Heat Pump Water Heater Performance Results
Purpose of Field Trial:

To test the performance of cold climate heat pump water heaters and to quantify the value of their widespread adoption in British Columbia.
Project Overview

- Installed (7) Sanden CO₂ HPWHs and (5) Rheem integrated HPWHs
- Test sites include a range of climates from cold mountain climate of Rossland, BC to temperate coastal climate of Vancouver Island, BC
- Field test was approximately one year
- Three Rheem units were fully ducted
- One Rheem units was partially ducted (outlet only) in semi-conditioned garage; one was unducted in conditioned basement

7/18/2018
Technology Overview

Sanden CO₂ HPWH
- “Split System”
- CO₂ as Refrigerant
- -29°C to 60°C Rated Operation
- High Performance Cold Climate Unit
- Tier 3 Advanced WH Spec, 3.84 EF, 3.3 UEF<sub>NC</sub>

Rheem Integrated HPWH
- Integrated Unit
- R134A Refrigerant
- 2.8°C to 62.8°C Rated Operation
- High Performance Direct Replacement
- Tier 3 Advanced WH Spec, 3.5 EF, 3.4 UEF<sub>NC</sub>
Installation Locations

Location: **Vancouver Island, BC**
- Units Tested: 2 Sanden, 3 Rheem
- Avg Air Temp: 13.1°C
- HDD < 18°C: 2,700
- Sanden aCOP: 2.75
- Rheem aCOP: 1.85

Location: **Kelowna, BC**
- Units Tested: 2 Sanden, 2 Rheem
- Avg Air Temp: 8.1°C
- HDD < 18°C: 3,400
- Sanden aCOP: 2.74
- Ducted Rheem aCOP: 1.62

Location: **Rossland, BC**
- Units Tested: 3 Sanden
- Avg Air Temp: 4.1°C
- HDD < 18°C: 4,600
- Sanden aCOP: 2.61
Performance Definition

Coefficient of Performance (COP) = \frac{\text{Useful Work Done}}{\text{Required Energy Input}}

\[ COP = \frac{\sum \text{Heat Load Delivered (Btu)}}{\sum \text{Energy In (kWh)}} \times \frac{kWh}{3,412 \text{ Btu}} \]

\[ COP = \frac{700,000 \text{ Btu}}{120 \text{ kWh}} \times \frac{kWh}{3,412 \text{ Btu}} = 1.71 \]

\[ \alpha COP = \text{Average Annual Coefficient of Performance} \]
## Performance Results

### Sanden Performance

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

### Rheem Performance

<table>
<thead>
<tr>
<th>Site</th>
<th>aCOP</th>
<th>Tank Size (Litres)</th>
<th>Climate Zone</th>
<th>HDD Below 18°C</th>
<th>Average Ambient Temp (°C)</th>
<th>Average Water Flow (L/Day)</th>
<th>Average Hot Water Temp (°C)</th>
<th>Average Inlet Water Temp (°C)</th>
<th>Months of Data</th>
</tr>
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<tbody>
<tr>
<td>Kelowna Site 4</td>
<td>1.62</td>
<td>303</td>
<td>5</td>
<td>3,400</td>
<td>9.8</td>
<td>324</td>
<td>50.8</td>
<td>14.4</td>
<td>8</td>
</tr>
<tr>
<td>V. Island Site 1</td>
<td>1.76</td>
<td>246</td>
<td>4</td>
<td>2,700</td>
<td>9.5</td>
<td>195</td>
<td>49.4</td>
<td>10.3</td>
<td>4</td>
</tr>
<tr>
<td>V. Island Site 4</td>
<td>1.73</td>
<td>246</td>
<td>4</td>
<td>2,700</td>
<td>16.2</td>
<td>65</td>
<td>48.3</td>
<td>16.0</td>
<td>11</td>
</tr>
<tr>
<td>V. Island Site 5</td>
<td>2.06</td>
<td>246</td>
<td>4</td>
<td>2,700</td>
<td>16.7</td>
<td>279</td>
<td>49.7</td>
<td>13.5</td>
<td>12</td>
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<tr>
<td>Average</td>
<td>1.79</td>
<td>260</td>
<td>4.3</td>
<td>2,875</td>
<td>13.0</td>
<td>216</td>
<td>49.6</td>
<td>13.6</td>
<td>9</td>
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</tbody>
</table>

| Kelowna Site 3  | 2.08 | 303               | N/A          | N/A             | 20.6                      | 175                        | 51.4                        | 10.5                          | 15             |
Both units perform very well at warmer outside air temperatures; Sanden excels at low ambient temperatures.
Even in colder climate of Kelowna at high water using Site 4, electric element ran only 5% of total hours, while heat pump ran 38%.
COP vs. Daily Water Draw

Sanden: high water usage = high COP (regardless of outside air temperature)

Rheem: performance flattens out at higher draws (or even drops at colder temperatures)
# Energy Savings Summary

## Sanden

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

## Rheem

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

| Kelowna Site 3   | 2.08 | 8 [27]                                                   | 3,333                       | 1,387                      | 1,947                     | 58%       | 15             |
Installation Cost and Complexity

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Installation Complexity</th>
<th>Dedicated Electrical Circuit?</th>
<th>Electrical Permit Required?</th>
<th>Average Installation Labor Hours</th>
<th>Average Installation Cost (CAD)</th>
<th>Average Incremental Cost (CAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanden</td>
<td>Higher</td>
<td>Required</td>
<td>Yes</td>
<td>21.3</td>
<td>$8,588</td>
<td>$5,955</td>
</tr>
<tr>
<td>Rheem</td>
<td>Lower</td>
<td>Not Required</td>
<td>Not Typically</td>
<td>10.5</td>
<td>$4,135</td>
<td>$1,558</td>
</tr>
</tbody>
</table>

Sanden installation is more complex and total installation cost is double the Rheem.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Electrician Labor</th>
<th>Plumber Labor</th>
<th>Freeze Protection /Ducting</th>
<th>Total Labor Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanden</td>
<td>7.0</td>
<td>12.3</td>
<td>2.0</td>
<td>21.3</td>
</tr>
<tr>
<td>Rheem</td>
<td>0.0</td>
<td>7.1</td>
<td>3.4</td>
<td>10.5</td>
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</table>
### Sanden

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
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<th></th>
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<th></th>
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<tbody>
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<td>$127</td>
<td>$375</td>
<td>$806</td>
<td>$1,450</td>
<td>$160</td>
<td>$229</td>
<td>$5,560</td>
<td>$221</td>
<td>$8,929</td>
<td></td>
<td>$2,806</td>
<td>$6,122</td>
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<td>$143</td>
<td>$450</td>
<td>$806</td>
<td>$1,450</td>
<td>$151</td>
<td>$229</td>
<td>$5,560</td>
<td>$227</td>
<td>$9,016</td>
<td></td>
<td>$2,806</td>
<td>$6,209</td>
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<td>$152</td>
<td>$450</td>
<td>$806</td>
<td>$1,450</td>
<td>$146</td>
<td>$229</td>
<td>$5,560</td>
<td>$228</td>
<td>$9,021</td>
<td></td>
<td>$2,806</td>
<td>$6,215</td>
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<td>$179</td>
<td>$383</td>
<td>$593</td>
<td>$1,424</td>
<td>$187</td>
<td>$261</td>
<td>$5,360</td>
<td>$208</td>
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<td>$598</td>
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<td>$261</td>
<td>$5,360</td>
<td>$222</td>
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<td>$6,066</td>
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<td>$608</td>
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<td>$2,633</td>
<td>$5,955</td>
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### Rheem

<table>
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<th></th>
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<td>$2,806</td>
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<td>$494</td>
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<td>$2,452</td>
<td>$65</td>
<td>$4,662</td>
<td></td>
<td>$2,806</td>
<td>$1,856</td>
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<td>$633</td>
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<td>$4,005</td>
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<td>$518</td>
<td>$588</td>
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<td>$380</td>
<td>$2,129</td>
<td>$51</td>
<td>$3,784</td>
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<tr>
<td>Average</td>
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<td>$0</td>
<td>$496</td>
<td>$779</td>
<td>$135</td>
<td>$408</td>
<td>$2,258</td>
<td>$59</td>
<td>$4,135</td>
<td></td>
<td>$2,577</td>
<td>$1,558</td>
</tr>
</tbody>
</table>
Sanden Installed Outdoor Unit & Monitoring

- Heat Trace Power & Thermostat
- Power Supply Disconnect (220V, 15 amp)
- "Whip" from disconnect to outdoor unit
- Outdoor air temperature sensor
- Plumbing & thermocouple between outdoor unit & tank (plumbing is heat traced)

Sanden requires dedicated electrical circuit to power heat trace (for freeze protection) as well as a power supply disconnect run by electrician.
Heat Trace still uses power in warmer weather

- Self regulating heat trace resistance (and associated heat and energy use) vary with temperature, using less energy in warmer weather. However…
Heat Trace has Meaningful Impact on Sanden Performance

- Heat trace decreased COP by 14.4% during our monitoring period.
- We believe heat trace is unnecessary in coastal climates as well as the population centers of the I5 corridor (Vancouver Island sites for example).
Challenges & Issues Identified
Ducting Rheem Units Adds Complexity/Cost & Limits Application
Ducted Vs. Unducted Rheem Units

Kelowna Site 3

- Unducted in conditioned basement
- Average annual room temperature: 20.6°C
- aCOP: 2.08

Kelowna Site 4

- Ducted inlet and outlet
- Average inlet (outside) air temperature: 9.8°C
- aCOP: 1.79
- Average ducting Labor & Material: $679

Ducting Rheem units to eliminate interactive effects with heating system does not appear to significantly penalize the performance on an annual basis. However, it does impact installation cost, complexity, and limit to fewer applications.
Excellent application is a semi-conditioned space (like garage or basement) which gets small performance boost, cost reduction, and avoids most (or all) of interactive effects by avoiding some or all of ducting.
Vancouver Island Site 5: Semi-Conditioned Garage Unit

- Nearly same performance as unducted Kelowna Site 3
- Least expensive total cost
Cold Climate Issue with Sanden Units

- 2 of the 2nd generation Sanden units installed in Rossland failed.
- Water vapor entered upper section of outdoor unit condensing on unit controls
- The 3rd generation units are much better configured to protect electronics from moisture.
Ideas for Improvements for Sanden Unit

• We had to run two electrical circuits, one for the Sanden unit and one for the heat trace. It would be helpful if the heat trace could be powered by the Sanden unit. This would also allow for a built-in thermostat to minimize heat trace losses in warmer weather.

• It’s difficult to insulate the connection point between the plumbing and outdoor unit. These fittings could come factory insulated. We feel confident installers won’t insulate this connection.
After Rossland Site 2 unit failure, occupants continued to draw hot water for over 40 hours before noticing the unit had failed.
Demand Response Potential

• Both Sanden and Rheem units provide more than enough thermal storage to maintain HW temperature for a four-hour DR event

• Rheem comes standard with EcoNet® interface which according to manufacturer is “future-compatible with demand-response system”
Pros/Cons of Sanden Unit

Pros

➢ Very high efficiency
  ➢ Without heating element, real world efficiency is closer to lab rated efficiency.

➢ Interactive effect with heating is eliminated

➢ Low global warming potential refrigerant
  ➢ GWP of CO2 = 1, R-134a = 1,430)

Cons

➢ Requires heat trace in colder climates

➢ There’s a risk of freezing in colder climates (power outage or unit failure)

➢ Installation complexity

➢ Cost remains high
Rheem unit observations

- All of the Rheem units have worked very well
- The unit comes “duct ready”
- All HPWHs have designed their system to the DOE tests. As such, none of the EF/UEF ratings reflect any electric element use, and real world efficiency is lower than rated efficiency. However, this generation of Rheem unit has really minimized the amount the element comes on in “Energy Saver” mode.
- Cost is competitive with other integrated HPWHs
Both technologies have shown impressive real world performance
  - Sanden as high-performance cold-climate unit
  - Rheem as drop-in replacement for electric WH with significantly improved performance
We see an economic barrier with the Sanden unit. For this to be widely viable, some combination of the following is required:
  - Reduced cost
  - Focus on high DHW users such as multifamily and nursing for improved economics
  - Combination unit to include space heating (current maximum return temp is 75F, so this is not currently possible)
Garage or “semi-conditioned” application for integrated HPWHs with unducted intake and ducted exhaust appears to show improved efficiency over fully ducted units.
Rheem has done a great job on the controls with this product to minimize the disconnect between real world efficiency and lab rated efficiency.
With wi-fi enabled options becoming available and significant thermal storage, HPWHs are a strong candidate for Demand Response
Thank You
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 manually with the “Hold” setting. Tank temperature will be maintained at about 65°F.
Impact on Peak System Demand

➢ 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 Demand Response resource, which can allow the hot water heater to be interrupted for several hours without the loss of delivered hot water.
On average the peak Rheem unit heat pump operation in the field trial avoided the coldest hours of the morning.
Monthly Performance

Sanden

Rheem

7/18/2018
Rheem Operating Modes by Energy Consumption (kWh)

V. Island Site 1
- Element, 341, 59%
- Heat Pump, 233, 41%
Avg. Outside Air Temp: 9.5C, aCOP: 1.76

V. Island Site 5
- Element, 1,247, 59%
- Heat Pump, 859, 41%
Avg. Outside Air Temp: 16.7C, aCOP: 2.06

Kelowna Site 3
- Heat Pump, 1,321, 73%
- Element, 495, 27%
Avg. Room Temp: 20.6C, aCOP: 2.08

Kelowna Site 4
- Heat Pump, 840, 32%
- Element, 1,793, 68%
Avg. Outside Air Temp: 15.9C, aCOP: 1.62
Baseline Cost Assumptions

The baseline costs used to calculate the incremental install costs were based on the average plumbing labor costs and Taxes and Permit costs for the Rheem units. For equipment cost, each unit was compared to a similarly sized electric resistance water heater.

<table>
<thead>
<tr>
<th>Tank Size (gal)</th>
<th>Equip Cost</th>
<th>Labor Cost</th>
<th>Taxes &amp; Permit</th>
<th>Total Cost (USD)</th>
<th>Total Cost (CAD)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>83</td>
<td>$899</td>
<td>$1,275</td>
<td>$59</td>
<td>$2,174</td>
<td>$2,806</td>
<td>Based on A.O. Smith 80-Gallon Price at Lowes.com</td>
</tr>
<tr>
<td>80</td>
<td>$899</td>
<td>$1,275</td>
<td>$59</td>
<td>$2,174</td>
<td>$2,806</td>
<td>Based on A.O. Smith 80-Gallon Price at Lowes.com</td>
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<tr>
<td>65</td>
<td>$603</td>
<td>$1,275</td>
<td>$59</td>
<td>$1,878</td>
<td>$2,424</td>
<td>Based on Rheem Performance Plus 60 Gallon Price at <a href="http://www.homedepot.ca">www.homedepot.ca</a> Victoria, BC</td>
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<tr>
<td>43</td>
<td>$428</td>
<td>$1,275</td>
<td>$59</td>
<td>$1,703</td>
<td>$2,198</td>
<td>Based on Rheem Performance Plus 40 Gallon Price at <a href="http://www.homedepot.ca">www.homedepot.ca</a> Victoria, BC</td>
</tr>
</tbody>
</table>
Sanden Installed Outdoor Unit & Monitoring

- Heat Trace Power & Thermostat
- Power Supply Disconnect (220V, 15 amp)
- “Whip” from disconnect to outdoor unit
- Outdoor air temperature sensor
- Plumbing & thermocouple between outdoor unit & tank (plumbing is heat traced)

Sanden requires dedicated electrical circuit to power heat trace (for freeze protection) as well as a power supply disconnect run by electrician.
Sanden Installed Tank & Monitoring

- Cold water inlet from well & inlet water temperature sensor
- Hot water to house & supply temperature sensor
- Cold water to outdoor unit (with isolation valve)
- Hot water from outdoor unit (with isolation valve)
- Pressure relief
- Thermocouple to control outdoor unit
Sanden Plumbing & Monitoring

- Cold water to tank
- Hot water from tank
- Flow meter
- Check valve
- Hot water supply to house
- Cold water from well
- Pressure reducing valve
- Mixing valve
- Pressure tank
  (homeowners equipment)
- Expansion tank

7/18/2018
Metering

Gateway for data collection, storage & communication via Wi-Fi (reads real time, collects data in 1 minute intervals & uploads to web every 4-hours)

Real Power Meter

Temperature sensors & flow meter relays

Computer for setup only

**Metering Points**

- Supply Temperature
- Inlet water temperature
- Inlet air temp (or outdoor air temp)
- Hot water flow
- Real Power
- Heat Trace Power for Sanden units