Take Charge and Electrify That Building!

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James Moriarty (Sustainable Comfort)
Brendan Mangino (Taitem Engineering)

Curated by Marc Rosenbaum (Energysmiths)

Northeast Sustainable Energy Association (NESEA)
March 1, 2022
Learning Objectives

• Electrification can be the cost-effective higher performance alternative to replacement in kind.

• Understand that operational heartaches cost more than energy.
Project 1: Heating & Cooling Retrofit

48 Unit Luxury Condo
Project 1: 140,000 sq.ft with 48 units

- Central Heating (oil)
- 60% of distribution failing
- WSHPs end of life
- Lack of control
- Indoor cooling towers
Project 1: What was wrong
Project 1: Perpetual Rain Dance
Project 1: What was wrong
Project 1: Logistical snags (they happen), they can be managed

Nauset virtual mockup during pandemic.

2nd Temp. CT rental, pandemic project delays.

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Project 1: Finished Product
# Project 1: Energy Usage

## Metered Energy Usage

<table>
<thead>
<tr>
<th></th>
<th>Electricity Usage* (kWh/year)</th>
<th>Oil Usage (gal/ year)</th>
<th>Total Site Energy Usage* (MMBtu / year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSHP / Cooling Tower</td>
<td>987,369</td>
<td>11,607</td>
<td>4,974</td>
</tr>
<tr>
<td>VRF</td>
<td>961,984</td>
<td>-</td>
<td>3,280</td>
</tr>
</tbody>
</table>

Metered usage shows 34% savings in site energy based on 1 year of data

*Does not include apartment baseload
Project 1: Metered Data

WSHP Heating and Conditioning Energy Usage

VRF Heating and Conditioning Energy Usage

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## Project 1: GHG & Emission Reduction

<table>
<thead>
<tr>
<th></th>
<th>Carbon Dioxide (CO2) (kg)</th>
<th>Sulfur Oxide (SO2) (kg)</th>
<th>Nitrogen Oxide (NOx) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WSHP</strong></td>
<td>534,353</td>
<td>1,358</td>
<td>2,834</td>
</tr>
<tr>
<td><strong>VRF</strong></td>
<td>396,054</td>
<td>433</td>
<td>2,639</td>
</tr>
<tr>
<td><strong>% Reduction</strong></td>
<td>26%</td>
<td>69%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Significant reductions in emissions (nearly all of SO2 reduction due to elimination of oil)
### Project 1: Life Cycle Cost Analysis

#### Lets Talk Money!

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>WSHP</td>
<td>$4,200,000*</td>
<td>$237,000</td>
<td>$175,000***</td>
<td>$8,070,000</td>
<td>Existing Deferred: High!</td>
</tr>
<tr>
<td>VRF</td>
<td>$3,300,000</td>
<td>$175,000</td>
<td>$130,000</td>
<td>$6,420,000</td>
<td>Preventative: Low</td>
</tr>
</tbody>
</table>

- Assumes 20-year life cycle and 3% escalation rate for capital costs
- *Investment Cost: Only accounts for piping and cooling tower upgrades on site; does not include replacement of original WSHP’s
- **Same blended rate. Demand Rates!
- ***Compares electricity at same blended rates for simplicity.
Project 2: Historical Rehab

Refrigerant Reduction. Like golf, less is more.
GTI: 86,000 sq.ft with 92 units

- Central Heating (Natural Gas)
- Distribution end of life
- FCUs
- Through wall AC to enclosed patios
GTI: Great maintenance, but FCUs not maintainable
Business As Usual (BAU)

No – don’t do that!!!
BAU – Terms and Conditions Apply!

Primary Loops

Secondary Loop

Not Part of Scope!

(It leaks)

FCUs

Not Part of Scope to add cooling!
Variable Refrigerant Flow (VRF)

The Go-To Option for Electrification

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VRF

Refrigerant

Condensing Unit  Branch Controller  Fan Coil Unit
VRF – Typical Diagram

All new refrigerant distribution

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Heat Exchanger (HEX)

What the HEX is it?!
(An alternative to VRF and Hybrid VRF)
HEX System

Refrigerant

Hydronic
Hot or Cold Water
HEX Install Example

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HEX Units – As it progressed: WSHP

Condensing Unit

Refrigerant

HEX
3-6 Tons

Hydronic

Water Source Heat Pump

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VRF vs. HEX: Refrigerant

- No refrigerant in occupied spaces.
- About 20% less refrigerant.
**HEX vs. VRF: Energy Modelling**

<table>
<thead>
<tr>
<th></th>
<th>Site Energy (kBtu/year)</th>
<th>Source Energy (kBtu/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEX / WSHP</td>
<td>2,602,001</td>
<td>6,487,986</td>
</tr>
<tr>
<td>VRF</td>
<td>2,418,049</td>
<td>5,965,489</td>
</tr>
<tr>
<td>Boiler &amp; Chiller</td>
<td>3,898,009</td>
<td>6,941,583</td>
</tr>
</tbody>
</table>

- All building components except mechanical systems are identical
- Site: Source ratios based on WUFI Standard USA (not updated for PHIUS 2021 electric ratio which is more favorable for electric)
- “It's only a model”
## Project 2: GHG & Emission Reduction

### No More Gas!

<table>
<thead>
<tr>
<th></th>
<th>Carbon Dioxide (CO2) (kg)</th>
<th>Sulfur Oxide (SO2) (kg)</th>
<th>Nitrogen Oxide (NOx) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEX/ WSHP</td>
<td>147,820</td>
<td>162</td>
<td>985</td>
</tr>
<tr>
<td>VRF</td>
<td>125,083</td>
<td>137</td>
<td>834</td>
</tr>
<tr>
<td>Boiler / Chiller</td>
<td>223,921</td>
<td>960</td>
<td>840</td>
</tr>
</tbody>
</table>

*Assumes 20-year life cycle*
### Project 2: Energy & Cost Comparison

<table>
<thead>
<tr>
<th></th>
<th>Investment Cost</th>
<th>Annual Energy Cost</th>
<th>Life Cycle Cost</th>
<th>Maintenance Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEX / WSHP</td>
<td>$3,370,000</td>
<td>$57,450</td>
<td>$4,301,409</td>
<td></td>
</tr>
<tr>
<td>VRF (Estimated)</td>
<td>$3,010,000</td>
<td>$48,600</td>
<td>$3,798,148</td>
<td></td>
</tr>
<tr>
<td>Boiler / Chiller</td>
<td>$2,820,000</td>
<td>$65,100</td>
<td>$4,536,784</td>
<td></td>
</tr>
</tbody>
</table>

- Assumes 20-year life cycle and 3% escalation rate for capital costs
- Southcoast did not price VRF, not feasible. Simple $/sq.ft. used for LCC
- Boiler/Chiller
Thank You.

Wesley Stanhope, CEM, EBCP, CCP, CPHC®
Founder & CEO
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President

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BUILDING EVOLUTION CORPORATION
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All Electric
Domestic Hot Water

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Design considerations

LEGIONAIRES DISEASE
Grows below 122°F, Dies above 140°F

STORING AT 140°F
Kills Legionella and increases effective tempered water volume when mixed down.

SLOWER RECOVERY RATE
Heat pumps water heaters known to have a slower recovery rate when compared to traditional water heater methods.

BALANCE GENERATION VS. STORAGE
Find balance between reasonable amount of water storage and number/size of pumps.

LIMIT USE OF ELECTRIC RESISTANCE
Use staged electric resistance only if other options not available.
Reserve back up electric resistance for emergency use only.

*Image courtesy of Powers

*Image courtesy of 2015 ASHRAE HVAC APPLICATIONS HANDBOOK
<table>
<thead>
<tr>
<th></th>
<th>OPERABLE DOWN TO</th>
<th>PRODUCES H2O TEMP UP TO</th>
<th>GLOBAL WARMING POTENTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R 134 A</strong></td>
<td>40°F</td>
<td>170°F</td>
<td>1300 GWP</td>
</tr>
<tr>
<td><strong>R-410A</strong></td>
<td>-5°F</td>
<td>140°F</td>
<td>2088 GWP</td>
</tr>
<tr>
<td><strong>R-744 (CO2)</strong></td>
<td>-20°F</td>
<td>170°F</td>
<td>1GWP*</td>
</tr>
</tbody>
</table>

*May not require double wall heat exchanger.
LOCATION
Ithaca, New York

MULTIFAMILY
PROJECT STATS - Arthaus Ithaca

PROJECT TEAM
Owner: Vecino Group
Architect: BW Architecture and Engineering
Engineers: Taitem Engineering

PROJECT SIZE
100,000 SF, 124 affordable housing units, 5-story

ENERGY PROGRAMS
NYSERDA’s Multifamily New Construction Program, Tier 2 Energy Star MFHR

STATUS: COMPLETE
DHW SYSTEM DESIGN
MULTIFAMILY

Sized with the following assumptions

- 1.5 GPM shower head flow
- 104 1-bathroom units, 1.8 ppl/apt
- 20 2-bathroom units, 2.5 ppl/apt
- 8 commercial washers

Peak hourly usage
1248 GPH

Max daily usage
4740 Gallons
DHW SYSTEM OPTIONS
MULTIFAMILY

1. Central GSHP
2. Central R-410A ASHP
3. Central CO2 ASHP
4. Semi-Central Hybrid Water Heater
selected system
SIZING

**Total storage:**
Peak usage @ 125°F

**Number of heat pumps:**
Capacity to recover max daily usage at 16-hour maximum to allow for heat pump rest and defrost

Or

Capacity to recover peak usage in 4 hours normal capacity or 6 hours de-rated capacity

**Peak usage**
1248 GPH

**Max daily usage**
4740 Gallons
Design challenges

DOMESTIC HOT WATER DESIGN

- Freeze protection of water
- 100% back up system
- Space limitation, large hot water storage requirement
Freeze protection of water
DOMESTIC HOT WATER DESIGN

- Water exits building envelope, which presents risk of freezing during a power outage
- Automatic drain back and refill system
- 6 W/ft self regulating heat trace tape
Space limitation
DOMESTIC HOT WATER DESIGN

- Limited space in hot water room
- 1248 gallons of 125F water required
- Combined extra storage of 120 Gallon electric resistance tanks
- "Charge" tanks to 150F to allow for 30% more capacity
100% back up
DOMESTIC HOT WATER DESIGN

- 100% electric resistance
- (2) 36 KW 120 Gallon water heaters in series between heat pumps and storage tanks
- Manual switch over to limit reliance on electric resistance
Final System Selection

Central CO2 ASHP with 100% electric resistance backup

- **Primary** Two parallel systems made up of (8)HP WHs in parallel (piped reverse return) (1) electric resistance water heater and (1) 500 gallon storage tank with target temp 150F
  - Total of (16) 15,400 BTU/hr HP WHs; auto drain back; 1248 gallons of storage

- **Secondary** (2) 36 kw electric resistance water heaters and (2) 500 gallon storage tanks

  Estimated annual COP = ~4.2
Final System Selection
Final System Selection
System install and operation

TROUBLESHOOTING
Automatic drainback

TROUBLESHOOTING

- Automatic drain back system (triggered by a power outage) was trapping air in the heat pumps on refill causing an airlock at several units, resulting in an error code requiring a manual air purge and restart of the affected heat pumps.

- 1st image shows that even though most of these units had their fans running, only two (the ones with the blue and purple) were actually transferring heat correctly.

- 2nd image shows all units operations correctly. With some minor adjustments to the timing of the startup of the system, we confirmed that the system could be fully purged of air, allowing all the units to operate as intended.
Condensate drip and freezing

TROUBLESHOOTING

CONCERN
Condensate from drain pan can drip on units below and freeze during the winter.
Operation during construction

TROUBLESHOOTING

Contractor turned on the heat pump system to provide tempered water to the building. Usage profile was low (<100 gallon/day) with recirculation system operable and set to 104F

RESULT

- No new cold water introduced to the system and the tanks being mixed.
- Observed that tanks were not able to rise 120F and heat pumps would shut down due to high pressure (Low heat transfer at heat exchanger)
- Contractor temporarily switched to back up electric resistance for the rest of construction which addressed the issue.
**Pipe length and layout**

**TROUBLESHOOTING**

With the insulation requirements and amount of pipe penetrations clustered together, the contractor struggled to run piping through the wall as designed.

**TOP IMAGE**
- Original system design with pipe manifold within building envelope

**BOTTOM IMAGE**
- Final design with pipe headers outside building envelope

**NEW DESIGN ISSUES**
- Pipe length now got close to the total ~70' allowed per SanCO2 requirements
CURRENT POINTS OF MEASUREMENT

- **POWER**: Heat trace tape, recirculation pump, all (16) heat pumps individually
- **TEMPERATURE**: Cold water inlet to system, cold water to each heat pump array and hot water from each heat pump array, Hot water out of each tank, hot water to mixing valve and tempered water to building.
- **FLOW RATE**: Cold water to DHW plant, cold water to one heat pump array.
Measurement & Verification: Heat pump water outlet temp

-5 F minimum, 32 F maximum ambient temperature.
Measurement & Verification: Total power

-5 F minimum, 32 F maximum ambient temperature.
Hot Water Heating Systems – Alternative Central Options

Central CO2 System  LG VRF System  Shared Integrated DHW
Hot Water Heating Systems – Electric Central Plant

Central CO2 Based System (Ex. Sanden SanCO2, Mitsubishi QAHV, Aegis A)
- Runs hot water outside of the building to exterior condensers.
- CO2 refrigerant means hot water system needs to go outside.
- May need many outdoor condensers, Sanden smaller capacity units.
- Indoor storage tank capacity large
- Central distribution system with associated piping and pumps needed
- Freeze protection needed if water running outside, or if allowed using glycol to outdoor units
  (Currently Mitsubishi unit does not have freeze protection option available)
- COP: 3-3.75

Sanden SanCO2

Mitsubishi QAHV

Lync by Watts Aegis A 350
Hot Water Heating Systems – Electric Central Plant

LG VRF Central System

- Standard outdoor condensing unit – LG VRF Systems
- Indoor unit with additional heat pump – Hydrokit K3 to boost temp from outdoor condenser loop
- Additional heat exchanger to large indoor storage tank
- Central distribution system with associated piping and pumps needed
- Simulated COP of 3.18 for Rochester, NY climate
Hot Water Heating Systems – Electric Central Plant

LG VRF Central System

Pros
• No additional freeze protection needed due to using refrigerant systems
• Less outdoor units, 1 outdoor unit with 2 compressors capable of handing whole building.

Cons:
• Higher global warming potential refrigerants
• Controls, startup and operation may be more complex
Hot Water Heating Systems – Electric

LG VRF Central Systems
R-410A refrigerant to outdoor unit, separate R-134A cycle within K3 hydrokit to boost temperature.
Storage tank able to achieve 150F
Hot Water Heating Systems – System Cost Comparisons

### Electric Central Plant Installation Cost Comparison

<table>
<thead>
<tr>
<th>System</th>
<th>Equipment Cost</th>
<th>Piping + Install Cost</th>
<th>Total Cost</th>
<th>Total Cost/SF</th>
<th>Cost Premium</th>
<th>Premium/Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanden SanCO2</td>
<td>$86,000</td>
<td>$107,000</td>
<td>$193,000</td>
<td>$1.89</td>
<td>$104,000</td>
<td>$838</td>
</tr>
<tr>
<td>LG Hydrokit</td>
<td>$91,000</td>
<td>$77,000</td>
<td>$168,000</td>
<td>$1.64</td>
<td>$79,000</td>
<td>$637</td>
</tr>
<tr>
<td>Base: Gas Boiler</td>
<td>$46,400</td>
<td>$42,200</td>
<td>$89,000</td>
<td>$0.87</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Pricing Assumptions**

- Pricing based off the Ithaca Arthaus, 124 Unit Building, ~102,000sf in Ithaca, NY
- Costs include domestic water systems within the mechanical room to the storage tanks, excludes distribution which is expected to be the same in each scenario
- Pricing based on 2021 costs
- Pricing provided by installing contractor Woodcock and Armani, Syracuse, NY [www.csusyr.com](http://www.csusyr.com) Daniel.bruyere@comfortsystemsusa.com
- Additional LG Hydrokit and boiler pricing supported by Ben Curwin, VP Supply Corp, Rochester, NY [www.vpsupply.com](http://www.vpsupply.com) bcurwin@vpsupply.com
Alternative Hot Water Heating System – Shared Heat Pump Water Heaters

While individual heat pump water heaters per apartment are an option, results in higher space needs, installation and maintenance costs. To reduce the number of tanks, reduce noise to tenants, and keep apartment temperatures consistent, a heat pump water heater off the corridor can be shared among units.
Alternative Hot Water Heating System – Shared Heat Pump Water Heaters

Since the system takes heat from the surrounding air, there needs to be adequate air distribution for small closets. It is recommended to provide ducting of air to avoid a cold closet, and ducting air to corridor allows additional cooling in the summer. Corridor heat pumps need to be sized for additional heating load in winter.

Closet Option 1 - Recommended

Heater: Ducted with inlet OR outlet duct
Room size: Any size room
Requirements: Air gap under door equal to 18 in² (0.75” clearance)
What about Individual Electric Resistance?

## Individual Heat Pump Operating Cost Comparison

<table>
<thead>
<tr>
<th>Category</th>
<th>Electric Resistance kWh / Year</th>
<th>Heat Pump Water Heater kWh / Year</th>
<th>Costs</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Bedroom</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating</td>
<td>2.114</td>
<td>1.710</td>
<td>$134</td>
<td>$188</td>
</tr>
<tr>
<td>Cooling</td>
<td>222</td>
<td>91</td>
<td>$24</td>
<td>$10</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>2.432</td>
<td>924</td>
<td>$268</td>
<td>$102</td>
</tr>
<tr>
<td>Lighting</td>
<td>277</td>
<td>277</td>
<td>$30</td>
<td>$30</td>
</tr>
<tr>
<td>Miscellaneous Loads</td>
<td>2.188</td>
<td>2.188</td>
<td>$241</td>
<td>$241</td>
</tr>
<tr>
<td>Service Charge</td>
<td>-</td>
<td>-</td>
<td>$204</td>
<td>$204</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6.333</td>
<td>5.190</td>
<td>$901</td>
<td>$775</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td>$1,143</td>
<td>$126</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Electric Resistance kWh / Year</th>
<th>Heat Pump Water Heater kWh / Year</th>
<th>Costs</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2 Bedroom</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating</td>
<td>1.600</td>
<td>2.271</td>
<td>$176</td>
<td>$250</td>
</tr>
<tr>
<td>Cooling</td>
<td>307</td>
<td>133</td>
<td>$34</td>
<td>$15</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>3.303</td>
<td>1.255</td>
<td>$363</td>
<td>$138</td>
</tr>
<tr>
<td>Lighting</td>
<td>365</td>
<td>365</td>
<td>$40</td>
<td>$40</td>
</tr>
<tr>
<td>Miscellaneous Loads</td>
<td>2.660</td>
<td>2.660</td>
<td>$293</td>
<td>$293</td>
</tr>
<tr>
<td>Service Charge</td>
<td>-</td>
<td>-</td>
<td>$204</td>
<td>$204</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>8.235</td>
<td>6.684</td>
<td>$1,110</td>
<td>$940</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td>$1,552</td>
<td>$170</td>
</tr>
</tbody>
</table>

*Savings based on energy modeling only, including heat pump DHW results in an associated increase in heating usage, and reduction in cooling.
*Assumptions: Rates: $0.11/kWh, $17/month meter fees, 1 Bed = 630sf, 2 Bed = 830sf, Location: Buffalo, NY
Questions?

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