CO2 & Integrated Heat Pump Water Heater Performance Report

Submitted to

FORTIS BC

In Partnership with BC Hydro, BC Ministry of Energy & Mines and Natural Resources of Canada

Submitted by

ENERGY350

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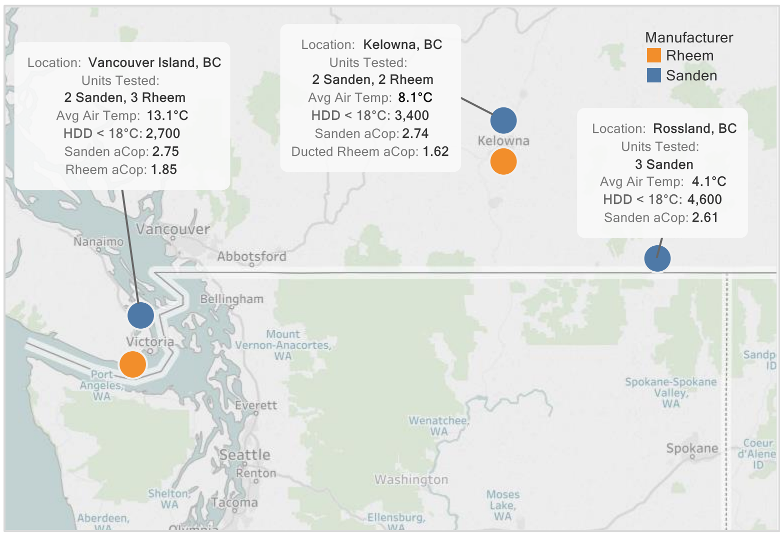
Table of Contents

1. Executive Summary

This report presents the field test performance results of Sanden's CO_2 split system heat pump water heater (HPWH) and Rheem's integrated HPWH. Energy 350 installed seven Sanden units and five Rheem units across three British Columbia locations including Kelowna, Rossland, and Vancouver Island. This report includes over a year of data for ten of the twelve sites. Figure 1 shows the results and geographic locations of the test sites.

Figure 1: Map of Water Heater Sites



Sanden's split system includes an indoor tank and an outdoor heat pump. By locating the heat pump outdoors, one can avoid the interactive heating penalty typically associated with heat pump water heaters. Most of the integrated Rheem units installed were ducted, which also eliminates the interactive space heating penalty typically associated with heat pump water heaters.

1.1 Cold Climate Operation

The two units use different strategies to operate in cold weather. With CO_2 as the refrigerant, the Sanden heat pump can operate even in very cold temperatures. The Rheem units rely on an electric resistance heating element for continued operation when ducted outside air is too cold for the heat pump cycle. Even in cold climates, the home heating penalty can be avoided with both units while maintaining a high average annual coefficient of performance (aCOP) and minimal impact on hot water delivery. Table 1 summarizes the field test results.

Table 1: Field Test Results

# of Units Tested	Manufacturer	Heat Pump Water Heater Technology	Storage Tank Sizes Tested (L)	Rated Northern Climate UEF	Field Tested aCOP	Incremental Installed Cost (CAD)	Energy Savings (kWh)	% Energy Savings
7	Sanden	CO2 "Split" System	160 and 315	2.9/3.3	2.69	$6,776	1,923	67%
5	Rheem	Integrated Unit	246 and 303	3.4	1.79	$2,346	2,180	51%

While both the Sanden and Rheem HPWHs performed well during field testing, the Sanden units performed with higher aCOPs than the Rheem units, particularly at lower outside air temperatures (OAT) as seen in Figure 2. The difference in performance at low OAT is due to the Sanden heat pumps ability to operate with conditions as low as -29°C while the Rheem switches to electric resistance heating at 2.8°C according to the manufacturer specifications which are summarized in Table 2.

Figure 2: Weekly COP vs. Outside Air Temperature

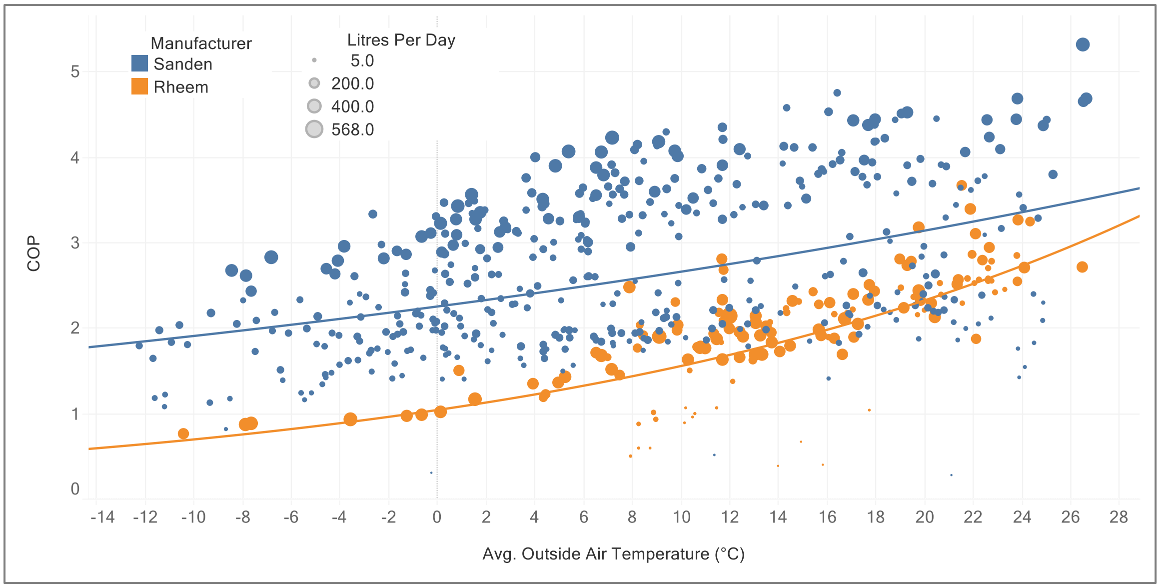


Table 2: Rated & Field-Tested Operating Temperatures

Manufacturer	Minimum Heat Pump Operating Temperature	Average Outside Temperature During Field Test	Average HDD (18°C Base)	aCOP
Sanden	-29°C	7.2°C	3,911	2.69
Rheem	2.8°C	13.0°C	2,875	1.79

1.2 Installation Cost and Complexity

The cost and complexity of the installation of the two technologies differs significantly. The Sanden units cost on average over $4,000 more than the Rheem units due to a higher cost of equipment and increase in installation costs. The Rheem is designed with an integrated heat pump and water heater to be a "drop in" replacement for a standard electric water heater. However, when ducted to avoid interactive effects, the suitable unit locations become limited and the installation becomes more complicated than a standard electric water heater. For this reason, to be a truly "drop in" replacement for a wide range of residences, unducted units in unconditioned or semi-conditioned spaces are preferable. The Sanden units are a split system with the heat pump located outside necessitating two dedicated electrical circuits being run to the outside unit for the unit power and for freeze protection. These factors lead to an additional 10+ labor hours, required electrical permits and an average incremental cost of $5,955 relative to a standard electric water heater. Table 3 shows a descriptive summary of the relative complexity and cost of each unit.

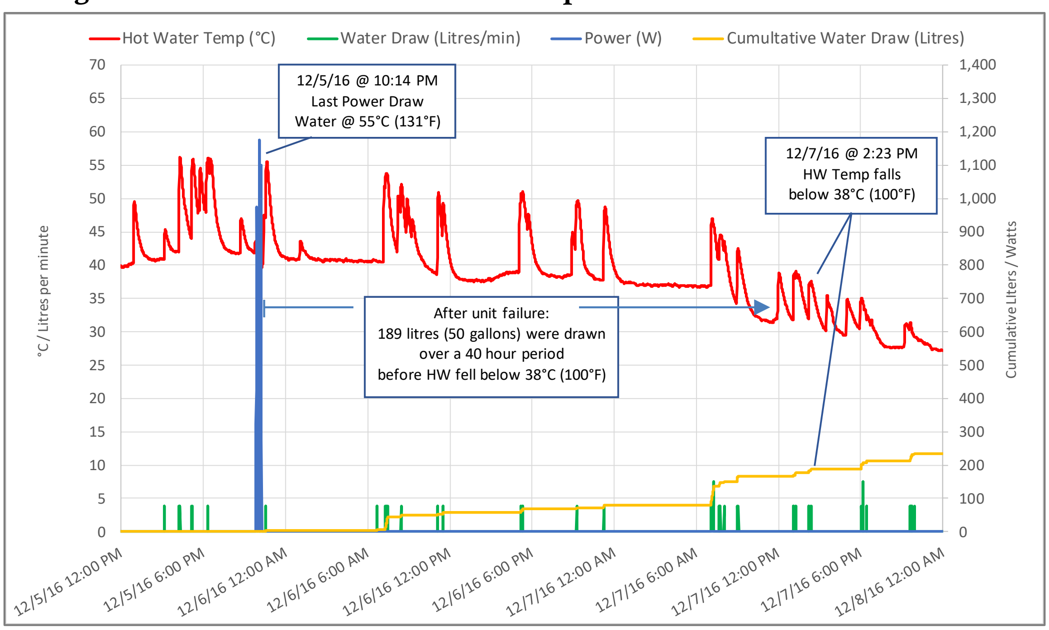
Table 3: Installation Complexity and Cost Summary

Manufacturer	Installation Complexity	Dedicated Electrical Circuit?	Electrical Permit Required?	Average Installation Labor Hours	Average Installtion Cost (CAD)	Average Incremental Cost (CAD)
Sanden	Higher	Required	Yes	21.3	$8,588	$5,955
Rheem	Lower	Not Required	Not Typically	10.5	$4,135	$1,558

1.3 Demand Response Potential

While assessing the demand response (DR) potential of these technologies was not the primary objective of this field trial, we did have a unique event that allowed us to simulate a DR event in the real world. On December 5th, 2016 one of the 315 litre (83 gallon) Sanden units stopped operating after the printed circuit board (PCB) failed.[1] After the heat pump stopped operating the participant continued to draw 189 litres (50 gallons) over a 40 hour period before hot water temperature fell below 38°C (100°F).[2] A previous demand response study (Sullivan et al., 2015)[3] also found that the 315 litre Sanden could deliver water at 49°C (120°F) hot water temperature for 12 hours after the system was powered off with a much higher simulated water draw of 492 litres per day (130 gallons). The 315 L Sanden tank has more than enough thermal storage to maintain hot water temperature during a four-hour demand response event. Based on tank size and water temperature, the smaller Sanden and two Rheem units also likely have sufficient capacity for a four-hour demand response event. The Rheem units also comes standard with the EcoNet interface which according to the manufacturer is "future-compatible with demand-response system".

Figure 3: Hot Water Draws and Temperature After Unit Powers Off



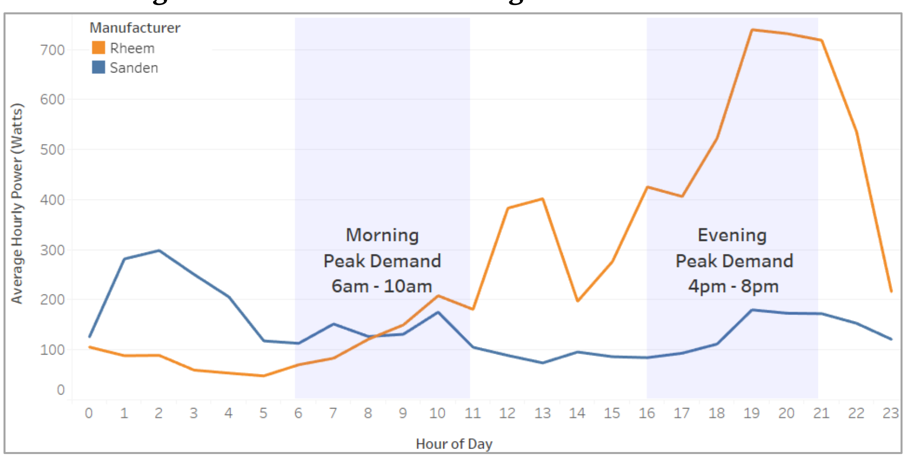
[1] The PCB failed due to a condensation issue from ambient air infiltration. The unit was quickly replaced by Sanden and the issue has been resolved in the 3rd generation units (GS3). For more information see the installation details of Rossland Site 3 in Section 10.3.
[2] The participant continued to draw hot water after the 40-hour period and did not contact Fortis BC about the loss of hot water until nearly 3 days after the unit failed.
[3] Sullivan, G.; Petersen, J.; 2015. Demand-Response Performance of Sanden Unitary/Split-System Heat Pump Water Heaters, Pacific Northwest National Laboratory

1.4 Impact on Peak Demand

The peak power of the Sanden units measured at 1.2 kW in the coldest weather, while the Rheem unit consumed 5.5 kW of peak power when both the heat pump and electric element operate simultaneously. Considering that most of the water heaters replaced had a rated power of 3 to 4.5 kW, this poses the question of whether there is a demand penalty associated with the new Rheem units with larger elements. To explore this, we looked at the average power consumption of all ducted units over the 36 coldest days[4] from the 2017-2018 heating season to better understand the coincidence between water heater use and system peak. As shown in in Figure 4, the Sanden units show their highest hourly average demand of 300-watts at 2 am, well before the morning peak window and another smaller 180-watt demand from 7 to 9 pm. The peak Rheem demand does line up with the evening peak demand reaching 750 watts at 7 pm. Part of this difference is explained by differing water draw patterns (Rheem participants drew almost double the amount of water in the evenings than the Sanden participants[5]) across a limited sample size (7 Sanden units and 4 ducted Rheem units). However, the results suggest the following:

- Sanden units display a more even demand profile as they run more hours throughout the day and have no backup electric element that causes a demand spike during high water draws.
- Even on the coldest days, the time the electric element comes on for one Rheem unit does not always coincide with other units and when it does some of the units operate in heat pump mode. The result is an average peak demand across all units that is significantly less than the 5.5 kW instantaneous power.
- Even if the backup electric element in a new water heater is larger, this should not exacerbate the system peak depending on coincidence, because increased element will result in shorter runtimes.
- The stored energy in hot water tanks is an excellent DR resource, which can allow the hot water heater to be interrupted for several hours without the loss of delivered hot water.

Figure 4: Average Demand Profile During the 36 Coldest 2017-2018 Days[6]



[4] Weather taken from the Victoria University weather station. Actual weather varied across the sites at three different climate zones, but should align well with the peak demand windows. The 36 coldest days during the performance period averaged 3.5°C and saw temperatures as low as -2.4°C. The Kelowna sites saw temperatures as low as -17.6°C and the Rossland sites saw a minimum temperature of -15.7°C.
[5] Sanden sites peaked at 21.7 litres/hour average at 7pm; Rheem sites peaked at 11.9 liters/hour at 7pm
[6] Figure 4 shows average hourly power for all Sanden and Rheem units excluding the unducted Rheem unit.

2. Overview of Technology

This section provides an overview of the two technologies tested.

2.1 Sanden CO_2 Heat Pump Water Heater

The Sanden CO_2 heat pump units consist of:

- One outdoor unit with compressor, condenser, evaporator, heat exchanger, pump, etc. The unit uses outdoor air as a heat source and CO_2 as the refrigerant. (Model GUS-A45HPA or GS3-A45HPA)[7]
- One indoor water tank with water loop and thermistor connection to outdoor unit to provide a start/stop signal.
    a. 160-litre (43-gallon) option – Model GAUS-160QQTA (SAN-43SSAQA)
    b. 315-litre (83-gallon) option – Model GAUS-315EQTD (SAN-83SSAQA)
- Heat trace and insulation[8] on exterior water pipes to prevent freezing.
- Manufacturer rated performance:
    a. 3.09 EF, 2.9 UEF_{NC}[9] (160-litre system)
    b. 3.84 EF, 3.3 UEF_{NC} (315-litre system)
    c. -29 to 60°C (-20 to 140°F) ambient air temperature operating range
    d. Tier 3 Advanced Water Heater Specification (formerly Northern Climate Spec)
- All Sanden units are factory-shipped with 65°C (149°F) hot water temperature set-point

2.2 Rheem Integrated Heat Pump Water Heater

The Rheem integrated heat pump units consist of:

- One integrated unit with hot water tank, compressor, condenser, evaporator, backup heating element and controls combined; the unit uses outdoor air or indoor air as the heat source depending on if the system is ducted or unducted.
    a. 246-litre (65-gallon) option – Model PROPH65 T2 RH350
    b. 303-litre (80-gallon) option – Model PROPH80 T2 RH350
- Manufacturer rated performance
    a. 3.5 EF, 3.4 UEF_{NC} (246 and 303-litre systems)
    b. 2.8 to 62.8°C (37 to 145°F) ambient air operating range
    c. Tier 3 Advanced Water Heater Specification (formerly Northern Climate Spec)
- All Rheem units were shipped with factory-default hot water temperature

[7] See Appendix for Sanden and Rheem product specification sheets provided by the manufacturers.
[8] Heat trace and insulation is not provided by the manufacturer.
[9] Uniform Energy Factor NC from Advanced Water Heater Specification (formerly Northern Climate Specification). Source: neea.org/advancedwaterheaterspec

set-points of 130°F (54.4°C) except Kelowna Site 4 which was reset at 135°F (57.2°C) at the occupant's request.

- All Rheem units were set to the factory-default Energy Saver mode which optimizes heat pump and electric resistance heat for low power consumption and high recovery. See Appendix for description of the other operating modes (Heat Pump, High Demand, Electric, and Vacation).

3. Field Testing Results Summary

Installation of the twelve field test units began in October of 2016. For all sites except Vancouver Island Site 1 and Vancouver Island Site 4 we have over a year of performance data.[10] On average colder temperatures were experienced at the Sanden sites compared to the Rheem sites (see Tables 2 & 3, Average Ambient Temp). This can be accounted for primarily due to the installation of three of the Sanden units in the colder climate of Rossland. The Sanden units achieved a higher average annual coefficient of performance[11] "aCOP" (2.69) than the Rheem units (1.79). Table 4 summarizes the effective performance and independent variables of the Sanden units and Table 5 summarizes the performance of the Rheem units separating the Kelowna Site 3 results as it is an unducted unit in a conditioned space. Table 6 and Table 7 show the respective technologies' performance in IP units.

Table 4: Sanden Performance (SI units)

Site	aCOP	Tank Size (Litres)	Climate Zone	HDD Below 18°C	Average Ambient Temp (°C)	Average Water Flow (L/Day)	Average Hot Water Temp (°C)	Average Inlet Water Temp (°C)	Months of Data
Rossland Site 1	2.62	314	6	4,600	2.6	102	52.9	11.0	15
Rossland Site 2	3.15	314	6	4,600	3.2	120	59.4	10.5	15
Rossland Site 3	2.06	314	6	4,600	6.6	100	52.5	10.7	15
Kelowna Site 1	1.86	163	5	3,400	6.6	74	52.4	16.5	15
Kelowna Site 2	3.62	163	5	3,400	8.0	288	51.6	10.2	15
V. Island Site 2	1.98	163	4	2,700	12.2	122	61.9	17.5	12
V. Island Site 3	3.52	163	4	2,700	10.8	148	61.3	15.8	12
Average	**2.69**	**228**	**5.1**	**3,911**	**7.2**	**136**	**56.0**	**13.2**	**14** [12,13]

Table 5: Rheem Performance (SI units)

Site	aCOP	Tank Size (Litres)	Climate Zone	HDD Below 18°C	Average Ambient Temp (°C)	Average Water Flow (L/Day)	Average Hot Water Temp (°C)	Average Inlet Water Temp (°C)	Months of Data
Kelowna Site 4	1.62	303	5	3,400	9.8	324	50.8	14.4	8
V. Island Site 1	1.76	246	4	2,700	9.5	195	49.4	10.3	4
V. Island Site 4	1.73	246	4	2,700	16.2	65	48.3	16.0	11
V. Island Site 5	2.06	246	4	2,700	16.7	279	49.7	13.5	12
Average	**1.79**	**260**	**4.3**	**2,875**	**13.0**	**216**	**49.6**	**13.6**	**9**
Kelowna Site 3	2.08	303	N/A	N/A	20.6	175	51.4	10.5	15 [14]

[10] The lack of performance data for Vancouver Island Site 1 is due to a change of owner at the site. The new owner declined to continue participating in the study.
[11] We define aCOP = (total useful energy delivered) / (input energy). This is a measure of efficiency over an annual basis at the respective site and includes tank skins losses. For sites with over a year of data, the performance of the duplicate months is averaged. For the sites with less than a year of data, the performance is extrapolated based on weather regressions and neighboring sites' weather during the missing periods.
[12] Heating Degree Day (HDD) values are from Table C-2 of Division B of the National Building Code of Canada (NBC) and are a measure of the heating demand for a specific location derived from outside air temperature.
[13] At Rossland Site 3 the first Sanden unit (GS2) failed on 2/7/17 and was replaced by a newer model (GS3) on 2/16/17. See the Rossland Site 3 section for the cause and details of the failure.
[14] Vancouver Island Site 5 is partially conditioned, drawing inlet air from the enclosed but unconditioned garage with the outlet air vented outside. Kelowna Site 3 is an un-ducted unit drawing air from a wood-pellet conditioned space. Kelowna Site 4 has a relatively high water temperature setpoint of 57°C (135°F), and very high water draws, both of which contribute to significant use of the electric elements and lower efficiency than the other Rheem units.

Table 6: Sanden Performance (IP units)

Site	aCOP	Tank Size (Gal)	Climate Zone	HDD65	Average Ambient Temp (°F)	Average Water Flow (Gal/Day)	Average Hot Water Temp (°F)	Average Inlet Water Temp (°F)	Months of Data
Rossland Site 1	2.62	83	6	8,280	40.8	27	127.1	51.8	15
Rossland Site 2	3.15	83	6	8,280	44.6	32	139.0	50.9	15
Rossland Site 3	2.06	83	6	8,280	43.9	26	126.6	51.3	15
Kelowna Site 1	1.86	43	5	7,009	43.9	20	126.4	61.7	15
Kelowna Site 2	3.62	43	5	7,009	46.4	76	124.8	50.4	15
V. Island Site 2	1.98	43	4	5,413	54.0	32	143.4	63.5	12
V. Island Site 3	3.52	43	4	5,413	51.5	39	142.3	60.5	12
Average	**2.69**	**60**	**5.1**	**7,360**	**46.4**	**36**	**132.8**	**55.7**	**14** [15]

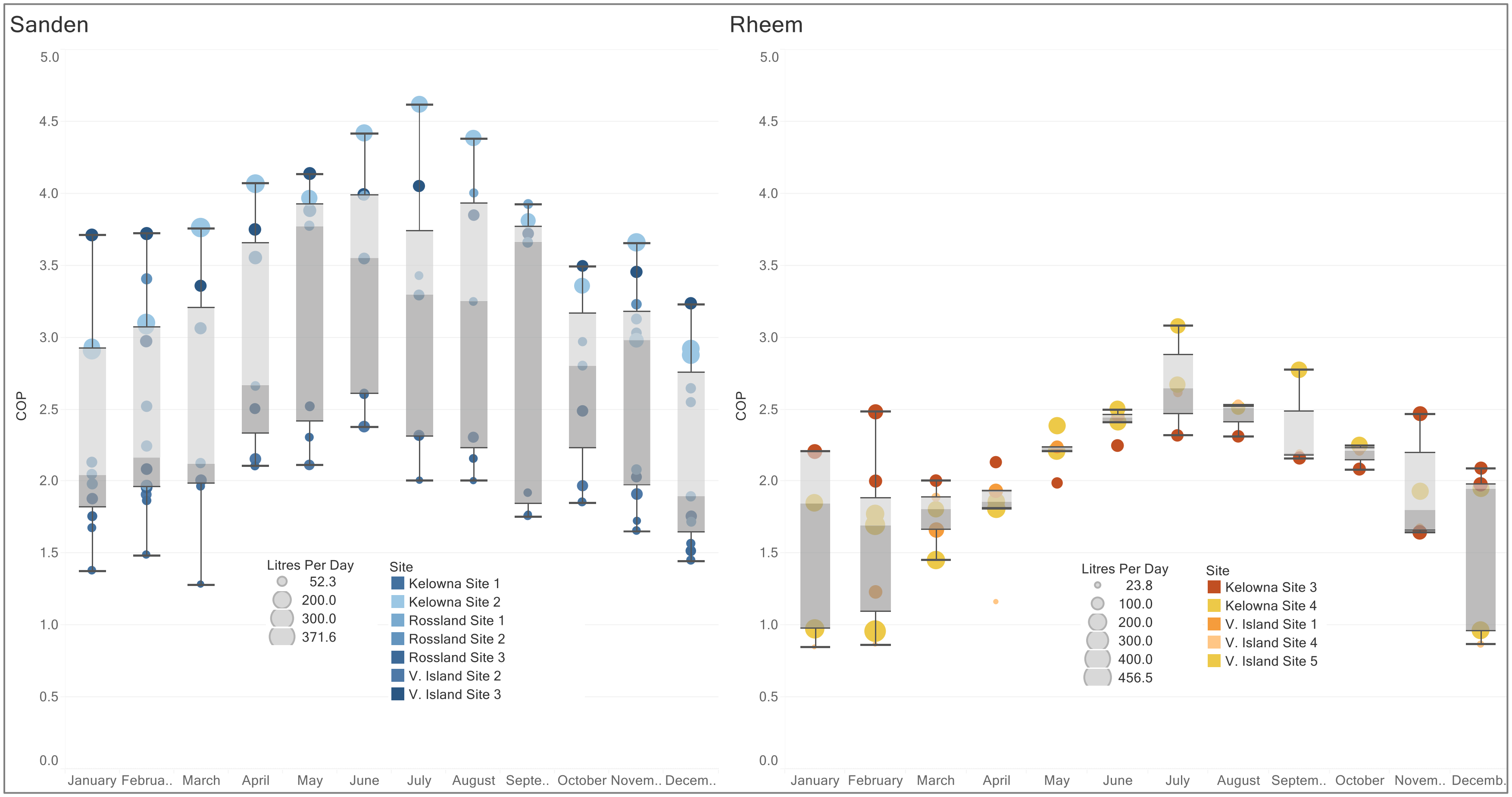
Table 7: Rheem Performance (IP units)

Site	aCOP	Tank Size (Gal)	Climate Zone	HDD65	Average Ambient Temp (°F)	Average Water Flow (Gal/Day)	Average Hot Water Temp (°F)	Average Inlet Water Temp (°F)	Months
Kelowna Site 4	1.62	80	5	7,009	59.8	86	123.4	57.9	8
V. Island Site 1	1.76	65	4	5,413	49.1	52	121.0	50.6	4
V. Island Site 4	1.73	65	4	5,413	61.1	17	118.9	60.8	11
V. Island Site 5	2.06	65	4	5,413	62.0	74	121.4	56.3	12
Average	**1.79**	**69**	**4.3**	**5,812**	**58.0**	**57**	**121.2**	**56.4**	**9**
Kelowna Site 3	2.08	80	N/A	N/A	69.1	46	124.5	51.0	15

Figure 5 shows the monthly average COP of all sites along with the median, upper and lower quartiles. Across the board the Sanden units perform with a higher COP than the Rheem units – 2.7 versus 1.8. On average, both technologies performed with a COP of 1.5 or better in every month of the study including the coldest winter months.

[15] HDD65 values are from 2017 ASHRAE Handbook: Fundamentals (IP), Appendix: Design Conditions for Selected Locations.

Figure 5: Monthly COP by Technology and Site



2.1 Energy Savings Summary

We calculate the average energy savings of the Sanden units to be 67%[16] and the Rheem units to be 51% relative to the calculated baseline. The baseline energy is calculated using a standard electric resistance water heater with an energy factor (EF) between 0.86 and 0.91, depending on the size of the tank per the U.S. Department of Energy Federal Standards. We apply this EF to the delivered hot water load measured during the performance period. See Section 8.3 for more details on the baseline energy factors used. On an annual savings basis, both units perform similarly with the Sanden units saving 1,923 kWh per year (relative to the calculated baseline) and the Rheem units saving 2,180 kWh per year on average. However, the Sanden sites saved more energy on a percentage basis than the Rheem units (67% savings at Sanden sites versus 51% at Rheem sites). This difference in kWh savings and percentage savings is due mainly to the Rheem sites having a higher hot water demand of 10 kWh per day delivered hot water (216 litres per day) than the 7 kWh per day (136 litres per day) at the Sanden sites.

Data collection periods varied between 4 and 15 months in length. For the sites with less than 12 months of data we calculated the aCOP by developing relationships between performance and ambient temperature and daily water usage, and extrapolating based on neighboring sites' temperature data and the individual sites' water draw patterns. For the sites with more than 12 months of data, we averaged the performance and water heating load of the duplicate months in order to annualize the energy savings results. Table 8 summarizes the calculated energy savings of the Sanden units and

Table 9 summaries the energy savings of the Rheem units.

Table 8: Sanden Energy Savings

Site	aCOP	Average Water Heating Load Delivered (kWh/day) [kBtu/day]	Annual Baseline Energy (kWh)	Annual Sanden Energy (kWh)	Annual Energy Savings (kWh)	% Savings	Months of Data
Rossland Site 1	2.62	6 [19]	2,406	790	1,617	67%	15
Rossland Site 2	3.15	7 [24]	2,928	799	2,129	73%	15
Rossland Site 3	2.06	5 [16]	1,967	821	1,145	58%	15
Kelowna Site 1	1.86	3 [12]	1,360	668	692	51%	15
Kelowna Site 2	3.62	14 [47]	5,494	1,388	4,106	75%	15
V. Island Site 2	1.98	7 [22]	2,624	1,212	1,412	54%	12
V. Island Site 3	3.52	8 [27]	3,191	829	2,362	74%	12
Average	**2.69**	**7 [24]**	**2,853**	**929**	**1,923**	**67%**	**14**

[16] Assuming a typical EF of 0.88 for an electric hot water tank the Sanden savings are equal to 1 – 0.88/2.69 = 0.67 or 67% and the Rheem savings are equal to 1 – 0.88/1.79 = 0.51 or 51%. See Section 8.3 for more details on the baseline energy factors used.

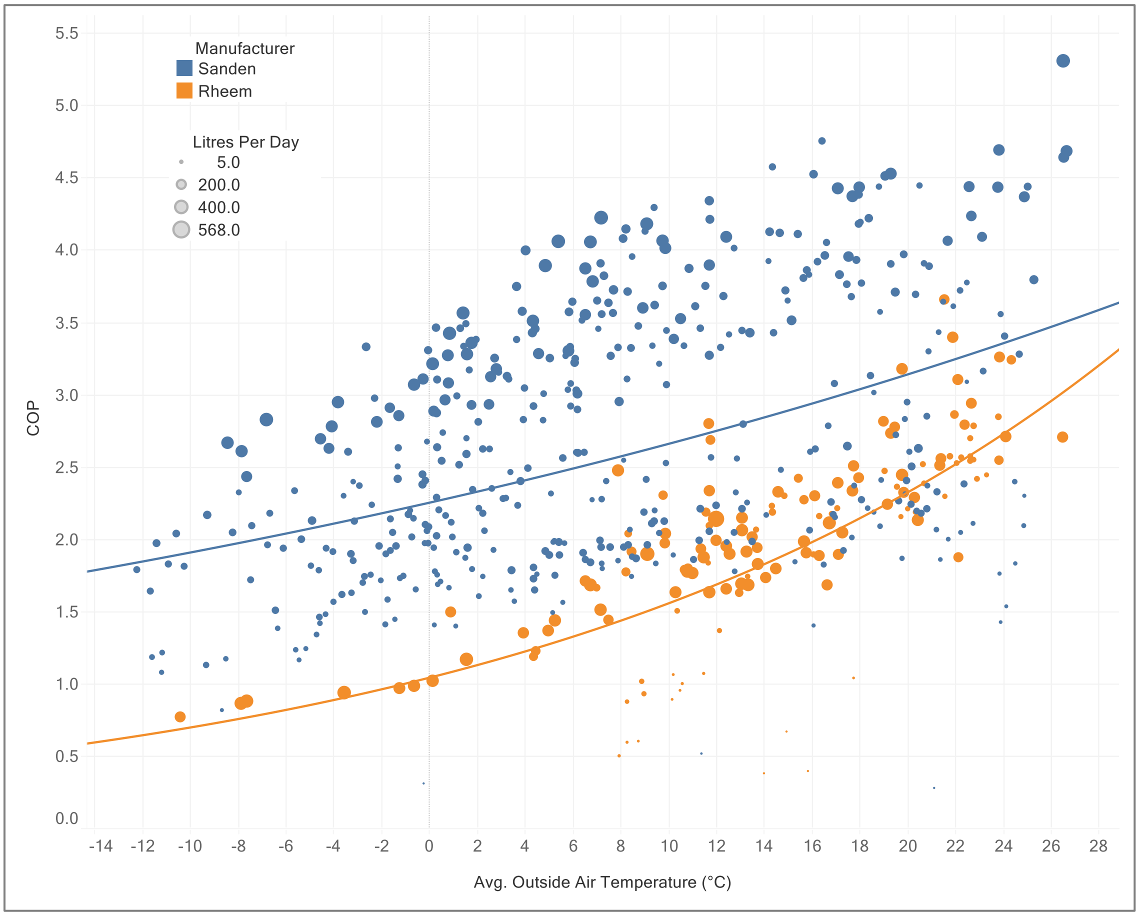
Table 9: Rheem Energy Savings Summary

Site	aCOP	Average Water Heating Load Delivered (kWh/day) [kBtu/day]	Annual Baseline Energy (kWh)	Annual Rheem Energy (kWh)	Annual Energy Savings (kWh)	% Savings	Months of Data
Kelowna Site 4	1.62	16 [53]	6,557	3,494	3,064	47%	8
V. Island Site 1	1.76	12 [39]	4,749	2,382	2,367	50%	4
V. Island Site 4	1.73	2 [8]	1,019	522	497	49%	11
V. Island Site 5	2.06	12 [40]	4,884	2,093	2,791	57%	12
Average	**1.79**	**10 [35]**	**4,302**	**2,123**	**2,180**	**51%**	**9**
Kelowna Site 3	2.08	8 [27]	3,333	1,387	1,947	58%	15

2.2 Impact of Outside Air Temperature on Performance

Both the Sanden and Rheem units show a positive correlation between performance (COP) and outside air temperature (OAT). However, as seen in Figure 6, the Sanden units perform with higher COPs at nearly every temperature. In fact, the only weeks a Sanden site performed near or below a Rheem site at a similar temperature, were weeks with very low water draws (less than 50 litres per day). More discussion on the impacts of water draw patterns is found in Section 2.3 below. The data shows a tighter correlation for the Rheem performance (tighter spread in COP) with OAT than in the Sanden units. The Rheem units operate in electric resistance mode more often than in heat pump mode at lower OATs. The manufacturer specifications for the Rheem unit states the heat pump can operate at temperatures as low as 2.8°C (37°F). Consequently, all weeks the average air temperature was below 2.8°C, the Rheem units performed with a COP of 1.0 or below, performing much like a standard electric resistance water heater. There is also a strong, yet variable relationship between COP and OAT in the Sanden units (wider range of COP). This greater variability is primarily due to water draw patterns that more strongly affects the performance of the Sanden units compared to the Rheem units. Sanden states that its heat pump units operate effectively at temperatures as low as -29°C (-20°F), which is why we see COPs as high as 2.0 during some weeks with average OATs lower than -10°C (14°F). This differs from Rheem's heat pump cut-off temperature of 3°C (37°F)

Figure 6: Weekly COP vs. Outside Air Temperature[17]



2.3 Impact of Water Draw Patterns on Performance

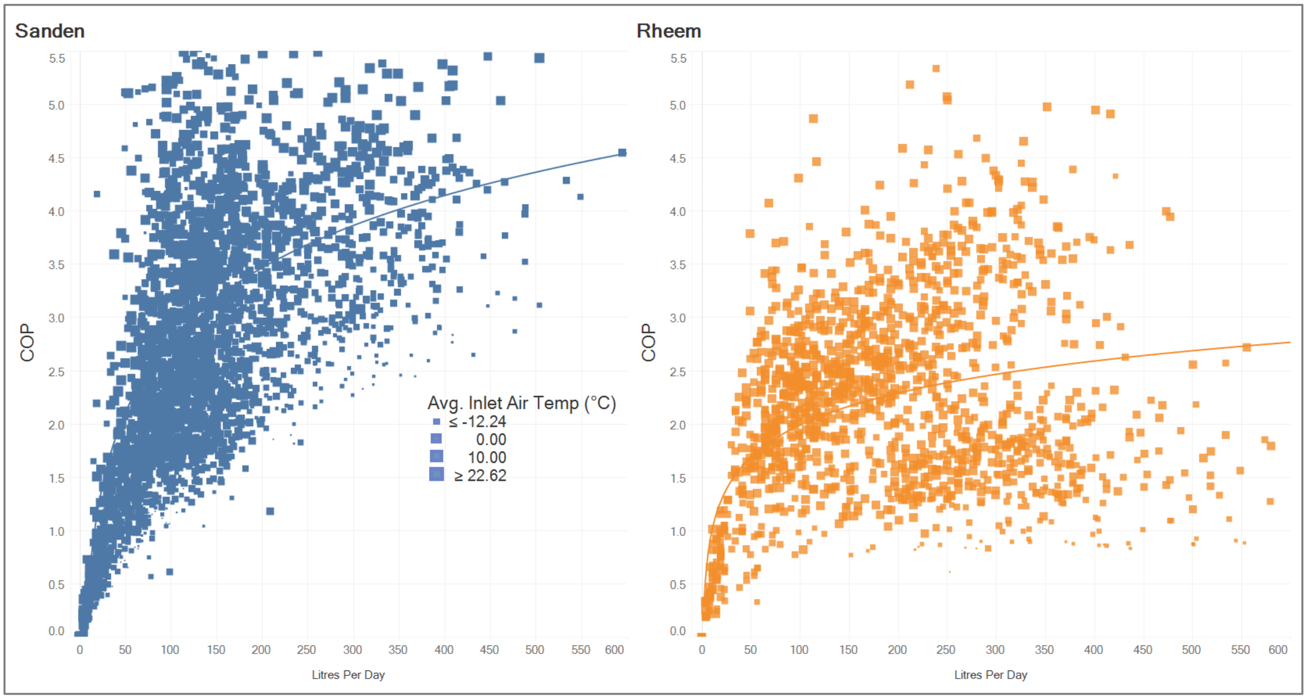
Water draw patterns have slightly different impacts on the performance of the Sanden and Rheem units.

Figure 7 shows the relationship between COP and litres per day (LPD) for all sites separated by technology. The Sanden units show a strong positive relationship between COP and water draws. As the average daily water draw goes up for the Sanden units, the COP increases across the board. While OAT also affects the Sanden performance, even the coldest days with high water draws (small blue points above 300 litres per day) have COPs greater than 2.5 and are consistently higher than warm days with low water draw. The Rheem unit performance also increases with higher water draws on warm days, but appears to flatten out or even decrease on colder days, as the units run in electric resistance mode more often. While the performance of both technologies is affected by both

[17]Temperatures in Figure 6 for all Sanden units and all Rheem units except Kelowna Site 3 are OAT.

water draw patterns and air temperature, the water draw patterns appear to be a better predictor of performance in the Sanden units while temperature is the better predictor in the Rheem units.

Figure 7: COP vs. Daily Water Draw (Litres/Day)



The primary reason high water draw increases performance is that the useful hot water delivered increases, and the nearly constant standby losses have less of an impact on COP. As shown in the equation below, COP is calculated as the ratio of useful work to required input. As heater work increases on high flow days, the fixed standby losses are a smaller proportion of total work delivered, causing the HPWH System COP to approach that of the heat pump COP. Additionally, for the Sanden units higher water draws result in colder return water to the outside unit increasing the effectiveness of the vapor compression cycle and thus, COP.

$$COP = \frac{Useful\ Work}{Required\ Input} = \frac{Delivered\ Hot\ Water}{Electrical\ Input\ to\ Heat\ Water} = \frac{Heater\ Work - Standby\ Losses}{Electrical\ Input\ to\ Heat\ Water}$$ [18]

[18] Electrical Input = Heat Pump (compressor) Power + Heat Trace Power (Freeze Protection) for all Sanden units. See Section 4 for details on the impact of heat trace on the Sanden unit performance.

4. Installation Time and Cost Summary

As seen in Table 10 and Table 11, the average installation costs for the Sanden units were $8,588 while the Rheem units were $4,135 [19]. When compared to a similarly sized standard electric water heater we estimate the incremental cost of the Sanden unit to be $5,955 and $1,558 for the Rheem unit[20]. The largest portion of the total installation costs was the cost of the appliance. The Sanden installations include significantly more electrical and plumbing complexity and costs due to the split system design as well as freeze protection and electrical permit costs. The Rheem installations on the other hand costs also include full ducting for bringing in and exhausting outside air which is not required for operation but eliminates interactive effects with the heating systems. The average Sanden installation required 21.3 hours of skilled labor while the Rheem units required 10.5 hours (see Table 12 for breakdown). All installation costs are in Canadian dollars and labor costs are based on typical skilled labor rates. Energy 350 installed materials such as ductwork and pipe insulation in parallel with their performance monitoring equipment. All monitoring equipment costs and associate labor are excluded from the costs shown below. The plumber labor hours are reduced by 25% to account for the time spent plumbing to Energy 350's performance monitoring equipment which will not be a part of standard installations for either the Sanden or Rheem water heating systems. As the installation of both Sanden and Rheem HPWH systems become more familiar to contactors, the installation costs associated to the labor hours is expected to decrease.

Table 10: Sanden Installation Costs (CAD)

	Electrical		Plumbing		Freeze Protection						
Site	Material	Labor	Material	Labor	Material	Labor	Equipment Cost	Taxes & Permit	Sanden Total	Standard Electric Water Heater	Sanden Incremental Cost
Rossland Site 1	$127	$375	$806	$1,450	$160	$229	$5,560	$221	$8,929	$2,806	$6,122
Rossland Site 2	$143	$450	$806	$1,450	$151	$229	$5,560	$227	$9,016	$2,806	$6,209
Rossland Site 3	$152	$450	$806	$1,450	$146	$229	$5,560	$228	$9,021	$2,806	$6,215
Kelowna Site 1	$179	$383	$593	$1,424	$187	$261	$5,360	$208	$8,595	$2,806	$5,789
Kelowna Site 2	$194	$600	$598	$1,513	$123	$261	$5,360	$222	$8,872	$2,806	$6,066
V. Island Site 2	$179	$770	$608	$640	$105	$253	$5,360	$98	$8,014	$2,198	$5,815
V. Island Site 3	$185	$345	$658	$588	$200	$253	$5,360	$76	$7,666	$2,198	$5,467
Average	$165	$482	$697	$1,216	$153	$245	**$5,446**	**$183**	**$8,588**	**$2,633**	**$5,955**
	$647		**$1,913**		**$398**						

Table 11: Rheem Installation Costs (CAD)

	Electrical		Plumbing		Ducting/Insulation						
Site	Material	Labor	Material	Labor	Material	Labor	Equipment Cost	Taxes & Permit	Rheem Total	Standard Electric Water Heater	Rheem Incremental Cost
Kelowna Site 3	$0	$0	$494	$1,290	$0	$0	$2,452	$85	$4,320	$2,806	$1,514
Kelowna Site 4	$0	$0	$494	$905	$223	$523	$2,452	$65	$4,662	$2,806	$1,856
V. Island Site 1	$0	$0	$496	$562	$162	$506	$2,129	$48	$3,903	$2,424	$1,479
V. Island Site 4	$0	$0	$475	$551	$171	$633	$2,129	$47	$4,005	$2,424	$1,580
V. Island Site 5	$0	$0	$518	$588	$119	$380	$2,129	$51	$3,784	$2,424	$1,360
Average	$0	$0	$496	$779	$135	$408	**$2,258**	**$59**	**$4,135**	**$2,577**	**$1,558**
	$0		**$1,275**		**$543**						

[19] For more details on individual installation costs, see the individual site descriptions in Section 10 and Section 11. See Section 12 for installation and equipment issues identified.
[20] See Table 53 in the Appendix for details on the cost estimates of the standard electric water heaters.

Table 12 shows the average labor hours spent on the installation by the different tradespeople. There is a significant difference in the electrician and plumber hours between the two technologies. The electricians spent on average 7.0 hours wiring the Sanden units while no electrician was required for the Rheem unit installations[21]. The difference is that the Sanden units always need an electrical disconnect installed near the outside unit, and a dedicated circuit in the electrical panel. This work required an electrical permit resulting in an average of $183 in taxes and permit costs for the Sanden unit installations relative to $59 for the Rheem units. In addition, the Sanden units require heat trace for freeze protection of the water pipes that run from the outside unit to the wall. The power for the heat trace currently requires a dedicated electrical circuit which adds time and cost to the installation. We recommend that Sanden include a power source in the unit for freeze protection in order to eliminate the need for a second dedicated electrical circuit reducing electrical materials, labor and permitting costs. Since the integrated Rheem units are essentially drop-in replacements for the existing electric resistance water heaters, their installation does not typically need an electrician.

An additional 2.0 hours were required to wire and install heat trace for the Sanden units. However, the Rheem units required an additional 3.4 hours on average to duct the units to outside air more than making up for the heat trace labor requirements. This ducting is not a manufacturer's requirement and chosen for this field testing to eliminate the interactive effects of the HPWH drawing heat from a conditioned space.

There is an even greater difference in the plumber labor hours as the Sanden units required 12.3 hours on average relative to the 7.1 hours required for the Rheem units. The Sanden units require significant water piping to be plumbed from the outside heat pump to the inside hot water tank. The Sanden unit is a newer technology to the local trades and we expect some decrease in labor hours as familiarity increases. However, the increased complexity in both electrical and plumbing ensures there will always be a significant increase in installation costs relative to a drop-in integrated unit like the Rheem.

Table 12: Average Installation Labor Hours

Technology	Electrician Labor	Plumber Labor	Freeze Protection /Ducting	Total Labor Hours
Sanden	7.0	12.3	2.0	**21.3**
Rheem	0.0	7.1	3.4	**10.5**

[21] Two Rheem units did require electrician time because they needed upgraded circuits. This was due to the fact that we replaced 48-gallon tanks with 65-gallon tanks which required larger breakers and wiring. We pulled out these costs as we do not expect this to be a typical cost for a Rheem installation that replaces a similarly sized hot water tank.

5. Sanden Unit Performance

5.1 Heat Trace Impact

Heat trace is used for freeze protection on the exposed water pipes from the Sanden outdoor unit to the wall of the house. Figure 8 shows the effect of the heat trace power consumption on aCOP and Table 13 shows a summary of the impacts of heat trace across the 7 Sanden sites. On average across the sites the heat trace consumed 21 watts or 14.4% of the total power of the combined heat pump system. The impact of the heat trace on performance is approximately 14.5% (reducing the aCOP to 2.69 from 3.14 on average). The heat trace draw reduces as outside air temperature increases. As such, the impact of the heat trace is generally more significant at the colder weather sites.

Figure 8: Heat Trace Effect on Sanden aCOP

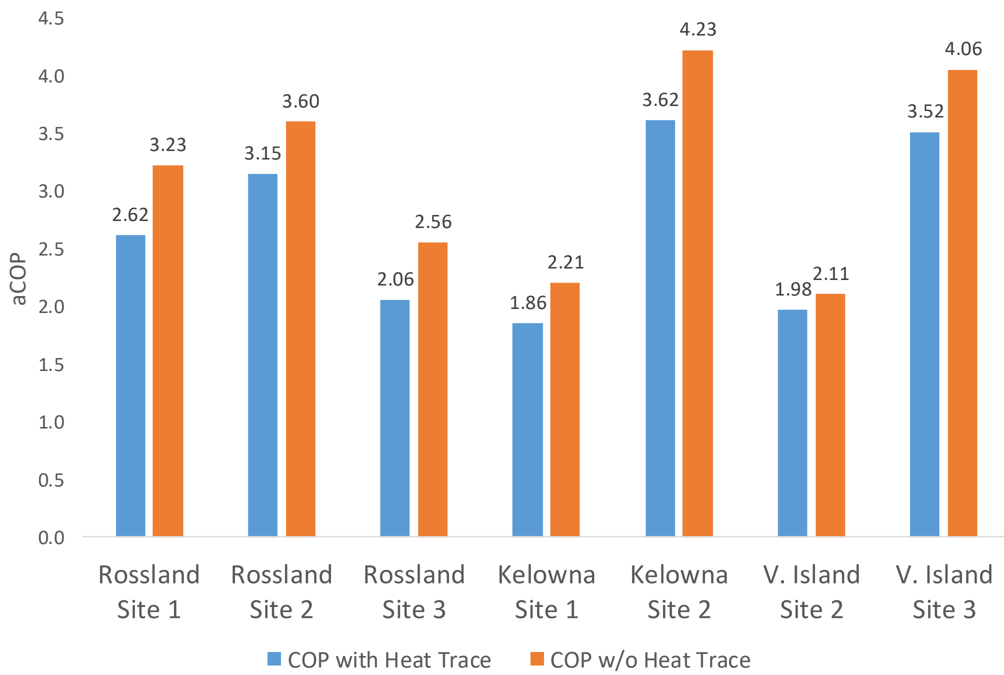
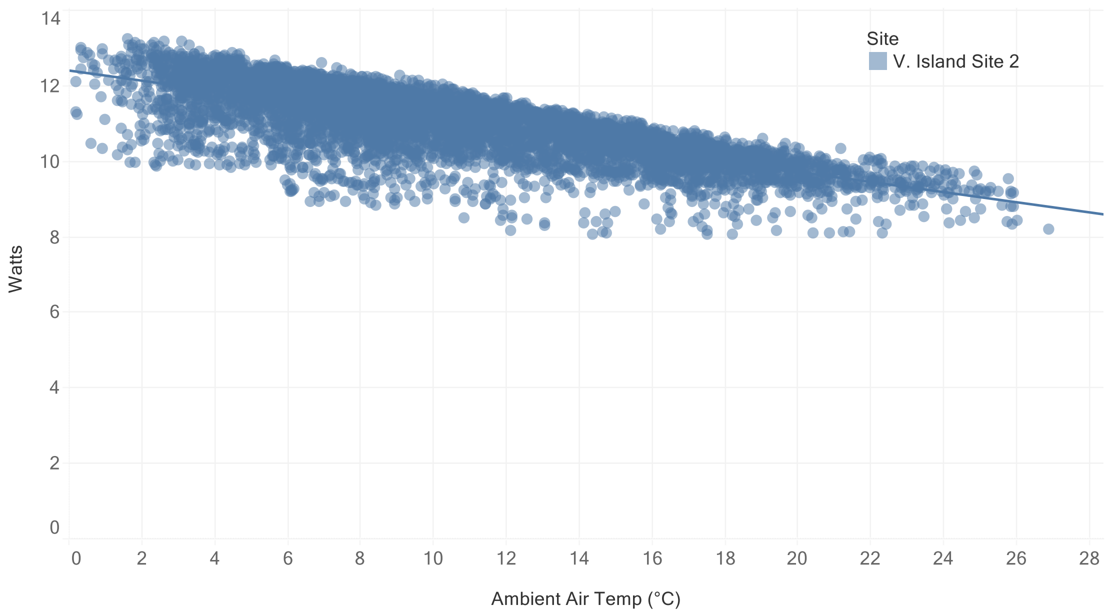


Table 13: Summary of Heat Trace Impact

Site	On Temp Control?	Length of Heat Trace (Meters)	Average Heat Trace (Watts)	Average Heat Trace (Watts/Meter)	Heat Trace % of Load	aCOP w/o Heat Trace	aCOP w/ Heat Trace
Rossland Site 1	Yes	3.0	38	12.6	18.7%	3.23	2.62
Rossland Site 2	No	3.4	25	7.6	12.5%	3.60	3.15
Rossland Site 3	No	3.2	20	6.3	19.5%	2.56	2.06
Kelowna Site 1	No	4.6	14	3.0	15.9%	2.21	1.86
Kelowna Site 2	Yes	2.4	25	10.1	14.5%	4.23	3.62
V. Island Site 2	No	1.8	11	5.9	6.3%	2.11	1.98
V. Island Site 3	Yes	2.1	13	6.0	13.4%	4.06	3.52
Average	**--**	**2.94**	**21**	**7.4**	**14.4%**	**3.14**	**2.69**

The heat trace is temperature dependent and increases its power use as the temperature decreases. Figure 9 shows that there is also a slope to the heat trace power versus ambient air temperature.

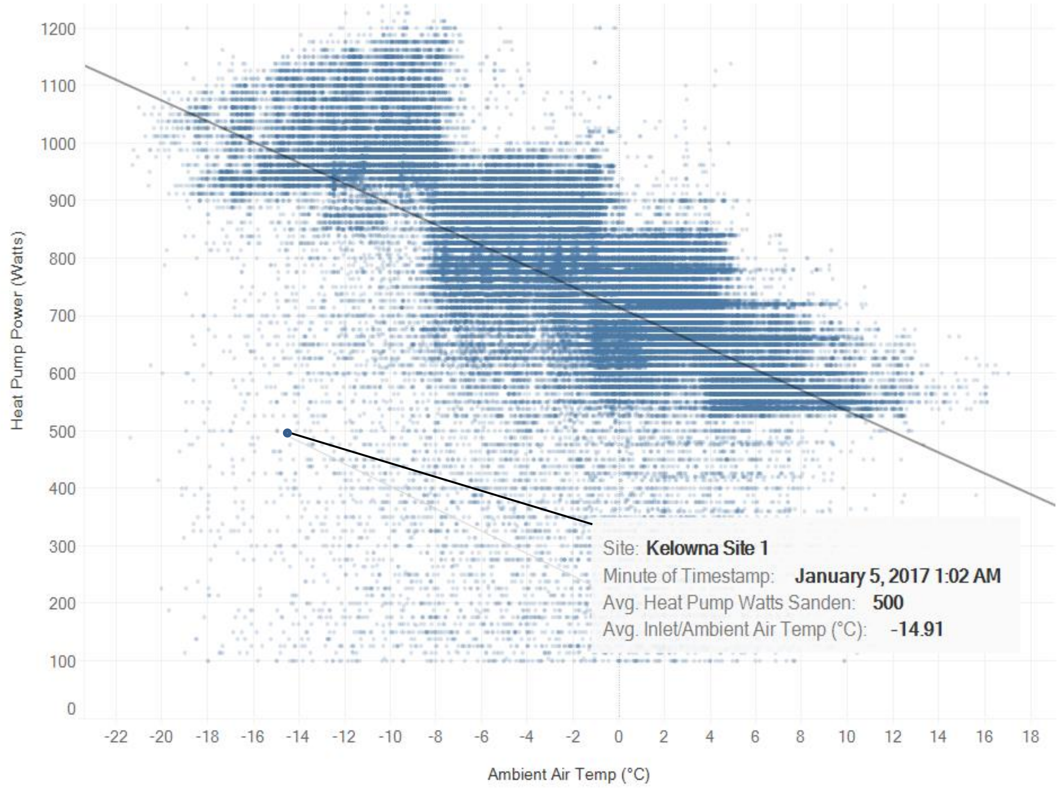
Figure 9: Heat Trace Power vs. Ambient Air Temperature

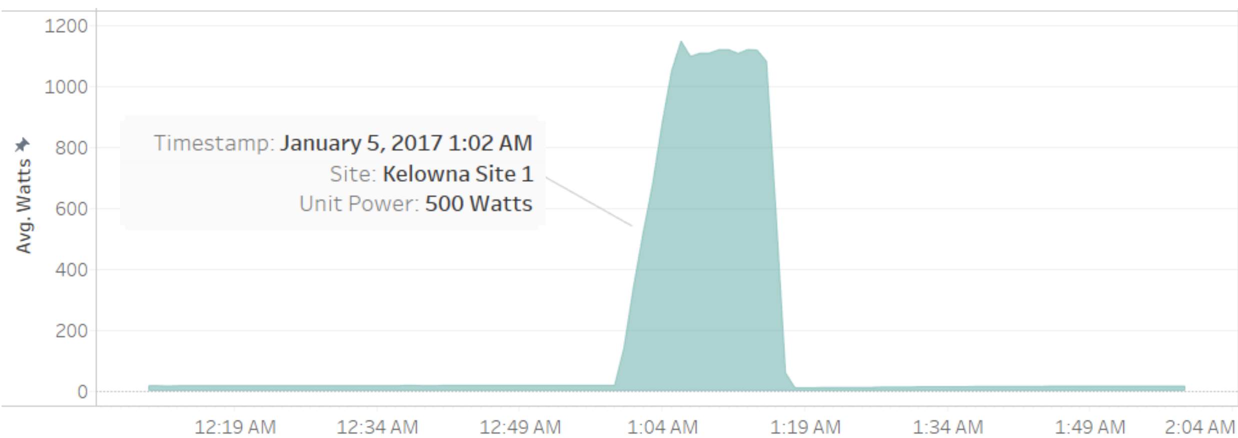


5.2 Impact of Outside Air Temperature on Unit Power

Figure 10 shows the relationship between outside air temperature and the power consumption of all Sanden units on a one-minute time interval. All sites have a downward slope showing that the higher the outdoor air temperature (OAT, heat source), the lower the power required. The minutes in which only the heat trace was drawing power have been removed to better show the temperature dependence of power consumption on the heat pump unit itself. The significant variance in power consumption at different ambient temperatures is due to the variable speed compressor and fan "working harder" to extract heat out of a low-grade heat source (low OAT). The compressor experiences a higher lift (difference between suction and discharge pressure) and must do more work to provide hot water. While there are many points that fall below the trendline, the correlation between power and outside air temperature is quite strong (R-squared greater than 0.5 for most sites). The data points with power draws between 0 and 500 watts are partial minutes the heat pump compressor ran. For example, if at -15 °C the heat pump compressor ran for 30-seconds at 1,000 watts, the power logger would record a 500-watt pulse output. Other points below 600 watts are either the compressor ramping up at the beginning of a heating cycle, or a defrost cycle as shown at Kelowna site 1 in Figure 10 below.

Figure 10: Power vs. Outside Air Temperature of Sanden Units



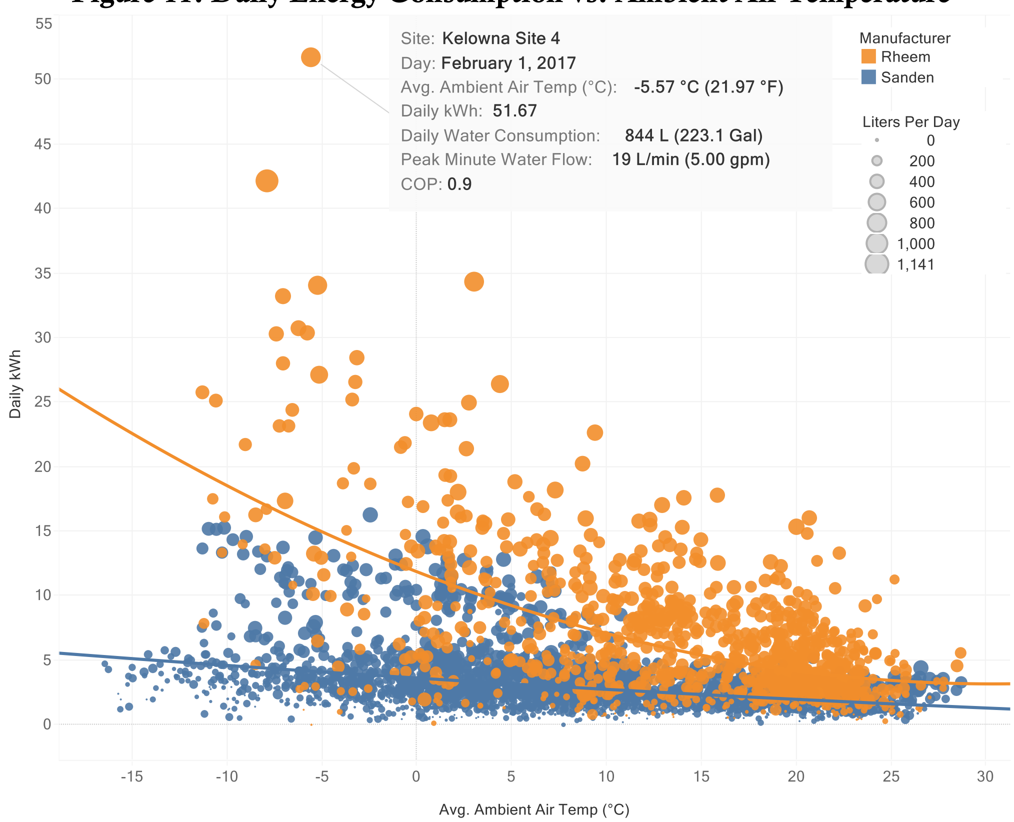


6. Rheem Unit Performance

5.1 Use of Backup Heating Elements for Water Heating

The daily average power consumption is more closely related to OAT in the Rheem units than the Sanden units. There is a sharp rise in the average power consumption of the Rheem units at lower temperatures due to the Rheem unit operating primarily in electric residence mode. This typically happens on days when the average daily temperature is below 5°C. On these days, the daily energy consumption is often above 15 kWh. The days above 5°C with high energy consumption are typically days with larger water draws indicated by large circles in Figure 11 below. On days with large water draws the lower tank temperature falls too quickly for the heat pump to maintain the set-point temperature and the lower electric element turns on[22]. The colder days with large water draws, such as February 1st, 2017 at Kelowna Site 1 are often the highest energy consumption and lowest performance days. On days with temperatures above 5°C and lower water consumption, the Rheem units operate most of the time in heat pump mode and consume less than 10 kWh on average for the day, resulting in the highest performance.

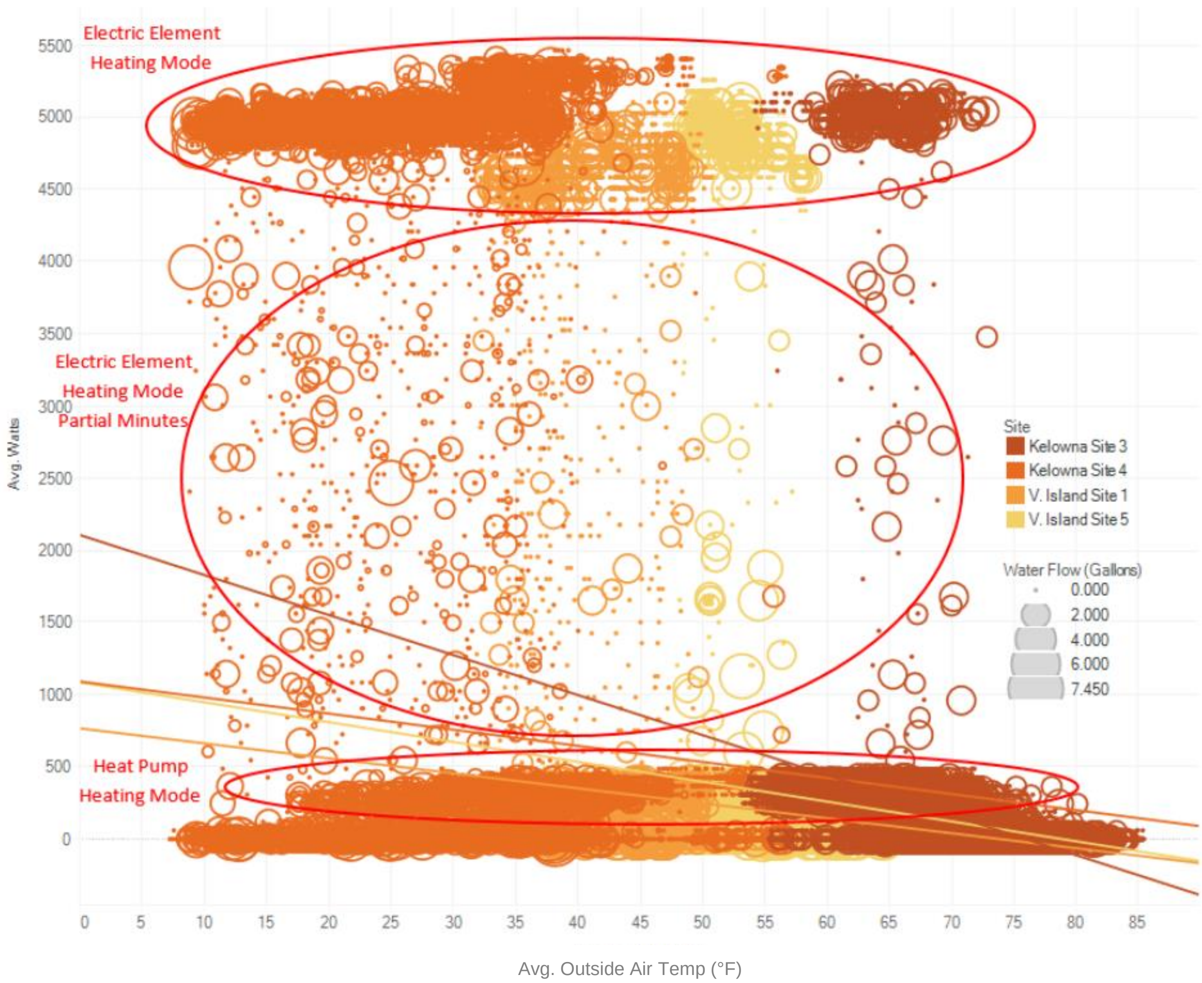
Figure 11: Daily Energy Consumption vs. Ambient Air Temperature



[22] The Rheem units are designed so that the tank water remains stratified, with the lower section of the tank remaining colder than the upper tank. As a comfort feature to avoid cool water delivery, the electric element in the tank kicks on, when the temperature in the lower third of the tank drops significantly below the hot water setpoint temperature.

The Rheem units differ from the Sanden units in that they have multiple heating operation modes including using only the heat pump, just the backup electric element or both heat sources. Figure 12 below shows these distinct modes by showing the unit power consumption against the average inlet air temperature (or outside air temperature in all except Kelowna Site 3). Across the 4 sites the element uses on average around 5 kW while the heat pump alone uses between 300 and 450 watts. The middle data points are minutes in which the element ran for less than the full minute. The power meters provided pulses on 1-minute intervals that provided average power over that minute. The dense group of lower power minutes (between 280-599 watts) are when the unit was in heat pump only mode (heat pump compressor and fans were operating).

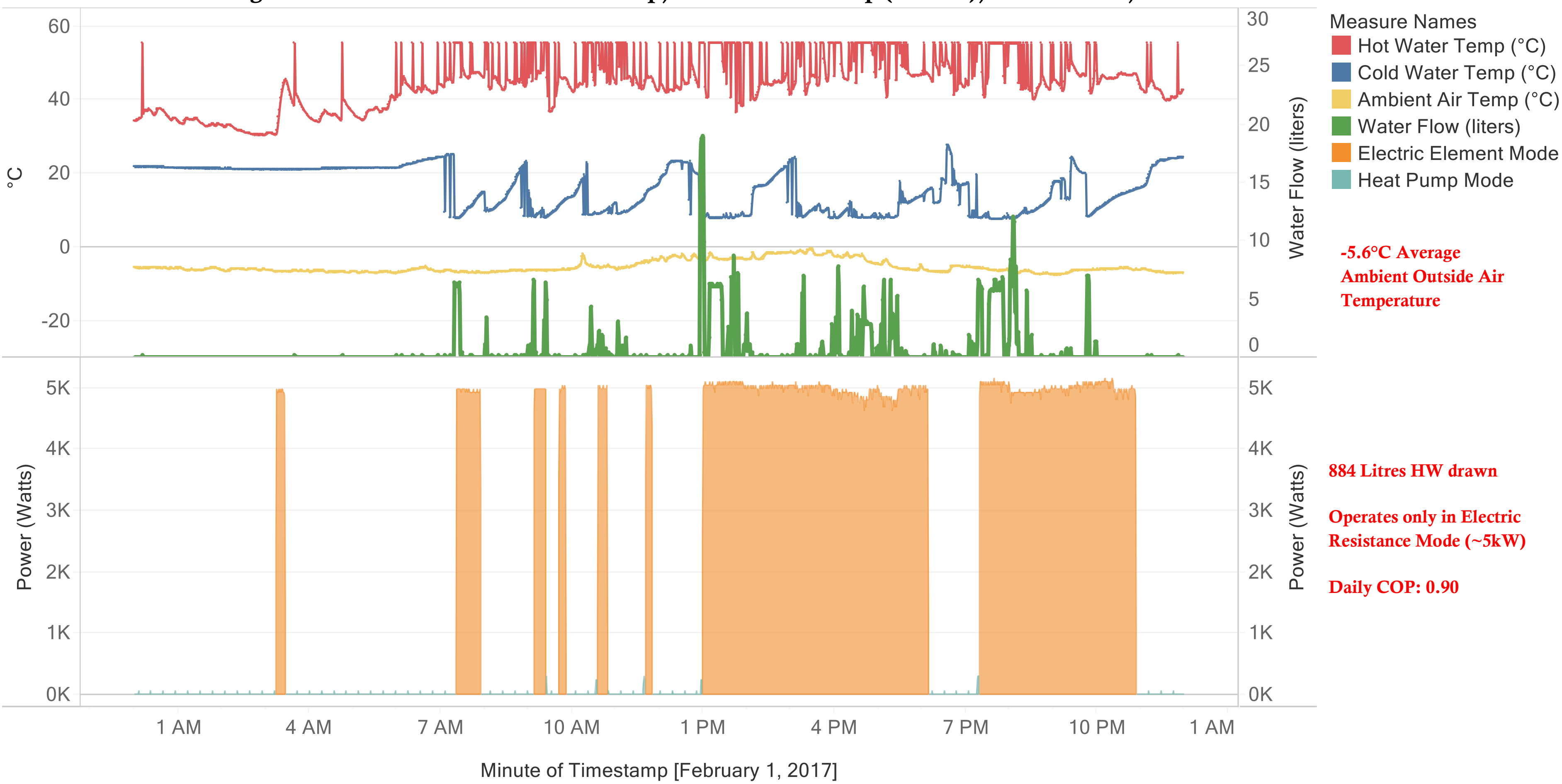
Figure 12: Power vs. OAT All Rheem Units



The power consumption of the original water heaters that were replaced was between 3kW and 4.5kW. With the Rheem unit consuming a peak load of 5.25 kW, the instantaneous demand (kW) increases from the baseline between 17%-75% depending on the water heater replaced, even though the energy consumption (kWh) decreases at all sites.

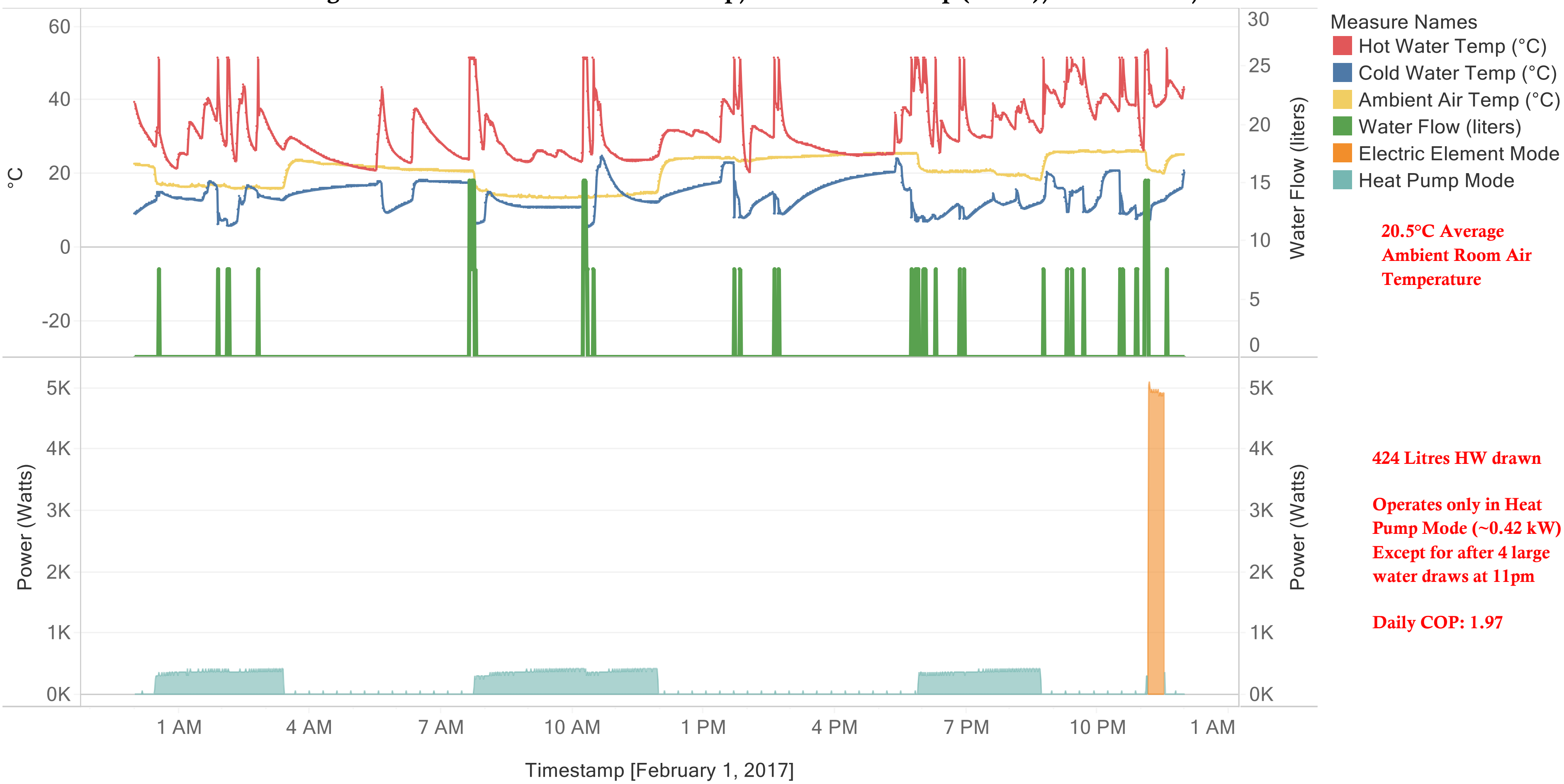
To illustrate the operation of the Rheem unit in different modes, Figure 13 and Figure 14 show the water temperatures, water draw, and power consumption over one day at two locations (Kelowna Site 4 and Kelowna Site 3) on February 1st, 2017. Kelowna Site 4 is a ducted system which saw a daily average inlet air temperature of -5.6°C and 884 litres of water drawn. Due to the low temperature and high water draw, the unit operated in electric resistance mode over 9 hours this 24-hour period and ended with a daily COP of 0.90.

Figure 13: Kelowna Site 4 - Water Temp, Ambient Air Temp (outside), Water Draw, & Power



Kelowna Site 3 is an un-ducted unit with a warmer inlet air temperature of 20.5°C on average throughout the day and only 424 litres of water draw. Because of the high inlet air temperature and lower draws (15 litres/minute max), the unit operated in heat pump mode all except after a series of water draws in the late evening in which the electric element switched on to provide supplemental water heating. With the heat pump primarily providing the hot water, the measured daily COP is 1.97 compared to 0.90 at site 4. Additionally, the electric element did not run at all during the evening peak window of 4-9pm.

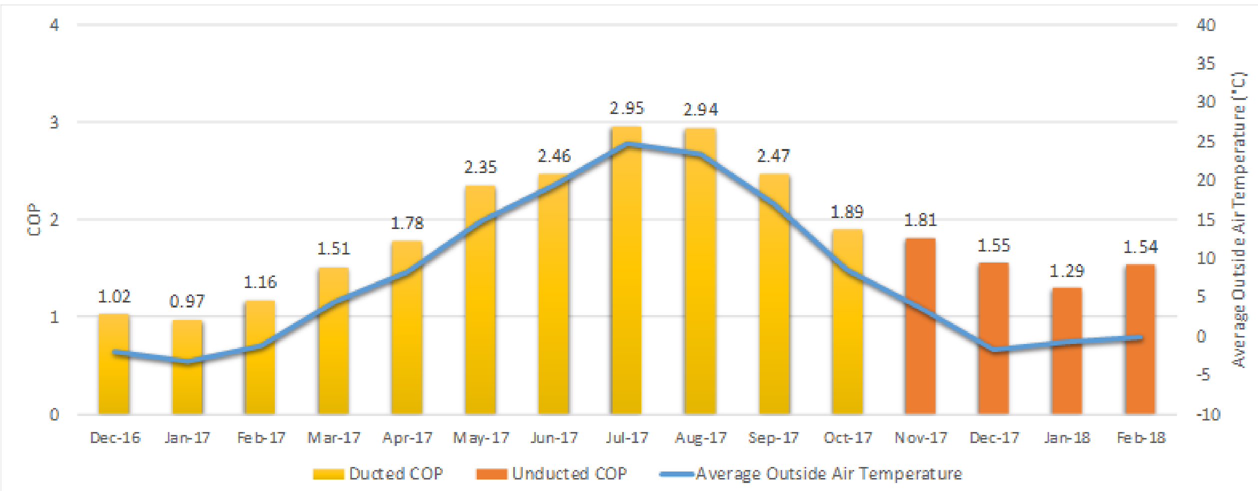
Figure 14: Kelowna Site 3 - Water Temp, Ambient Air Temp (inside), Water Draw, & Power



5.2 Impacts of Ducting Units

We did not test unducted Rheem units for a full year as a part of this study, but on November 1st, 2017 we detached the ducting which draws in outside air on the Kelowna Site 4 Rheem unit. The heat pump is located in the basement, and as expected, the unducted unit performed significantly better than the same unit did when ducted during the previous winter. As shown in Figure 15, the unducted unit performed with an average COP of 1.47 in December 2017 through February 2018 when the average outside air temperature remained below 0°C. During the previous winter of December 2016 through February 2017, the ducted unit performed with an average COP of 0.96. However, we do not have summer data for an unducted unit, and we expect that a ducted unit would perform better when the outside air is warmer than the basement air.

Figure 15: Kelowna Site 4 Ducted and Unducted Performance

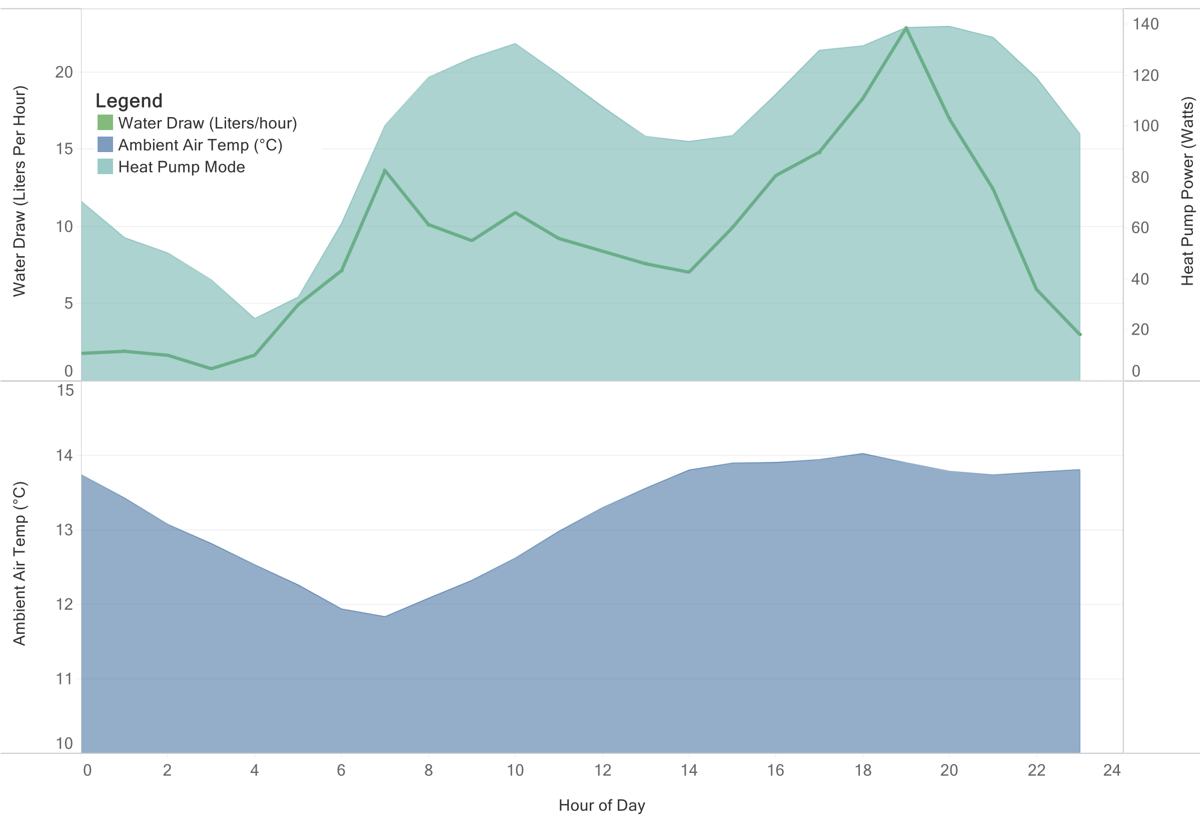


Ducting the Rheem units to mitigate the interactive effects of the heat pump water heater with space heating appears to have limited impact on COP for several reasons:

- The climates of Vancouver Island (CZ4) and Kelowna (CZ5) are temperate, resulting in limited annual hours that are below the heat pump minimum temperature.
- The winter COP penalty of ductwork is largely offset by increased COP resulting from warm summertime air.
- The heat pump primarily ran in late morning and late evening coincident with warmer outside air temperature.

Figure 16 shows the average daily water draw and heat pump profile of all ducted Rheem sites over the entire performance period. The water draw profile peaks are at 7am and 7pm with the heat pump power draw peak coming shortly after at 10am and 8pm. The two peak power draws of the heat pump do not occur between 5am and 8am when the outside temperature is the coldest and heat pump performance is the lowest.

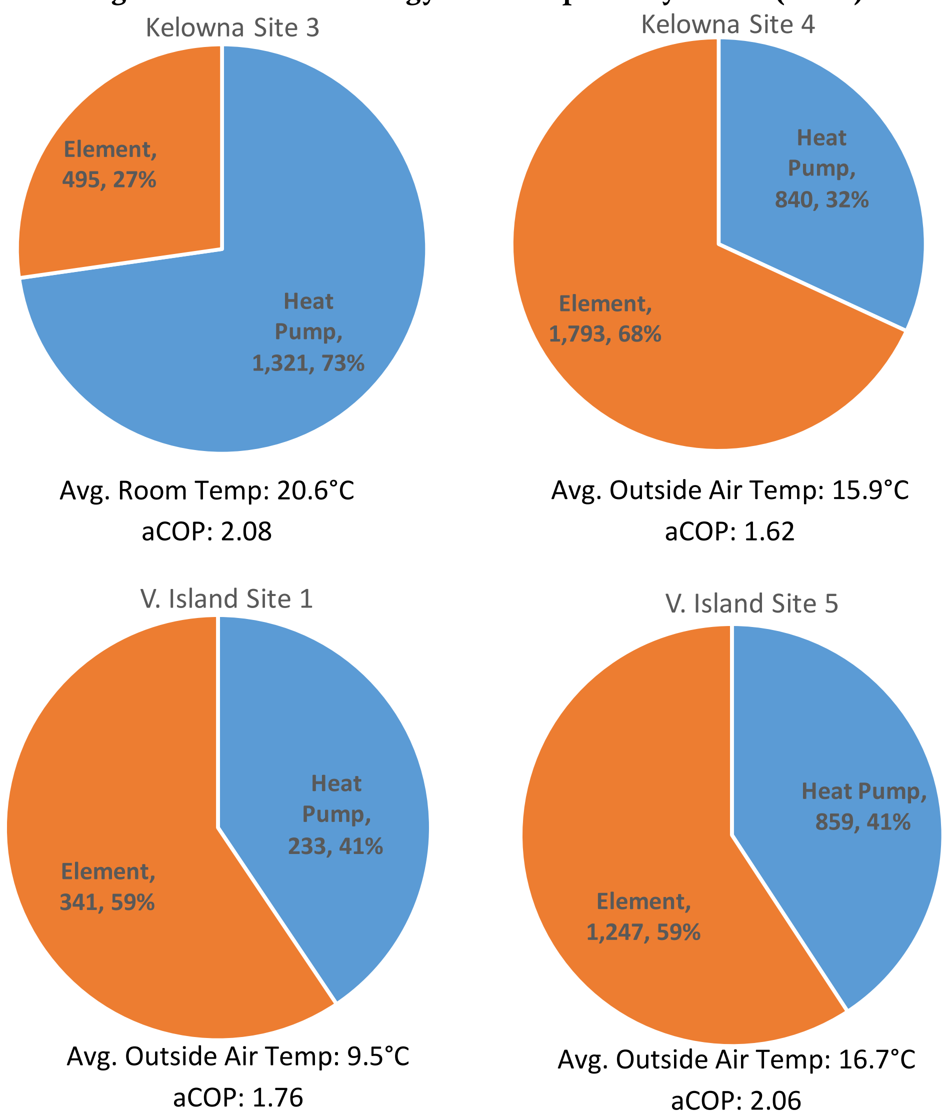
Figure 16: All Rheem Units Average Daily Power and Water Draw Profile



5.3 Energy Consumption by Heating Type

Figure 17 shows the percent of energy consumed by the different modes of operation. Kelowna Site 3 is unducted and draws indoor air instead of outdoor air. Due to the average room temperature being 20.6°C, the unit was nearly always in heat pump mode (73% of the power consumed by heat pump operation compared to 27% by the electric element) and performed very well with an aCOP of 2.08. On the other hand, the Kelowna Site 4 system is ducted to use outside air, which was on average 15.4°C over the monitoring period and consumed 68% of the energy with the electric element and only 32% with the heat pump cycle. Consequently, Kelowna Site 4 performed with the lowest aCOP of all units tested at 1.62. Figure 18 also shows the breakdown of the percentage of hours spent heating in the different modes.

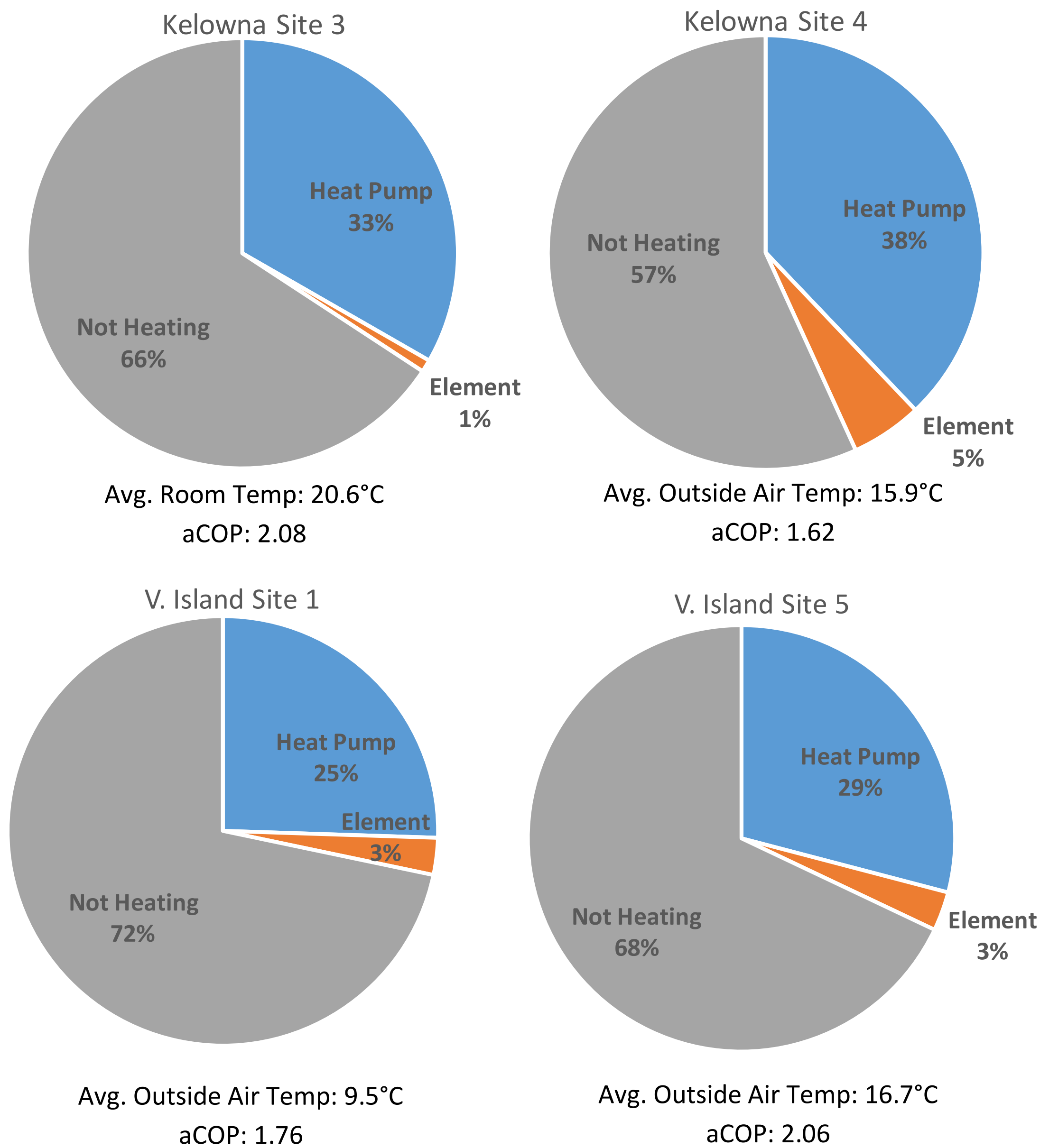
Figure 17: Rheem Energy Consumption by Mode (kWh)



Vancouver Island Site 5 is located inside a garage with warmer average inlet air temperatures than the other Vancouver Island Sites and achieved a higher aCOP.

Figure 18 shows the percentage of time each of the Rheem units spent in each heating mode. The total amount of time heating water is similar for all sites (34%-43% of the time). The primary difference between sites is the proportion of time is spent in Heat Pump mode relative to Electric Element mode. Sites with low air temp and high water draws such as Kelowna Site 4 spend more time operating with the element on than warmer sites such as unducted Kelowna Site 3.

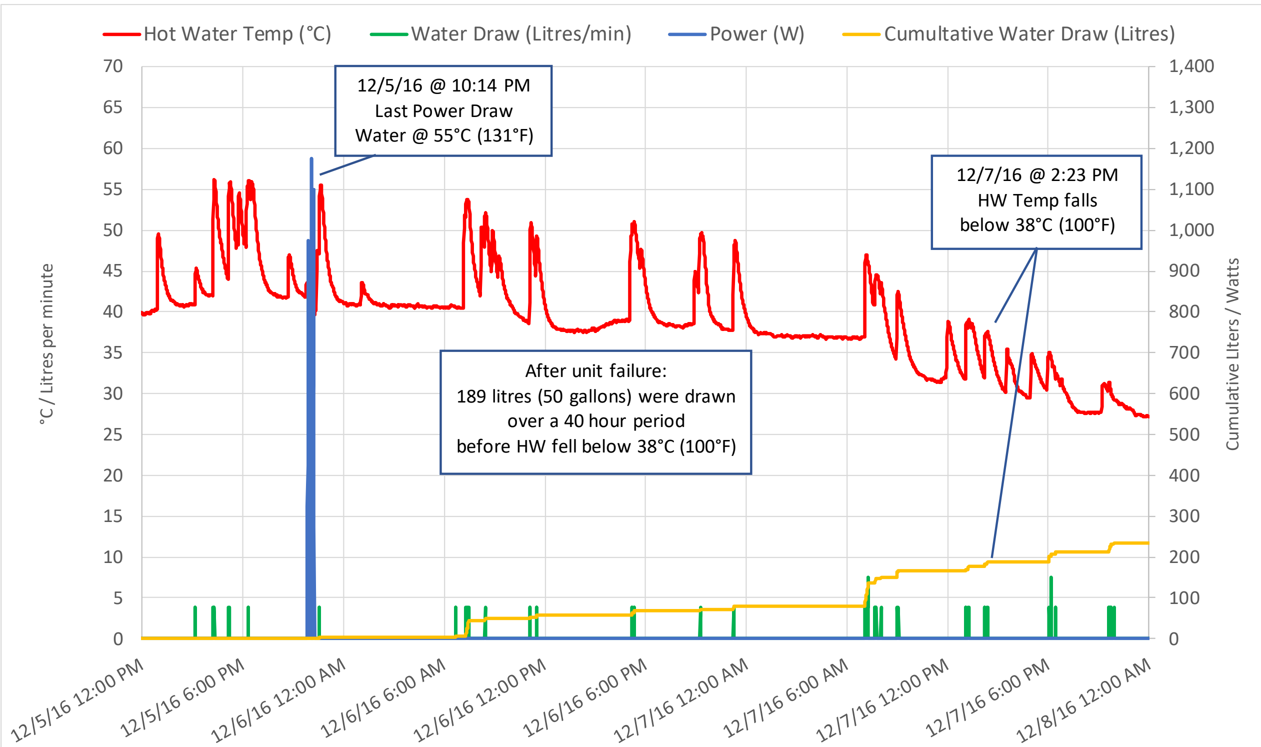
Figure 18: Rheem Operating Modes by Hours of Operation



7. Demand Response Potential

Both the Rheem and Sanden HPWHs have good potential for Demand Response (DR). With their large storage tanks, power could be locked out from the heat pump (and electric element of the Rheem) in a 5-hour DR event without any noticeable loss in hot water temperature. Figure 19 illustrates this by showing the period just after a component of one of the 314-litre (80-gallon) Sanden units failed on December 5th, 2016. The last power draw can be seen at 10:14pm when the heat pump stopped heating the water. Without knowing the unit was off, the participants went on to draw 189 litres (50 gallons) of hot water over a 40-hour period before hot water temperature fell below 38°C (100°F) at 2:23pm of December 7th. Especially in the case of the larger tank HPHWs (314-L Sanden and 303-L Rheem), even the largest hot water users would likely not be impacted by a 4 or 5-hour DR event.

Figure 19: Hot Water Storage



8. Calculations

The following section summarizes the primary calculations used in the analysis.

8.1 Water Heating Load

Our metered data is in 1-minute intervals, and we calculated the water heating load using the following equation:

$$Heating\ Load\ (Btu) = HW\ flow\ \left(\frac{gal}{min}\right) x\ \ [T_{outlet} - T_{inlet}]^{23}(°F)\ x\ interval\ (min) x\ \bar{c}_{p,water}{}^{24}\ x\ \rho_{water}{}^{25}$$

Example Calculation:

$$Water\ Heating\ Load\ (Btu) = 1.5\ \frac{gal}{min}\ x\ \ (140°F - 50°F)\ \ x\ 1\ min\ x\ 0.997\frac{Btu}{lbs\ °F}\ x\ 8.3077\frac{lbs}{gal} = 1{,}118\ Btu$$

7.2 Coefficient of Performance

The power meter at each site monitors the system's average power by the minute, which equates to energy consumed. To calculate performance, we sum the total water heating load delivered and the total energy consumed by the unit over the monitoring period. The following equation shows the calculation for COP:

$$\text{COP} = \frac{\Sigma \text{ Heat Load Deliverd (Btu)}}{\Sigma \text{ Energy In (kWh)}} \text{ x } \frac{\text{kWh}}{3{,}412 \text{ Btu}}$$

Example Calculation:

$$\text{COP} = \frac{700{,}000 \text{ Btu}}{120 \text{ kWh}} \text{ x } \frac{\text{kWh}}{3{,}412 \text{ Btu}} = 1.71$$

8.3 Baseline Energy Factors

To calculate the baseline Efficiency Factor (EF), we used the U.S. Department of Energy Federal Energy Conservation Standards for residential water heaters. The following calculation depends on tank size and results in a range of EFs between 0.86 and 0.91.

$$EF = 0.97 - (\ 0.00132\ x\ Rated\ Storage\ Volume\ in\ gallons\ )$$

Example Calculation:

$$EF = 0.97 - (\ 0.00132\ x\ 43\ gallons\ ) = 0.913$$

[23] $\boldsymbol{T_{outlet}}$ is the HW temperature measured at the outlet of the tank. $\boldsymbol{T_{inlet}}$ is the cold water temperature from the city or well measured at the inlet of the tank.

[24] $\boldsymbol{\bar{c}_{p,water}}$ is the average specific heat of water at 90°F (assuming HW temp raised from 50-140°F).

[25] $\boldsymbol{\rho_{water}}$ is the density of water at 90°F.

Table 14 and Table 15 summarize the baseline Efficiency Factors used for the Sanden and Rheem units used to calculate energy savings.

Table 14: Sanden Efficiency Factors

Site	Tank Size (gal) [L]	Calculated Baseline EF
Rossland Site 1	83 [315]	0.860
Rossland Site 2	83 [315]	0.860
Rossland Site 3 GS2	83 [315]	0.860
Rossland Site 3 GS3	83 [315]	0.860
Kelowna Site 1	43 [160]	0.913
Kelowna Site 2	43 [160]	0.913
V. Island Site 2	43 [160]	0.913
V. Island Site 3	43 [160]	0.913

Table 15: Rheem Efficiency Factors

Site	Tank Size (gal) [L]	Calculated Baseline EF
Kelowna Site 3	80 [303]	0.864
Kelowna Site 4	80 [303]	0.864
V. Island Site 1	65 [246]	0.884
V. Island Site 4	65 [246]	0.884
V. Island Site 5	65 [246]	0.884

8.4 Hot and Cold Water Temperature Adjustment

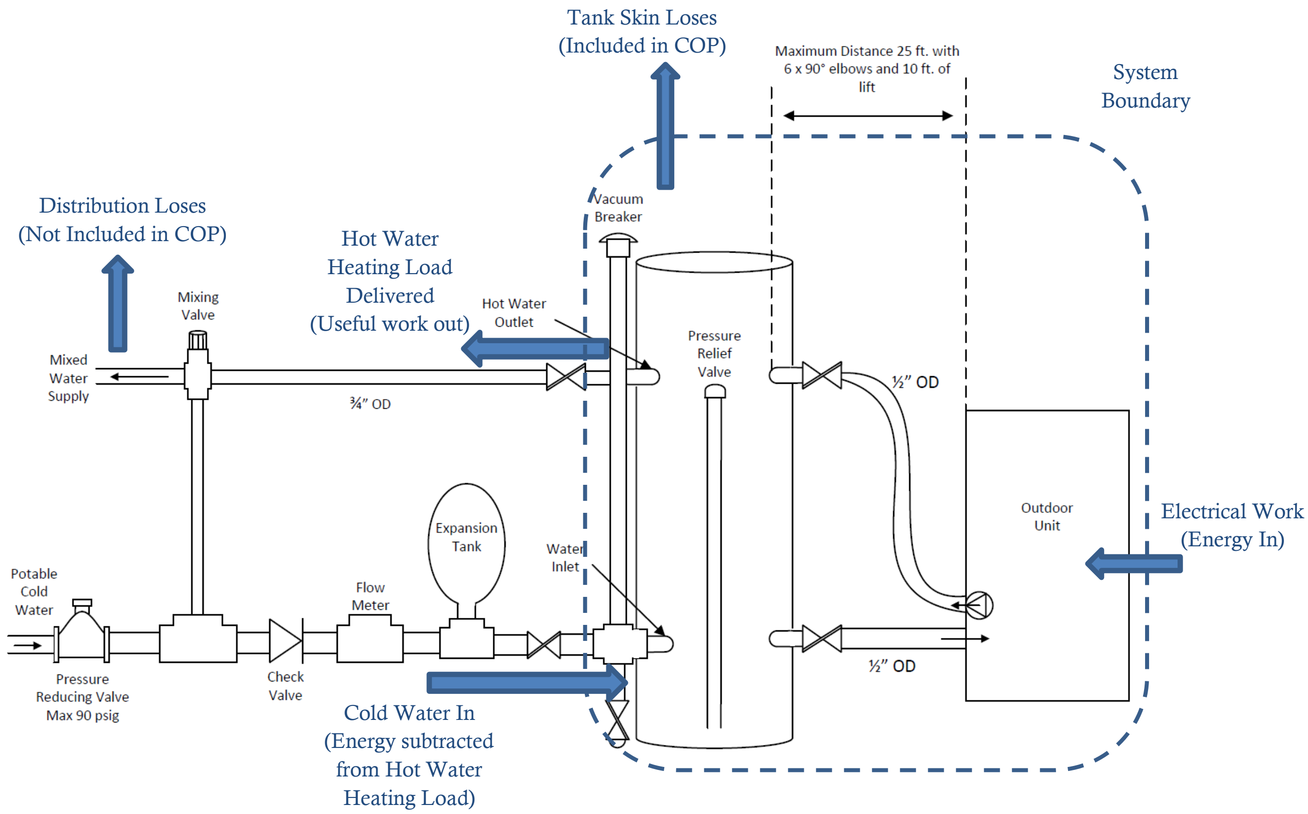
As water remains stagnant in pipes, the temperature approaches that of its surroundings. As such, we disregard any water temperature readings when there is no water flow. Additionally, when flow is first initiated, there is a slight lag in response by the temperature sensor. To compensate for this, we have corrected our cold and hot water temperature readings to use the maximum[26] temperature observed during or immediately following the draw.

[26] Minimum temperature in the case of cold water as ambient room temperature is typically warmer than cold water temperature, and the cold water floats upwards instead of downwards.

9. Assumptions

The calculated COP does not include distribution loses, but it does include skin loses from the tank itself. The hot and cold water temperature sensors are located near the tank itself and the work delivered is calculated using the temperature difference between the two when the flow meter reads a water draw. See Figure 20 for a schematic of the system boundary used in the energy balance for calculating the performance of both the Sanden and Rheem systems.

Figure 20: System Boundary



10. Sanden Site Descriptions and Performance

10.1 Rossland Site 1 (Sanden)

Observed data:

Rossland Site 1 is a 315-litre (83-gallon) Sanden unit for which 468 days of metered data are included in the Winter performance results. This unit performed relatively well over the winter period delivering a COP of 2.62 even with a relatively cold average ambient temperature of 4.9°C [40.8°F] over the 15 months of data. Figure 21 shows the average monthly COP of Rossland Site 1 along with the average ambient air temperature over that month.

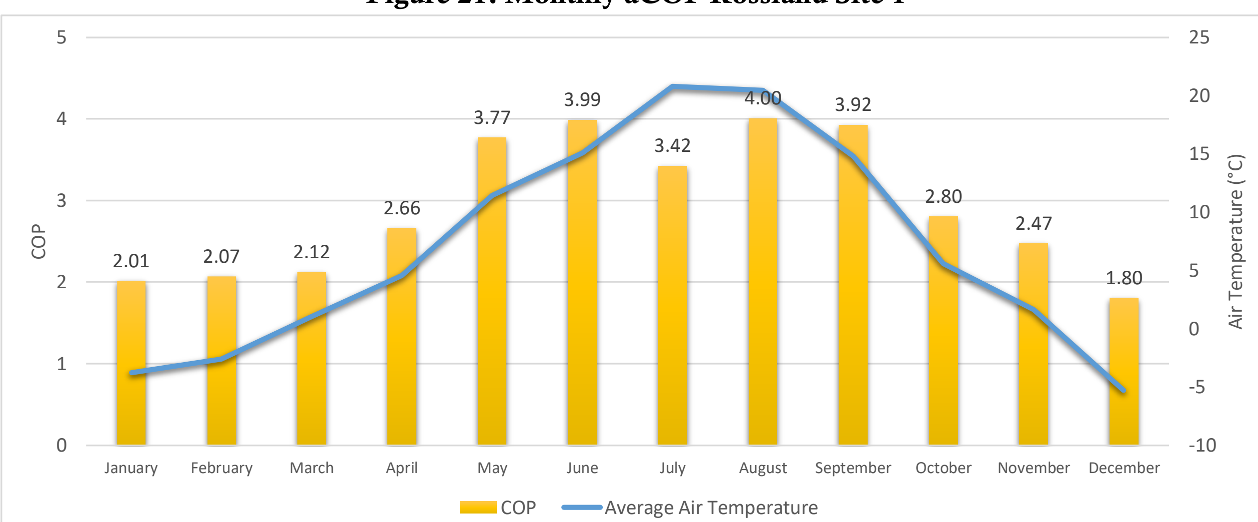
Table 16: Rossland Site 1 Summary

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period Data
Rossland Site 1	Sanden	315 L [83 gal]	11/5/16	2/16/18	468

Table 17: Rossland Site 1 Variables

Site	COP	Average Ambient Temp	Average Water Flow	Average Hot Water Temp (°F)	Average Inlet Water Temp (°F)
Rossland Site 1	**2.62**	4.9°C [40.8°F]	102 LPD [27 GPD]	52.9°C [127.1°F]	11.0°C [50.9°F]

Figure 21: Monthly aCOP Rossland Site 1



Rossland Site 1 is on well-water, and the pump pressurizes the system on a constant interval. This pumping to meet the residential water pressure setpoint causes the flow meter to register a 1-gallon (3.8 litre) pulse every hour even when there is no actual hot water draw. The water being pumped is compressing the air bladders inside of the expansion tanks, which serve as pressure storage to allow the well pump to cycle on/off. These 1-gallon pulses do not actually result in hot water leaving the tank or cold water entering the tank and therefore should not result in any useful hot water heating work done by the unit. Figure 22 below shows a typical day. The 1-gallon pulses occur every hour without a change in the hot water temperature in the pipe. We removed all water draws not resulting in a hot water temperature increase to be conservative. This site still performs extremely well over the monitoring period.

Figure 22: Rossland Site 1 – Corrected Water Draw (11/30/16)

Estimated Energy Savings:

Table 18 below summarizes the estimated energy savings between calculated baseline and the monitoring period.

Table 18: Rossland Site 1 Energy Savings

Site	Water Heating Load Delivered kWh/day [kBtu/day]	Annual Baseline Energy (kWh)	Annual Sanden Energy (kWh)	Annual Energy Savings (kWh)	% Savings
Rossland Site 1	6 [19]	2,406	790	1,617	67%

Time and Cost of Installation:

Table 19 below shows the time and cost of the installation for this site broken down by activity, and based on typical skilled labor costs.

Table 19: Rossland Site 1 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,560	$5,560
Electrical	5	$375	$127	$623
Plumbing	16.4	$1,450	$806	$2,357
Heat Trace & Insulation	2	$229	$160	$389
Total	**23.4**	**$2,054**	**$6,654**	**$8,929**

Installation Notes:

- Well water system with pump and expansion tank
- Took out 184-litre (48.6-gallon) electric water heater
- Installed 80-gallon water tank
- Outdoor unit and outdoor air temperature sensor protected by staircase to front door
- About 5 feet of pipe length from wall penetration to outdoor unit
- Heat trace on temperature control

Updates/Issues:

- 2/18/2017 – Water collecting inside of outdoor unit by Printed Circuit Board (PCB). Outdoor unit infiltration hole to PCB was blocked with tape to prevent further moisture issues.

Figure 23 through Figure 26 show annotated photos from the Rossland Site 1 installation. While the locations and details of the Sanden installations vary slightly, the major components called out in the following figures are valid for all 7 Sanden sites. Note that the pictures are taken prior to insulating the pipes, but the pipes are now insulated. The Rossland Site 1 outdoor unit was installed partially protected under a deck, and the unit was still exposed to outdoor air.

Figure 23: Installed Outdoor Unit & Monitoring

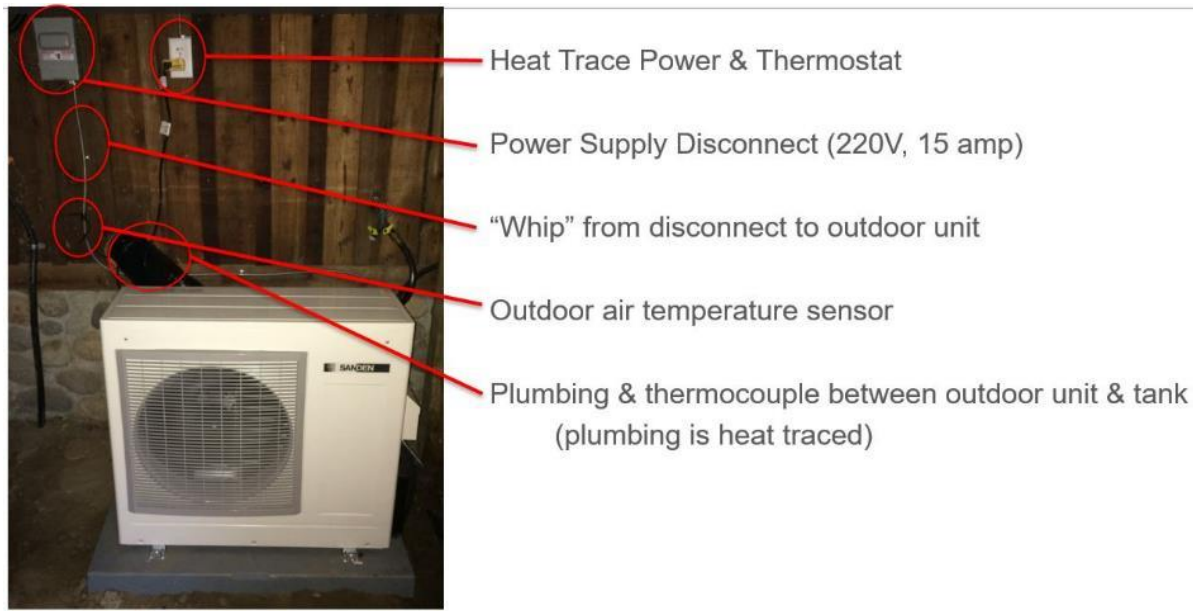


Figure 24: Installed Tank & Monitoring

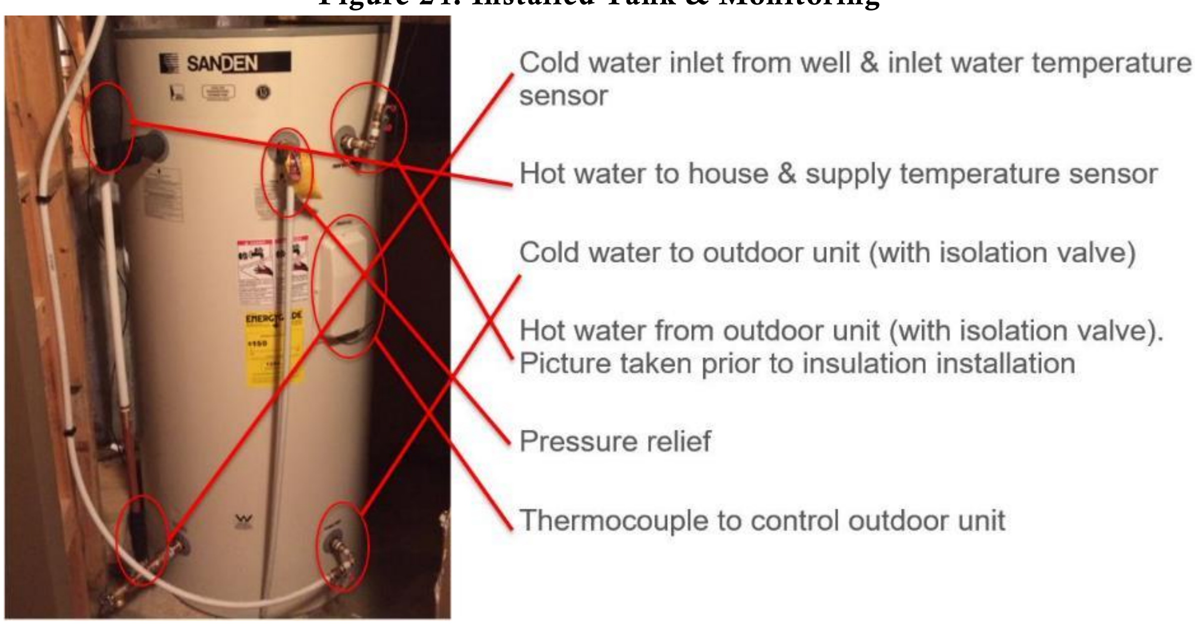


Figure 25: Plumbing

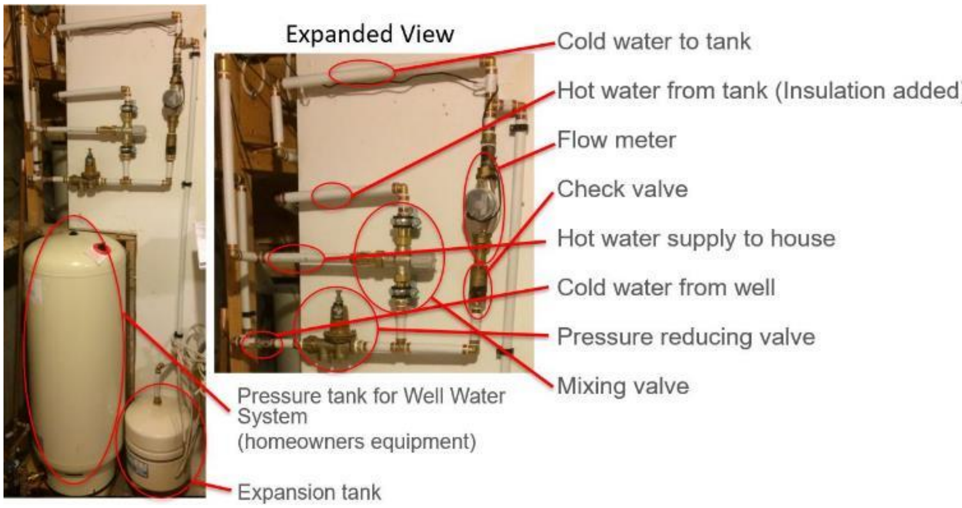


Figure 26: Sensors & Metering

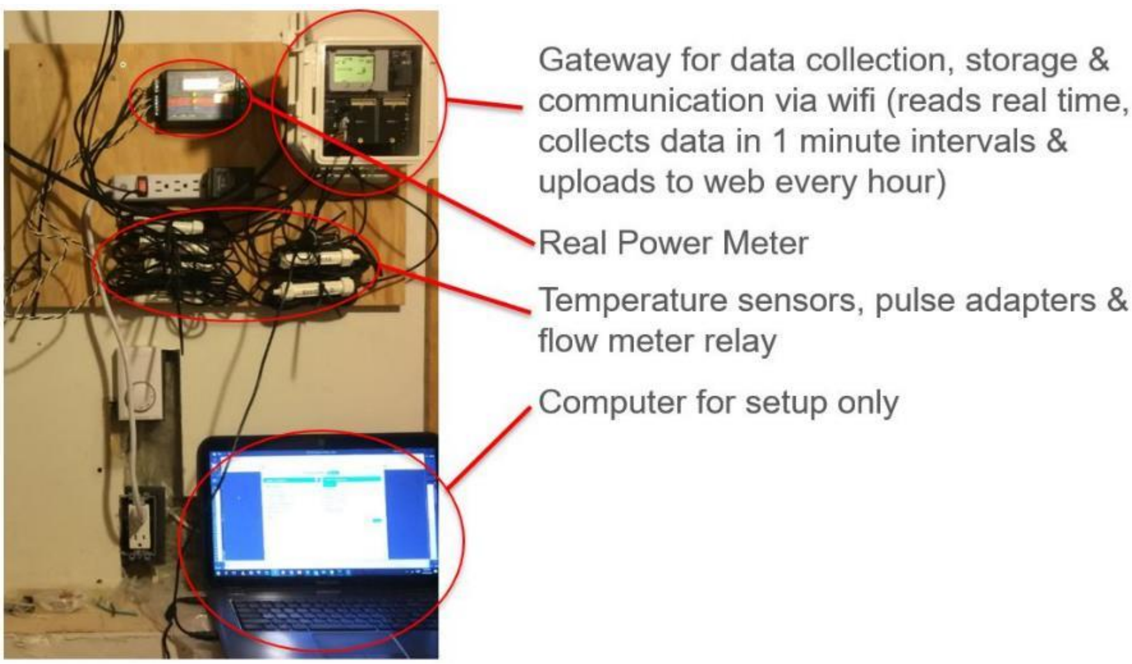


Figure 27: Rossland Site 1 Additional Photos

On a February 27th visit to Rossland Site 1 we discovered that the unit's components in the upper section, especially the PCB, were covered in condensation. This water was infiltrating the upper section of the outdoor unit through a hole leading to the fan section. We wiped up the collected water and patched the hole to prevent further damage.

Figure 28: Normal controller (left) and Condensation in Unit from Infiltration (right)

10.2 Rossland Site 2 (Sanden)

<u>Observed data:</u>

Rossland Site 2 is equipped with a 315-litre (83-gallon) tank and has been observed so far over a 455-day monitoring period during the Winter performance period. The unit has performed with a COP of 3.15 with an average ambient temperature of 7°C (44.6°F) and saw an average water flow of 102 litres per day (32 gallons per day).

Table 20: Rossland Site 2 Summary

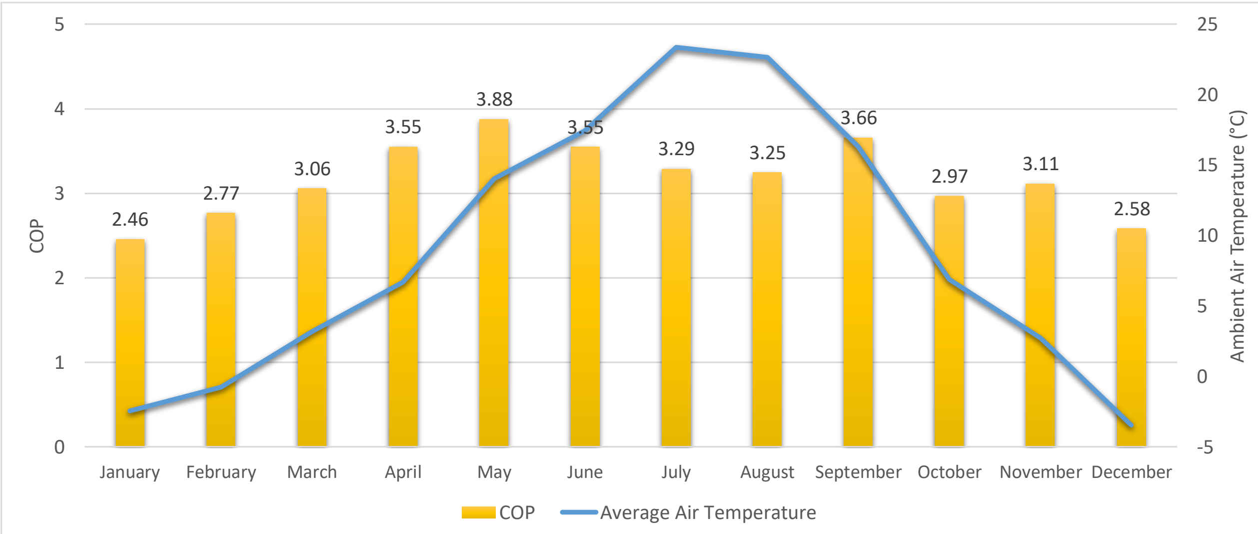
Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period Data
Rossland Site 2	Sanden	315-L [83-gal]	11/5/16	2/16/18	455

Table 21: Rossland Site 2 Variables

Site	COP	Average Ambient Temp	Average Daily Water Flow	Average Hot Water Temp	Average Inlet Water Temp (°F)
Rossland Site 2	**3.15**	7°C[27] [44.6°F]	102 LPD [32 GPD]	59°C [139°F]	10.5°C [50.9°F]

[27] The outdoor unit of Rossland Site 2 is near a south facing concrete wall. Thus, the average ambient temperature is 2-4°C warmer than the other two Rossland sites over the same period. This is part of the reason this unit perform better than the other two sites during the Winter months.

Figure 29: Rossland Site 2 Average Monthly aCOP



Estimated Energy Savings:

Table 22: Rossland Site 2 Energy Savings

Site	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Sanden Energy (kWh)	Energy Savings (kWh)	% Savings
Rossland Site 2	6 [19]	2,828	799	2,129	73%

Estimated Time and Cost of Installation:

The table below shows the estimated time and cost of the installation for this site broken down by activity.The costs are based on typical skilled labor costs.

Table 23: Rossland Site 2 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,560	$5,560
Electrical	6	$450	$143	$719
Plumbing	16.4	$1,450	$806	$2,357
Heat Trace & Insulation	2	$229	$151	$379
Total	**24.4**	**$2,129**	**$6,660**	**$9,016**

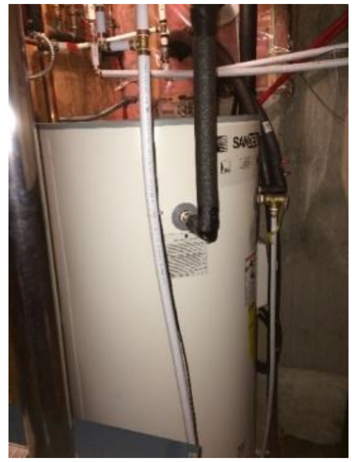
Installation Notes:

- Took out 284-litre (75 gal) electric water heater
- Put in 315-litre (80-gallon) water tank
- About 1.7 meters (5.5 feet) of pipe length from wall to outdoor unit
- No heat trace temperature control
- Redundant pressure reducing valves, 50 psig then 90 psig

Updates/Issues:

- 12/5/16 23:16 – Outdoor unit cut out and threw error code e111 with "Replace PCB Board" as corrective action
- 12/14/2016 – PCB board replaced, outdoor unit froze up due to GFCI outlet to heat trace not being on and OAT between 10-20F, outdoor unit sitting in error code 073
- 12/16/2016 – Outdoor unit thawed out, leak detected at pump
- 12/17/16 – Outdoor unit replaced, gave error codes 073, 111, and 111 within the first hour
- 12/18/2016 2:13 – System back up to temperature
- 2/18/2017 – Water collecting inside of outdoor unit by PCB, Outdoor unit infiltration hole to control board blocked with tape to prevent further moisture issues.

Rossland Site 2 Photos:



10.3 Rossland Site 3 (Sanden)

Observed data:

The Rossland Site 3 data is split into two separate periods. On February 7th, 2017, the original unit failed due to condensation issues on the printed control board (PCB). The outdoor unit was replaced with a newer generation (GS3) on February 16th, 2017. We have 94 days of metered data for the old GS2 unit and 363 days for the new GS3 unit. The GS2 unit performed with a COP of 1.94 with an average air temperature of -3.9°C (25°F). The GS3 unit performed with a COP of 2.03 over a period of 363 days with an average ambient temperature of 6.9°C (44°F). The GS3 unit's performance was negatively impacted by multiple periods totaling over 4-weeks in which the occupant drew no hot water. The unit ran to maintain the hot water temperature setpoint, but no useful work was done resulting in an effective COP of 0 over the interval.

Table 24: Rossland Site 3 Summary

Site	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
Rossland Site 3 GS2	315-L [83-gal]	11/5/16	2/7/17	94
Rossland Site 3 GS3	315-L [83-gal]	2/16/17	2/16/18	363
Combined:				**457**

Table 25: Rossland Site 3 Variables

Site	aCOP	Average Ambient Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
Rossland Site 3 GS2	**1.94**	-3.9°C [25°F]	109 LPD [29 GPD]	57°C [134°F]	9°C [48°F]
Rossland Site 3 GS3	**2.03**	6.9°C [44°F]	97 LPD [26 GPD]	52°C [127°F]	11°C [51°F]
Combined:	**2.06**	6.6°C [43.9°F]	100 LPD [26 GPD]	53°C [127°F]	11°C [51°F]

The average annualized COP (aCOP) of the combined data set of Rossland Site 3 is higher than the individual COPs of the GS2 and GS3 units during their respective monitoring periods. This is due to the GS2 having slightly better performance during November, December, and January than the GS3 despite similar ambient temperatures. When the two are combined together the annual performance of the GS3 unit which has nearly 12 months by itself increases from the impact of the GS2 winter performance. This is shown graphically in Figure 30.

Figure 30: Rossland Site 3 GS2 and GS3 Separated Performance

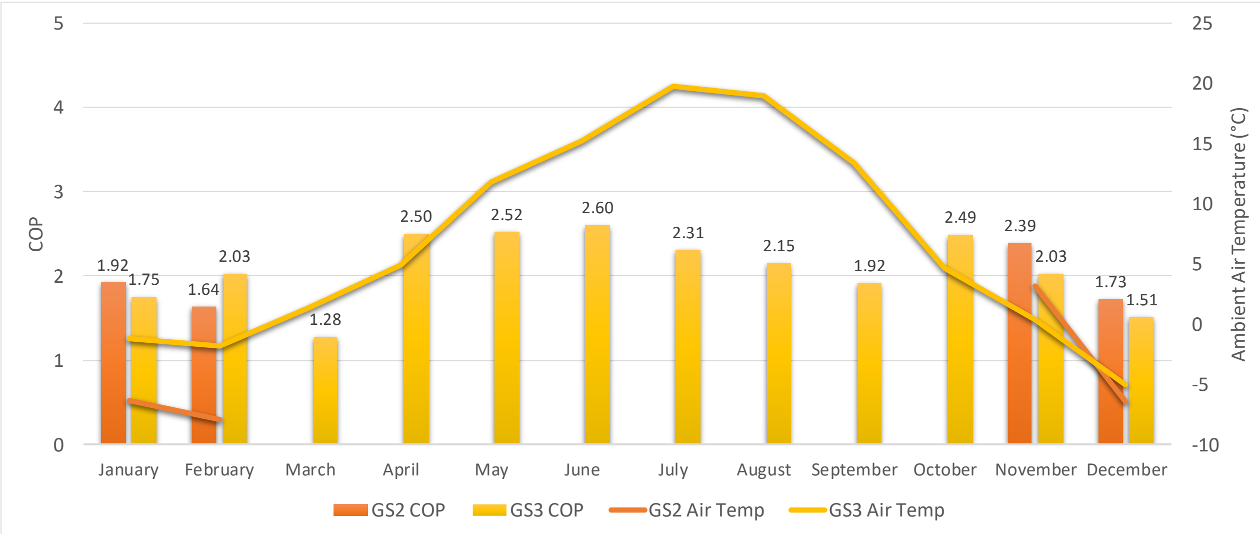
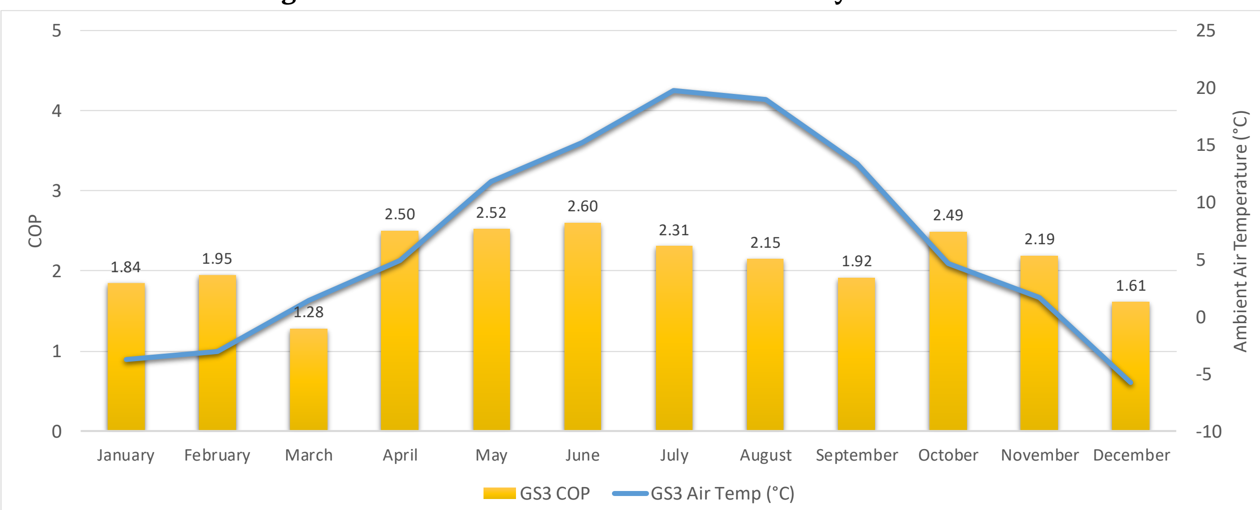


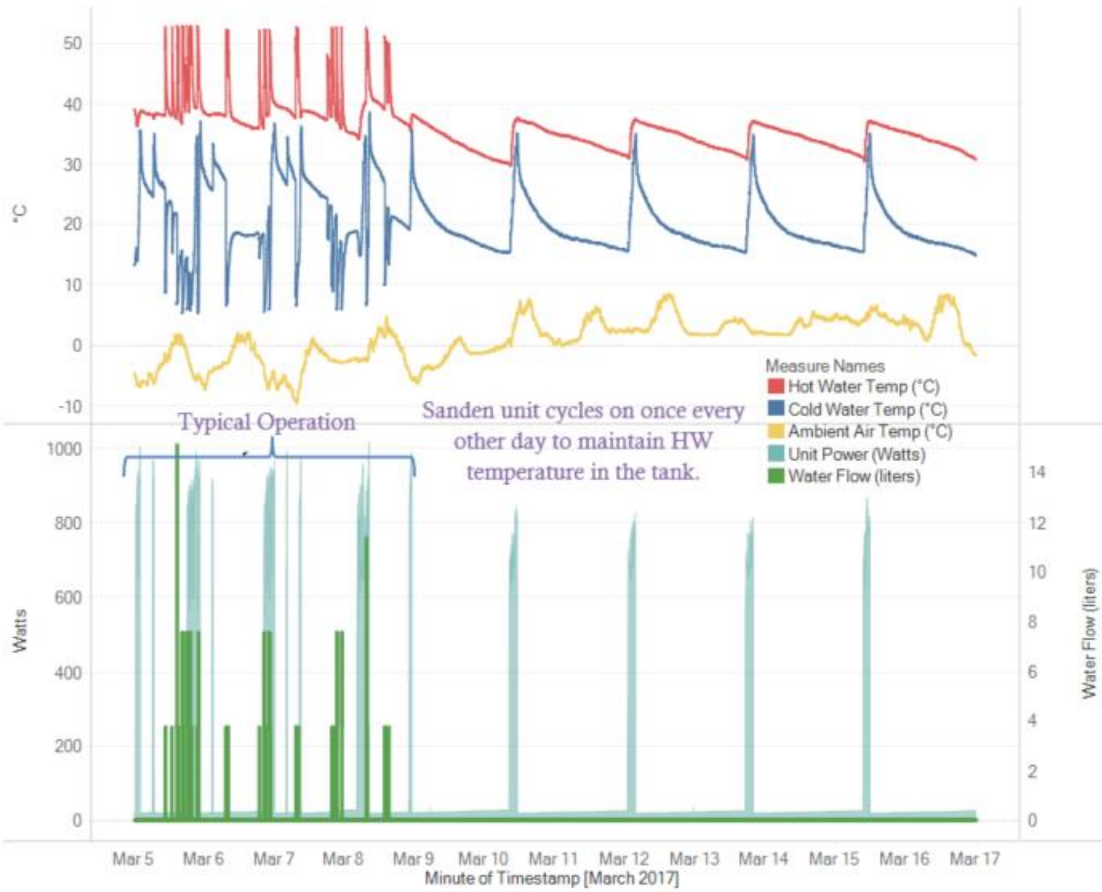
Figure 31: Rossland Site 3 Combined Monthly Performance



Tank Skin Losses:

Over a 13-day period from March 9th through March 21st, 2017 there was no water draw from this site. The unit continued to cycle on to maintain the hot water setpoint in the tank. The average OAT for this period was 2°C (35.6°F) and the unit used 21.8 kWh (1.7 kWh/day) to maintain the hot water temperature. Figure 32 below shows the temperature and unit power trended over this measurement period.

Figure 32: Energy Required to Reheat Tank from Skin Losses



Estimated Energy Savings:

Table 26: Rossland Site 3 Energy Savings

Site	aCOP	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Sanden Energy (kWh)	Energy Savings (kWh)	% Savings
Rossland Site 3 GS2	1.94	5 [16]	2,002	889	1,113	56%
Rossland Site 3 GS3	2.03	5 [16]	1,937	822	1,115	58%
Total:	**2.06**	**5 [16]**	**1,967**	**821**	**1,145**	**58%**

Estimated Time and Cost of Installation:

Table 27 below shows the estimated time and cost of the installation for this site broken down by activity, and based on typical skilled labor costs.

Table 27: Rossland Site 3 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,560	$5,560
Electrical	6	$450	$152	$730
Plumbing	16.4	$1,450	$806	$2,357
Heat Trace & Insulation	2	$229	$146	$375
Total	**24.4**	**$2,129**	**$6,665**	**$9,021**

Installation Notes:

- Took out 184-litre (48.6 gal) electric water heater
- Put in 315-litre (80-gallon) water tank
- About 1.6 meter (5.25 feet) of pipe length from wall to outdoor unit
- No heat trace temperature control

Updates/Issues:

- 10/24/2016 – No hot water, thermistor connection at water tank checked, outdoor unit reset by electrician
- 12/7/2016 – Outdoor unit cut out and tripped the breaker, error code e111 with "Replace PCB Board" as corrective action. The cause was moisture in the control board (see picture below).
- 2/16/2017 – Outdoor unit replaced with a GS3 unit
- 3/9/2017 – Tenants away for 17 days, March 9th – 26th (negative impact on performance)
- 8/5/2017 – Tenants away for 8 days, March 5th – 13th
- 9/21/2017 – No water draw for 7 days, September 21st – 28th
- 1/20/2018 – No water draw for 8 days, January 20th – 28th

Figure 33: Rossland Site 3 GS2 Photos

Figure 34: Rossland Site 3 GS2 (Original) Unit Failure

Figure 35: Rossland Site 3 GS3 (New) Unit Installation Photos

10.4 Kelowna Site 1 (Sanden)

Observed data:

Kelowna Site 1 is equipped with a 160-litre (43-gallon) tank and this Winter report includes 134-days of metered data. The unit has performed with a COP of 1.56 over a period with an average ambient temperature of -1.5°C [29°F] and an average water draw of 73 litres per day (19.4 gallons per day).

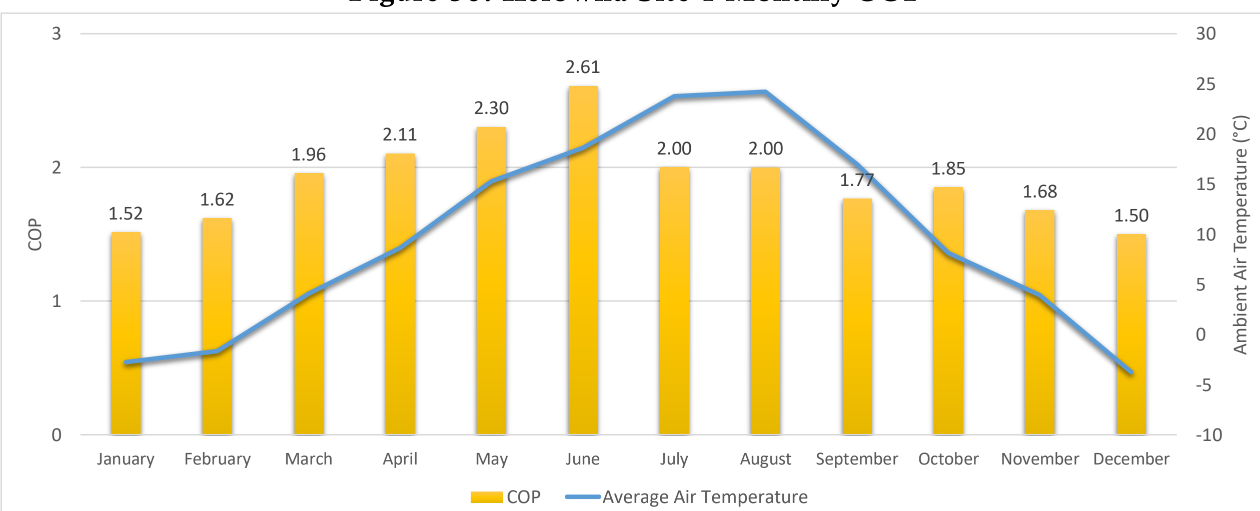
Table 28: Kelowna Site 1 Summary

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
Kelowna Site 1	Sanden	160-L [43-gal]	11/8/16	2/16/18	447

Table 29: Kelowna Site 1 Variables

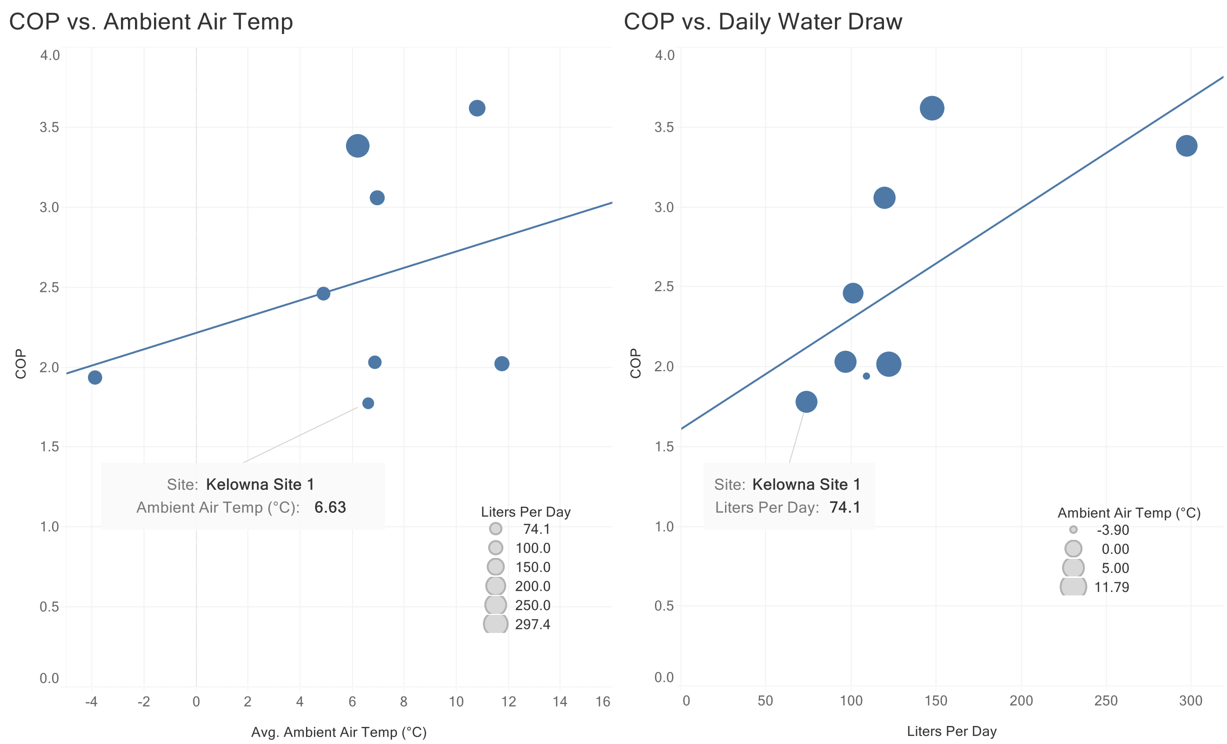
Site	COP	Average Ambient Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
Kelowna Site 1	**1.86**	6.6°C [44°F]	74 LPD [20 GPD]	52.4°C [126°F]	16.5°C [61.7°F]

Figure 36: Kelowna Site 1 Monthly COP



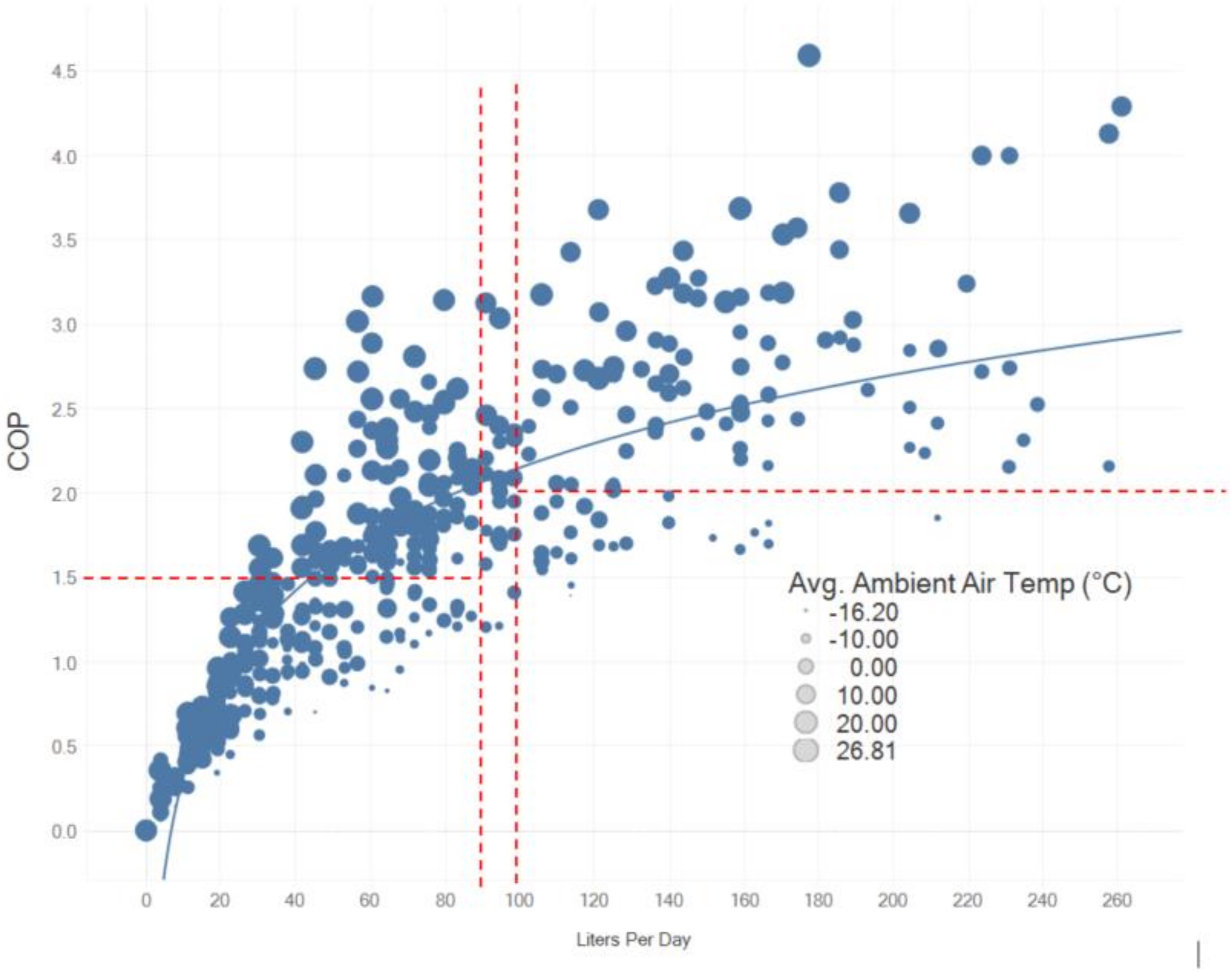
Kelowna Site 1 performed the lowest of all Sanden units with a total COP of 1.76 over the 15 month monitoring period (aCOP of 1.86). This is primarily due to the site having a very low water draw (85 litres/day) relative to the other sites (136 litres/day on average for Sanden sites), and seeing low local ambient air temperatures (6.6°C on average). Figure 37 below shows all the relationship of COP versus air temperature and COP versus average daily water flow for all Sanden sites over the total monitoring period. Both factors are positively correlated with performance, and Kelowna's low water draw and ambient temperatures result in a low COP. The COPs displayed in the figure below are the total COP over the monitored period and therefore differ slightly than the annualized average aCOP.

Figure 37: Sanden Units – Impact of Low Air Temperature and Water Draw on COP



If we zoom in and look at the daily performance of Kelowna Site 1 at different water draws we also see the clear increase in performance on the larger water draw days. As seen in Figure 38 below, every day in which the water draw was less than 40 litres (10-gallons) has a COP of less than 1.7, and nearly every day with a draw of greater than 100-litres (26-gallons) except sub-zero days have a COP greater than 2.0. Furthermore, most of these days with high water flows had a COP of greater than 2.5 except those with very low ambient air temperatures, which is indicated by small circles in the figure below.

Figure 38: Kelowna Site 1 – Daily COP vs. Water Draw



To further illustrate the performance dependence on water flow, Figure 39 below shows the water temperatures, flow, and system performance of Kelowna Site 1 over the month of January. The system performs quite well on days with higher water flows. Figure 40 shows the January 9th, 2017 water temperatures, draws, and system power consumption. There are two 1-hour periods in which the heat pump runs to maintain the water temperature set-point even though there are only 30-litres (8-gallons) drawn throughout the day, mostly in the morning and evening. The small amount of useful work results in a COP of 0.69 for this cold January day.

Figure 39: Kelowna Site 1 – System Performance in January Days

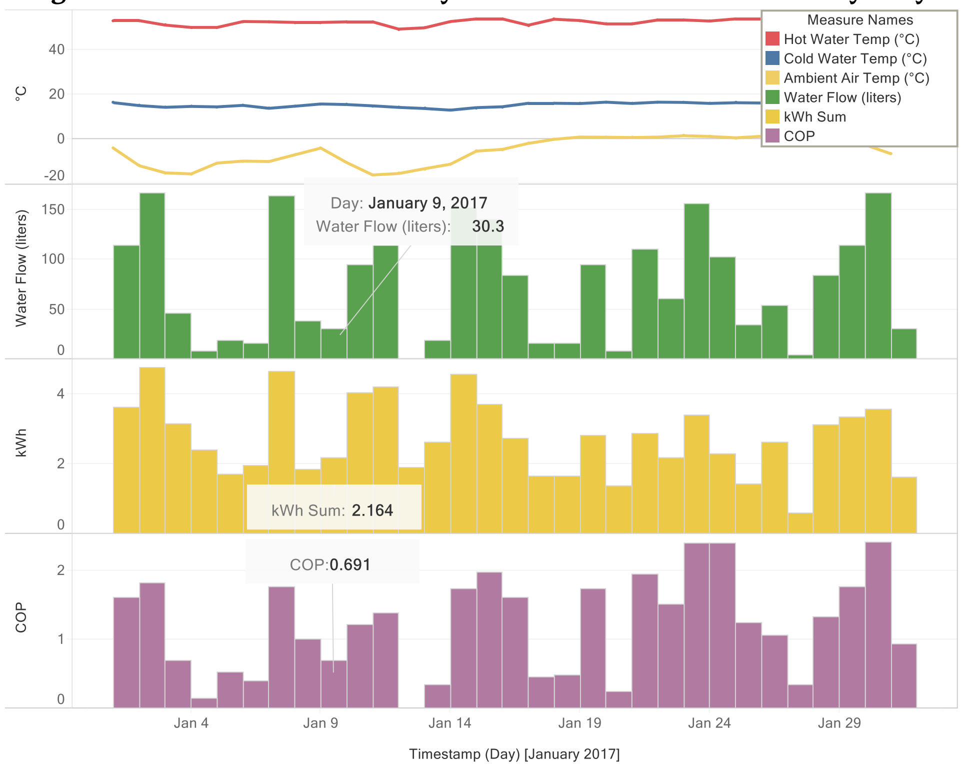


Figure 40: Kelowna Site 1 – January 9th, 2017 Water Temperature, Flow, & System Power

Even with the relatively low performance of Kelowna Site 1 compared to the other Sanden units, we estimate the savings to be 213 kWh over the calculated baseline electric resistance water heater, or a 51% savings.

Estimated Energy Savings:

Site	aCOP	Water Heating Load Delivered (kWh/day) [kBtu/day]	Calculated Baseline Energy (kWh)	Sanden Energy (kWh)	Energy Savings (kWh)	% Savings
Kelowna Site 1	1.86	3 [12]	1,360	668	692	51%

Estimated Time and Cost of Installation:

Table 30 below shows the estimated time and cost of the installation for this site broken down by activity, and based on typical skilled labor costs.

Table 30: Kelowna Site 1 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,360	$5,360
Electrical	4.5	$383	$179	$681
Plumbing	12.0	$1,424	$593	$2,105
Heat Trace & Insulation	2	$261	$187	$449
Total	**18.5**	**$2,068**	**$6,319**	**$8,595**

Installation Notes:

- Took out 175-litre (46.2 gal) electric water heater
- Put in 163-litre (43-gallon) water tank
- About 2.3 meter (7.5 feet) of pipe length from wall to outdoor unit
- No heat trace temperature control

Updates/Issues:

- 8/11/2017 – Site upgraded to fiber optic
- 8/11/2017 – 8/30/2017 – Missing data as WiFi logger could not connect to internet when modem was switched out

Figure 41: Kelowna Site 1 Installed Photos

10.5 Kelowna Site 2 (Sanden)

<u>Observed data:</u>

Kelowna Site 2 has a 43-gallon tank Sanden unit installed and has been monitored for 134 days thus far. The unit performed very well at a COP of 3.17 with an average ambient temperature of 0°C (32°F). The high performance is due to a very high daily water draw which generally improves performance in the Sanden units as discussed in Section 2.3.

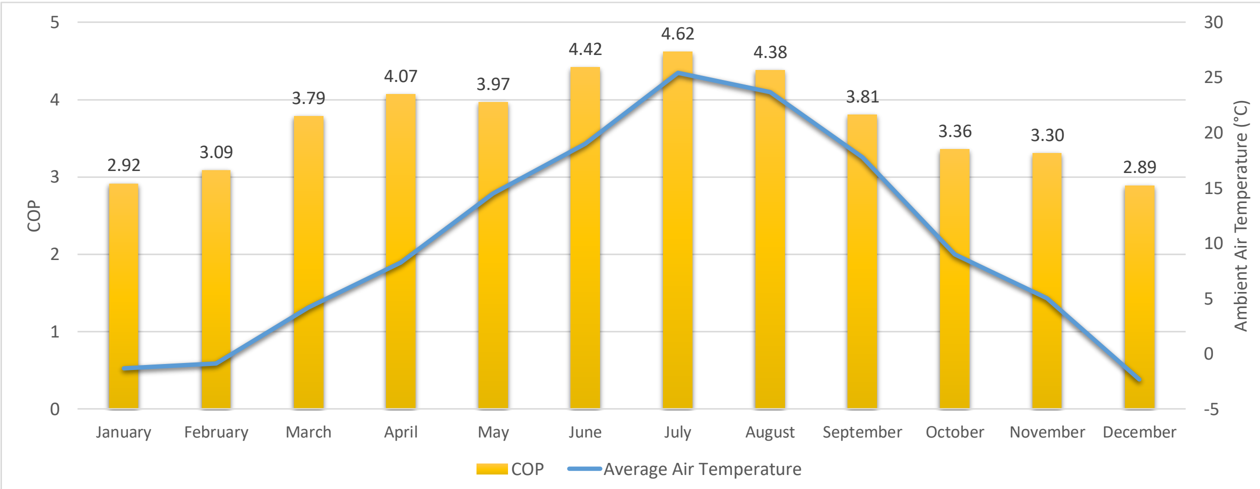
Table 31: Kelowna Site 2 Summary

Site	Unit Type	Tank Size (L) [gal]	Beginning Date	Ending Date	Days of Monitoring Period
Kelowna Site 2	Sanden	163 [43]	11/8/16	2/17/18	465

Table 32: Kelowna Site 2 Variables

Site	aCOP	Average Ambient Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
Kelowna Site 2	**3.62**	8°C [46°F]	288 LPD [76 GPD]	52°C [125°F]	10°C [50°F]

Figure 42: Kelowna Site 2 Monthly Performance



Estimated Energy Savings:

Site	COP	Water Heating Load Delivered (kBtu/day)	Calculated Baseline Energy (kWh)	EEM Energy (kWh)	Energy Savings (kWh)	% Savings
Kelowna Site 2	3.62	14 [47]	5,494	1,388	4,106	75%

Estimated Time and Cost of Installation:

Table 33 below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

Table 33: Kelowna Site 2 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,360	$5,360
Electrical	8	$600	$194	$925
Plumbing	12.8	$1,513	$598	$2,202
Heat Trace & Insulation	2	$261	$123	$385
Total	**22.8**	**$2,374**	**$6,275**	**$8,872**

<u>Installation Notes:</u>

- Took out 286.6-litre (75.7-gallon) electric water heater
- Put in 163-litre (43-gallon) water tank
- About 1.2 meter (4-feet) of pipe length from wall to outdoor unit
- Heat trace temperature control

Figure 43: Kelowna Site 2 Installed Photos

10.6 Vancouver Island Site 2 (Sanden)

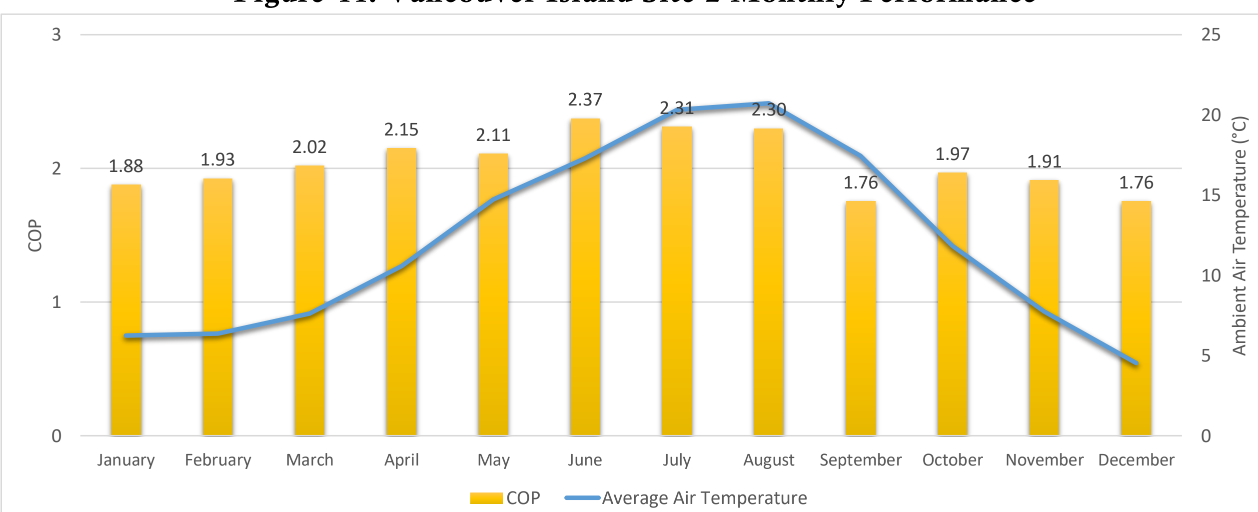
Observed data:

Vancouver Island Site 2 is equipped with a 163-litre (43-gallon) tank and this Winter report includes 361 days of data. The unit performed with a COP of 1.98 with an average outside air temperature of 12.2°C (54°F) and a daily water draw of 122 LPD (39 GPD).

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
V. Island Site 2	Sanden	163-L [43-gal]	2/20/17	2/16/18	361

Site	COP	Average Ambient Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
V. Island Site 2	**1.98**	12.2°C [54°F]	122 LPD 39 GPD	62°C [143°F]	18°C [64°F]

Figure 44: Vancouver Island Site 2 Monthly Performance



Estimated Energy Savings:

Site	Water Heating Load Delivered (kBtu/day)	Calculated Baseline Energy (kWh)	EEM Energy (kWh)	Energy Savings (kWh)	% Savings
V. Island Site 2	7 [22]	2,624	1,212	1,412	54%

Estimated Time and Cost of Installation:

The table below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

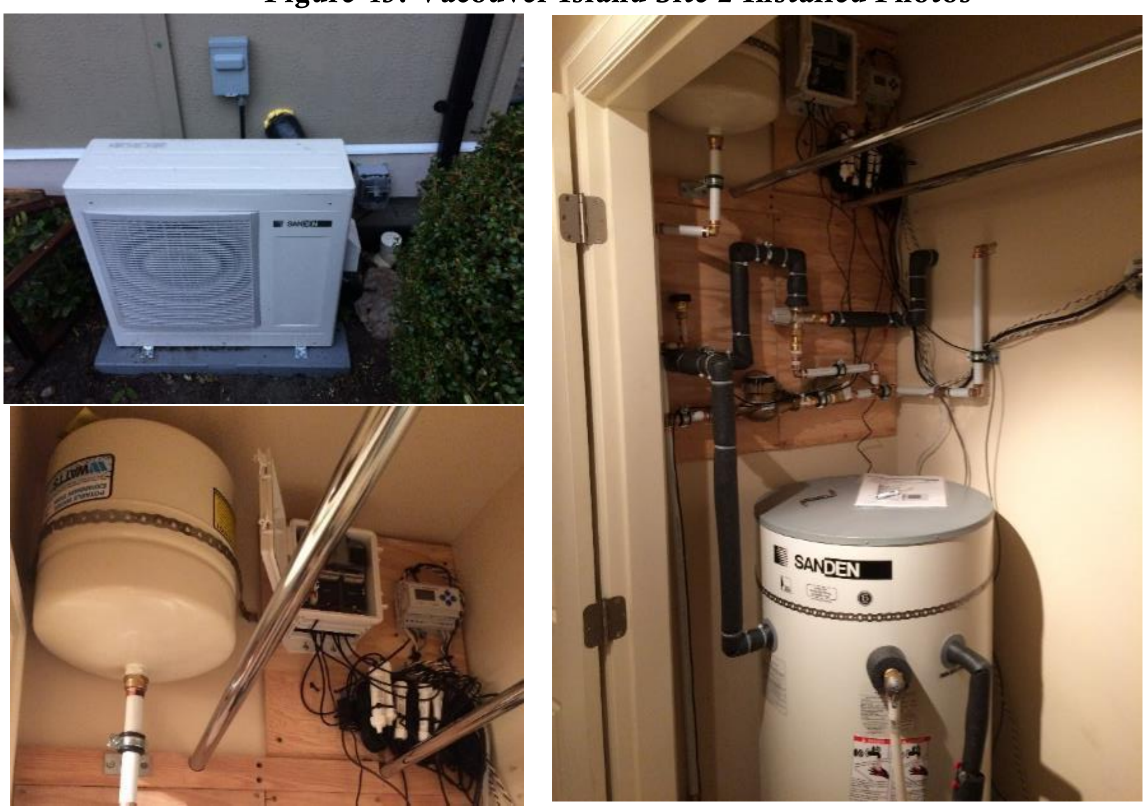
Table 34: Vancouver Island Site 2 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,360	$5,360
Electrical	13.5	$770	$179	$997
Plumbing	6.5	$640	$608	$1,299
Heat Trace & Insulation	2	$253	$105	$358
Total	**22.0**	**$1,663**	**$6,253**	**$8,014**

Installation Notes:

- Took out 284-litres (75-gallon) electric water heater
- Put in 43-gallon water tank
- About 3-feet of pipe length from wall to outdoor unit
- No heat trace temperature control

Figure 45: Vacouver Island Site 2 Installed Photos



10.7 Vancouver Island Site 3 (Sanden)

Observed data:

The 163-litre (43-gallon) Vancouver Island Site 3 Sanden system performed very well over a 375-day monitoring period with an aCOP of 3.52. This site has a high performance due to it seeing warm ambient temperatures of 6.4°C (51.5°F on average) and large spread out water draws averaging 148 litres per day (39 gallons per day).

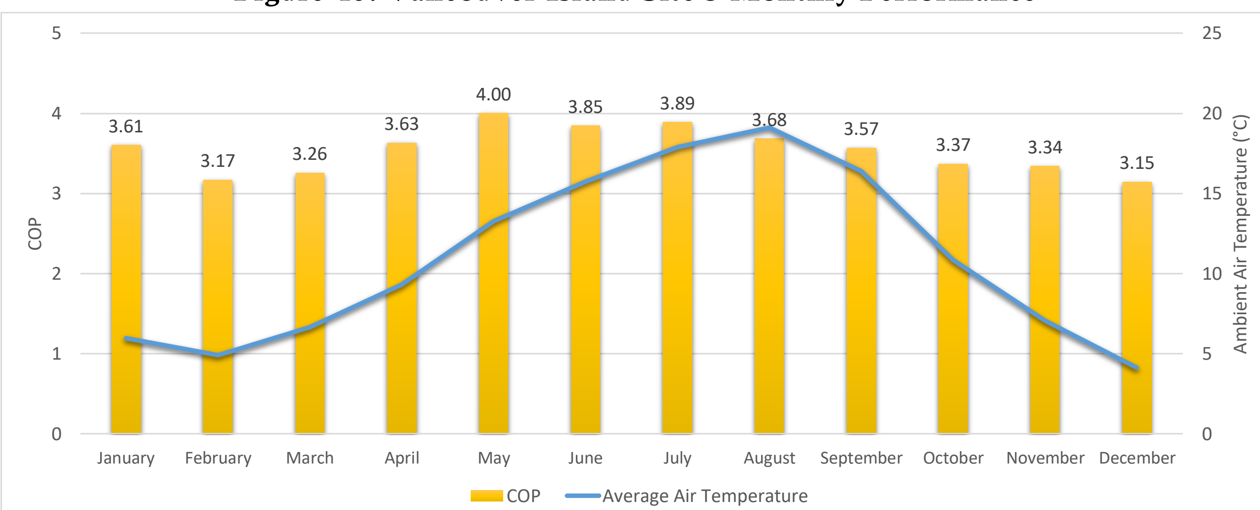
Table 35: Vancouver Island Site 3 Summary

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
V. Island Site 3	Sanden	163-L [43-gal]	2/6/17	2/16/18	375

Table 36: Vancouver Island Site 3 Variables

Site	COP	Average Ambient Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
V. Island Site 3	**3.52**	10.8°C [51.5°F]	148 LPD [39 GPD]	61.3°C [142°F]	15.8°C [60.5°F]

Figure 46: Vancouver Island Site 3 Monthly Performance



Estimated Energy Savings:

Table 37: Vancouver Island Site 3 Energy Savings

Site	COP	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Sanden Energy (kWh)	Energy Savings (kWh)	% Savings
V. Island Site 3	2.99	8 [27]	3,191	829	2,362	74%

Estimated Time and Cost of Installation:

The table below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

Table 38: Vancouver Island Site 3 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$5,360	$5,360
Electrical	6	$345	$185	$556
Plumbing	6.0	$588	$658	$1,296
Heat Trace & Insulation	2	$253	$200	$453
Total	**14.0**	**$1,186**	**$6,403**	**$7,666**

Installation Notes:

- Took out 270-litre (71-gallon) electric water heater
- Put in 163-litre (43-gallon) water tank
- About 1-meter (3.5-feet) of pipe length from wall to outdoor unit
- Heat trace temperature control

Updates/Issues:

- 5/25/2017 – Modem replace by Shaw
- 5/26/2017 – SSID and password changed back to original settings to allow logger to connect, no aparant data loss
- 11/15/2017 – Large hot water draw which depleted the tank temp to 80F, approximately

Figure 47: Vancouver Island Site 3 Installed Photos

11. Rheem Site Descriptions and Performance

We completed installations of 5 Rheem integrated units at two Kelowna and three Vancouver Island sites. On average the units performed with an aCOP of 1.83 with average ambient temperatures of 60.4°F and daily water draws of 204 litres per day. One unit (Kelowna Site 3) is unducted and draws air from a conditioned space. The remaining units are ducted to bring in outside air.

11.1 Kelowna Site 3 (Rheem)

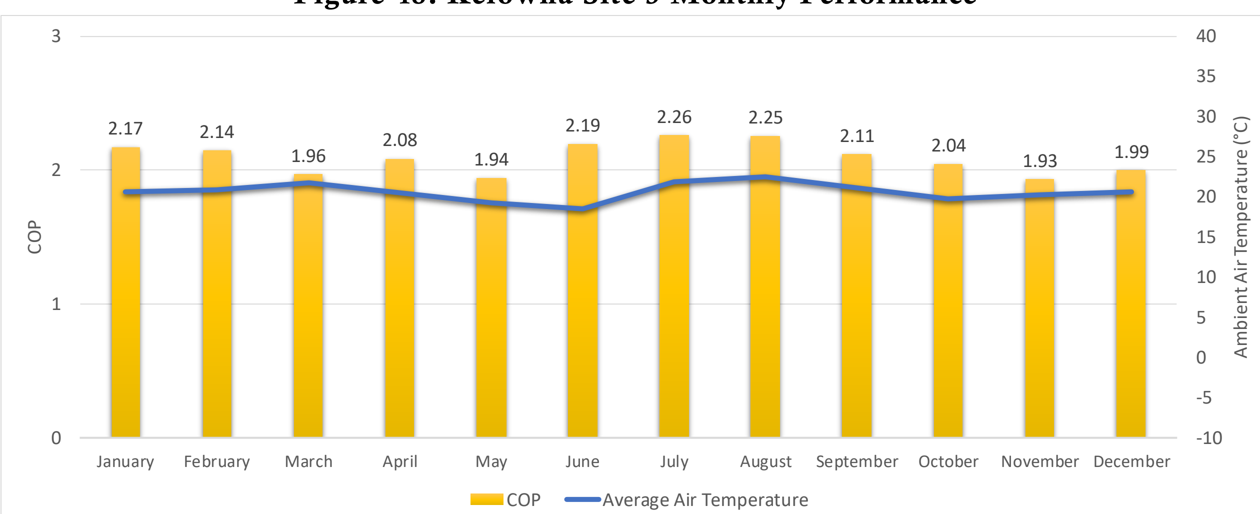
Observed data:

The Kelowna Site 3 is a 303-litre (80-gallon) Rheem unit which performed with a COP of 2.08 over 457 days with an average room temperature of 20.6°C (69.1°F). This site performed better than all other integrated Rheem units mainly due to the unit being located in a conditioned basement and having steadily warm air to draw heat from.

Site	Unit Type	Tank Size (gal)	Beginning Date	Ending Date	Days of Monitoring Period
Kelowna Site 3	Rheem	303-L [80-gal]	11/3/16	2/16/18	457

Site	COP	Average Inlet Air Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp (°F)
Kelowna Site 3	**2.08**	20.6°C [69.1°F]	175 LPD [46 GPD]	51.4°C [125°F]	10.5°C [51°F]

Figure 48: Kelowna Site 3 Monthly Performance



Unlike the other Rheem sites, Kelowna Site 3 is un-ducted and uses wood-pellet conditioned space air as the heat source. This is clear in Figure 49 as the inlet temperature is consistently higher than the cold-water temperature. Over this 3-day period from January 2nd to January 5th the electrical element only comes on twice during the same evening after a series of high water draws. Consequently, the average COP over this 3-day period is 2.0 which is quite high relative to the other Rheem units during January. However, it is important to note that this heat was drawn from a space that was being heated by wood pellets. We can calculate the upper limit of this parasitic load on the wood pellet stove by calculating the amount of heat removed from the space. Over a 12-month period we estimate 3,394 kWh (11,580 kBtu) or 226 kWh/day (771 kBtu/day) were pumped out of the space to heat water. Assuming a $16/GJ[28] cost of wood pellets, this is approximately $195/year ($0.54/day).[29] This calculation is only for illustration as we did not actually measure the parasitic load on the stove.

Figure 49: Kelowna Site 3 – 3-day Period

[28] 947.817 kBtu/GJ

[29] The parasitic load on the wood pellet stove is calculated from the measured water heating load delivered per the following equation: $Parasitic\ Load\ (Btu) = Water\ Heating\ Load\ Delivered\ (Btu) * (COP - 0.9)$. This assumes a 10% tank loss and is the energy "pumped" out of the room air and what allows a heat pump to achieve a COP greater than 1.0. For various reasons, the heat removed by the heat pump will not always equal the heat put back in the space. For example, heat removed during the summer is valuable and is not replaced by the heating source.

Estimated Energy Savings:

Table 39: Kelowna Site 3 Energy Savings

Site	COP	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Rheem Energy (kWh)	Energy Savings (kWh)	% Savings
Kelowna Site 3	2.08	8 [27]	3,333	1,387	1,947	58%

Estimated Time and Cost of Installation:

Table 40 below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

Table 40: Kelowna Site 3 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$2,452	$2,452
Electrical	N/A	$0	$0	$0
Plumbing	9.8	$1,290	$494	$1,869
Ducting & Insulation	0	$0	$0	$0
Total	**9.8**	**$1,290**	**$2,946**	**$4,320**

Installation Notes:

- Took out 284-litre (75-gallon) electric water heater
- Put in 303-litre (80-gallon) integrated water heater
- No ducting, shares the level with a wood pellet stove

Updates/Issues:

- 3/26/2017 – 3/31/2017 – Power meter unplugged; 5 days of missing data
- 6/23/2017 – Hot water temperature increased from 140F (60C) to 143.6F (62C)
- 10/8/2017 – 10/17/2017 – Power meter unplugged; 9 days of missing data

Figure 50: Kelowna Site 3 Installed Photos – Unducted System in Condition Space

11.2 Kelowna Site 4 (Rheem)

Kelowna Site 4 has the lowest performance of all units tested with an aCOP of 1.50. As shown in the Rheem Unit Performance section above, this is due to the site having the highest and peakiest water draw (308 litres per day [81 gallons per day] with a maximum flow of 34.4 litres per minute [9.1 gallons per minute]), and a higher hot water temperature setpoint of 57°C (135°F) than the other Rheem units which are set at 54°C (130°F). With these 3 factors combined, this integrated unit operated with marginal performance improvements over an electric resistance heater during the winter month. In fact, 67% of the total energy used by the unit was with the electric elements.

Observed data:

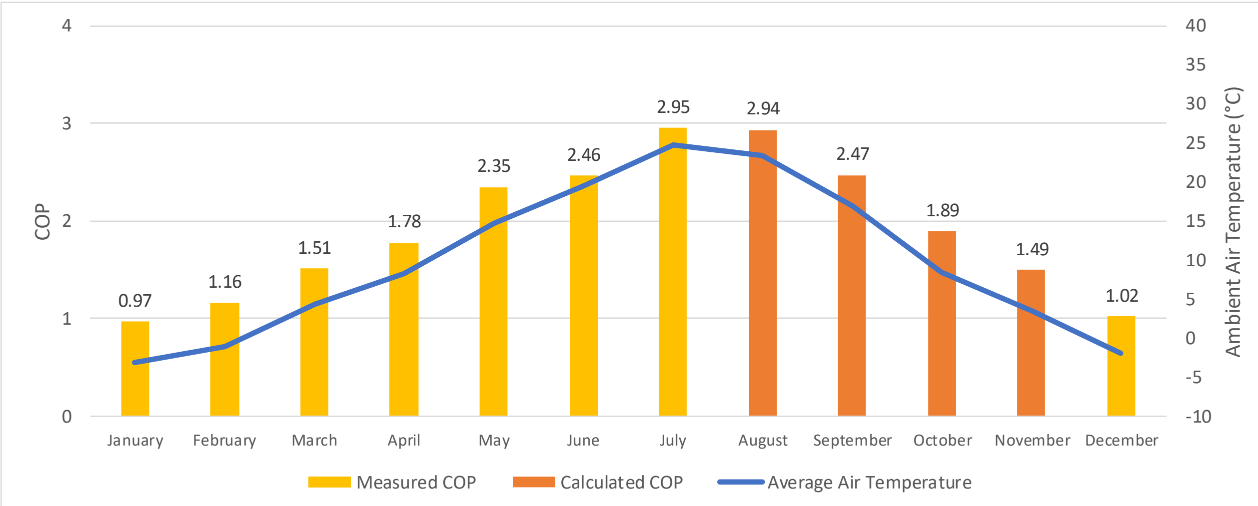
Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
Kelowna Site 4	Rheem	303-L [80-gal]	12/16/16	2/16/18	258[30]

Site	aCOP	Average Ambient Air Temp	Average Water Flow	Average Hot Water Temp (°F)	Average Inlet Water Temp (°F)
Kelowna Site 4	**1.62**	15.4°C [59.8°F]	324 LPD [86 GPD]	50.8°C [123°F]	14.4°C [58°F]

Due to a failed pulse adapter on the water draw flow meter, the Kelowna Site 4 ducted monitoring period does not include data between August and November. We calculate the performance for these months by developing a relationship between COP, daily average air temperature and water draw. Figure 51 shows the monthly performance separating the measured and calculated values.

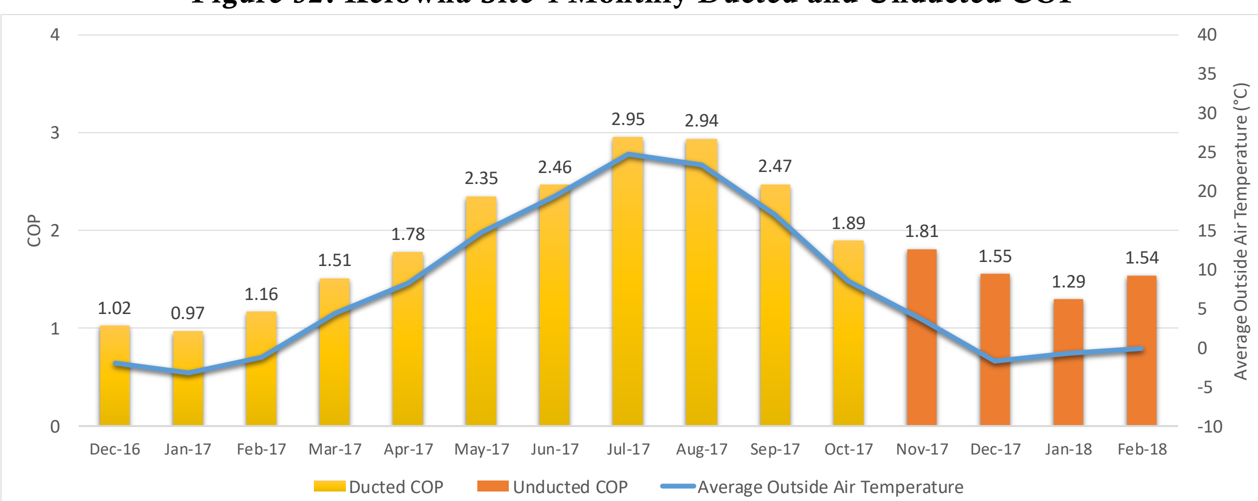
[30] The power meter failed on February 4th, 2017, and multiple subsequent meters failed until it became operational on March 14th. Thus, there is a one-month gap in the data for this site during this period. Additionally, the pulse output adapter for the water flow meter began failing on July 8th, 2017 and the issue was not resolved until November 1st, 2017.

Figure 51: Kelowna Site 4 Monthly Performance



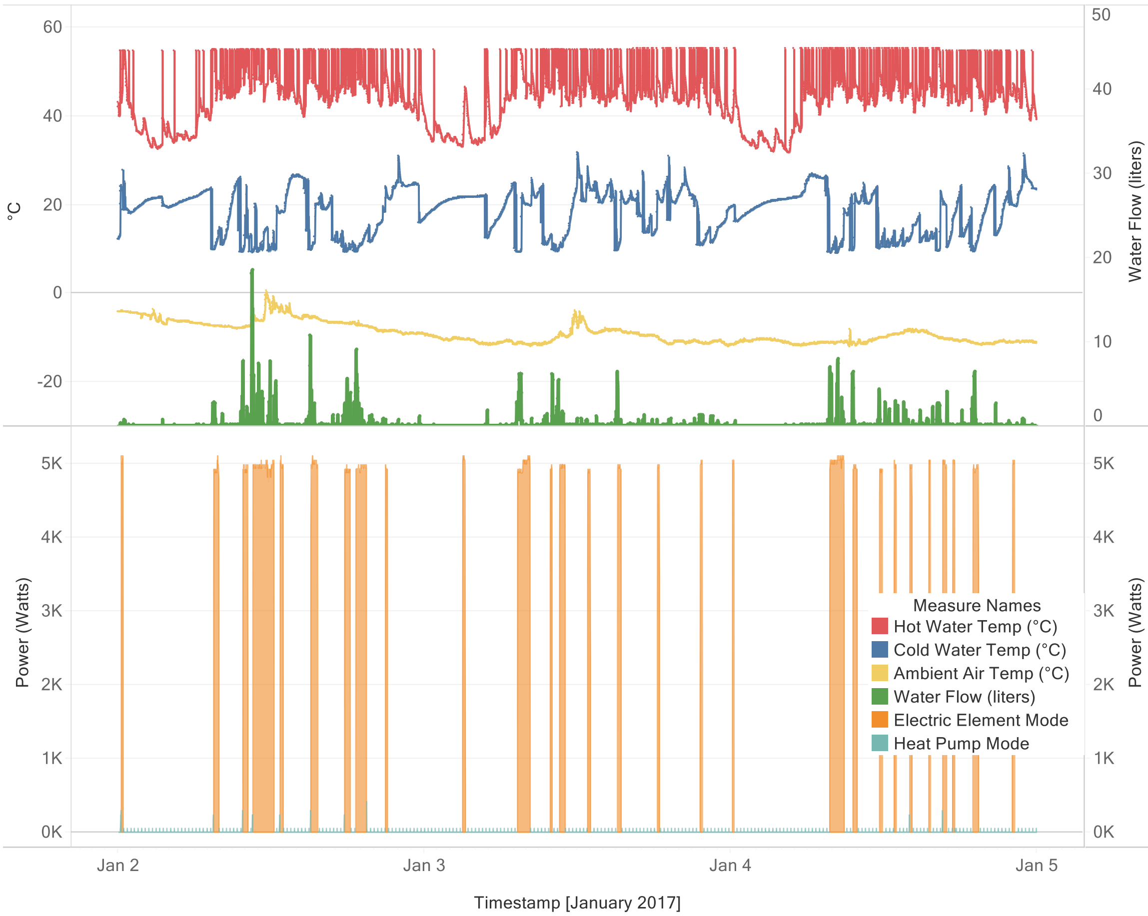
In November 2017, towards the end of the monitoring period, we unducted the Kelowna Site 4 unit to measure the impacts of using tempered basement air during the cold Kelowna winter. Figure 52 compares the ducted and unducted performance from the first winter of the study (ducted) and the second winter (unducted). Expectedly, even though the average outside air temperature was similar from one year to the next, the unducted unit performed better than the ducted unit due to the basement temperature remaining warmer during the cold winter. We did not calculate the interactive space heating effects that occur when using the unducted method as a part of this study. Additionally, an unducted unit would take a penalty during the summer months when the basement remained cooler than outside air.

Figure 52: Kelowna Site 4 Monthly Ducted and Unducted COP



Looking at the same 3-day period shown before in Figure 49 of Kelowna Site 3 (January 2nd to January 5th), there is a much different picture. Figure 53 shows that during the same period, the unit runs entirely in electric resistance mode during water heating with numerous water draws over 15 litres in a minute (4 gallons). The resulting COP over this period was 0.76 compared with 2.0 at Kelowna Site 3.

Figure 53: Kelowna Site 4 – Water and Power Trend - 3 Day Period



Estimated Energy Savings:

Table 41: Kelowna Site 4 Energy Savings

Site	aCOP	Water Heating Load Delivered kWh/day [kBtu/day]	Annual Baseline Energy (kWh)	Annual Rheem Energy (kWh)	Annual Energy Savings (kWh)	% Savings
Kelowna Site 4	1.50	10 [36]	4,421	2,541	1,880	43%

Estimated Time and Cost of Installation:

Table 42 below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

Table 42: Kelowna Site 4 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$2,452	$2,452
Electrical	N/A	$0	$0	$0
Plumbing	8.3	$905	$494	$1,465
Ducting & Insulation	4	$523	$223	$746
Total	**12.3**	**$1,428**	**$3,169**	**$4,662**

Installation Notes:

- Took out 285-litre (75.3-gallon) electric water heater
- Put in 303-litre (80-gallon) integrated water heater
- Inlet ducting: 2x rigid metal 8" elbows (insulated) and 18.5' of 8" flexible insulated ducting, 8" to 6" reducer (insulated), 6" termination vent
- Outlet ducting:18' of 8" flexible insulatled ducting, 8" to 6" reducer (insulated), 6" termination vent
- Static pressure from inlet to outlet of 0.18 "w.c., 950 fpm
- Water heater parameters also being monitored remotely by Rheem

Issues/Updates:

- 12/16/16 - Water Meter Replaced, meter output of 20 pulses per gallon, replaced at ~15:00
- 2/4/2017 – 2/28/2017 – Missed connections until router was reset
- 7/27/2017 – Pulse adapter for water meter stopped working
- 11/1/2017 – Removed ducting to outside air; changed setpoint from 140°F to 132°F
- 1/15/2018 – 1/29/2018 – Modem switched out again; 14 days of missing data

Equivalent Duct Length	Max Allowable
76.5 feet	125 feet

Figure 54: Kelowna Site 4 Installed Photos

11.3 Vancouver Island Site 1 (Rheem)

Observed data:

Vancouver Island Site 1 is equipped with a 246-litre (65-gallon) Rheem unit and performed with a COP of 1.76 over a 113-day Winter period with an average ambient temperature of 9.5°C (49°F) and 195 litres per day (52 gallons per day). In June of 2017 the tenant moved out of the residence and was unresponsive to our requests. Because of this, no data was collected and this site has 113 days of data.

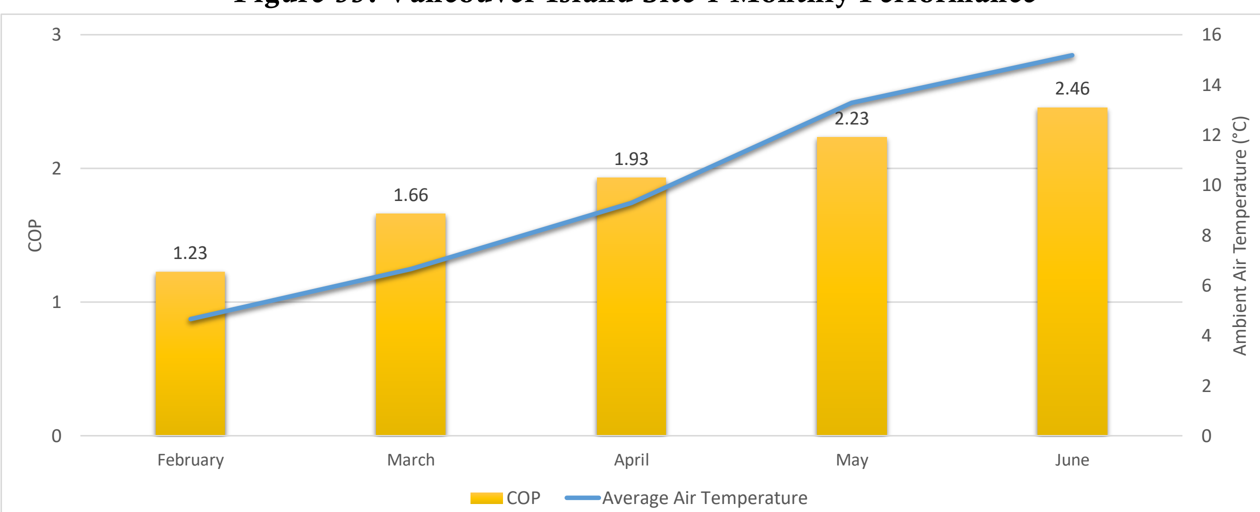
Table 43: Vancouver Island Site 1 Summary

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
V. Island Site 1	Rheem	246-L [65-gal]	2/15/17	6/8/17	113

Table 44: Vancouver Island Site 1 Variables

Site	aCOP	Average Ambient Air Temp	Average Water Flow	Average Hot Water Temp (°F)	Average Inlet Water Temp (°F)
V. Island Site 1	**1.76**	9.5°C [49°F]	195 LPD [52 GPD]	49.4°C [121°F]	10.3°C [51°F]

Figure 55: Vancouver Island Site 1 Monthly Performance



Estimated Energy Savings:

Table 45: Vancouver Island Site 1 Energy Savings

Site	aCOP	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Rheem Energy (kWh)	Energy Savings (kWh)	% Savings
V. Island Site 1	1.76	12 [39]	4,749	2,382	2,267	50%

Estimated Time and Cost of Installation:

The table below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

Table 46: Vancouver Island Site 1 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$2,129	$2,129
Electrical	N/A	$0	$0	$0
Plumbing	5.7	$562	$496	$1,106
Ducting & Insulation	4	$506	$162	$668
Total	**9.7**	**$1,068**	**$2,787**	**$3,903**

Installation Notes:

- Took out 175-litre (46.2-gallon) electric water heater
- Put in 246-litre (65-gallon) integrated water heater
- Inlet ducting: 5' of 8" flexible insulated ducting, 1x rigid metal 8" elbow (insulated), and 8" to 6" reducer (insulated), 6" termination vent
- Outlet ducting: 1x rigid metal 8" elbow (insulated), 5' of 8" flexible insulated ducting, 8" to 6" reducer (insulated), 6" termination vent

Equivalent Duct Length	Max Allowable
50 feet	125 feet

Figure 56: Vancouver Island Site 1 Installed Photos

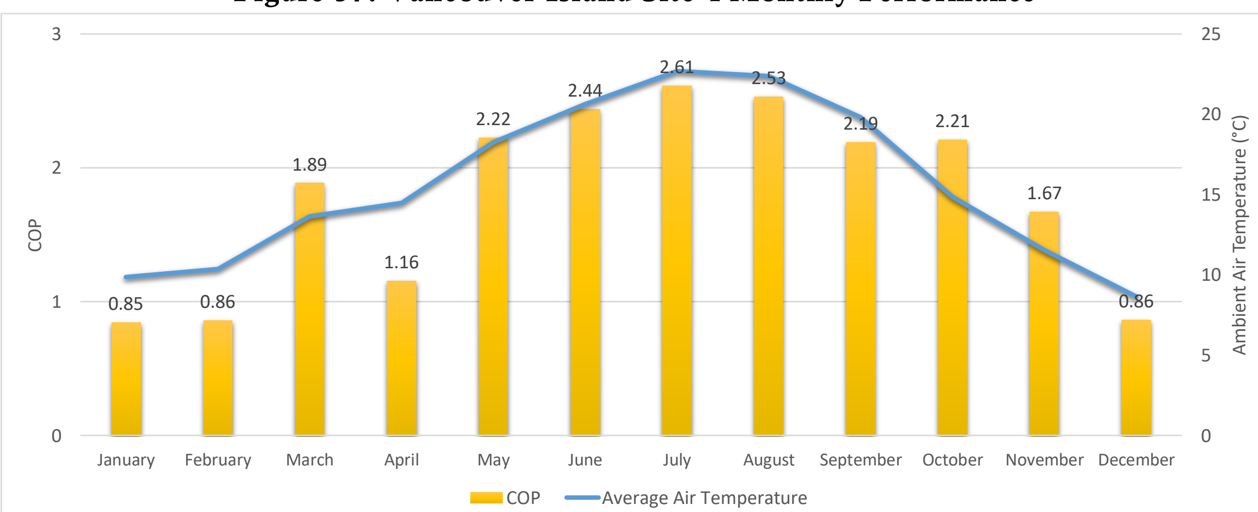
11.4 Vancouver Island Site 4 (Rheem)

Vancouver Island Site 4 is a 246-L (65 gallon) integrated Rheem unit that performed with an aCOP of 1.73 over 324-day monitoring period with an average ambient air temperature of 16.2°C (61°F) and a daily water draw of 65 litres (17 gallons). The residents of this site went on holiday for 22 days in April of 2017. During this time, there was no water draw and hence no useful work done by the hot water heater. The heat pump still ran to maintain hot water temperature negatively impacting performance.

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
V. Island Site 4	Rheem	246-L [65-gal]	3/30/17	4/5/17	324

Site	aCOP	Average Ambient Air Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
V. Island Site 4	**1.73**	16.2°C [61°F]	65 LPD [17 GPD]	48°C [119°F]	16°C [61°F]

Figure 57: Vancouver Island Site 4 Monthly Performance



<u>Estimated Energy Savings:</u>

Table 47: Vancouver Island Site 4 Energy Savings

Site	aCOP	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Rheem Energy (kWh)	Energy Savings (kWh)	% Savings
V. Island Site 4	1.73	2 [8]	1,019	522	497	49%

Estimated Time and Cost of Installation:

Table 48 below shows the estimated time and cost of the installation for this site broken down by activity. The costs are based on typical skilled labor costs.

Table 48: Vancouver Island Site 4 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$2,129	$2,129
Electrical	N/A	$0	$0	$0
Plumbing	5.6	$551	$475	$1,073
Ducting & Insulation	5	$633	$171	$803
Total	**10.6**	**$1,184**	**$2,774**	**$4,005**

Installation Notes:

- Took out 246-litre (48-gallon) electric water heater
- Put in 65-gallon integrated water heater
- Inlet ducting: 4.5' of 8" flexible insulated ducting, 1x rigid metal 8" elbow (insulated), and 8" to 6" reducer (insulated), 6" termination vent
- Outlet ducting: 6' of 8" flexible insulated ducting, 2x rigid metal 8" elbows (insulated), and 8" to 6" reducer (insulated), 6" termination vent

Updates:

- 2/2/2017 First power meter installed
- 2/15/2017 Second power meter installed, good data collected breifly before ceasing output
- 2/27/2017 Second power meter reinstalled
- 4/6/2017 – 4/28/2017 Residents on holiday; 22 days of no water draw

Equivalent Duct Length	Max Allowable
55.5 feet	125 feet

Figure 58: Vancouver Island Site 4 Installed Photos

11.5 Vancouver Island Site 5 (Rheem)

Observed data:

The Vancouver Island Site 5 unit is a 246-litre (65-gallon) Rheem water heater that has performed with a COP of 2.06 over a 363-day period with an average garage temperature of 16.7°C (62°F) and 279 litres per day (74 gallons per day) of average water draw. This unit was installed in the garage and saw slightly warmer ambient temperatures and better annual performance than the other Vancouver Island sites.

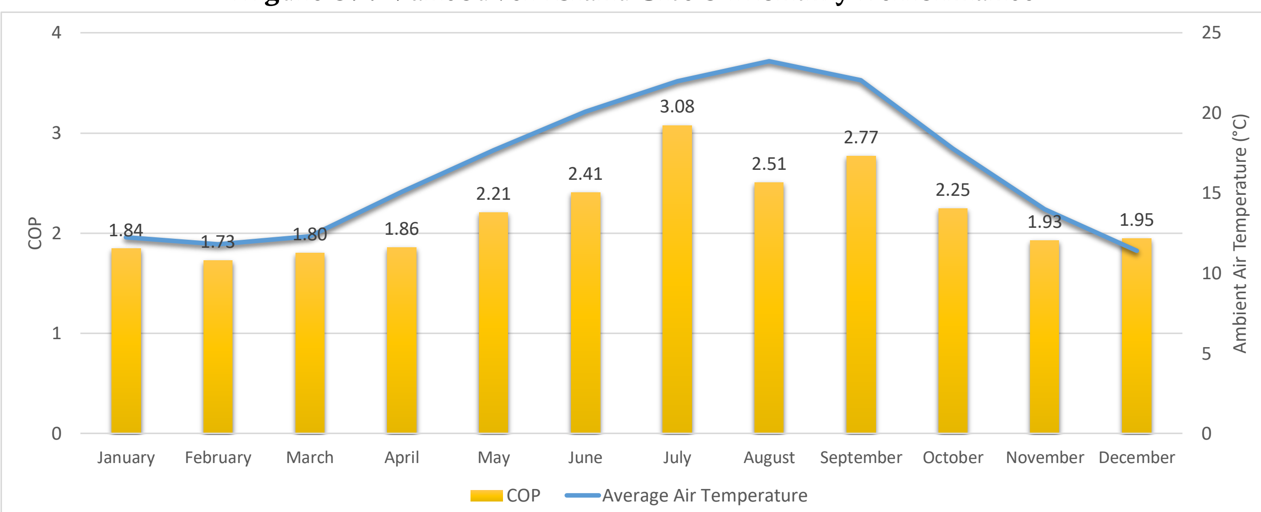
Table 49: Vancouver Island Site 5 Summary

Site	Unit Type	Tank Size	Beginning Date	Ending Date	Days of Monitoring Period
V. Island Site 5	Rheem	246-L [65-gal]	2/17/17	2/15/18	363

Table 50: Vancouver Island Site 5 Variables

Site	aCOP	Average Garage Air Temp	Average Water Flow	Average Hot Water Temp	Average Inlet Water Temp
V. Island Site 5	**2.06**	16.7°C[31] [62°F]	279 LPD [74 GPD]	49.7°C [121°F]	13.5°C [56°F]

Figure 59: Vancouver Island Site 5 Monthly Performance



[31] The Vancouver Island Site 5 unit is unducted and uses garage air as the heat source until outdoor air starts replacing the garage air after extended heat pump operation.

Estimated Energy Savings:

Table 51: Vancouver Island Site 5 Energy Savings

Site	aCOP	Water Heating Load Delivered kWh/day [kBtu/day]	Calculated Baseline Energy (kWh)	Rheem Energy (kWh)	Energy Savings (kWh)	% Savings
V. Island Site 5	2.06	12 [40]	4,884	2,093	2,791	57%

Estimated Time and Cost of Installation:

Table 52 below shows the estimated time and cost of the installation for the site broken down by activity. The costs are based on typical skilled labor costs.

Table 52: Vancouver Island Site 5 Installation Costs

Service	Labor Hours	Labor Cost (CAD)	Material Cost (CAD)	Total with Taxes and Permit (CAD)
Equipment	-	-	$2,129	$2,129
Electrical	N/A	$0	$0	$0
Plumbing	6.0	$588	$518	$1,157
Ducting & Insulation	3	$380	$119	$498
Total	**9.0**	**$968**	**$2,766**	**$3,784**

Installation Notes:

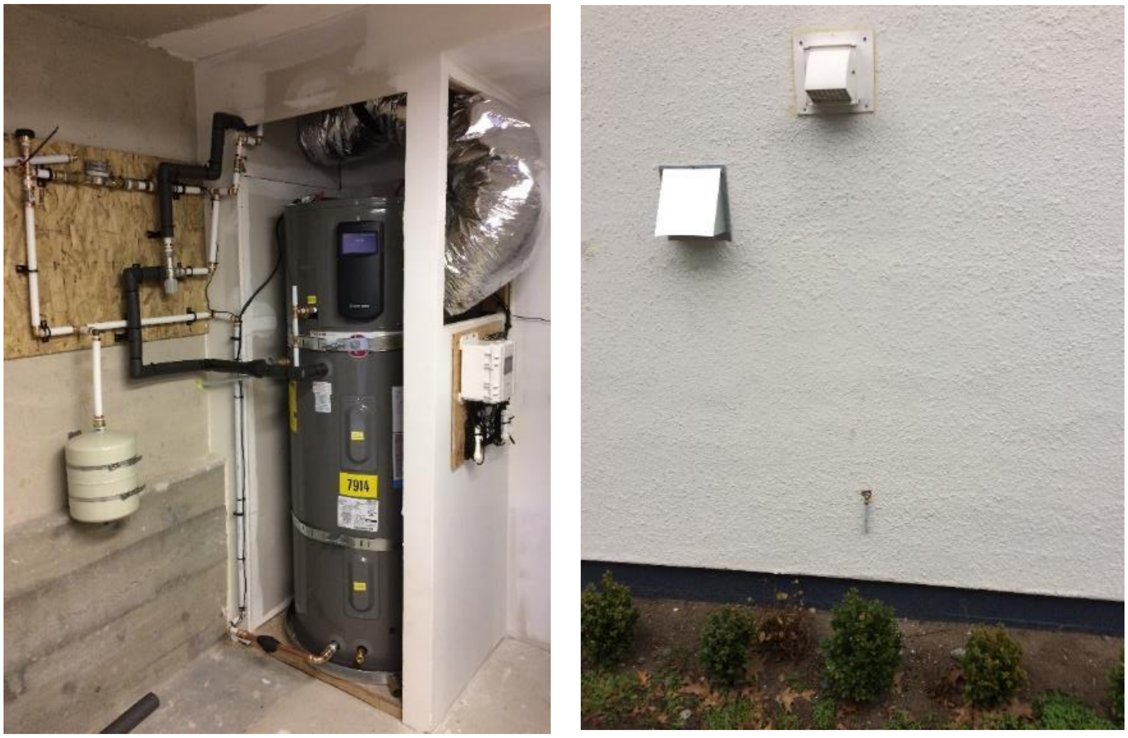
- Took out 184-L (48.6-gal) electric water heater
- Put in 246-L (65-gal) hybrid water heater
- Inlet ducting: None, taking in garage air. Walls seperating house and garage are insulated
- Outlet ducting: 5' of 8" flexible insulated ducting, 1x rigid metal 8" elbow (insulated), and 8" to 6" reducer (insulated), 6" termination vent

Issues/Updates:

- 2/15/2017 Second power meter installed roughly 18:00
- 5/22/2017 Logger did not connect for 3 days; modem resest and forced logger connection
- 7/31/2017 Logger would not connect for 2 weeks
- 10/29/2017 Data logger stopped working again for 3 days

Equivalent Duct Length	Max Allowable
31 feet	125 feet

Figure 60: Vancouver Island Site 5 Installed Photos



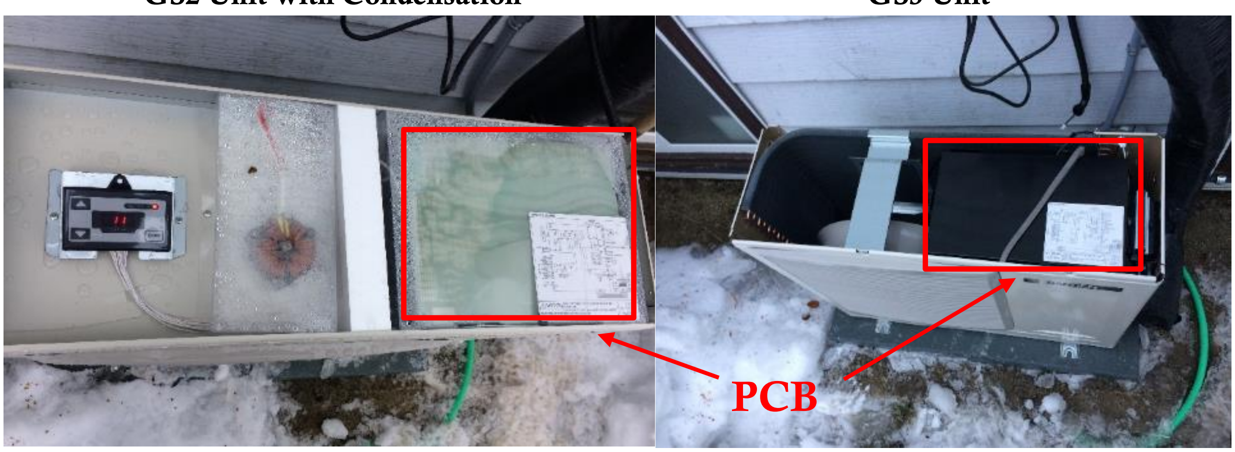
12. Issues Identified

We have identified two prominent issues with the Sanden outdoor unit and its installation process. The first issue became apparent during installation and the second became apparent after some operational time in the field.

Electrical installation costs for the Sanden unit could be kept down, if not cut in half, if the Sanden outdoor unit included an on-board electrical connection for the heat trace. The Sanden installations for this study required installation of a separate dedicated circuit for the heat trace. This is code compliant since the heat trace is considered a "heating appliance". One way around having to install the separate dedicated circuit for the heat trace while remaining code compliant is to have the Sanden outdoor unit control the operation of the heat trace. An added benefit of having the heat trace operation controlled by the Sanden outdoor unit is that the heat trace can be turned off while the unit is running. Heat trace used in this study is 110 VAC, but 220 VAC heat trace is also available.

The Sanden outdoor unit has a compartment above the fan and compressor sections. Contained inside this upper compartment is the display panel and printed circuit board (PCB). There is a small punch out from the manufacturing process which allows water vapor to travel from the fan section to the upper compartment, where it condenses. This condensation builds up on the PCB and is assumed to be the cause of two Sanden outdoor unit failures. The outdoor unit failure sequence starts with the PCB shorting-out, the water inside the outdoor unit freezing since the unit cannot turn on, followed by fracture of the plastic pump components. Upon being thawed out, the outdoor unit leaks from the fracture site. This issue is relevant with the GS2 series of outdoor unit. The GS3 series has rearranged the internal components and removed the upper compartment. The PCB in the GS3 is now contained inside a plastic compartment, but this compartment is in full contact with the air in the fan section. There has not been any recognizable issue with the GS3 outdoor unit.

GS2 Unit with Condensation | **GS3 Unit**



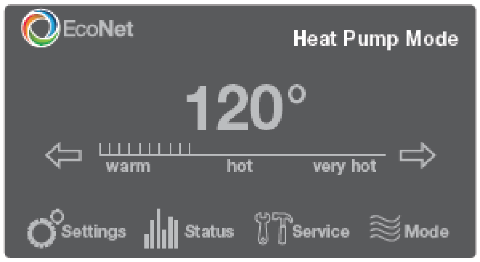
13. Conclusion

This field demonstration has shown encouraging results for heat pump water heating even in cold climates. Below are some conclusions from the study.

- The Sanden units are able to deliver hot water without backup electric elements even in the coldest weather of the cold mountain climate of Rossland, BC.
- With both the split and integrated technologies, it is possible to use heat pump technology for water heating without the heating penalty historically associated with heat pump water heating.
- The need to run an additional electric circuit for heat trace for the Sanden unit adds a meaningful cost to the installation. It seems reasonable that the Sanden unit could provide power for heat trace from the outdoor unit. Additionally, this would allow for built in thermostatic control of the heat trace, which would improve overall energy use.
- The heat trace on the Sanden unit plumbing creates a meaningful COP penalty, though COPs even with heat trace were quite impressive. More temperate locations may consider not installing heat trace.
- The COP penalty of ducting integrated units may not be as meaningful as previously thought. With an average annual COP of 1.8 with the ducted units, we see that the winter COP penalty from the ductwork is countered by the summertime benefit of warmer inlet air. Since this study did not include a control group of unducted integrated units, there remains some uncertainty of the impact of the ductwork on COP. However, based on the positive performance we've seen with the ducted units, we believe the COP impact of the ductwork to be modest.
- The Rheem units, as well as many other heat pump water heaters come "Demand Response ready". Hot water tanks have significant stored energy and can coast several hours through a DR event even in high draw homes while still delivering hot water. This stored energy, combined with a low incremental cost for DR communications make heat pump water heaters a promising DR resource. While these attributes make a strong case for heat pump water heaters to be used as a DR resource, one must consider that the act of installing a heat pump water heater provides a significant permanent demand reduction, leaving only a modest DR potential per home. Based on our limited dataset, we estimate the DR potential to be approximately 0.15-0.2 kW per home. When considering heat pump water heaters as a DR resource, one should evaluate the cost of the enabling technology and program administration relative to the value of the resource.

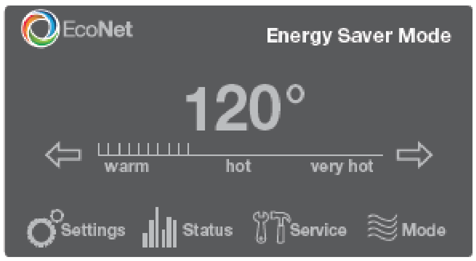
14. Appendix

Rheem Operating Modes:



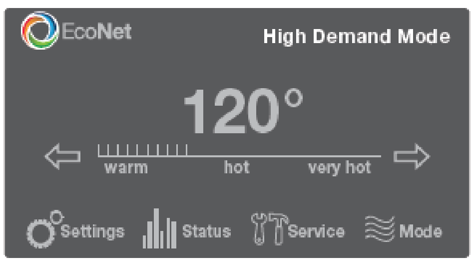
Heat Pump

This mode will heat with Heat Pump operation and will not use electric heat during typical heating and demand cycles. This mode has a low recovery, but minimizes power consumption.



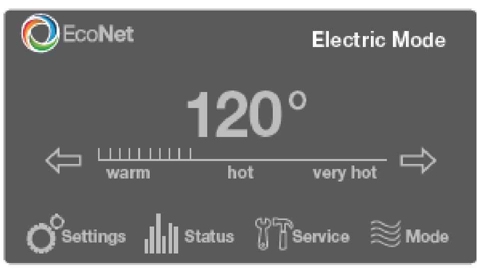
Energy Saver - Factory set mode for shipping.

This mode optimizes Heat Pump and electric heat that results in low power consumption and High recovery.



High Demand

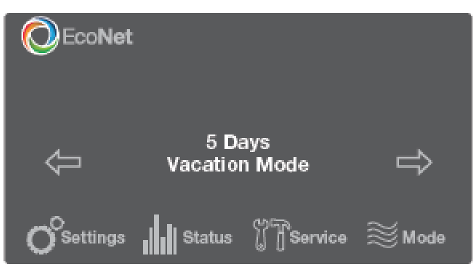
This mode provides the highest recovery while still providing good energy savings. Water heater operates Heat Pump and electric heat simultaneously.



Electric

This Mode will heat with the electric resistance elements. This mode should only be used during filter and condensate drain maintenance periods. This mode will result in maximum power consumption.

(See "Elec. Heat Override Time" in Settings).



Vacation

This mode will allow duration setting between 1 and 28 days or set indefinitely with the "Hold" setting. Tank temperature will be maintained at about 65° F.

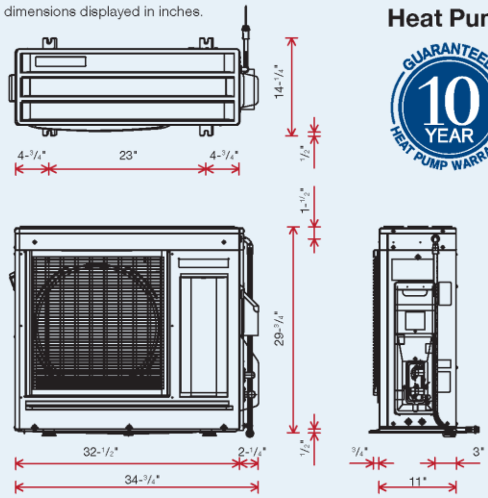
Second Generation (GS2) Sanden Specifications:

SANCO2 Specifications

All dimensions displayed in inches.

Heat Pump

GUARANTEED 10 YEAR HEAT PUMP WARRANTY

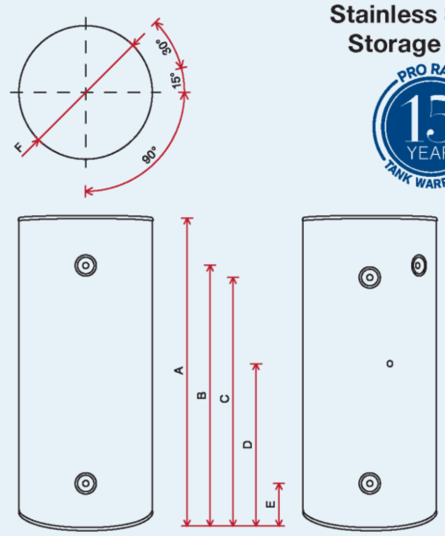


Outdoor Unit (Heat Pump) Model No. GUS-A45HPA

Performance	With 43-gal.	With 83-gal.
Energy Factor	3.5	3.4
First Hour Rating	66 gallons	97 gallons
Specifications		
Water Temperature Setting	149°F	
Ambient Air Operating Temperature	-15°F to +110°F	
Heat Pump Capacity	15,400 Btu/h	
Heat Pump Capacity	4.5 kW	
Heat Pump COP	4.5	
Refrigerant Type	R744 (CO_2)	
Compressor Type	Inverter	
Power Voltage	208/230v –1Ph – 60Hz	
Breaker Size	15 Amps	
MCA	7.7 Amps	
Outdoor Operating Noise Level	38 dB	
Weight	123 lbs	
Pipe Size (Tank to Heat Pump)	1/2" (Cold & Hot)	
Max Length Inc Vertical	25 ft	
Max Vertical Separation	10 ft	
Max Water Pressure	95 Psig	

Stainless Steel Storage Tank

PRO RATA 15 YEAR TANK WARRANTY



	Tank Model No:	GAUS-160QTA	GAUS-315EQTD
A	Height	47-1/4"	58-5/8"
B	Hot Water Outlet & PR Valve	37-3/8"	49-5/8"
C	Heat Pump Return	37-3/8"	49-5/8"
D	Sensor Port	17-1/8"	37"
E	Cold Water Inlet / Cold Water to HP	8-1/4"	7-7/8"
F	Diameter	22-1/2"	26-3/4"
	Weight (lbs)	88 lbs	154 lbs
	Tank Capacity (gallons)	43 gallons	83 gallons
	Connection Sizes		
	Cold Water Inlet	3/4" NPT	3/4" NPT
	Hot Water Outlet	3/4" NPT	3/4" NPT
	Cold Water to Heat Pump	1/2" NPT	1/2" NPT
	Hot Water Return from Heat Pump	1/2" NPT	1/2" NPT
	Pressure Relief Valve Setting (Psig)	125 Psig	125 Psig

Note: Materials and specifications are subject to change without notice.

REV 0616

C INTERTEK ETL LISTED US

For more information, please call **1-844-SANDCO2** or email **info@sandenwaterheater.com**.

SANDEN
Delivering Excellence

Sanden International (U.S.A.) Inc.
47772 Halyard Drive, Plymouth, MI 48170

Phone: 1-844-726-3262 or 1-844-SANDCO2
Email: info@sandenwaterheater.com
Website: www.sandenwaterheater.com

Sanden Dealer

Third Generation (GS3) Sanden Specifications:

SANDEN
Delivering Excellence

SUBMITTAL : GS3-A45HPA
Split Heat Pump Water Heater

SAN CO_2

Job Name	Location
Purchaser	Engineer
Submitted to	Reference ☐ Approval ☐ Construction ☐
Unit Designation	Schedule #

Specifications	GS3-A45HPA
Performance	
Energy Factor - 43 Gal System	3.09
First Hour Rating - 43 Gal System	71 Gallons
Energy Factor - 83 Gal System	3.84
First Hour Rating - 83 Gal System	101 Gallons
Nom Heating Capacity (Btu/h)	15,400 Btu/h
Nom Heating Capacity (kw)	4.5kw
Heating COP	5.0
Water Temperature Setting	130 to 175 DegF
Refrigerant Type	R744 (CO_2)
Refrigerant Charge (Oz)	22oz
Power Voltage	208/230v-1Ph-60Hz
Breaker Size	15A
MCA (Amps)	13.0A
Compressor RLA/LRA (Amps)	7.5/9.8A
Fan Motor RLA/Watts	0.3A / 70W
Pump RLA/Watts	0.2A / 30W
Noise Level (DbA)	37
Weight (lbs)	106lbs
Storage Tank	
GAUS-160QQTA/SAN-43SSAQA	43 Gallons
GAUS-315EQTD/SAN-83SSAQA	83 Gallons
Tank Connection Sizes	
Cold Water Inlet	3/4" NPT
Hot Water Outlet	3/4" NPT
Cold Water to Heat Pump	3/4" NPT
Hot Water Return from Heat Pump	3/4" NPT
Press Relief Valve Setting	125 Psig
Pipe Size - Tank to Heat Pump	
Size	1/2" & 1/2"
Max Pipe Length inc	50ft
Max Vertical Separation of	16ft
Certifications	
Safety	ETL & ETLc
Performance	AHRI
ARI Certification reference #	TBA
Warranty - System	3 Years Labor
Heat Pump	10 Years Parts
Tank	15Yrs Limited Lifetime

Construction
The Outdoor unit shall be galvanized steel with a with a baked on powder coated finish for durability

Heat Exchangers
Evaporator coil shall be mechanically bonded Aluminum fin to copper tube. Fins shall be coated to resist corrosion
The Refrigerant to Water HX (Gas Cooler) shall be a Double Wall co-axial type pressure tested to 6000 psi

Refrigerant System
Compressor shall be a hermetically sealed DC Inverter drive Scroll
Refrigerant shall be R744 (CO_2).
Refrigerant flow shall be controlled by Electronic Expansion Valve

Fan & Motor
The outdoor unit fan shall be a propeller type, driven by a BLDC Motor

Water Pump
The pump shall be a BLDC Impellor type

Controls
The unit shall be operated using a temperature sensor mounted in the Storage tank
Control wiring shall require 16AWG shielded wire
Unit operating range shall be -20 DegF to 104 DegF

Storage Tank
Storage tank shall be constructed from a blend of 316/444 Stainless Steel with R12 Insulation
Storage Tank connections shall be NPT
Storage Tank capacities shall be 43 Gallons and 83 Gallons

Interconnect Piping
Interconnect Piping shall be 1/2" soft copper or where permitted 1/2" PEX tubing
Both Cold and Hot piping should be insulated with 1" closed cell foam and where required Heat Trace used

Sanden International (USA) 47772 Halyard Drive, Plymouth MI 48170, Tel : 1-844 SAND CO2 (1-844 726 3262)
www.sandenwaterheater.com

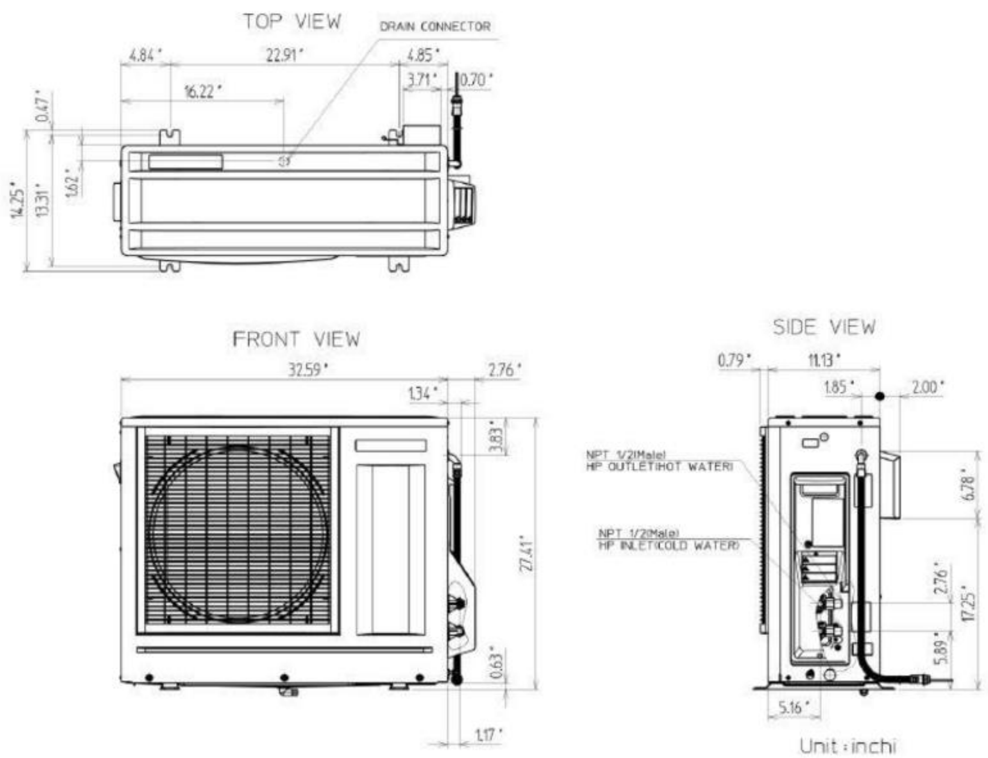
Due to Sanden's policy of on-going product development specifications are subject to change without notice **SUB-SAN-GS3-0217**

SUBMITTAL : GS3-A45HPA

Split Heat Pump Water Heater

Job Name	Location
Purchaser	Engineer
Submitted to	Reference ☐ Approval ☐ Construction ☐
Unit Designation	Schedule #

GS3-45HPA Dimensions



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SUB-SAN-GS3-0217

SANDEN Delivering Excellence

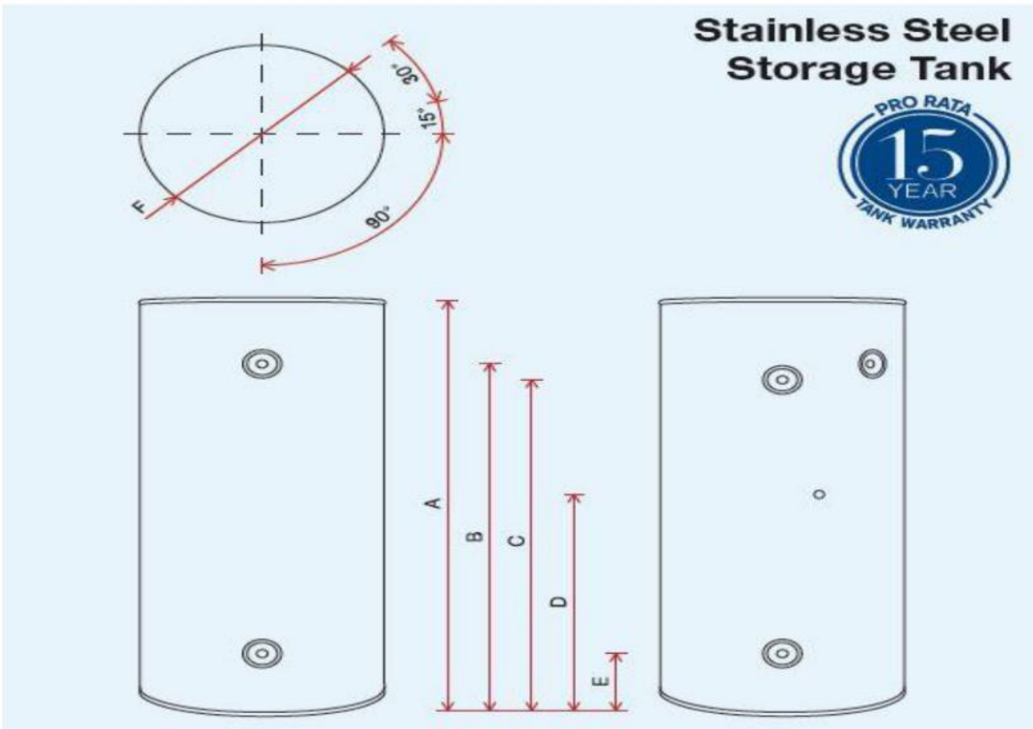
SUBMITTAL : GS3-A45HPA

Split Heat Pump Water Heater

SANCO2

Job Name	Location
Purchaser	Engineer
Submitted to	Reference ☐ Approval ☐ Construction ☐
Unit Designation	Schedule #

Stainless Steel Storage Tank Dimensions



	Tank Model No:	GAUS-160QTA	GAUS-315EQTD	SAN-43SSAQA	SAN-83SSAQA
A	Height	47-1/4"	58-5/8"	38-1/8"	68-7/8"
B	Hot Water Outlet & PR Valve	37-3/8"	49-5/8"	29-1/2"	60-1/4"
C	Heat Pump Return	37-3/8"	49-5/8"	29-1/2"	60-1/4"
D	Sensor Port	17-1/8"	37"	9-3/4"	40 3/8"
E	Cold Water Inlet / Cold Water to HP	8-1/4"	7-7/8"	8-3/4"	8-3/4"
F	Diameter	22-1/2"	26-3/4"	24-1/2"	24-1/2"
	Weight (lbs)	88 lbs	154 lbs	88 lbs	115 lbs
	Tank Capacity (gallons)	43 gallons	83 gallons	43 gallons	83 gallons

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Rheem Specifications:

Rheem

The new degree of comfort.™

Water | Residential Electric
Professional *Prestige*
Hybrid Water Heaters

Professional *Prestige*® Hybrid Heat Pump 3.5 is the most efficient water heater available - with up to $4,000 in lifetime savings and less than 2 year payback*

Efficiency

- High 3.50 EF reduces operating cost $404 annually compared to a standard 50-gallon electric model
- ENERGY STAR® rated

Performance

- Delivers hot water faster than most standard electric water heaters – 70 gallons first-hour delivery for 50-gallon model, 78 gallons FHD for 65-gallon model and 90 gallons FHD for 80-gallon model
- Ambient operating range: 37-145° F is widest in class, offering more days of HP operation annually; designed to meet Northern Climate Spec (Tier 3)

Easy Installation

- Easy access side connections
- Quick access to electrical junction box
- Easily replaces a standard electric water heater

Integration

- LCD Screen with built-in water sensor alert with audible alarm

EcoNet™

- EcoNet™ WiFi-connected[†] technology and free mobile app gives users control over water systems, allowing for customizable temperature, vacation settings, energy savings and system monitoring at home or away. Visit Rheem.com/EcoNetConnect
- Water sensor detects water outside of the unit and sends an alert via the free Rheem EcoNet™ mobile app to the homeowner

Operation Modes

- Energy Saver
- Heat Pump
- High Demand
- Electric
- Vacation: 2-28 days (or placed on hold indefinitely)

Plus...

- Premium grade anode rod with resistor extends the life of the tank
- 3/4" NPT water inlet and outlet; 3/4" condensate drain connections
- Incoloy stainless steel resistor elements
- Dry-fire protection
- Easy access, top mounted washable air filter
- 2" Non-CFC foam insulation
- Enhanced flow brass drain valve
- Temperature and pressure relief valve installed
- Low lead compliant

Accessories

- Earthquake Kit part number SP20882, sold separately
- Vibration Isolation Kit part number SP20883, sold separately

Warranty

- 10-Year limited tank and parts warranty
  See Residential Warranty Certificate for complete information

Units meet or exceed ANSI requirements and have been tested according to D.O.E. procedures. Units meet or exceed the energy efficiency requirements of NAECA, ASHRAE standard 90, ICC Code and all state energy efficiency performance criteria.

*Based on comparison of a 50-gallon Rheem *Prestige* Series Hybrid Heat Pump Water Heater with a 3.50EF and a 50-gallon standard residential electric water heater with a .95EF.
[†] WiFi broadband internet connection required.

Professional *Prestige* Hybrid
50, 65 and 80-Gallon Capacities
208-240 Volt / 1 PH / 24 Amps
Electric

LEED Points = 3

See specifications chart on back.

INTEGRATED HOME COMFORT

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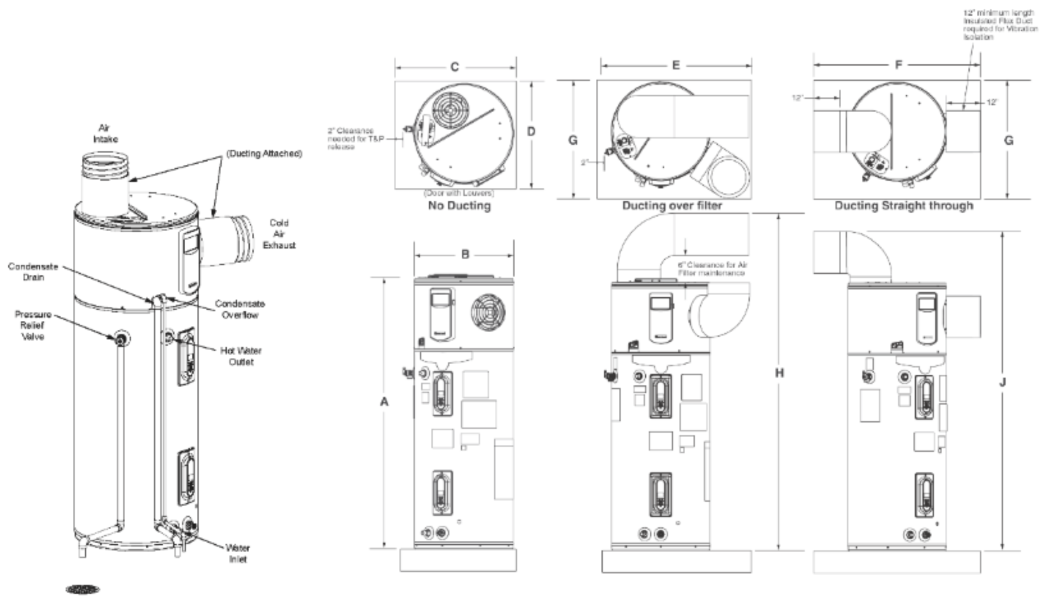
The new degree of comfort.™

Water | Residential Electric
Professional *Prestige*
Hybrid Water Heaters

Professional *Prestige*® Hybrid Specifications

DESCRIPTION			FEATURES				ROUGHING IN DIMENSIONS (SHOWN IN INCHES)				ENERGY INFO.	
TYPE	GAL. CAP.	MODEL NUMBER	COMPRESSOR BTU/H	SOUND LEVEL (dBa)	FIRST HOUR RATING G.P.H.	RECOVERY IN G.P.H. 90° F RISE	HEIGHT A	DIAMETER B	UNIT WT. (LBS)	APPROX. SHIP WT. (LBS)	ENERGY SAVER	ESTIMATED YEARLY ENERGY COST
Tall	50	PROPH50 T2 RH350	4200	49	70	29	61	22-1/4	178	218	3.50 EF	$151
Tall	65	PROPH65 T2 RH350	4200	49	78	29	64	24-1/4	225	262	3.50 EF	$151
Tall	80	PROPH80 T2 RH350	4200	49	90	29	74	24-1/4	244	281	3.50 EF	$151

Estimated energy cost based on a national average electricity cost of 12.00 /kWh. Energy Factor determined by U.S. Department of Energy (DOE) test procedures.



DESCRIPTION		DIMENSIONS (SHOWN IN INCHES)								
GAL. CAP.	MODEL NUMBER	A	B	C	D	E	F	G	H	J
50	PROPH50 T2 RH350	61	22-1/4	28	24	36	50	27	77	73
65	PROPH65 T2 RH350	64	24-1/4	30	26	38	52	29	80	76
80	PROPH80 T2 RH350	74	24-1/4	30	26	38	52	29	90	86

In keeping with its policy of continuous progress and product improvement, Rheem reserves the right to make changes without notice.

Rheem Water Heating • 101 Bell Road
Montgomery, Alabama 36117-4305 • 1.800.621.5622

Rheem Canada Ltd./Ltée • 125 Edgeware Road, Unit 1
Brampton, Ontario L6Y 0P5 • 1.800.268.6966

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The costs shown in Table 53 show the baseline costs used to calculate the incremental cost to install a Sanden or Rheem unit. We used the average plumbing labor costs and Taxes & Permit costs for the Rheem units to estimate the baseline costs. Each Sanden and Rheem unit was compared to a similarly sized electric resistance water heater.

Table 53: Estimated Standard Electric Resistance Water Heater Costs

Tank Size (gal)	Equip Cost	Labor Cost	Taxes & Permit	Total Cost (USD)	Total Cost (CAD)	Notes
83	$899	$1,275	$59	$2,174	$2,806	Based on A.O. Smith 80-Gallon Price at Lowes.com
80	$899	$1,275	$59	$2,174	$2,806	Based on A.O. Smith 80-Gallon Price at Lowes.com
65	$603	$1,275	$59	$1,878	$2,424	Based on Rheem Performance Plus 60 Gallon Price at www.homedepot.ca Victoria, BC
43	$428	$1,275	$59	$1,703	$2,198	Based on Rheem Performance Plus 40 Gallon Price at www.homedepot.ca Victoria, BC