Commercial Water Heating Using Gas Absorption Heat Pumps

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ACEEE Hot Water Forum
Portland, OR
February, 2016
Topics of Discussion

- GAHP Technology Background
- GAHP Development Status
- Energy Use Modeling: Full-Service Restaurant
  - Engineering Equation Solver (SMTI)
  - EnergyPlus (ORNL)
Commercial Water Heating Uses Significant Energy

- 7% U.S. Commercial Energy Use (1.2 Quads)
- 9% Canadian Commercial Energy Use
- 5.5% U.S. Commercial Sector CO₂ Emissions

Source: US DOE and NRCAN
## Commercial Gas Water Heating Equipment

<table>
<thead>
<tr>
<th>Type</th>
<th>Thermal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Condensing:</strong></td>
<td>80 - 82%</td>
</tr>
<tr>
<td><strong>Condensing:</strong></td>
<td>90 – 95%</td>
</tr>
</tbody>
</table>
| **Gas Absorption Heat Pump**| 130 - 160%         | +70%  

(1.3 – 1.6 COP)
How Does It Work?

\[ \text{COP}_h = \frac{Q_{\text{cond}}}{E_{\text{in}}} = 3.0-4.0 \]
\[ \text{Qheat} = \sim 1.2 \times \text{Qevap} \]

\[ \text{COP}_h = \frac{(Q_{\text{cond}} + Q_{\text{abs}})}{Q_{\text{in}}} = 1.4-2.0 \]
\[ \text{Qheat} = (Q_{\text{cond}} + Q_{\text{abs}}) \sim 2.5 \text{ times Qevap} \]

*Capacity & COP Remain High at Low Ambient Temperatures*
Gas Absorption’s Renewable Energy Content: 35%

Renewable Energy (via atmosphere) → 0.5 → Natural Gas

1.0 → 1.5
COP\textsubscript{HHV} = 1.4 at 47/120°F

- Gas-Fired, Air to Water Heat Pump
- Condensing
- 4:1 Modulation

- 10,000 to 140,000 Bth Heating Output Models
- 20°F Hydronic Differential
- Outdoor Installation (no venting)
- SCAQMD NOx Compliant
GAHP Development Status

10,000 btu/hr
Field Testing

80,000 btu/hr
Field Testing

140,000 btu/hr
Lab Testing
1. Using Engineering Equation Solver (SMTI)*
   Case 1: 2080 gpd
   Case 2: 4060 gpd

2. Using EnergyPlus (ORNL)
   Case 1: 2080 gpd

199 kBth Cond Storage + 199 kBth NC Storage
Vs.
140 kBth GAHP + 199 kBth NC Storage

* Dr. Chris Keinath
GAHP Commercial Water Heating

Pre-Heater Installation

Heat Pump → Storage Tank

Cold Water → Booster Water Heater

140°F → Hot Water
Ambient Temperature from Energy Plus

Oakland, California

Ambient High and Low Temperature for Year

Yearly Average: 58°F
Engineering Equation Solver Model: Assumptions

- A hot water draw happens at the start of each 15 minute period
- Water is drawn into the bottom of Tank 1 at 54.7°F
- Water exiting the top of Tank 1 enters the bottom of Tank 2
- COP for the GAHP and Condensing units use *average* bottom node temperature for each 15 minute step
- Modulation is neglected
- GAHP electrical load of 900 W, Condensing unit electrical load of 150 W
Commercial Water Heating: Case 1

Simulated Draw Pattern

Full Service Restaurant - Daily draw pattern
Daily use: 2080 Gallons of Hot Water

15 Minute Draw Volumes

Draw Volume (gallons)

Time (5 AM to 12 AM)

5 am

12 am

Commercial Water Heating: Case 1

GAHP Performance

Avg Daily COP_{gas} for GAHP

COP_{gas} for December 31
### GAHP Avg. Gas COP of 1.53

140 kbtu/hr GAHP Tank unit and 199 kbtu/hr Standard Tank Unit, 2 x 100 gallon tanks

<table>
<thead>
<tr>
<th>Month</th>
<th>Gas Used (Thers)</th>
<th>Electricity Used (kWh)</th>
<th>Cost of Gas ($)</th>
<th>Cost of Electricity ($)</th>
<th>Gas Used (Thers)</th>
<th>Electricity Used (kWh)</th>
<th>Cost of Gas ($)</th>
<th>Cost of Electricity ($)</th>
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</thead>
<tbody>
<tr>
<td>January</td>
<td>282</td>
<td>432</td>
<td>$282</td>
<td>$52</td>
<td>7.4</td>
<td>0</td>
<td>$7</td>
<td>$0</td>
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<td>391</td>
<td>$256</td>
<td>$47</td>
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<td>0</td>
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<tr>
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<td>281</td>
<td>432</td>
<td>$281</td>
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<td>0</td>
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<tr>
<td>April</td>
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<td>419</td>
<td>$271</td>
<td>$50</td>
<td>6.6</td>
<td>0</td>
<td>$7</td>
<td>$0</td>
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<tr>
<td>May</td>
<td>279</td>
<td>432</td>
<td>$279</td>
<td>$52</td>
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<td>0</td>
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<td>June</td>
<td>269</td>
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<td>$6</td>
<td>$0</td>
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<tr>
<td>July</td>
<td>278</td>
<td>432</td>
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<td>0</td>
<td>$6</td>
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<td>$6</td>
<td>$0</td>
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<td>419</td>
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<td>$0</td>
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<tr>
<td>November</td>
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<td>0</td>
<td>$7</td>
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<tr>
<td>December</td>
<td>283</td>
<td>432</td>
<td>$283</td>
<td>$52</td>
<td>7.8</td>
<td>0</td>
<td>$8</td>
<td>$0</td>
</tr>
</tbody>
</table>

**Total** | **3299** | **5092** | **$3,299** | **$611** | **81.0** | **0.00** | **$81** | **$0**

**Total Operating Cost** $3,991

**Note:** Assumed cost of Natural Gas – $1.00/therm, Electricity $0.12/kWh
Commercial Water Heating: Case 1

Water Temperature Exiting GAHP Coupled Tank

Temperature, °F

Time, 5 AM to 12 AM
### Commercial Water Heating: Case 1

**Condensing + Non-Condensing**

<table>
<thead>
<tr>
<th>Month</th>
<th>Gas Used</th>
<th>Electricity Used</th>
<th>Cost of Gas</th>
<th>Cost of Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank 1 (Condensing)</td>
<td>Therms</td>
<td>kWh</td>
<td>$</td>
<td>$</td>
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<tr>
<td>January</td>
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<td>72</td>
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<td>March</td>
<td>459</td>
<td>72</td>
<td>$459</td>
<td>$9</td>
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<td>April</td>
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<td>$8</td>
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<tr>
<td>May</td>
<td>459</td>
<td>72</td>
<td>$459</td>
<td>$9</td>
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<tr>
<td>June</td>
<td>444</td>
<td>70</td>
<td>$444</td>
<td>$8</td>
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<tr>
<td>July</td>
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<td>72</td>
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<tr>
<td>November</td>
<td>444</td>
<td>70</td>
<td>$444</td>
<td>$8</td>
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<tr>
<td>December</td>
<td>459</td>
<td>72</td>
<td>$459</td>
<td>$9</td>
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<tr>
<td>Total</td>
<td>5401</td>
<td>849</td>
<td>$5,401</td>
<td>$102</td>
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</table>

<table>
<thead>
<tr>
<th>Gas Used</th>
<th>Electricity Used</th>
<th>Cost of Gas</th>
<th>Cost of Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank 2 (NC)</td>
<td>Therms</td>
<td>kWh</td>
<td>$</td>
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<td>January</td>
<td>1.6</td>
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<td>March</td>
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<tr>
<td>October</td>
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<tr>
<td>November</td>
<td>1.6</td>
<td>0</td>
<td>$2</td>
</tr>
<tr>
<td>December</td>
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<td>$2</td>
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<tr>
<td>Total</td>
<td>19.0</td>
<td>0.00</td>
<td>$19</td>
</tr>
</tbody>
</table>

**Total Operating Cost** $5,522

**Note:** Assumed cost of Natural Gas – $1.00/therm, Electricity $0.12/kWh
## Commercial Water Heating: Case 1

*Comparison between Condensing and GAHP Pre-Heat*

### Table: Comparison of Condensing and GAHP Pre-Heat

<table>
<thead>
<tr>
<th></th>
<th>Condensing Pre-Heat</th>
<th>GAHP Pre-Heat</th>
<th>Annual Savings</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Natural Gas Used</td>
<td>Therms 5,420</td>
<td>3,380</td>
<td>2,040</td>
<td>38%</td>
</tr>
<tr>
<td>Cost of Gas Used</td>
<td>$5,420</td>
<td>$3,380</td>
<td>$2,040</td>
<td>38%</td>
</tr>
<tr>
<td>Total Electricity Used</td>
<td>kWh 849</td>
<td>5,092</td>
<td>-4,243</td>
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</tr>
<tr>
<td>Cost of Electricity Used</td>
<td>$102</td>
<td>$611</td>
<td>-$509</td>
<td></td>
</tr>
<tr>
<td>Total Energy Used</td>
<td>kWh 159,665</td>
<td>104,123</td>
<td>55,542</td>
<td>35%</td>
</tr>
<tr>
<td>Total Primary Energy Used</td>
<td>kWh 175,783</td>
<td>123,983</td>
<td>51,800</td>
<td>29%</td>
</tr>
<tr>
<td>Annual Operating Cost</td>
<td>$5,522</td>
<td>$3,991</td>
<td>$1,531</td>
<td>28%</td>
</tr>
</tbody>
</table>

**Note:** For Primary Energy Conversion: Electric use multiplied by 3.15, Gas use multiplied by 1.09  
Natural Gas = $1.00/therm  
Electricity = $0.12/kWhr
Commercial Water Heating: Case 2

Simulated Draw Pattern

Daily use: 4160 Gallons of Hot Water

15 Minute Draw Volumes
Commercial Water Heating
Case 2 Exiting Water Temperature (4160 gpd)

Water Temperature Exiting GAHP Coupled Tank

Temperature, °F

Time, 5 AM to 12 AM
## Commercial Water Heating: Case 2
### Comparison between Condensing and GAHP Pre-Heat

<table>
<thead>
<tr>
<th></th>
<th>Condensing Pre-Heat</th>
<th>GAHP Pre-Heat</th>
<th>Annual Savings</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Natural Gas Used</strong></td>
<td>10,934</td>
<td>7,895</td>
<td>3,039</td>
<td>28%</td>
</tr>
<tr>
<td><strong>Cost of Gas Used</strong></td>
<td>$10,934</td>
<td>$7,895</td>
<td>$3,039</td>
<td>28%</td>
</tr>
<tr>
<td><strong>Total Electricity Used</strong></td>
<td>876</td>
<td>5,420</td>
<td>-4,544</td>
<td>28%</td>
</tr>
<tr>
<td><strong>Cost of Electricity Used</strong></td>
<td>$105</td>
<td>$650</td>
<td>-$545</td>
<td>28%</td>
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<tr>
<td><strong>Total Energy Used</strong></td>
<td>321,229</td>
<td>236,737</td>
<td>84,492</td>
<td>26%</td>
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<tr>
<td><strong>Total Primary Energy Used</strong></td>
<td>351,944</td>
<td>269,209</td>
<td>82,735</td>
<td>24%</td>
</tr>
<tr>
<td><strong>Annual Operating Cost</strong></td>
<td>$11,039</td>
<td>$8,545</td>
<td>$2,493</td>
<td>23%</td>
</tr>
</tbody>
</table>

**Note:** For Primary Energy Conversion: Electric use multiplied by 3.15, Gas use multiplied by 1.09

- Natural Gas = $1.00/therm
- Electricity = $0.12/kWhr
Energy Plus Modeling

Oak Ridge National Lab
System Configurations

Primary High Efficiency Tank

Inlet Water

Standard Efficiency Water Heater

Hot Water

Storage Tank

Inlet Water

Standard Efficiency Water Heater

Hot Water

Heat Pump

Return Water

Return Water
System Assumptions

GAHP
- WaterHeater:HeatPump
- WaterHeater:Stratified
- COP related to the ambient air and mains hydronic temperature
- Second tank 80% efficient
- Set Point 140 °F
- Oakland, CA
- Full service restaurant

Condensing Tank Pre-Heat
- WaterHeater:Stratified
- COP ranging from 98% to 82% depending on Flue Gas Exit Temperature (assumed node 6)
- Second tank 80% efficient
- Set Point 140 °F
- Oakland, CA
- Full service restaurant
Ambient Air and Mains Water temperatures for Oakland, CA

- Outdoor Air Drybulb Temperature [°F] (Hourly)
- Site Mains Water Temperature [°F] (Hourly)
Daily draw pattern

GAHP COP and Heating Load as functions of Hydronic and Air Ambient Temperatures
Tank Stratification

Nodal tank temperatures on May 18th

Temperature (°F)

Node 1  Node 2  Node 3  Node 4  Node 5  Node 6
Performance Comparison

GAHP

- Average daily consumption of 1104 ft³

Condensing Tank Pre-Heat

- Average daily consumption of 1638 ft³

Assumed 1020 BTU/ft³
Future Plans

• Investigate how each regional climate affects the performance
• Explore other water draw data resources
• Better understand the EnergyPlus HeatPump and Stratified models
• Model a water heating tank with internal heat exchanger coil
Thank You!