PON 3127: Air-to-Water Heat Pump Demonstration Project

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Prepared for: NYSERDA
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Overview of project

Demonstrate use of air-to-water heat pump technology in NYS
- Identify sites & suitable technology
- Prepare design & cost estimates
- Support project through installation
- Monitor systems post-installation for performance & efficiency (Frontier)
Some notes about air-to-water heat pumps

Like air-to-air heat pumps, output capacity drops when outdoor air temperatures drop.

None of the currently available single phase (residential) models in the US can operate at return water temperatures above 130F

Highest efficiencies are achieved with lower return water temperatures, constant loads and limited cycling.
Demonstration Equipment

Air-to-water Heat Pump
15 different units investigated, two installed:
- Solstice Extreme (4 sites)
- Sanden SanCO2 (1 site)

Buffer Tank
- 40-80 gallons, varied by site
- Important design element

Controls
- System level controls needed
Some notes about air-to-water heat pumps

- Like air-to-air heat pumps, output capacity drops when outdoor air temperatures drop.
- None of the currently available single phase (residential) models in the US can operate at return water temperatures above 130°F.
- Highest efficiencies are achieved with lower return water temperatures, constant loads and limited cycling.

Why is a buffer tank needed?
Controls required to trigger backup heat source.
Some notes about air-to-water heat pumps

Like air-to-air heat pumps, output capacity drops when outdoor air temperatures drop. Currently available Air-to-Water Heat Pumps are not the same as a BOILER & NOT A DIRECT REPLACEMENT FOR A BOILER. None of the currently available single phase (residential) models in the US can operate at return water temperatures above 130°F. Highest efficiencies are achieved with lower return water temperatures, constant loads and limited cycling.

A buffer tank is needed for an air-to-water HP system. Required demonstration projects have a backup heat source.
Existing Mechanical System

(Located in garage)
Design Process

New Mechanical System

No changes were made within the apartments
Design
Process

Extensive design work

Significantly more involved than a 1-to-1 replacement
Control sequence

Existing Boiler Operation

Simultaneous ATW Heat Pump and Boiler Operation

New ATW Heat Pump Operation

As Shown on Drawings

Control Sequence:
Heat pump on its own controller:
HP controller maintains buffer tank temperature and cuts heat pump out if the return temperature is too high.
Boiler is on its own controller, with internal temperature sensor, but is enabled/disabled by ECO controller.
- Boiler controller is set to 165°F supply temperature.
- ECO controller has temperature sensor on secondary supply water, which is reset by outdoor air temperature.
- First stage of heat is the heat pump (enable).
- If the heat pump cannot maintain the setpoint the boiler is enabled (with delay). Boiler pump speed is high, roughly double the flow of the secondary loop.

Boiler Only

Boiler + HP

Active Systems

Supply Water Temperature – Ideal reset curve

Likely actual reset curve

HP Only

Supply Water Temperature – High heat curve

Minimal load

Building Load (kWh)

0F 5F 10F 15F 20F 25F 30F 35F 40F 45F 50F 55F 60F

(cold) Outdoor Air Temperature (hot)
That simple control sequence required:

- **Extensive energy modeling**
  - Load vs Temperature relationship not just peak load

- **Review of hydronic system output capacity**
  - Function of water temperatures, space load and flow rate

- **Multi-variable calculus** - solving for 273 points:
  - Temperature
  - Water Flow
  - Heat output

  → at 7 different locations in the system
  → at 13 outdoor temperatures & loads

- **Multiple visits to correctly program**
Observations & Lessons

Factors for Success
Measuring:

- Power inputs
- Heat outputs (flows & temperatures)
- Component status
- Other temps

Data Logger collects readings at 5-min intervals. Can determine delivered heating and efficiency.
Temperatures near freezing
Some boiler operation
5 defrost cycles
Calc COPs for:
- HP alone
- HP & tank
- HP, tank, Blr

WHP=88.12 kWh  WBE=13.04 kWh  WVP= 0.99 kWh  WP= 2.36 kWh

QHP=405.1 MBtu  COP_HP= 1.35  QT=394.7 MBtu  COP_T= 1.31  COP_ALL= 1.26

SP= 15.7 hrs  SZ1= 24.0 hrs  SZ2= 19.4 hrs
COPs depend on ambient temps (as expected)

- COP of system is lower than COP for HP device
Electric Use

- Boiler operation starts below about 30°F
- Heat pump energy decreases at low temps
Temperature Reset

Good control practice:
- tank temp is hottest when ambient is coldest
- tank is 140°F at 10°F, down to 80°F at 70°F
- Better COP, less losses
Expected COPs

- Actual COPs lower than manufacturers specification
- HP not rated according to a standard
- Defrost and other cycling issues may have an impact
### Annual Energy Use

#### Corrected HP COP = 1.48

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<tr>
<th>Month</th>
<th>Avg Outdoor Temp (F)</th>
<th>Heat Pump</th>
<th>Boiler</th>
<th>Pumps</th>
<th>Total (kWh)</th>
<th>HP Pump</th>
<th>Zone 1 Valve</th>
<th>Zone 2 Valve</th>
<th>Heat Pump</th>
<th>Fron Tank</th>
<th>Total (MBtu)</th>
<th>Heat Pump</th>
<th>HP &amp; Tank</th>
<th>Total (HP, tank, Blr)</th>
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**Annual**

- **Energy Use (kWh):** 16,043
- **Runtimes (hrs):** 4,736
- **Heat Output (MBtu):** 2,1065
- **COP:** 1.44
- **Total (HP, tank, Blr):** 93,161

**Energy Use (kWh)** 16,043  **Runtimes (hrs)** 4,736  **Heat Output (MBtu)** 2,1065  **COP** 1.44  **Total (HP, tank, Blr)** 93,161

76% 22% 1% 100%
Firetower Site
Design Process

Iterative Design

Sanden CO2 Heat Pump
A few Notes on the Sanden Unit

Popular Features:

▪ Uses CO2 as refrigerant
▪ Able to supply 170F water*
▪ Can be used for domestic water and space heating*
▪ Operates down to -15F*
▪ Max rated COP of 5.2*
Designed as a Domestic Hot Water (DHW) heater
- Return water never expected to exceed 100F
- Intermittent loads, allows for defrost cycles
- Low heat capacity, low flow rate, recharge the buffer tank

<table>
<thead>
<tr>
<th>Inlet Water Temp °F</th>
<th>Unit Capacity (kw) / Btu/h</th>
<th>Unit COP</th>
<th>Flow Rate (GPM)</th>
<th>Calculated dT (F)</th>
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<td>4.5 / 15,400</td>
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<td>0.32</td>
<td>96.3 F</td>
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<td>80</td>
<td>3.4 / 11,600</td>
<td>3.3</td>
<td>0.38</td>
<td>61.0 F</td>
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<td>100</td>
<td>3.0 / 10,200</td>
<td>2.7</td>
<td>0.45</td>
<td>45.3 F</td>
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<td>115</td>
<td>2.6 / 8,900</td>
<td>2.4</td>
<td>0.49</td>
<td>36.3 F</td>
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<td>120</td>
<td>2.4 / 8,100</td>
<td>2.0</td>
<td>0.58</td>
<td>27.9 F</td>
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</table>

Gen2 Data – Gen3 Product is + 5% in efficiency
Caveats:

Able to supply 170F water...
- Unable to run when return water exceeds 122F

Can be used for domestic water and space heating...
- Manufacturer requires any heating application be in combination with domestic water heating (minimum of 25 gallons per day!)
- Specific heat exchanger/pumps required to maintain warranty
- Potable water introduces additional requirements, complications
- For heating uses the 15,400 Btu/h capacity drops to 8,000 Btu/h

Operates down to -15F...
- Not approved for heating use at temperatures below 27F

Max rated COP of 5.2...
- At return water temperatures suitable for heating and lower outdoor temperatures the units rated COP is 2
Caveats:

Able to supply 170F water…
- Unable to run when return water exceeds 122F

Can be used for domestic water and space heating…
- Manufacturer requires any heating application be in combination with domestic water heating (minimum of 25 gallons per day!)
- Specific heat exchanger (Taco X-Block) required to maintain warranty
- Potable water introduces additional requirements, complications

Operates down to -15°F…
- Not approved for heating use at temperatures below 27°F

Max rated COP of 5.2…
- At return water temperatures suitable for heating and lower outdoor temperatures

DHW & Heating Combination

- Only use with HEAT LOADS < 8,000 Btu/h to ensure adequate cycle times on the Heat Pump

- Only use in climates with a design winter temperature (minimum expected coldest winter temperature of > 27°F

- DHW use is very important to maximize the energy in the tank. Minimum of 25 Gallons of DHW use is required daily

- Follow piping diagram – Use Potable / Non Potable separation and standard installation
Recommendations for Sanden Unit

When using for heating:

- Heat capacity less than rated due to defrost cycles
- Low flow rate:
  - Flow rate in distribution system usually much higher than flow rate through heat pump
  - Difficult but important to balance system
  - Practical limitation on water temperatures
- Make sure the required components can meet your needs
- Freeze Protection, Water Quality, Pressure Relief
Observations & Lessons

Factors for Success

- Involved and engaged owner
- Compatible existing systems
- Combination heating and domestic hot water approach
Monitoring at Firetower

Measuring:
- Power inputs (HP, Blrs)
- Heat Outputs
  - HP output
  - DHW output
  - Space Htg (inferred)
- Status & temps

Data at 1-minute intervals. Integrate Q’s at 1-sec scan.
Typical Day

- Cold day, unit runs continuously
- Power dips indicate defrost (frequent)
- Most heat goes to space heating
- QDHW is correct, FDHW is low
Typical Day (cont)

- HP Outlet is 165°F
- Delta-T is high, water flow is small
- Defrosts shown by “dips”

\[ \Delta T = 75 ^\circ F \]
Electric Use

- HP maxed out at about 20°F
- ASHP used as needed
- Boilers come on as Needed
Defrosts lower COP
Net COP for DHW

- Net COP depends on amount HW use (gal/day)
- COP for HP is 3+, but tank losses are 20 MBtu/day (not really “losses” in the winter)
Monthly Results

- HP COP is 1.5-1.9 in Winter
- HP COP is 3+ for water heating

<table>
<thead>
<tr>
<th>Month</th>
<th>Avg Outdoor Temp (F)</th>
<th>ASHP</th>
<th>Sanden HP</th>
<th>Boiler 1 DHW</th>
<th>Boiler 2 Space Ht</th>
<th>X-Block HX Pump (hrs)</th>
<th>Heat Pump</th>
<th>DHW</th>
<th>Heat Pump COP</th>
<th>HW Use (gal/day)</th>
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Observations & Lessons

Factors for Success

- Involved and engaged owner (HVAC professional)
- Optimally compatible heating system (high thermal mass, low temperature)
- High efficiency, low load site
- Continual adjustment and refinement
Measuring:
- Power inputs
- Heat output to radiant floor (flows & temperatures)
- Component status
- Other temps

Data Logger collects readings at 1-min intervals. BTU Meter at HP. Can determine delivered heating and efficiency.
Very Cold Day

- Below zero day
- Power dips indicate defrost (more than one per hour)
- COP is 1.5
- Tank element starts later in the day
- ASHP also comes on later in day
Cold Day (cont)

- Outlet temperature from HP is 100-110°F
- Space Temperature is unchanged
- Tank element starts later in the day
- Element stayed on for next 2 weeks
Energy Use

- HP energy use is very linear, up to Jan 21
- ASHP used for heating for first time.
HP COP

- HP COP is high at this site...before Jan 21
HP COP

- Tank & Solar Tank operation decreased HP COP
- 10°F higher return temperatures into HP hurts COP
- But delivered temperatures into floor are the same

Solar tank installed on Feb 7. New tank may have reduced DHW energy, but hurt HP COP
Steuben Valley Site
Observations & Lessons

Factors for Success

- Involved and engaged owner (HVAC professional)
- Compatible heating system
- High efficiency, low load site
- Continual adjustment and refinement
- Availability of at-cost materials to owner
Monitoring at Stuben Valley

Measuring:

- Power inputs
- Heat outputs (flows & temperatures)
- Component status
- Other temps
- Cooling operation

Data Logger collects readings at 1-min intervals. BTU Meters at HP and Tank. Can also determine delivered heating and efficiency.
- Unit cycles ON twice a day (with main loop pump)
- COP is about 1.5
- Very little heat injected into main loop
- HP Pump power 360 W
HP COP

- HP COP is above 1.5 at 20°F outdoors
- HP outlet water cycles from 110 to 130 °F
- Used Heat Pump Controls
- Very little heat injected into loop
- Most space heating provided by tank standby losses
Expected COPs

- Actual COPs below manufacturers specifications (again)
- Defrost and cycling are expected reasons (again)
Proposed System – 4088 Garrett Road

Controls Sequences (rough outline)
1) The existing control station (which receives heat demand signals from the various zone thermostats and relays them to the zone pumps, and makes a contact enabling the central heating system) will remain. The contact signaling demand will be routed to a new double pole relay. This relay will route the signal to either the existing boiler, or the new heat pump system based on a signal from a new outdoor thermostat (T-1, set to trigger the boiler on at temperatures below 59°F Adj.). The new boiler pump (P5) will be controlled by the boiler and runs only when the boiler is engaged.
2) The new heat pump will cycle on when a signal from the existing controller is received indicating one or more zones is in demand. The heat pump will send a run signal to pump P5, and pump P7. The heat pump and pumps will run for an additional 10 minutes after the last demand signal is received, or until the return water temperature entering the heat pump exceeds setpoint.
3) A new multi-pole relay will be installed to lock out the circulation pumps while the heat pump is in defrost mode (tied to the aux. heat output signal from the heat pump controller).
Observations & Lessons

Factors for Success

- Involved and engaged owner (HVAC professional)
- Owner-installed supplemental heat emitters
- Central wood heat (backup/supplement)
- Continual adjustment and refinement
Monitoring at Garret

Measuring:
- Power inputs
- HP Heat output (flows & temperatures)
- Component status
- Other temps

Data Logger collects readings at 1-min intervals. BTU Meter at HP. Can determine delivered heating and efficiency.
Cold Morning

- HP Turns off and Boiler Comes ON
Boiler cycles on/off to maintain 160°F supply temperature

- Baseboard temps go from 110°F to 150°F
Removing HX (Feb 23)

- HX caused short-cycling
- HP temps were higher with HX
- Better performance after HX removed:

\[ \text{WHP}=62.14 \text{ kWh} \]
\[ \text{WS1}=8.86 \text{ kWh} \]
\[ \text{WS2}=9.04 \text{ kWh} \]

\[ \text{QHP}=355.0 \text{ MBtu} \]
\[ \text{COP}_{\text{HP}}=1.7 \]
\[ \text{QDEF}=3.4 \text{ MBtu} \]
\[ \text{DEF}=5.0 \text{ min} \]
Removing HX (Feb 23)

- HP temps are lower
- Baseboard temps are higher
- Much less cycling
Conclusions

Frontier Results and Analysis
**Conclusions from Field Monitoring**

- Seasonal COPs are less than 2.0. Lower than expectations (manufacturers published data)
  - probably due to defrost and cycling losses
- Lower entering temperatures improve HP COP
  - best performance on radiant floor at Riders Mills (90-100°F at HP outlet)
Conclusions from Field Monitoring (cont)

- **Adding a Heat Exchanger (HX) may hurt performance**
  - increases HP temperatures
  - increases pump power (extra pump)
  - increases cycling if undersized (negates purpose of buffer tank)
- **“System-Level” control details matter**
  - use HP unit controls OR separate tank controller?
  - tank temperature reset controls help
  - warm weather shut down controls help / HP lockout when cold?
- **Tank placement is important**
  - will standby losses help space heating?
Conclusions

Taitem Observations and Recommendations
Barriers to Adoption

- Cost
- Reliability & Support
- Low Capacity & Operating Range
Observations

Cost and lack of Contractor experience greatest limitations

Some solutions for cost limitations:
- Target sites with many zones, no natural gas available
- Keep reasonable expectations – don’t design for peak loads
- Cost not the primary factor for many owners

Contractor lack of experience still a major hurdle
- Increasing customer interest will eventually drive service
Lessons Learned

Limited scope of installation

Used to supplement not replace existing systems

Experienced, early adopter owners
Key Demonstration Takeaways

- Not a boiler
- Technically viable option for some, but not all, sites
- Commercially available, but not yet fully mature
- Increasing customer interest
Systems may not be fully ready for mass adoption, but it is a rapidly expanding market.
New and Expected Air-to-Water Heat Pump Products

Mayekawa - Model: HWW-2HTC
• Water source heat pump that uses CO₂ as the refrigerant (NOT an air-to-water heat pump)

Nyle - Models: C25A, C60A, C90A, C125A, C185A, C250A
• Air-to-water heat pump series, available with single phase power option. Major concern is that operation is limited to ambient temperatures above 40F, limiting heating use in New York climates.

Colmac - Model: CxV Series
• Potentially promising air-to-water heat pump. Output appears to drop significantly below 10F.

Taco - Model: TBD
• New air-to-water heat pump expected to be released in 2020.

SpacePak - Model: TBD
• New air-to-water heat pump model expected to be released in Q3 or Q4 of 2019. SpacePak is the distributor of the Solstice Extreme.

Enertech - Model: TBD
• Split system style air-to-water heat pump expected to be released in 2020.
THANK YOU

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3127 Air-to-Water Heat Pump Demonstration Sites

Sapsucker Woods
Firetower
Riders Mills
Steuben Valley
Garrett