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

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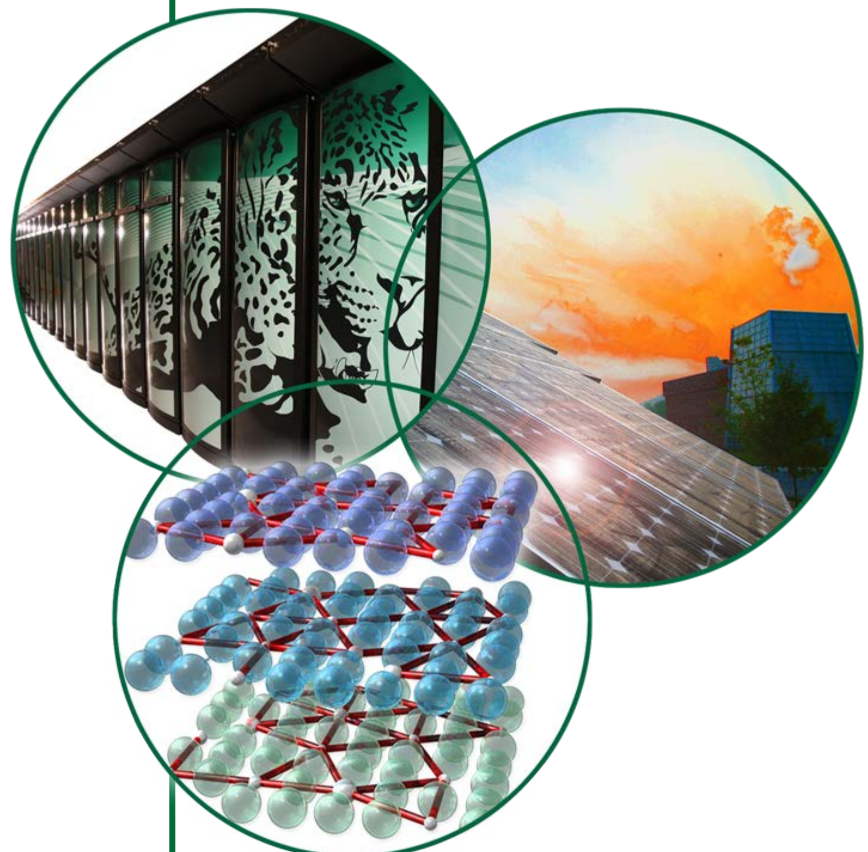

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Assessment of Advanced HVAC/WH Technology Options for NZEH Applications

- 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 ft^2 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 ft^2 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 ft^2 (167 m2) – heat pump size requirements for 5 U.S Locations

Location – climate zone	**Heat Pump Cooling Capacity** Tons (kW)
Atlanta – mixed humid	1.25 (4.4)
Houston – hot humid	1.25 (4.4)
Phoenix – hot dry	1.5 (5.3)
San Francisco – marine	1.0 (3.5)
Chicago - cold	1.25 (4.4)

ZEH/Low Energy House 1800 ft^2 (167 m2) – HVAC/WH Energy Service Loads for 5 U.S Locations

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

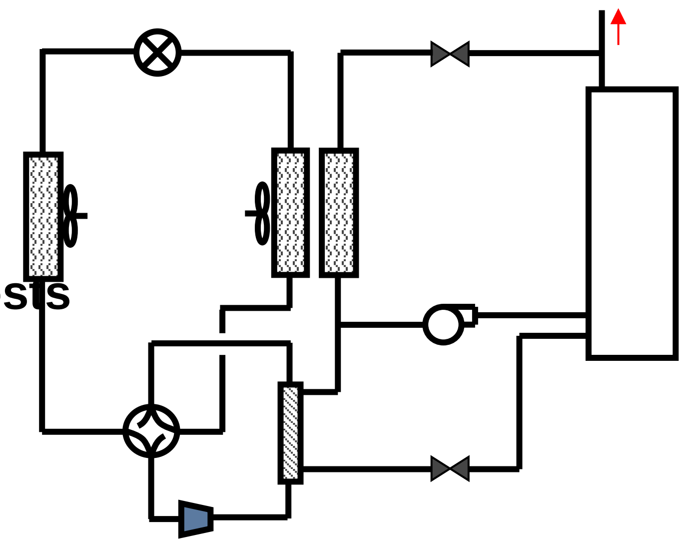
* Dedicated dehumidification – to maintain ID RH≤60% year-round

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**

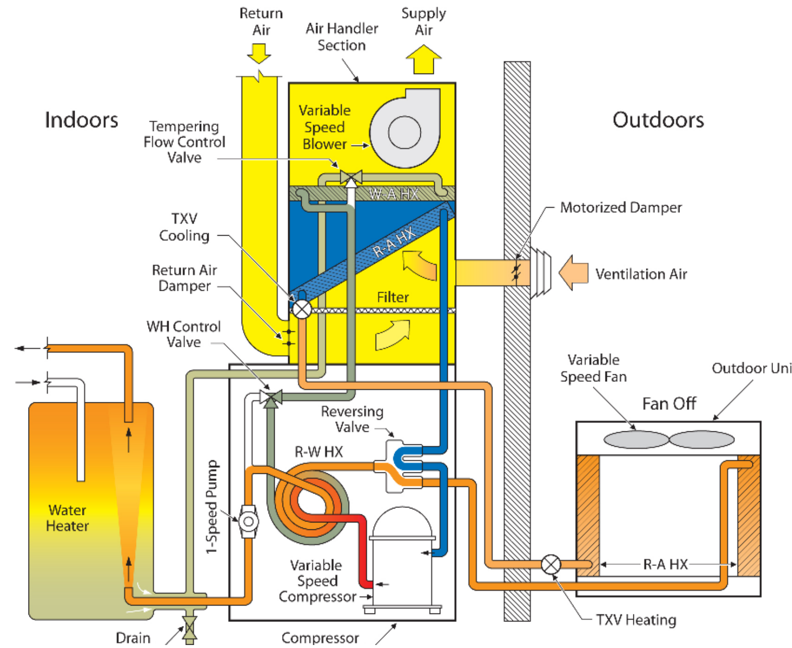
IHP – Initial Equipment Concept

- **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**

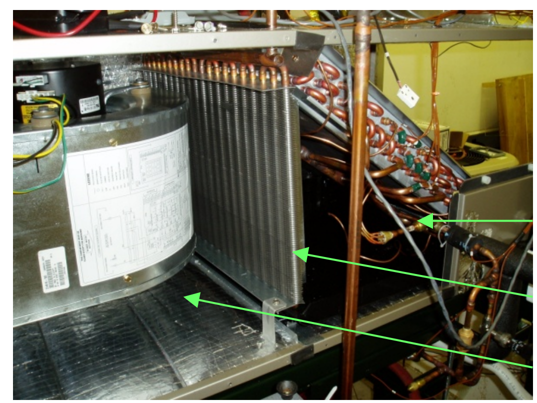


AS-IHP Concept

- **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



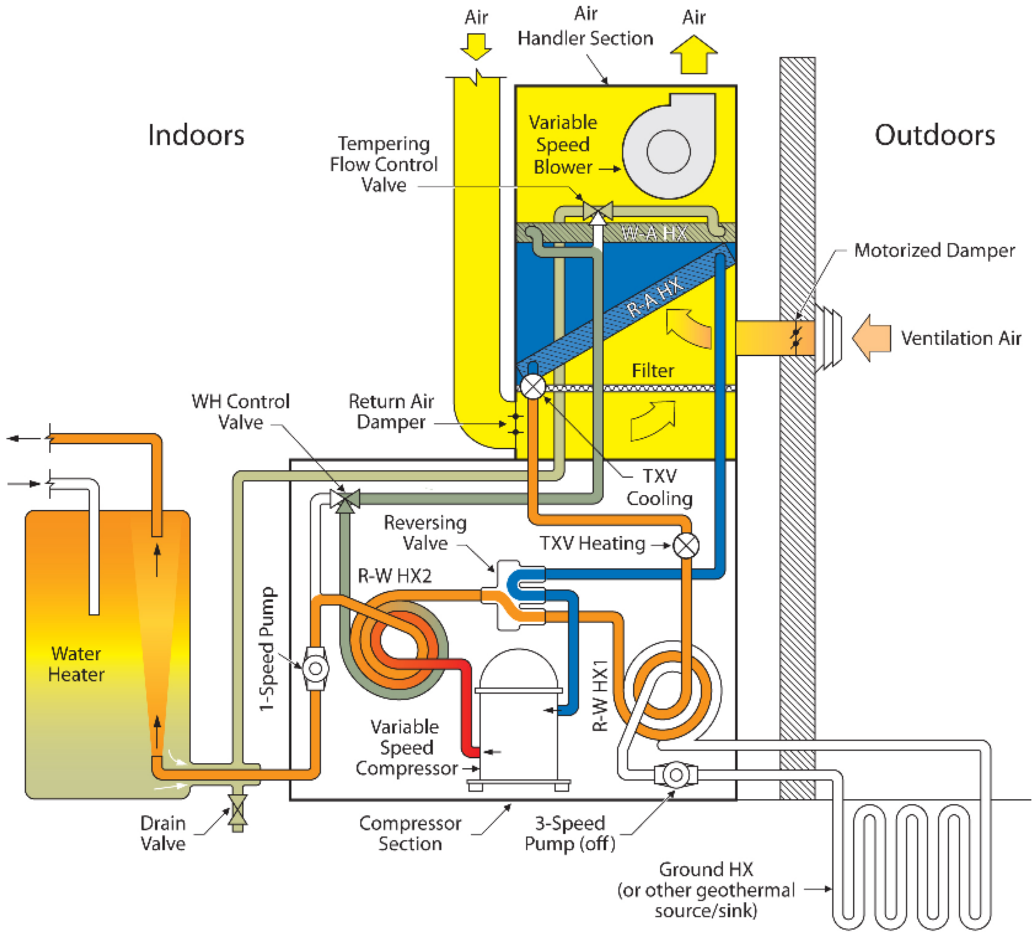
Lab prototype air handler

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**

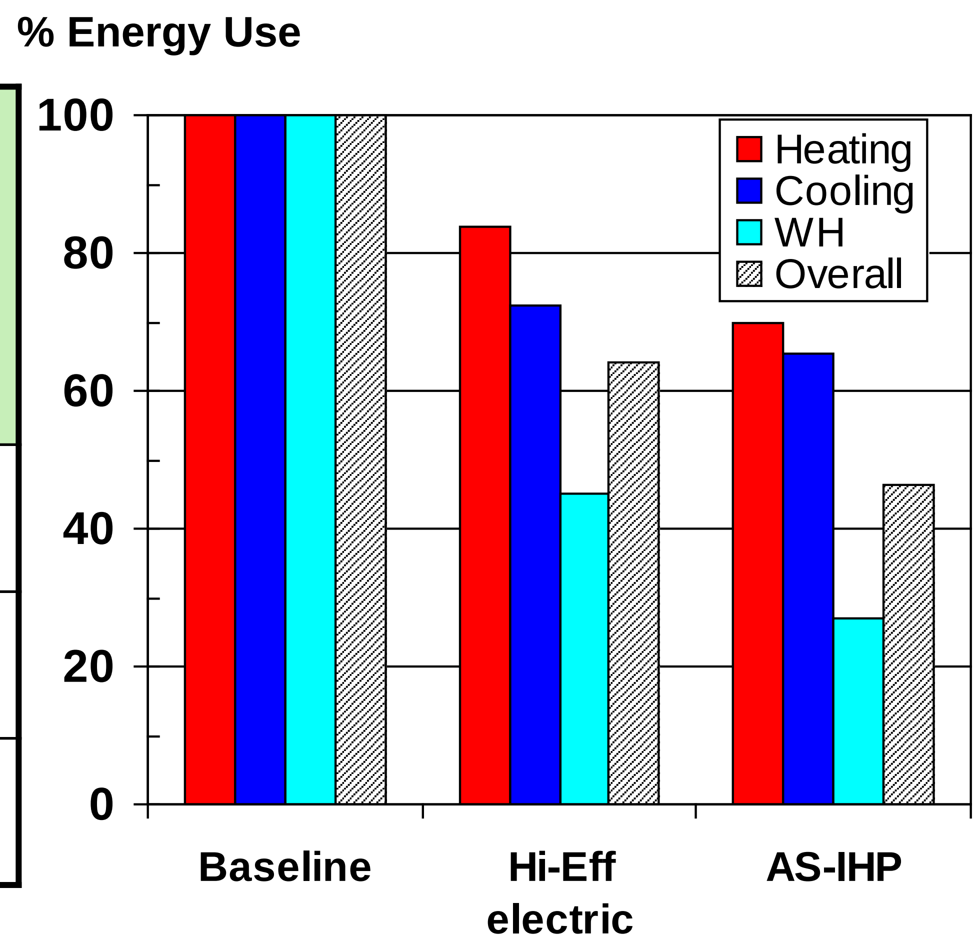
IHP – Seasonal Performance Analysis

- 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 167m^2 ZEH in Atlanta - ~54% savings vs. Baseline, ~20% more than for "Hi-Efficiency" stand-alone suite

Efficiency Equivalent

	Baseline (air/air heat pump + electric resistance water heater)	"Hi-Eff" ASHP + Energy Star heat pump water heater	AS-IHP
Seasonal heating COP	2.67	3.19	3.82
Seasonal cooling COP	3.49	4.83	5.34
WH annual COP	0.89	1.98	3.30



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 ft^2 (167 m^2) ZEH in 5 U.S Locations

Location	Heat Pump Cooling Capacity Tons (kW)	HVAC/WH Energy Consumption Total & (I^2r) backup kWh	% Energy Savings Versus Baseline HVAC/WH System
Atlanta	1.25 (4.4)	3349 (142)	53.7
Houston	1.25 (4.4)	3418 (91)	53.7
Phoenix	1.5 (5.3)	3361 (19)	48.4 (~59%*)
San Francisco	1.0 (3.5)	1629 (100)	67.2
Chicago	1.25 (4.4)	10773 (941)	45.6

*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 ft^2 (167 m^2) ZEH in 5 U.S locations

Location	**Heat Pump Cooling Capacity** Tons (kW)	**% Summer Peak Load Reduction Versus Baseline HVAC/WH System**
Atlanta	1.25 (4.4)	42.9
Houston	1.25 (4.4)	50.0
Phoenix	1.5 (5.3)	19.0 (~40*)
San Francisco	1.0 (3.5)	50.0
Chicago	1.25 (4.4)	58.3

*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 over-speed 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