechanical contractor take a look to see if they could reconnect the C-RTU to the old Thermostat (still in place) and cycle heating off based on space temperature as 91%+ unit would consume less gas than 80% efficient restaurant units (as well as providing better air quality in the kitchen during the Winter)

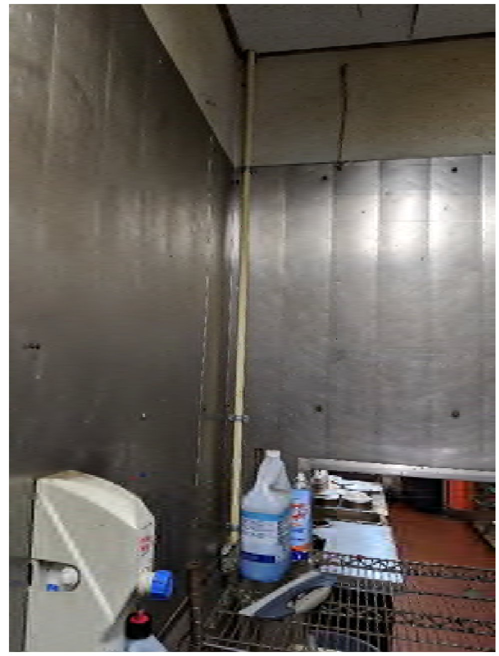
SITE C: UNION GAP RESTAURANT

SITE C UNIT

UNIT GAS METER



CONDENSATE LINE TERMINATING IN KITCHEN SINK



Site D: Spokane Bar & Grill (Avista)

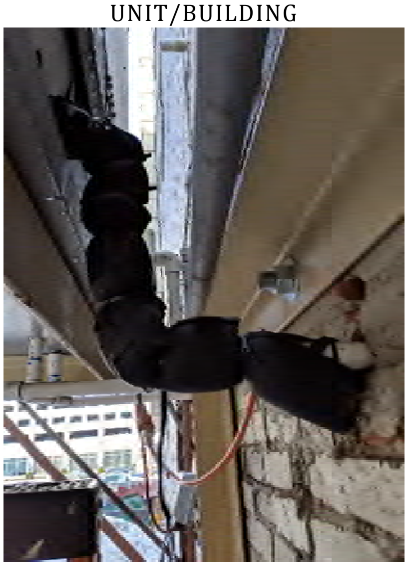
- Background
  - Bar and grill kitchen in Spokane, WA
  - 12/9/2016 – Heat Tape unplugged, melted control board, flame rollout on attempted restart
- Notes
  - Holiday Heating installed and has maintained the unit
  - As far as restaurant owner knows, the unit has been operating great ever since (did not mention failure or flame rollout
  - Left VM on 2/8/19, no response
  - Follow up call with Holiday front desk on 2/15/19, left message with front desk, no response
- Site visit 3/7/2019
  - 3:20pm, 34°F outside air temperature, clear day
  - Unit off when arrived, staff had turned off early afternoon due to hot kitchen
  - Turned switch on, unit fired right up
  - Supply air temperature setpoint was at 60.3°F
  - I was having trouble getting a good combustion analysis result due to low fire
  - Temporarily bumped up setpoint to 70.0°F
  - Combustion results: 98.5% combustion efficiency (41°F Stack temp, 34°F OAT!)
  - In speaking with kitchen manager, the unit has run well except in very cold weather
  - According to manager, every time in last 3 years that outside temperature has fallen into the low 20's or below, the unit has stopped running
  - Holiday Heating who comes out to check on unit has explained to him that the condensate line within the unit freezes

    - There is heat tape installed on condensate line between unit and building, which was working when on site
    - However, this unit was installed on a platform above a parking lot on the side of the building, and is effectively exposed to the elements on all six sides of the RTU
    - The unit remains down for a few cold days and then once unfrozen Holiday Heating switches the unit back on
  - Other than freezing issues, the manager has said the unit runs great and he enjoys checking the condensate line window that Holiday Heating installed and has instructed him to make sure condensate is flowing when the unit is on during the summer

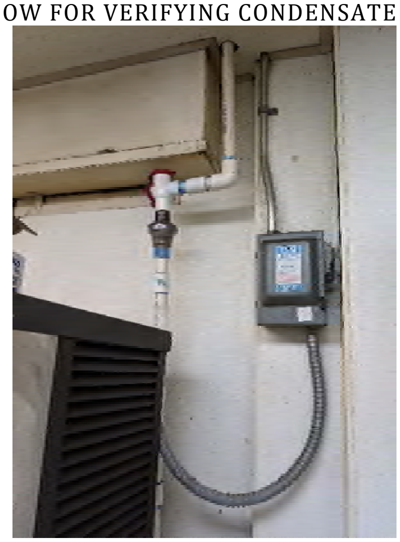
SITE D UNIT INSTALLED ON PLATFORM

UNIT UNDERSIDE (A/C CONDENSATE LINE AND HEAT TAPE)

HEAT TRACE AROUND CONDENSATE LINE BETWEEN UNIT/BUILDING



CONDENSATE LINE IN KITCHEN WITH WINDOW FOR VERIFYING CONDENSATE FLOW



COMBUSTION ANALYSIS RESULTS

DOWNTOWN SPOKANE

Appendix C – Manufacturer Condensate Drain Instructions

The installation instructions for the condensate drain and neutralizer tank from both manufacturer's installation and operation manuals are included below for reference.

FIGURE 39 – ICE WESTERN CONDENSATE INSTRUCTIONS (1 OF 5)

HEAT EXCHANGER CONDENSATE DRAIN

The Heat Exchanger unit is provided with a condensate drain. The 3/8" (PLC w/ Braided S.S.) condensate drain connection is located on the underside of the flue discharge box of the heat exchanger. Both indoor and outdoor units **must** have the heat exchanger condensate piped to sanitary sewer drain. The drain line shall be installed in accordance with all plumbing codes. When the heat exchanger is located outdoors, the drain must be run inside the provided condensate drain-line chase of the unit, refer to (Figure 10). The chase shall provide piping access to the interior of the building space (preferably a mechanical room or maintenance room), where the condensate tank will be located for easy maintenance and service. All drain lines from the heat exchanger must be protected from freezing.

WARNING!

Failure to connect the condensate drain can result in uncontrolled condensate drainage into building and/or unit, resulting in standing condensate drainage fluid, which can cause damage to equipment and/or building damage, injury or death. Condensate fluid is high in pH, and is known to corrode and damage, equipment & structure, and may cause other unforeseeable operating problems.

WARNING!

In areas that experience prolonged below freezing outdoor temperatures, the condensate drain line must be routed through a heated space, as provided with condensate drain chase. Failure to protect the condensate drainage pipes from freezing can result in line freeze, condensate freeze-up in/at unit heat exchanger, causing equipment, building, or other damage, injury, or death.

DO NOT DRAIN CONDENSATE ONTO ROOF AREA

22

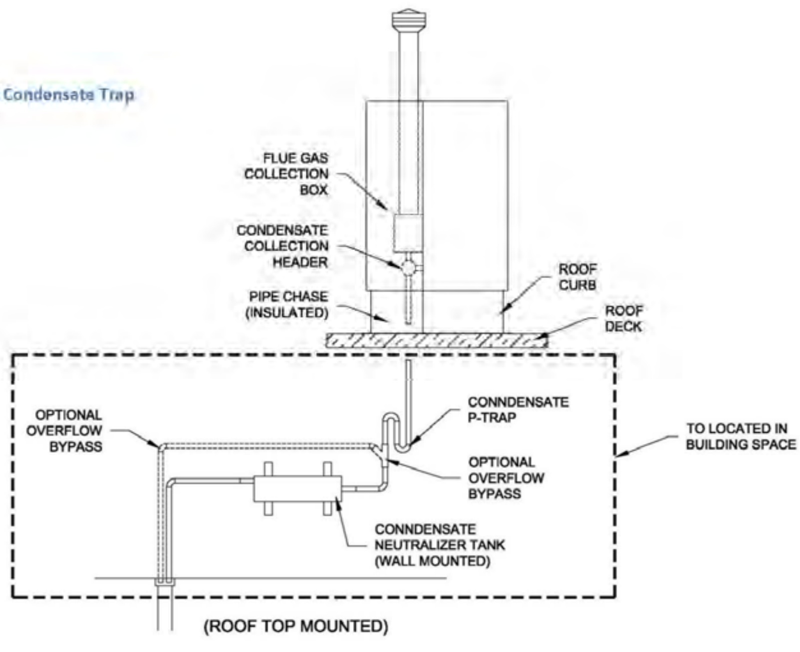
INSTALLATION OF THE CONDENSATE DRAIN / TRAP (Shipped Loose)

NOTE: the condensate trap is shipped loose with unit, and requires installation as per plumbing codes before operation of the heat exchanger appliance.

- **DO NOT** connect the unit gas lines to heater until all the following instructions have been completed.

- Before unit is placed on roof curb, ensure there is opening to building space (through provided condensate drain chase in unit and roof curb, refer to (Figure 11). Once the unit has been placed on the curb, locate the condensate collection header (located in the condensate drainage chase area). Connect the plumbing drop lines to the provided stainless steel connection nipple at the Heat Exchanger condensate collection header.

Figure 11 Installation of Condensate Trap

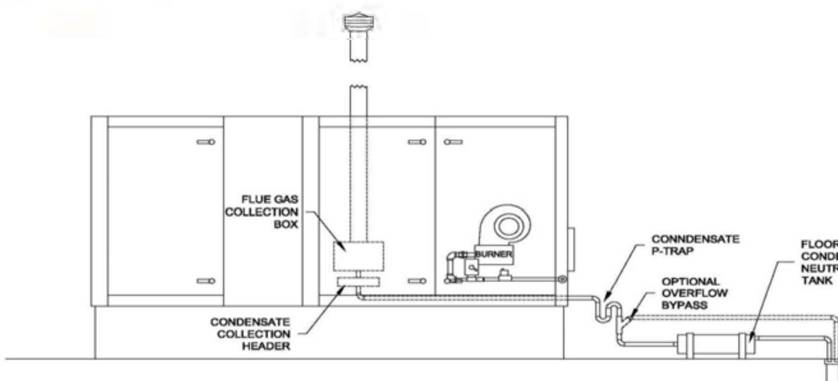


- In an event of an indoor installation, the condensate neutralization tank must be located at a lower point then the unit condensate drainage connection center line. A p-trap must also be installed, refer to (Figure 12).

- Determine an appropriate location for condensate neutralization tank to be located in either a mechanical or maintenance room & rigidly mount onto wall or appropriate structure. Ensure there is adequate access area around the condensate neutralization tank for service & maintenance.

- ❖ Connect the condensate trap to the intake nipple of the condensate neutralization tank.
- ❖ Connect the condensate drop line from the unit's heat exchanger condensate collection header outlet, to the intake end of the condensate neutralization tank.
- ❖ Connect a drainage line to the discharge nipple on the condensate neutralization tank, run drainage line to sanitary sewer connection as per National and Local plumbing codes.
- ❖ Seal all joints and connections with high temperature sealant caulking.

Figure 12 P-trap Installation



(INDOOR HORIZONTAL INSTALLATION)

CONDENSATE DRAINAGE/NEUTRALIZER INSTALLATION INSTRUCTIONS

All plumbing line for condensate drainage from Heat Exchanger appliance MUST adhere to national and local plumbing codes.

- ❖ Extend condensate drain line from unit, through the condensate drainage chase of unit into the building space. (Preferably a maintenance or mechanical equipment area.) Drainage line sizes are to be minimum of ¾" pipe & fitting size. PVC or CPVC pipe material or other suitable for corrosive condensate fluid.
- ❖ The condensate line runs shall be sloped (at minimum of 2%) toward the sanitary floor drain.

- The condensate PVC drain line and fittings shall conform to ASTM D1785 / CSA b137

- The condensate CPVC drain line and fittings shall conform to ASTM 2855 / CSA B1347.6

- Use approved methods and material; install all drain lines in accordance with local and National codes.

CONDENSATE NEUTRALIZATION TANK INSTALLATION INSTRUCTIONS

NOTE - Check with your local water authority for regulations regarding discharge of treated condensate to the drain or sewer system.

WARNING!

RISK OF DAMAGE TO APPLIANCE! The neutralization kit inlet and discharge must be at a lower elevation than the condensate drain from appliance.

WARNING!

DO NOT ALLOW EXHAUST FLUE GASSES TO MIGRATE THROUGH THE NEUTRALIZATION TANK.
All condensate drains must have a trap to prevent flue gas leakage. Flue gas leakage can cause injury or death from carbon monoxide.

WARNING!

Connection to the appliance and neutralization kit must be installed to ensure that no condensate backflow into the appliance can occur.

- The inlet has a center inlet connection port and the outlet connection is off center. Mount the neutralization capsule on the wall or floor securing it with the provided brackets. When mounting capsule in the horizontal position rotate the tube so the outlet is at its lowest point (Figure 10 and 11). The preferred mounting method is in the horizontal position.

- Connections to the appliance and neutralization kit must be installed to ensure that no condensate backflow can occur. Figure 10 and 11)

- Connect the provided hose or corrosion resistant piping and secure it to the floor or wall to prevent movement. Do not route the condensate line through any area that is exposed to freezing temperatures. If traffic poses a risk, install some protection to prevent movement and/or damage.
- The Y provided is a safety overflow in the event that the condensate drain becomes clogged. Mount as per installation diagram. Ensure that the condensate will flow freely from the appliance drain into the tank then to the drain.
- Access to the discharge is necessary for proper maintenance in order to check the effectiveness of the neutralizing media, using pH test strips.
- If there is no gravity drain available, install a condensate removal pump (by others) designed for use on condensing boilers and furnaces. The condensate pump must be equipped with an over flow switch to prevent the appliance from running should a failure occur.

CONDENSATE OPERATION AND MAINTENANCE

Operation

When the appliance is in operating mode the condensate will flow through the neutralizing media, raising the pH of the condensate to levels that will aid in preventing corrosion of the domestic drain and the public sewer system.

Maintenance

Monitor the level of the neutralization media in the capsule periodically. Check the pH level at the outlet of the neutralizing kit annually and use a suitable pH test strip paper or an electronic pH meter for precise measurement. The neutralizing media should be replaced when the pH level drops below the minimum level of the local water authority. For replacement media contact your local supplier or factory outlet.

RECOMMENDED CONDENSATE NEUTRALIZTION TANK MAINTENANCE SCHEDULE

UNIT	pH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
	pH												
	pH												
	pH												
	pH												
	pH												

LIMITED WARRENTY

The condensate tank (if provided with unit) is warranted against defects in materials and workmanship for one year.

6. Gas lines shall not interfere with unit access. The gas line connection at the heater shall have an approved drip leg with screwed cap.

7. A minimum 1/8 inch NPT plugged tapping, accessible for test gauge connection, must be installed immediately upstream of the gas supply connection to the unit.

8. On indoor units any control device (regulator, diaphragm valve, high and low pressure switch, etc.) that requires a bleed or vent line, must be vented in accordance with applicable codes.

GAS LINE TESTING (EXTERNAL TO THE UNIT)

The appliance and its individual shutoff valve must be disconnected from the gas supply piping system during any testing of that system at test pressures in excess of 0.5 psi (3.5 kPa).

The appliance must be isolated from the gas supply system by closing its individual shutoff valve during any testing of that system at test pressure equal to or less than 0.5 psi (3.5 kPa).

HEAT EXCHANGER CONDENSATE PIPING

All gas fired high efficiency condensing heat exchangers produce significant quantities of condensate due to very low leaving flue gas temperatures. There are essentially two methods of moving the condensate to a sanitary sewer drain; a sloped gravity drain pipe, and/or a purpose built condensate pump.

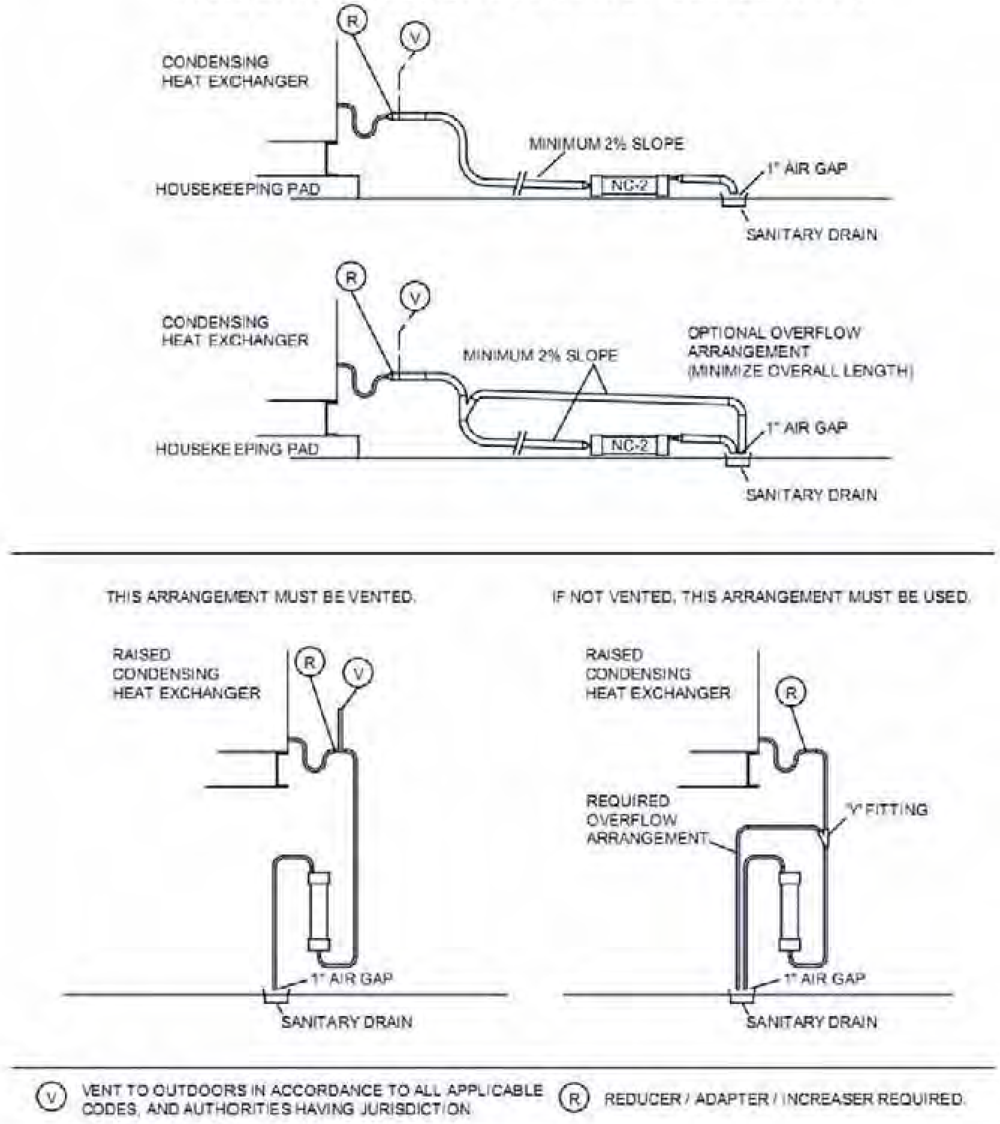
GENERAL PIPING

Gravity piping must be sloped down towards the drain at a minimum slope of ¼"per foot. Care should be taken to ensure that the slope is continuous throughout the length of the piping run. Poorly sloped piping could cause vapor locks or additional trapping, both of which could cause condensate water to back up and flood the heat exchanger. A flooded heat exchanger will result in poor combustion and heat exchanger failure. An internal conductivity sensor within the heating equipment will sense the increased water level and disable the heating controller. **The conductivity sensor must not be disabled, and unobstructed condensate drainage must be in place. Heat exchanger failure due to condensate drainage problems is rapid.**

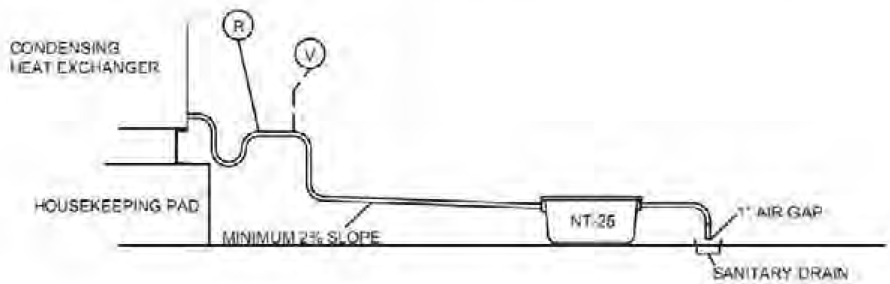
Standard drain connection sizes are tubing, ½" or ¾" (O.D.) stainless steel and will require a transition/reducer/increaser to connect to the drain piping.

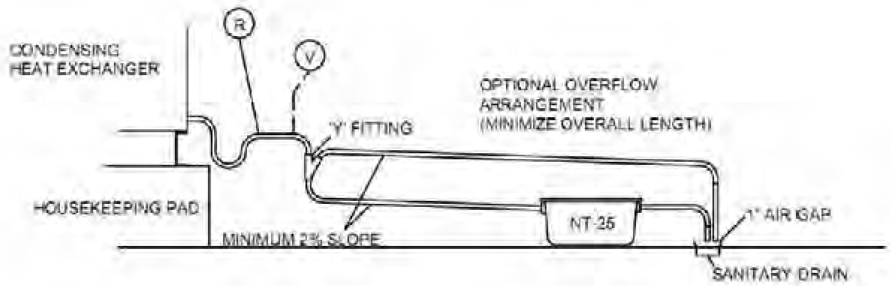
Proper plumbing practices must be followed. All piping and venting must be in accordance with all local codes and the authorities having jurisdiction. Attached are a number of suggested piping layouts. AAV (air admittance valves) may be used if allowed by code; however the installation should be confirmed with the local plumbing inspector. Finish piping the condensate drain to the building sanitary sewer in accordance with local codes. This may include installation of an optional neutralizer tank.

INDOOR CONDENSATE PIPING - SMALL TANK



INDOOR CONDENSATE PIPING - LARGE TANK





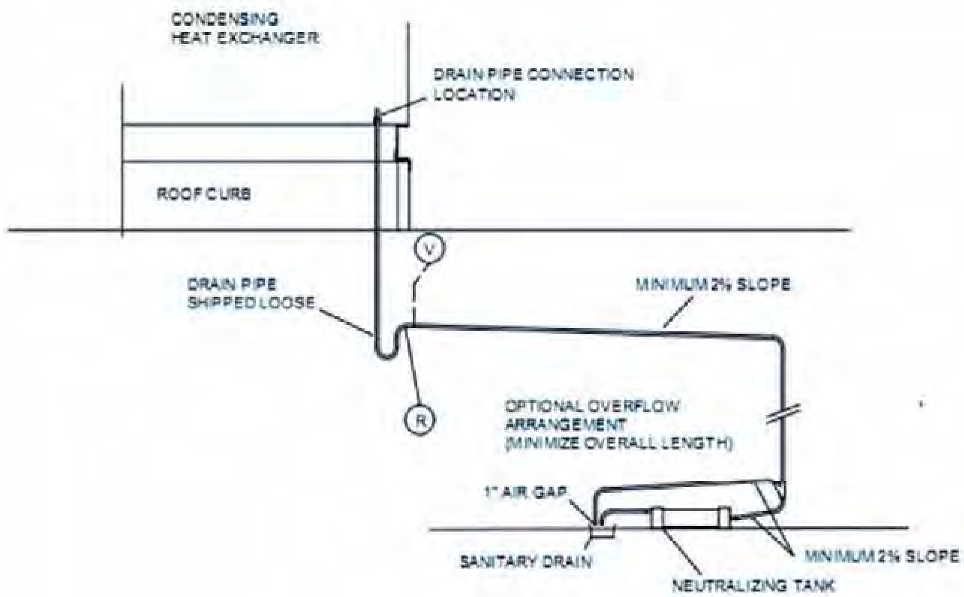
(V) VENT TO OUTDOORS IN ACCORDANCE TO ALL APPLICABLE CODES, AND AUTHORITIES HAVING JURISDICTION.
(R) REDUCER / ADAPTER / INCREASER REQUIRED.

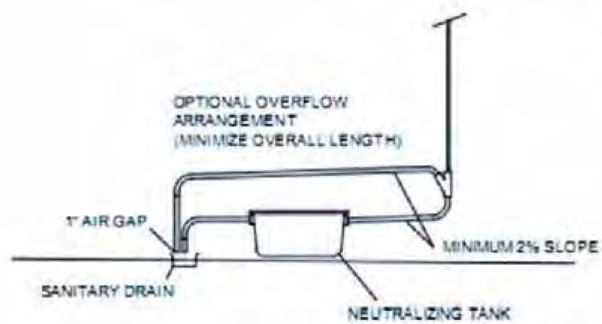
OUTDOOR INSTALLATIONS

Curb mounted rooftop equipment have a <u>bottom</u> drain connection extends down through the (relatively) warm area within the curb and into the building ceiling space. The extension rod and trap are supplied (shipped loose) by Engineered Air.

Base (or slab) mounted outdoor condensing equipment is NOT RECOMMENDED, and should be avoided in areas that experience freezing temperatures. If this installation method is necessary all piping must be maintained at a temperature above freezing. Increased slope of piping with continuous support is recommended.

ROOFTOP INSTALLATIONS





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NEUTRALIZING TANKS

The condensate is acidic, with pH values ranging from 3 to 4 (similar to vinegar). Neutralizing tanks are sized base on total flow (or total btuh). The NC2 (1/2" NPT inlet and outlet connections) cartridge style is for sizes up to and including DJX140 (max 1,400,000 btuh). The NT25 (1" NPT inlet and outlet connections) is used for sizes DJX200 and larger (max 3,000,000 btuh). The NT25 may be used for more than one unit. A NT25-P tank with a built in condensate pump is available for equipment without adequate gravity drainage.

DRAIN-WASTE-VENT PIPING MATERIAL

PVC, CPVC, and other materials suitable for corrosive condensate may be used, however care must be taken to support the piping, allow for expansion, and ensure no droops or sags are apparent during installation and operation. Piping may have to be continuously supported.

Drain pipe diameter should be no less than 1 ¼". Suggested hanger spacing is every 3 feet (1 meter).

The PVC condensate drain piping and pipe fittings must conform to ASTM D1785 / CSA B137.3. The CPVC condensate drain piping and pipe fittings must conform to ASTM 2855 / CSA B137.6. Use approved methods and material. Install drain lines in accordance with local and national codes

CONDENSATE PUMPS

Indoor installed equipment that does not have adequate gravity draining at the indicated slopes require a condensate pump to be installed. A large number of condensate pumps are available on the market for use in systems that require a vertical rise. Condensate pumps with internal neutralizing tanks are commercially available, as well. The high level limit switch should be interlocked to the unit to disable heat operation on pump failure. Refer to Electrical Diagram for interlock details.

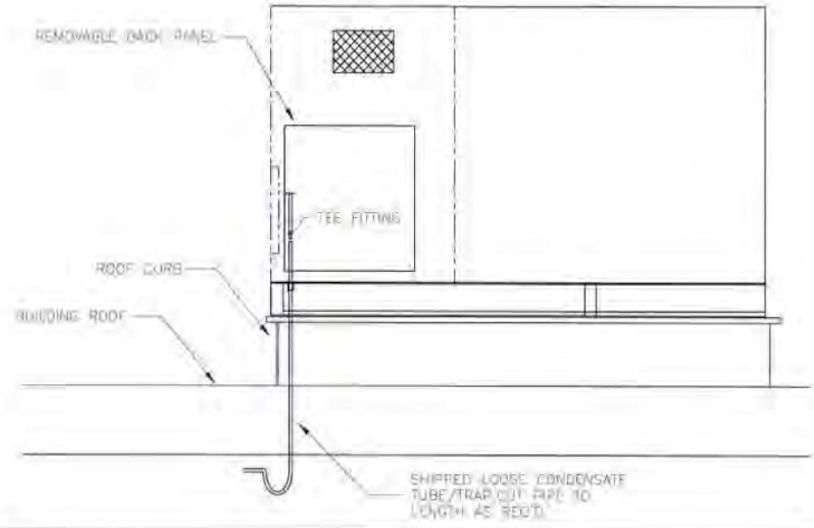
CALCULATED MAXIMUM FLOW RATE

The total volume of leaving water from the heat exchanger can vary dramatically depending on the operation type, control methods, and ambient conditions. Refer to the mechanical drawing for equipment drain tubing size.

BTUH	CONDENSATE (gph)*	Neutralizing Tank Size
100,000	0.3	NC-2
200,000	0.5	NC-2
300,000	0.8	NC-2
400,000	1.1	NC-2
500,000	1.4	NC-2
600,000	1.6	NC-2
700,000	1.9	NC-2
800,000	2.2	NC-2
900,000	2.5	NC-2
1,000,000	2.7	NC-2
1,100,000	3.0	NC-2
1,200,000	3.3	NC-2
1,300,000	3.6	NC-2
1,400,000	3.8	NC-2
1,500,000	4.1	NT-25
1,600,000	4.4	NT-25
1,700,000	4.7	NT-25
1,800,000	4.9	NT-25
1,900,000	5.2	NT-25
2,000,000	5.5	NT-25
2,100,000	5.8	NT-25
2,200,000	6.0	NT-25
2,300,000	6.3	NT-25
2,400,000	6.6	NT-25
2,500,000	6.9	NT-25
2,600,000	7.1	NT-25
2,700,000	7.4	NT-25
2,800,000	7.7	NT-25
2,900,000	8.0	NT-25
3,000,000	8.2	NT-25

* Calculation based on 91% efficiency.

THE CONDENSATE TRAP IS SHIPPED LOOSE AND REQUIRES INSTALLATION BEFORE ANY OPERATION OF THE APPLIANCE.



INSTALLATION OF THE SHIPPED LOOSE DJX CONDENSATE DRAIN/TRAP

1. **DO NOT CONNECT THE GAS LINE TO THE HEATER UNTIL ALL OF THESE INSTRUCTIONS HAVE BEEN COMPLETED.**
2. **Before the unit is placed on the curb ensure that an opening for the condensate drain has been provided through the roof/structure in the location shown on curb drawing and is the correct size as shown on the curb drawing.**
3. **Once the unit has been placed on the curb, remove the back panel from heat exchanger section and locate the condensate collection tube. Two arrangements are possible. One is a 1/1/2"Ø (42mm) stainless steel tube which collects condensate from various sections of the heat exchanger and also houses the blocked condensate sensor. The collection tube has a 1/2"Ø (12mm) drain tube. The second version has a 3/4"Ø (19mm) drain tube connected directly onto the heat exchanger, with the blocked condensate sensor threaded directly into the heat exchanger secondary header. Remove shipping condensate plug.**
4. **Have one person inside the building extend the stainless steel condensate drain/trap up through hole in roof and through the provided hole in the bottom of the unit.**
5. **Slide the condensate pipe up to the drain tube, cut pipe to length as required. Attach the condensate pipe to the condensate drain tube using the supplied silicone hose and the supplied hose clamps.**
6. **Seal the gap around the drain with high temperature caulking.**
7. **Caulk and replace the back panel of the heat exchanger section.**
8. **Finish piping the condensate drain to the building sanitary sewer in accordance with local codes. This may include installation of an optional neutralizer tank.**

Condensate from the heater will be acidic. How acidic, is dependent on the quality of the gas (sulphur content) and the quality of the combustion air. Combustion air contaminants such as chlorides will increase the acidity. Install a neutralizing tank if required by local codes.

A condensate pump with a reservoir (by others) may be used to pump the condensate to a sanitary sewer above the unit if a floor drain is not available or is inaccessible. When installing a condensate pump, select one approved for use with condensing furnaces. The pump must have an overflow switch to prevent property damage from condensate spillage.

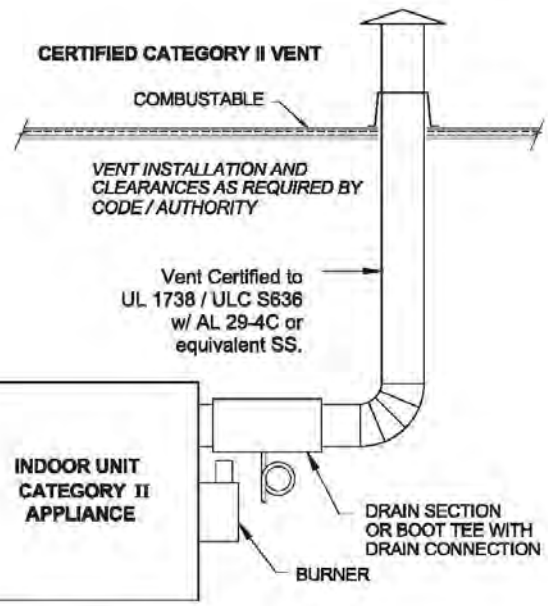
VENTING PRODUCTS OF COMBUSTION

Indoor model DJX heaters are Category II appliances. Venting material used shall be Type "BH" vent certified to UL 1738 / ULC S636 with AL 29-4C SS or equivalent suitable for temperatures up to 300°F (148.9°C). Do not intermix vent system parts from different manufacturers in the same venting system.

Installation shall be in accordance with the requirements of authorities having jurisdiction and ANSI Z2231/NFPA 54 or CSA B149.1. Heaters must be provided with sufficient combustion air and shall not be located in an area where a negative pressure will be created that will starve the burner of combustion air.

Do not connect the vent to any portion of a mechanical draft system that is under positive pressure. Do not connect the vent to any portion of a venting system that is not suitable for a Category II appliance. Do not install dampers or other restrictive devices in the vent.

Vent terminations shall be in accordance with the requirements of the authorities having jurisdiction.



The vent shall be installed in such a manner that access to the appliance or unit rating plate is not obstructed.

Appendix D – Research Questions and Answers

This field study has provided important real-world experience in testing the viability of condensing RTUs. Below are some key research questions and answers.

Q1: Do condensing RTUs perform adequately over a heating season without failure or downtime, while delivering satisfactory heating, air conditioning (if applicable), and ventilation to the conditioned space?

A1: Yes, although all 4 units have experienced downtime ranging from 1 day to 4 weeks over this heating season. Most/all issues have been non-condensing related issues (controls, PLC, BMS, fan belt failure, gas pressure issues, etc.) However, many of these issues were related to the RTUs being custom equipment with more robust controls and features. We expect many of these issues would not be as prevalent in mass-manufactured equipment with less customizability.

Q2: What is the simple payback of the four condensing RTUs relative to a standard efficiency RTU? How significant is the fan energy penalty?

A2: The simple payback of the four C-RTUs ranges from 11.3 to 57.4 years (32.8 on average) when incrementally compared to a standard efficiency (81-82%) RTU from the same manufacturer. The fan energy penalty for EngAir and ICE Western units is small relative to the gas savings and ranged from $7 to $19 annually for these four C-RTUs. Without fan penalties, the paybacks average 31.2 years.

Q3: Is NEEA's Condensate Management Best Practices Guide useful? What are its limitations? Does it conflict with codes or other standard practices?

A3: Yes, the Condensate Management Best Practices Guide provides excellent information regarding best practices for installing and maintaining C-RTU condensate drain systems. The guide aligns well with manufacturers' recommendations and Northwest building codes. Standard practice and code interpretation varies greatly, and the guide goes beyond what many contractors are currently practicing and what they are being held to. However, the guide does provide reasonable recommendations to sufficiently protect the C-RTU, building and sewer system.

Q4: Are there any operational, technical, or other barriers with Engineered Air or ICE Western products for installers or end users?

A4: In general, both manufacturers' products sufficiently meet the expectations of installers and end users. However, challenges with ICE Western technical support arose due to a lack of Northwest presence, and Engineered Air technical support was hesitant to support building maintenance without Energy 350 or HVAC technician involvement.

Q5: Were there installation efficiencies experienced after four RTU installations? What were the experiences of the crew?

A5: Yes, especially with the pipe fitter involved in condensation drainage and neutralizer systems. However, labor hours and costs did not significantly decrease, the pipe fitters were just better prepared and started doing more work before the day of replacement to avoid delays. Each condensate run installation required more than 30 hours of skilled labor and in follow up conversations with the installing pipe fitter and project manager, they do not expect the effort to significantly decrease on most installations.