Zero (or Low) Energy Home (ZEH) Equipment Needs in a Range of US Climates

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Sponsored by DOE Buildings Technology Program

ASHRAE
2010 Annual Meeting
Albuquerque, NM
June 27, 2010
Assessment of Advanced HVAC/WH Technology Options for NZEH Applications

- **Objective** – identify portfolio of system options with >50% savings potential

- **Initial scoping studies of HVAC options**
  - Identified integrated heat pump (IHP) concept as most promising equipment option for all electric homes
    - Based on small-capacity variable-speed compressor
  - System design options developed for air- and ground-source versions of IHP

- **Energy savings evaluated against baseline of minimum efficiency individual equipment suite for 1800 ft² ZEH**
  - 13 SEER heat pump; 0.9 EF water heater; 1.4 EFd dehumidifier; exhaust fans operated to achieve ventilation per ASHRAE std 62.2
  - and against suite of higher efficiency individual systems
    - 18 SEER heat pump; Energy Star heat pump water heater (2.0 EF); same DH & ventilation approach
ZEH/Low-Energy House Characteristics/Needs

• Highly insulated & very tight buildings

• Much lower space heating/cooling loads
  – smaller equipment capacities (1 – 1.5-ton for 1800 ft² size)

• Need for active ventilation and dehumidification (in some locales)

• Greater balance between water heating load (relatively unchanged) and space conditioning loads (smaller)

• Specifics for the building used in our analyses provided by NREL using their BEopt program
  – BEopt -> building energy optimization program
ZEH/Low Energy House 1800 ft² (167 m²) – heat pump size requirements for 5 U.S Locations

<table>
<thead>
<tr>
<th>Location – climate zone</th>
<th>Heat Pump Cooling Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta – mixed humid</td>
<td>1.25 (4.4)</td>
</tr>
<tr>
<td>Houston – hot humid</td>
<td>1.25 (4.4)</td>
</tr>
<tr>
<td>Phoenix – hot dry</td>
<td>1.5 (5.3)</td>
</tr>
<tr>
<td>San Francisco – marine</td>
<td>1.0 (3.5)</td>
</tr>
<tr>
<td>Chicago - cold</td>
<td>1.25 (4.4)</td>
</tr>
</tbody>
</table>
# ZEH/Low Energy House 1800 ft² (167 m²) – HVAC/WH Energy Service Loads for 5 U.S Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Total Load on HVAC/WH System kWh</th>
<th>% Load by component</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Space heat</td>
<td>Space cool</td>
<td>Water heat</td>
<td>DDH*</td>
</tr>
<tr>
<td>Atlanta</td>
<td>13700</td>
<td>34.9</td>
<td>41.8</td>
<td>22.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Houston</td>
<td>14900</td>
<td>11.9</td>
<td>66.6</td>
<td>16.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Phoenix</td>
<td>13525</td>
<td>11.7</td>
<td>72.1</td>
<td>16.2</td>
<td>0</td>
</tr>
<tr>
<td>San Francisco</td>
<td>6400</td>
<td>45.0</td>
<td>1.4</td>
<td>52.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Chicago</td>
<td>17875</td>
<td>64.0</td>
<td>14.2</td>
<td>21.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

* Dedicated dehumidification – to maintain ID RH≤60% year-round
DOE/ORNL IHP Development Objective

• Multifunction heat pump that provides:
  – Space heating and cooling
  – Domestic HW
  – Dedicated dehumidification as needed, and
  – Conditioning of the ventilation air

• To minimize energy consumption required to meet ZEH energy services (SH, SC, WH, humidity control, ventilation)

• To support meeting DOE goal of a ZEH at neutral owning cost
IHP – Initial Equipment Concept

- **Split-System Air Source HP**
  - Central indoor air handler with ducts in the conditioned space

- **Single Compressor Design**
  - High-efficiency at EER and SEER conditions
  - Modulating capacity
    - 2.8-to-1 turndown in cooling and heating,
    - 50% over-speed capability in heating
  - >1.5 hp design to reduce power electronics costs

- **Modulating Fans and Pump**
  - Wide-range air flow control, especially indoor
  - Multi-speed water flow
  - For range of conditioning requirements

- **Water-to-Refrig. Coil**
  - To meet water heating needs over a range of speeds

- **Water-to-Air Coil**
  - To assist with supply/ventilation air tempering
AS-IHP Concept

- Full integration to heat, cool, ventilate, dehumidify, and heat water as needed

- AS-IHP concept, in dehumidification/ventilation/WH mode, shown at right - many modes possible
  - H or C/ventilation/WH
  - Dedicated water heating
  - Dedicated dehumidification and/or humidification
  - Ventilation air pre-treatment; H in winter, C & dehumidify in spring/summer/fall

- Lab prototype constructed and tested

Possible AS-IHP packaging approach
AS-IHP: Salient Technical Features

- 2 discrete but interactive loops (refrigerant and domestic hot water)
- 1 VS compressor and 2 VS fans
- 1 SS pump for domestic HW loop
- Means for dedicated humidity control
- 4 HXs for space conditioning and water heating
  - One water-to-ref HX, two air-to-ref, one reheat coil
GS-IHP Concept

- Performance expected to exceed that of AS-IHP in most locations
  - Geothermal source sink (ground HX, etc) generally provides more favorable operating conditions for compressor than OD air

GS-IHP system concept – dehumidification/ventilation/WH mode shown
GS-IHP: Salient Technical Features

- 3 discrete but interactive loops (refrigerant, domestic hot water & ground loop)
- 1 VS compressor and 1 VS fan
- 1 SS pump for domestic HW loop
- 1 MS pump for ground loop
- Means for dedicated humidity control
- 4 HXs for space conditioning and water heating
  - Two water-to-ref HXs, one air-to-ref, one reheat coil
IHP – Seasonal Performance Analysis

• Calibrated HPDM linked to TRNSYS simulation engine
  – Enabled sub-hourly analysis of IHP annual performance
    • using optimized R-410A based design
    • simulated multiple modes of operation per t-stat calls
    • linked with domestic water tank for inlet water temp history

• Detailed annual performance assessments vs. baseline system & hi-eff heat pump+HPWH system

• Baseline system – individual systems to deliver same energy services
  – air-source heat pump + electric storage water heater + 40 pt/d stand alone dehumidifier (DH) + whole-house ventilation system
  – @ minimum efficiency levels (13 SEER, 0.9 EF) or “typical of market” (e.g., EFd=1.4 for DH)

• Predicted performance on following slides
AS-IHP in 167m² ZEH in Atlanta - ~54% savings vs. Baseline, ~20% more than for “Hi-Efficiency” stand-alone suite

### Efficiency Equivalent

<table>
<thead>
<tr>
<th></th>
<th>Baseline (air/air heat pump + electric resistance water heater)</th>
<th>“Hi-Eff” ASHP + Energy Star heat pump water heater</th>
<th>AS-IHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal heating COP</td>
<td>2.67</td>
<td>3.19</td>
<td>3.82</td>
</tr>
<tr>
<td>Seasonal cooling COP</td>
<td>3.49</td>
<td>4.83</td>
<td>5.34</td>
</tr>
<tr>
<td>WH annual COP</td>
<td>0.89</td>
<td>1.98</td>
<td>3.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Use</th>
<th>Baseline</th>
<th>Hi-Eff electric</th>
<th>AS-IHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>100</td>
<td>92</td>
<td>90</td>
</tr>
<tr>
<td>Cooling</td>
<td>85</td>
<td>80</td>
<td>75</td>
</tr>
<tr>
<td>WH</td>
<td>82</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>Overall</td>
<td>95</td>
<td>90</td>
<td>85</td>
</tr>
</tbody>
</table>

Base system – rated SEER/HSPF/EF – 13/7.7/0.90
“Hi-Eff” system – rated SEER/HSPF/EF – 18/9.2/2.0
All systems include year-round humidity control and Std 62.2 minimum ventilation

TRNSYS/HPDM simulation results
### AS-IHP – Unit Sizing and Energy Savings Predictions for 1800 ft² (167 m²) ZEH in 5 U.S Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Heat Pump Cooling Capacity</th>
<th>HVAC/WH Energy Consumption Total &amp; (I²r) backup kWh</th>
<th>% Energy Savings Versus Baseline HVAC/WH System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tons (kW)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlanta</td>
<td>1.25 (4.4)</td>
<td>3349 (142)</td>
<td>53.7</td>
</tr>
<tr>
<td>Houston</td>
<td>1.25 (4.4)</td>
<td>3418 (91)</td>
<td>53.7</td>
</tr>
<tr>
<td>Phoenix</td>
<td>1.5 (5.3)</td>
<td>3361 (19)</td>
<td>48.4 (~59%*)</td>
</tr>
<tr>
<td>San Francisco</td>
<td>1.0 (3.5)</td>
<td>1629 (100)</td>
<td>67.2</td>
</tr>
<tr>
<td>Chicago</td>
<td>1.25 (4.4)</td>
<td>10773 (941)</td>
<td>45.6</td>
</tr>
</tbody>
</table>

*Appx savings with evaporatively pre-cooled condenser

Estimated GS-IHP savings ~10% pts higher for cold & mixed humid locations
AS-IHP – Summer afternoon utility peak reduction predictions for 1800 ft² (167 m²) ZEH in 5 U.S locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Heat Pump Cooling Capacity</th>
<th>% Summer Peak Load Reduction Versus Baseline HVAC/WH System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta</td>
<td>1.25 (4.4)</td>
<td>42.9</td>
</tr>
<tr>
<td>Houston</td>
<td>1.25 (4.4)</td>
<td>50.0</td>
</tr>
<tr>
<td>Phoenix</td>
<td>1.5 (5.3)</td>
<td>19.0 (~40*)</td>
</tr>
<tr>
<td>San Francisco</td>
<td>1.0 (3.5)</td>
<td>50.0</td>
</tr>
<tr>
<td>Chicago</td>
<td>1.25 (4.4)</td>
<td>58.3</td>
</tr>
</tbody>
</table>

*Appx reduction with evaporatively pre-cooled condenser
Estimated GS-IHP red. ~2x greater for Phoenix, ~10-15% for other locations
Alternative “Individual Equipment” System Options – Can they do as well as IHP?

- Yes – with improved efficiencies
  - “Best available” suite – 23 SEER/10 HSPF; 2.5 EF HPWH; 2.0 EFd DH (50 pt/d): can yield ~40% savings vs. baseline

- Approaches to “individual suite” options that could achieve ≥50% savings vs. baseline in all locations (including Chicago if heat pump has enough overspeed capability at low ambient)
  - 23 SEER/10 HSPF; 3.0 EF HPWH; 3.0 EFd DH
  - 33 SEER/15 HSPF + best available HPWH & standalone DH
Concluding Observations

- IHP system simulations show significant electricity savings potential vs. current baseline equipment for all electric ZEH/low-energy homes in range of US climates
  - AS-IHP; 46% (Chicago) to 67% (San Francisco) improvement
  - GS-IHP; ~10% greater savings than AS-IHP in mixed-humid and cold climate locations

- Significant summer peak electric demand reduction also
  - AS-IHP; 19% (Phoenix) to 58% (Chicago) at utility peak time
  - GS-IHP; ~2x greater reduction than AS-IHP in Phoenix (~10-15% more in all other locations)

- Adding evaporative pre-cooling of outdoor condenser provides significant additional energy and peak savings in hot-dry climates for AS-IHP

- Efficiency of individual electric SH/SC, WH and DH systems will need relatively large increase to be able to match IHP energy savings potential