Ken Eklund

Building Science Team Leader – WSU

Ken was continually seeking the next steps in building efficiency based on his deep conviction to environmental action.

Ken was the point contact to all manufacturers in the first discussions to bring new split system CO2 refrigerant water heating to North America.
SANCO₂ Water Heater

• Split system HPWH, unique compared products currently sold

• 2 part system, either a 43 or 83 Gallon Stainless Steel or 119 Gallon Glass Lined storage tank coupled with a 4.5kw capacity Inverter Compressor Outdoor unit

• Why different? – Based on successful technology from a Global scale
<table>
<thead>
<tr>
<th>Utilities/Companies</th>
<th>Location / Year</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVA, Oak Ridge</td>
<td>Lab &amp; field testing, TN in 2012-13 (Residential)</td>
<td>Highest efficiency compared to Electric &amp; Solar water heaters in test homes over a 365 day period.</td>
</tr>
<tr>
<td></td>
<td>Field testing in North West (OR, WA, ID, MT) since 2013 (Residential)</td>
<td>Highest efficiency in cold climate. (3.2EF) Rebates available</td>
</tr>
<tr>
<td></td>
<td>Demand response testing in WA in 2014-2015 (Residential)</td>
<td>Demand response is feasible to defer electricity consumption during peak demand or store energy during periods of peak generation.</td>
</tr>
<tr>
<td></td>
<td>Field testing TN since 2016 (School cafeteria)</td>
<td>Annual average COP 3.0</td>
</tr>
<tr>
<td>Southern Company</td>
<td>Field test vs an Integrated HPWH in BC, Canada since 2016</td>
<td>SANCO₂ units delivered higher COP and efficiency vs Indoor installed R units despite SANCO₂ operating in very cold outdoor temperatures</td>
</tr>
<tr>
<td>BC Hydro, Power smart</td>
<td>Testing underway: NY State Field Testing California Lab &amp; Field Tests</td>
<td>SANCO₂ highest efficiency of all heat pump water heaters</td>
</tr>
</tbody>
</table>
Why use CO₂ Refrigerant?

Performance –
Refrigerant in the Transcritical Cycle is a gas with the density of a liquid, so high performance and high water temperatures are possible in very cold ambient temperatures

Environmental –
Minimal Global Warming, approx. 1/1500th compared to “normal” refrigerants
None ozone depleting, Safe & secure

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>ODP</th>
<th>GWP</th>
<th>Toxicity</th>
<th>Flammability</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fluorocarbon</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>refrigerant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R134a</td>
<td>0</td>
<td>1,430</td>
<td>No</td>
<td>No</td>
<td>Refrigeration &amp; HPWH</td>
</tr>
<tr>
<td>R410A</td>
<td>0</td>
<td>2,086</td>
<td>No</td>
<td>No</td>
<td>HP, AC &amp; HPWH</td>
</tr>
<tr>
<td>R407C</td>
<td>0</td>
<td>1,800</td>
<td>No</td>
<td>No</td>
<td>HP &amp; AC</td>
</tr>
<tr>
<td><strong>Natural</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>refrigerants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>0</td>
<td>1</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Propane Gas</td>
<td>0</td>
<td>20</td>
<td>No</td>
<td>Yes</td>
<td>Flammable</td>
</tr>
<tr>
<td>NH3 Ammonia</td>
<td>0</td>
<td>&lt;1</td>
<td>Yes</td>
<td>Yes</td>
<td>Plume Study required</td>
</tr>
</tbody>
</table>
GS3-45HPA performance (Test result in AP labo)

- Heat capacity (Outlet water temp setting 140°F)
- COP (Outlet water temp setting 140°F)
- COP (Outlet water temp setting 150°F)
- COP (Outlet water temp setting 160°F)
- COP (Outlet water temp setting 175°F)
- Inlet water temp

SANCO₂ can always make 160 DegF Hot Water (depending on set point) at all Outside Air temps

※ Heating capacity is constant irrespective of the Outlet water temp setting (However, excluding high Ambient temperature conditions)

ZERO Capacity loss at 5°F Ambient
COP (Power out/Power In) - Field test

Sanden unit was external
Hybrid unit was ducted
Intake & Return

<table>
<thead>
<tr>
<th>Gal per day</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gal</td>
<td></td>
</tr>
<tr>
<td>50 Gal</td>
<td></td>
</tr>
<tr>
<td>105 Gal</td>
<td></td>
</tr>
<tr>
<td>150 Gal</td>
<td></td>
</tr>
</tbody>
</table>
System Power Usage

This graph shows the unit in standard operation responding to the draw pattern & tank temperature

Energy use 5.05kw, operating time 5 hours, 139 Gallons
Cold Temperature Power Usage

Showing effect of Ambient temperature below freezing and a shut down period on power use

9.4kw total use over a 6 hours run time, no loss of HW performance
Demand Potential Power Usage

This graph shows the unit was shut off for 12 hours

Total Energy use 5.63 kw, no reduction in HW performance

Demonstrates that System can be operated in a Utility Demand Response program
System Component layout

OUTSIDE - INSIDE

User Set
130 to 175°F

2 x ½” Water Pipes
Power Supply
208/230V-1ph-60Hz

Outlet Water Temp.

Comp.
EVAP

inlet Water Temp.

Expansion valve

FA

N

Water Pump

1/2" NPT

Air purge valve.

Outlet Water Temp.

1/2" NPT

Air purge valve.

Pressure
Regulating Valve
95 Psi MAX

Mixing valve

130-176° F

130-176° F

120° F

Pressure Relief Valve
125 Psi MIN

1/2" NPT

3/4" NPT

3/4" NPT

1/2" NPT

3/4" NPT

PCB

208/230V-1ph-60Hz

Schematic & Sensors
Taco X – Pump Block
Wiring to the X Block

- Power – 115V

- Sensors provided with the X Block

- Depending on the application (# of zones etc) either a Taco SR relay or simply a zero volt open closed thermostat can turn on the X Block in a call for heating
Combi Heating Recap

• Radiant, Fan Coil and Low Temperature Radiators can be used to heat the space

• Only use the 83 Gallon or larger tank, important to keep the stratification of the tank to ensure highest COP

• Only use with HEAT LOADS < 8,000 Btu/h to ensure adequate cycle times on the Heat Pump OR add aux heat

• USE that DHW – more, more, more!!

• Follow piping diagram – Use Potable / Non Potable separation and standard installation practice
Notes:
Unions/Isolation Valves for all components not shown

Connect Tank Drain, PR Valve, Condensate Pipe to building drain per local codes

Install Check Valves on Heat Pump Hot return and Heating loop return to tank at a dimension of 3 pipe diameters from Tee

Size Fan Coil to ensure pump flow rate and capacity match output of the Heat Pump
SANDEN HEAT PUMP

NOTES:
Unions/Isolation Valves for all components not shown.
Connect Tank Drain & PR Valve to building drain per local codes.
Use with systems such as Fan Coil or Radiator where return water temp to Tank > 110°F.
Install Check Valves on Heat Pump Hot Return & X Block Return to tank, at a dimension of 3 pipe diameters from Tee.

Title: GS3-45HPA DHW & High Temperature Heating
Drg #: SIA-GS3-003  Drawn: JLM  4/21/2018  Rev: 00
Notes:
- Unions/Isolation Valves for all components not shown.
- Connect Tank Drain & PR Valve to building drain per local codes.
- Use with systems such as Radiant where return water temp to Tank < 90°F.
- Install Check Valves on Heat Pump Hot Return & X Block Return to tank, at a dimension of 3 pipe diameters from Tee.
• Depending on Heat Load look at a 3 or 4kw “instant” electric water heater – set temperature for 125°F, this way it only fires if outlet temperature falls due to higher heat or DHW loads – Relocate Protection sensor
Icing

One of the most significant lessons learned in the original trials was that the high return water temperature of combis would trick the outdoor unit into think that it’s summer.

You never need to run a defrost program in summer 😊

The G3 included a defrost program based on ambient temps.
Operation & Efficiency in Heating

Inlet water temperature (°F/C)

Elapsed time (hh:mm)

Heat capacity (kW) / Water flow rate (L/min)

Inlet water temperature
- Heat capacity
- Water flow rate
Operation & Efficiency in Heating

• Sanden units are weird
• The colder the water sent to the Heat Pump the higher our Capacity & Efficiency!!!
How CO$_2$ Heating Works (& why warm water is not helping)

Warm Water to Gas Cooler
Work done by the CO2 is reduced but the energy needed to heat the refrigerant is not
## 3 Combi Systems – Data comparison

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Grass Valley</th>
<th>Nevada City</th>
<th>Olympia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design T</td>
<td>19</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>Heating system</td>
<td>CO₂ Split</td>
<td>CO₂ Split</td>
<td>CO₂ Split</td>
</tr>
<tr>
<td>Distribution system</td>
<td>Air Handler</td>
<td>Air Handler</td>
<td>Radiant Panels</td>
</tr>
<tr>
<td>DHW T°F</td>
<td>143</td>
<td>121</td>
<td>120</td>
</tr>
<tr>
<td>Number of occupants</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Conditioned Floor Area</td>
<td>1,680</td>
<td>1,690</td>
<td>1,152</td>
</tr>
<tr>
<td>UA incl. Infiltration</td>
<td>407</td>
<td>210</td>
<td>281</td>
</tr>
<tr>
<td>Winter Design Temp °F</td>
<td>19.0</td>
<td>14.0</td>
<td>22.0</td>
</tr>
</tbody>
</table>
### Design Load and System Needs

<table>
<thead>
<tr>
<th>Location</th>
<th>Grass Valley</th>
<th>Nevada City</th>
<th>Olympia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set Point</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Design Temp.</td>
<td>19</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>$\Delta T$</td>
<td>51</td>
<td>56</td>
<td>48</td>
</tr>
<tr>
<td>UA + Infiltration</td>
<td>407</td>
<td>210</td>
<td>281</td>
</tr>
<tr>
<td>Design Load Btu/hr.</td>
<td>20,757</td>
<td>11,760</td>
<td>13,488</td>
</tr>
</tbody>
</table>

Auxiliary heat must be carefully designed to supplement the heat pump without harming its performance.
## Energy Measurements

<table>
<thead>
<tr>
<th>Season</th>
<th>HP (kWh)</th>
<th>Aux (kWh)</th>
<th>Pump &amp; Control (kWh)</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating</td>
<td>DHW</td>
<td>Heat</td>
<td>Non Heat</td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td>Non Heat</td>
<td>Heat</td>
<td>Non Heat</td>
</tr>
<tr>
<td>Olympia</td>
<td>521</td>
<td>49</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grass Valley</td>
<td>1,669</td>
<td>927</td>
<td>312</td>
<td>371</td>
</tr>
<tr>
<td>Nevada City</td>
<td>926</td>
<td>526</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Auxiliary Heat is only at Grass Valley
- The auxiliary system is an air to air Mini Split heat pump that was rarely used for backup heating in the winter
- The non heating season auxiliary use is mostly for air conditioning
• FEF – Field Energy Factor, simply put Energy out of Heat Pump/TOTAL Energy used by the system (fans, pumps, controls, etc.)
• Lowest Heating FEF correlates with highest return water temperature (Oly)
• Where DHW use drops, performance during Non Heating drops (Oly & NC)
• Largest daily water use correlates with highest FEF due to cold water (GV)
Comparison of Energy Used for Heating & DHW per Sq. Ft.
Based on Field Measured Data

<table>
<thead>
<tr>
<th></th>
<th>CO₂ Split System Combi, kWh/ft²</th>
<th>Air-to-Air Heat Pump (Mini Split) plus Tier 2 HPWH in Garage for DHW kWh/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olympia</td>
<td>2.4</td>
<td>5.2</td>
</tr>
<tr>
<td>Grass Valley</td>
<td>2.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Nevada City</td>
<td>1.4</td>
<td>4.1</td>
</tr>
</tbody>
</table>

- Space Heat Comparison from 2012 Residential Building Stock Assessment—Ecotope
- Heat Pump Water Heater Comparison from HPWH Model Validation Study—Ecotope
PHPP Modeling

How do we model a split system into the PHPP?

- We have the COP across ambient.
- We have independent tank loss data from Ken Eklund’s lab tests.
- Who can calculate???
Sanden G3 PHPP Input Data - DHW Sheet

**METRIC UNITS**

**DHW distribution**

- **Design forward flow temperature**: 60.0°C
- **Storage heat losses**:
  - **Heat loss rate**: W/K
  - **Storage volume**: litre
    - **W/K**: 2.1
    - **litre**: 315

Confirm tank temperature setpoint with designer/installer. Up to 77°C is possible.

**IP UNITS**

**DHW distribution**

- **Design forward flow temperature**: 140°F
- **Storage heat losses**:
  - **Heat loss rate**: BTU/hr ºF
  - **Storage volume**: gallons
    - **BTU/hr ºF**: 4.0
    - **gallons**: 83

Confirm tank temperature setpoint with designer/installer. Up to 170°F is possible.
Late 2016

On the market with a UL approved system.

Sales start with both DHW and Combi