Heat Pump Assisted Solar Thermal System

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July 11 -14, 2016
Introduction

- According to the U.S. Department of Energy, buildings are responsible for 40% of the total energy consumption
  - Almost half of that amount is used for heating or cooling
- Alternative heating technologies such as heat pumps and solar thermal collectors can...
  - greatly reduce the reliance on fossil fuels
  - provide reliable heating performance
- National Institute of Standards and Technology (NIST)
  - Net Zero Energy Residential Test Facility (NZERTF)
Annual
EF = 2.39
Wsolar = 319.6 kWh
Whp = 1112.2 kWh
Qtotal = 3427.5 kWh

March 2014
EF = 2.38
Wsolar = 22.6 kWh
Whp = 120.7 kWh
Qtotal = 340.5 kWh
HP COP = 2.19

Net-zero and beyond! Design and performance of NIST's net-zero energy residential test facility
Energy and Buildings, Volume 101, 2015, 95–109
http://dx.doi.org/10.1016/j.enbuild.2015.05.002
System Overview
Solar Collectors and Heat Pump
Energy Factor Computations

Energy Factor (EF) is the ratio of output energy to input energy.

\[
EF = \frac{Q_{\text{total}}}{W_{\text{total}}} = \frac{Q_{\text{solar}} + Q_{\text{hp}} + Q_{\text{air}}}{W_{\text{solar}} + W_{\text{hp}}}
\]

\[
Q_{\text{solar}} = 425 \times \text{gpm} \times \Delta T_F
\]

\[
Q_{\text{hp}} = Q_{\text{comp}} + Q_{\text{res}} = W_{\text{comp}} \times \text{COP} + W_{\text{res}} \times 100\
\]

\[
W_{\text{hp}} = W_{\text{comp}} + W_{\text{res}}
\]

\[
Q_{\text{air}} = Q_{\text{comp}} - W_{\text{comp}} \begin{cases} -Q_{\text{air}}, & OT < 60^\circ F \\ Q_{\text{air}}, & OT \geq 60^\circ F \end{cases}
\]
Test Conditions

**Test Dates:** March 15th to 28th, 2016

**Test Duration:** 2 weeks

**Heat Demand:** Constant rate of ~19.0 kWh per day  
(Compare to 16.4 kWh/day [1])

**Load Times:** Loaded equally night and day for solar and heat pump loading

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Test Period vs Annual Conditions

The test period accounts for only 3.8% of the year but...

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>Test Period</th>
<th>Percent of Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>27</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>331</td>
<td>287</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>305</td>
<td>220</td>
<td>72%</td>
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<tr>
<td>Median</td>
<td>179</td>
<td>177</td>
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### Sunny, Cloudy, or Partly Cloudy

#### Bar Graph

<table>
<thead>
<tr>
<th>Date</th>
<th>Avg. Solar Intensity (W/m²)</th>
</tr>
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<tbody>
<tr>
<td>3/15</td>
<td>229</td>
</tr>
<tr>
<td>3/16</td>
<td>260</td>
</tr>
<tr>
<td>3/17</td>
<td>251</td>
</tr>
<tr>
<td>3/18</td>
<td>241</td>
</tr>
<tr>
<td>3/19</td>
<td>90</td>
</tr>
<tr>
<td>3/20</td>
<td>186</td>
</tr>
<tr>
<td>3/21</td>
<td>263</td>
</tr>
<tr>
<td>3/22</td>
<td>257</td>
</tr>
<tr>
<td>3/23</td>
<td>110</td>
</tr>
<tr>
<td>3/24</td>
<td>59</td>
</tr>
<tr>
<td>3/25</td>
<td>142</td>
</tr>
<tr>
<td>3/26</td>
<td>287</td>
</tr>
<tr>
<td>3/27</td>
<td>200</td>
</tr>
<tr>
<td>3/28</td>
<td>67</td>
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#### Table

<table>
<thead>
<tr>
<th>Type of Day</th>
<th>Days</th>
<th>Solar EF</th>
<th>Heat Pump EF</th>
<th>Overall EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloudy</td>
<td>3</td>
<td>2.77</td>
<td>1.20</td>
<td>1.23</td>
</tr>
<tr>
<td>Partly Cloudy</td>
<td>3</td>
<td>18.67</td>
<td>1.27</td>
<td>1.74</td>
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<tr>
<td>Sunny</td>
<td>8</td>
<td>35.68</td>
<td>1.24</td>
<td>2.75</td>
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</tbody>
</table>

July 11-14, 2016
# Cold, Warm, or Hot

<table>
<thead>
<tr>
<th>Type of Day</th>
<th>Days</th>
<th>Solar EF</th>
<th>Heat Pump EF</th>
<th>Overall EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>5</td>
<td>18.21</td>
<td>1.00</td>
<td>1.66</td>
</tr>
<tr>
<td>Warm</td>
<td>8</td>
<td>27.76</td>
<td>1.32</td>
<td>2.38</td>
</tr>
<tr>
<td>Hot</td>
<td>1</td>
<td>36.65</td>
<td>1.81</td>
<td>3.53</td>
</tr>
</tbody>
</table>

![Bar chart showing the percent of days above 60°F for different types of days, comparing Solar EF, Heat Pump EF, and Overall EF.](chart.png)
Results

Average Consumption (left) and Collection (right) Percentages
Conclusions

- Average EF of 2.29
  - Solar EF = 27
  - Heat Pump EF = 1.3
- Solar Energy Collection was far more efficient when available
  - 3% of the electrical consumption compared to 44% of the heat
- Despite the rigorous heating demand the heat pump rarely resorted to direct resistive heating.
  => Higher EF!
Thank You!

QUESTIONS?