Hot Water Forum - 2019

Central Heat Pump Water Heating with 3 Case Studies

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Multifamily EUI
~(40 kBtu/ft^2/yr)

Goals:
• Reduce DHW EUI from 10 to 3 kBtu/sf/yr.
• Use Renewable Clean Grid Power to Heat DHW from 8 am to 4pm, coast through the rest of the day and night

1/3 to 1/2 of the DHW load is temperature maintenance

Half the Load is Thermal
Half is Process and Lights
Heat Pumps MOVE Heat

Central Heat Pump Water Heater Overview

- **EVAPORATOR**: 40°F
- **CONDENSOR**: 185°F
- **WATER HEATER**: 120°F
- **EXPANSION DEVICE**: -5°F
- **COMPRESSOR**: 30°F

**FLOW**:
- **ELECTRIC IN**
- **HEAT IN**
- **HEAT OUT**

**Temp Ranges**:
- 150°F-5°F (HEAT PUMP RANGE)
- 20°F-185°F (HEAT TRANSFER RANGE)
Refrigerant Types

**GWP OF SELECTED REFRIGERANTS**
(Carbon Dioxide Equivalents, CO$_2$e)

Refrigerants have 10% of the climate forcing impact of CO2 Emissions

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>GWP</th>
</tr>
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<tbody>
<tr>
<td>R-717</td>
<td>0</td>
</tr>
<tr>
<td>R-744</td>
<td>1</td>
</tr>
<tr>
<td>R-1270</td>
<td>2</td>
</tr>
<tr>
<td>R-290</td>
<td>3</td>
</tr>
<tr>
<td>R-600a</td>
<td>3</td>
</tr>
<tr>
<td>R-1234yf</td>
<td>4</td>
</tr>
<tr>
<td>R-1150</td>
<td>4</td>
</tr>
<tr>
<td>R-1234ze</td>
<td>6</td>
</tr>
<tr>
<td>R-170</td>
<td>6</td>
</tr>
<tr>
<td>R-152a</td>
<td>124</td>
</tr>
<tr>
<td>R-32</td>
<td>675</td>
</tr>
<tr>
<td>R-134a</td>
<td>1430</td>
</tr>
<tr>
<td>R-407C</td>
<td>1744</td>
</tr>
<tr>
<td>R-22</td>
<td>1810</td>
</tr>
<tr>
<td>R-410A</td>
<td>2088</td>
</tr>
<tr>
<td>R-125</td>
<td>3500</td>
</tr>
<tr>
<td>R-404A</td>
<td>3922</td>
</tr>
<tr>
<td>R-502</td>
<td>4657</td>
</tr>
<tr>
<td>R-12</td>
<td>10900</td>
</tr>
</tbody>
</table>

**Refrigerant Types**

- **CO2 Variable Capacity**: SANDEN, MAYEKAWA, MITSUBISHI *Eco-Cute*
- **Proposed HFO replacement refrigerant**
- **Fixed Capacity**: MOST HPWH’s COLMAC, AO SMITH
- **Variable Capacity**: PHNIX, ALTHERMA, VERSATI, VRF
- **Fixed Capacity**: COLMAC, AERMEC, NYLE
Two Different Loads in a Building,

Hot Water Load

- Hot water load, sized for morning and evening peak draws
- Typical design is small heat pumps and large storage
- Heat pump sized to make all the water needed in the determined amount of production time

Temperature Maintenance

- 24/7, 365 day load keeping lines hot
- Ranges from 50-400 Watts/apartment
- Recirculation load is hard to calculate accurately
- Dependent almost entirely on piping and plant UA and flow
- Since the load is continuous, the heat pumps need to be able to match the load, oversizing can be problematic
Single Pass
Heats up Water to working temp in single pass

Multi-Pass
Heats up water to working temp in multiple pass
**PROBLEM**
Recirculation return temps are too high and flowing too fast for single pass heat pumps and storage.
- Degrades system COP significantly
- Can destroy stratification
- Makes Load Shift Difficult

**SOLUTIONS**
Option 1. Primary Storage feeding Swing Storage
- Make 150°F water, Main storage feeds into swing tank.
- Add resistance coil to swing tank
- Single pass heat pump never sees recirc flow

Option 2. Dedicated TM Heat Pump Plant
- Primary plant is single-pass
- Secondary HWC plant is multi-pass
Variable Capacity (4) | PHNIX, ALTHERMA, VERSATI, VRF (Mitsu and LG)

Fixed Capacity (4) | COLMAC, NYLE, TRANE, CARRIER, MULTISTACK

R-410a Refrigerant Heat Pumps

- Colder Temperature range
- Designed for space heating, we use for DHW
- Inverter: -5F to 110F entering air
- Defrost Starts around 38F
- Water Temp – 120F possible
- Vapor injection technology can make 140F, COP hit.
- Requires additional double wall heat exchanger
- COP 2.5 in Seattle for DHW production
- Can do temp maintenance and water heating
- VRF Hydronic – COP 1.8-2.0 in Seattle for DHW
Mostly Fixed Capacity | Most Integrated HPWH ("hipwa"), COLMAC, AO SMITH, NYLE

R-134a Refrigerant Heat Pumps

- Warmer Air Temperature range
- Designed for DHW
- Constant Volume: 40F to 110F entering air
- Defrost Starts around 45F EA
- Water Temp – 130-160F possible
- Includes Double Wall Heat Exchanger
- Single Pass Water Heating in BG Garage- COP 2.7 Seattle
- Temperature Maintenance in BG Garage – COP 2.5 Seattle
- Available as Single or Multi-pass
- Temperature maintenance with single
- Available with communicating controls
**CO₂ Variable Capacity**
SANDEN (1.25 Ton)

**R-744 (CO₂) Refrigerant Heat Pumps**
- Entering Air Range -25 to 110°F
- Inverter Driven Compressors
- Available as Single Pass only
- Designed for DHW
- Water Temp – 150°F and 190°F possible
- Technically does NOT require double wall (CO₂)
- Water Heating COP 3.2
- Temperature Maintenance Challenging
CO₂ Variable Capacity (Available Internationally)
Mayekawa (22T), Mitsubishi (11T), MHI (8T), Itomic (3, 7, 22T), Sanden (larger 4.2T)

R-744 (CO₂) Refrigerant Heat Pumps
- Entering Air Range -14F to 110 F
- Inverter Driven Custom Compressors
- 1400+ PSI rated components
- Single Pass
- Designed for DHW
- Water Temp – 150F and 190F possible
- Technically does NOT require double wall (CO₂)
- Water Heating COP 3.2
- Temperature Maintenance Challenging
- No UL on any of these products yet (field test possible)
Table 3. Efficiency, Output, & Input vs. Outside Temperature

<table>
<thead>
<tr>
<th>Outside Air Temperature (F)</th>
<th>Energy Factor (EF)</th>
<th>COP</th>
<th>Output Capacity (kW)</th>
<th>Input Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>1.74</td>
<td>2.1</td>
<td>4.0</td>
<td>1.9</td>
</tr>
<tr>
<td>35</td>
<td>2.21</td>
<td>2.75</td>
<td>3.6</td>
<td>1.3</td>
</tr>
<tr>
<td>50</td>
<td>3.11</td>
<td>3.7</td>
<td>4.0</td>
<td>1.1</td>
</tr>
<tr>
<td>67</td>
<td>3.35</td>
<td>4.2</td>
<td>4.1</td>
<td>0.97</td>
</tr>
<tr>
<td>95</td>
<td>4.3</td>
<td>5.0</td>
<td>4.6</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Table 4. Annual Performance Estimates for 10 Climates

<table>
<thead>
<tr>
<th>Climate</th>
<th>Annual EF</th>
<th>Climate</th>
<th>Annual EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boise</td>
<td>2.9</td>
<td>Minneapolis</td>
<td>2.7</td>
</tr>
<tr>
<td>Kalispell</td>
<td>2.6</td>
<td>Raleigh</td>
<td>3.2</td>
</tr>
<tr>
<td>Portland</td>
<td>3.0</td>
<td>Boston</td>
<td>2.9</td>
</tr>
<tr>
<td>Seattle</td>
<td>2.9</td>
<td>Chicago</td>
<td>2.9</td>
</tr>
<tr>
<td>Spokane</td>
<td>2.8</td>
<td>Houston</td>
<td>3.5</td>
</tr>
</tbody>
</table>

COP 5.0 in literature, Actual COP is closer to 3.0

AHR Performance Ratings Issue – Lab Tests Required

Sanden Lab Test – (Larson-Ecotope 2012)
Ecotope Central HPWH Design Portfolio

Low Rise  |  10-65 dwelling units
- Elizabeth James - 65 units - (4) Sanden CO2 Heat Pumps
- Grow Communities - 3 bldgs. 12 units each - Daikin Althermas
- Puyallup Tribal - 20 units - VRF Plant, GSHP Plant

Mid Rise  |  50-400 dwelling units
- Stream - 134 units - (2) 10T Colmac Air-Source HP in below-grade parking
- Sunset Electric - 92 units - Colmac in below-grade parking
- Stackhouse - 120 units - Colmac in underground parking deck
- Augusta Apartments - 224 units - Colmac in below-grade parking
- Batik Apartments - 195 units - Colmac in underground parking deck
- Yesler 3 - 227 - Colmac in underground parking deck
- Jackson Apartments - 526 units - Colmac in underground parking deck
- Colina Apartments - 131 units, Sanden - Decentralized
- The Vale Apartments - 134 units - Versati 2, Multi-Pass
- Waterfront Place - 137/135 units - Versati 2, Multi-Pass
- Hopeworks - 67 units, Sanden CO2 Stacks

High Rise  |  200-450 dwelling units
- 4700 Brooklyn - 284 units - Colmac with VRF Temp Maintenance
- Cascade - 430 units - Colmac with VRF Temp Maintenance
- 1200 45th -245 units - In Design
Smart Grid Capable
Central DHW Heat Pump Product
Performance Specification

- Low GWP Refrigerant – Single Digits
- Single Pass Design to enable stratification
- Capable of making 150 F water.
- Operational from -13F to 110 F EAT
- Min COP Rating – 3.5 at 47F AHRI
- 208VAC, 3 Phase, 240 VAC Single Phase
- 5 to 10-Ton Air Source Heat Pumps
- Potable water rated everything
- Fully packaged controls with heat pump; no on-site programming, Demand response controls
- Fully optimized defrost controls
- Digital Thermostatic Mixing Stations
- Integrated M&V, diagnostics, alerts, alarms, app.
- Sizing support from manufacturer and rep.
Culver City Grid
Harmonize Pilot

- Demonstrate Demand Response, CO2 Central DHW
- All Heating from 8am-4pm
- High Performance Distribution System
- DHW EUI to 3 kBtu/sf/yr

2000 Gallon Primary (150F)
1000 Gallon Swing (150F)
20 Tons of Single Pass CO2 Heat Pump
- Controlled on time not aquastat
- All heating from 8 am to 4pm
- High Performance Distribution
- EUI 3 kBtu/sf/yr total load
Case Study: Batik Apartments
195 units
Buffered Garage
Located Air Source Heat Pumps
<table>
<thead>
<tr>
<th>Batik</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apartments</strong></td>
</tr>
<tr>
<td><strong>Primary Water Heating</strong></td>
</tr>
<tr>
<td><strong>HW temperature maintenance</strong></td>
</tr>
<tr>
<td><strong>HW storage</strong></td>
</tr>
<tr>
<td><strong>HW equipment capacity</strong></td>
</tr>
<tr>
<td><strong>HWC losses per apt</strong></td>
</tr>
<tr>
<td><strong>Primary system performance</strong></td>
</tr>
<tr>
<td><strong>Temperature maintenance performance</strong></td>
</tr>
</tbody>
</table>
Batik M&V Data

RCC Data Viewer

Input Power Variables
- Energy_RCC1
- Energy_RCC2

Temperature Variables
- OAT_NOAA
- GAT

Flow Variables
- GPM

COP Variables
- DHW_COP
- RCC4_COP

Other Variables

Date range input: yyyy-mm-dd
- 2018-07-02 to 2018-09-01

Draw a box and double click to zoom in. Double click again to zoom out.
Batik Lessons learned

1. With any large central heat pump system, full DDC control system is highly recommended.

2. 134a heat pumps start frosting of coils when the entering air drops below 45F. In parking garages this happens when outside air is around 25F or lower.

3. Keep the controls simple, KISS. We had to reprogram the heat pumps during a cold spell to optimize the backup systems. Primary RCC’s had trouble melting ice.

4. Focus on the backup systems and the sequence for these backup systems. Big buildings cannot have any downtime on hot water systems.

5. Use the derated equipment capacity for design, 15 tons is really 9 tons at entering air of 50F is an example at design.
Case Study – Sitka Apartments
384 unit Wastewater Source
Central Heat Pump Water Heater
### Sitka- WWHP Stats

<table>
<thead>
<tr>
<th></th>
<th>Sitka</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apartments</strong></td>
<td>384</td>
</tr>
<tr>
<td><strong>Primary Water Heating</strong></td>
<td>134a Colmac water source</td>
</tr>
<tr>
<td><strong>HW temperature maintenance</strong></td>
<td>134a Colmac air source</td>
</tr>
<tr>
<td><strong>HW storage</strong></td>
<td>5375 gallons</td>
</tr>
<tr>
<td><strong>HW equipment capacity</strong></td>
<td>37 tons</td>
</tr>
<tr>
<td><strong>HWC losses per apt</strong></td>
<td>74 watts/apt</td>
</tr>
<tr>
<td><strong>Primary system performance</strong></td>
<td>4 COP</td>
</tr>
<tr>
<td><strong>Temperature maintenance performance</strong></td>
<td>2.5 COP</td>
</tr>
</tbody>
</table>
Wastewater Source Heat Pump – Seattle - 384 Units
1. Get your local plumbing AHJ involved early in the design, make sure it is not a surprise.

2. There is not enough energy in the wastewater to heat both primary hot water and temperature maintenance. Use a separate heat pump system for temperature maintenance.

3. Assume concrete vaults always crack, install a liner in all concrete wastewater vaults.

4. This type of system has never been done before, the contractors have to be brought along during design, construction, plan for a lot more CA time.

5. With any all electric building, the grid will go down, make sure you consider power outage scenarios, we had a power outage and installed a battery backup UPS on the controls and internet modem to ensure someone is notified of any problems.

6. Recommend 100% redundancy and backup systems.
Case Study – Elizabeth James Central Hot Water Retrofit

60 Unit low income apartment
<table>
<thead>
<tr>
<th>Elizabeth James</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartments</td>
</tr>
<tr>
<td>60 units</td>
</tr>
<tr>
<td>Primary Water Heating</td>
</tr>
<tr>
<td>744 Sanden air source</td>
</tr>
<tr>
<td>HW temperature maintenance</td>
</tr>
<tr>
<td>Swing tank (backup electric)</td>
</tr>
<tr>
<td>HW storage</td>
</tr>
<tr>
<td>520 gallons</td>
</tr>
<tr>
<td>HW equipment capacity</td>
</tr>
<tr>
<td>5 tons</td>
</tr>
<tr>
<td>Primary system performance</td>
</tr>
<tr>
<td>2.7 COP</td>
</tr>
<tr>
<td>Temperature maintenance performance</td>
</tr>
<tr>
<td>0.9 COP *Existing electric boilers</td>
</tr>
<tr>
<td>Temperature maintenance performance</td>
</tr>
<tr>
<td>2.7 COP *Normal operating conditions</td>
</tr>
</tbody>
</table>
Elizabeth James Lessons Learned

1. Existing buildings have real space constraints, fitting the new hot water storage tanks through the door was a real constraint, 32” tanks were the largest we could fit.

2. Consider the downtime to install this system. Since the existing systems was a working system in a live building, we installed a bypass valve and after the system was installed and commissioned, we flipped the valve over.

3. First installation of the swing tank in practice, our sizing was too liberal, we should have added 50% more storage (175 gallon installed, should have been 300 gallon electric trim tank)

4. We had an issue with one of the four heat pumps, then we had a giant snow storm.....
Elizabeth James – Snowstorm took care of finicky heat pump.