# Integrated Heat Pump System Technology Development for Net Zero Energy Home (ZEH) Applications


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**IEA Annex 32 Workshop**
**Zurich, Switzerland**
**May 19, 2008**

# DOE/BT Strategic Goal – Net ZEH Technology Market Ready by 2020

## Net Zero Energy Home (ZEH) Definition:

A home with greatly reduced energy use (60% to 70% less) through efficiency gains, with the balance of energy needs supplied by renewable technologies.

## HVAC & Water Heating Program Supporting Goal:

Develop equipment that has potential to reduce HVAC/WH energy use by 50% (from Building America benchmark) in net ZEHs while providing indoor humidity control with no increase in net monthly costs for mortgage and utilities.



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# Assessment of Advanced HVAC/WH Technology Options for NZEH Applications

- Objective – identify portfolio of system options with potential to be developed into 50% savers in long term
- Completed initial scoping studies of HVAC and integrated appliance/water heating options in 2005
  - IHP system concept identified as highest ranked option



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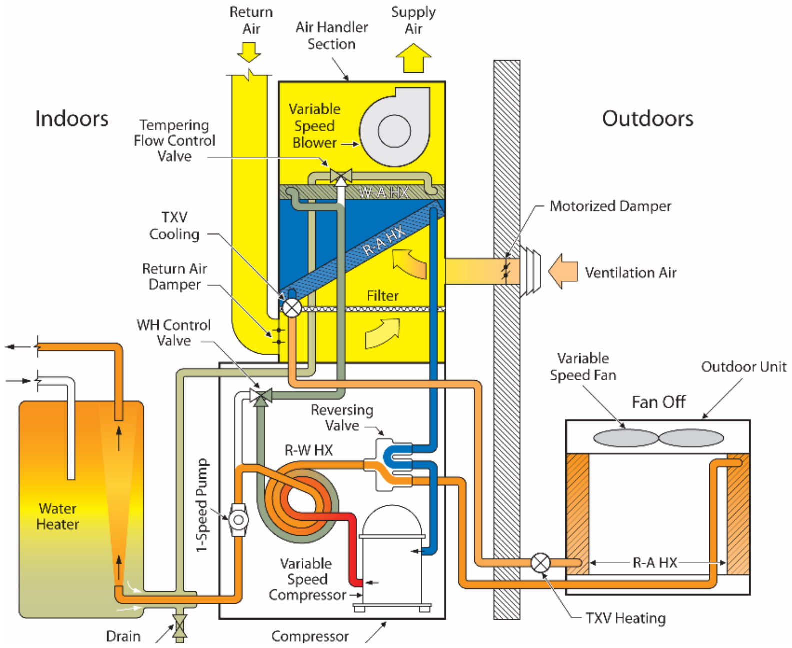
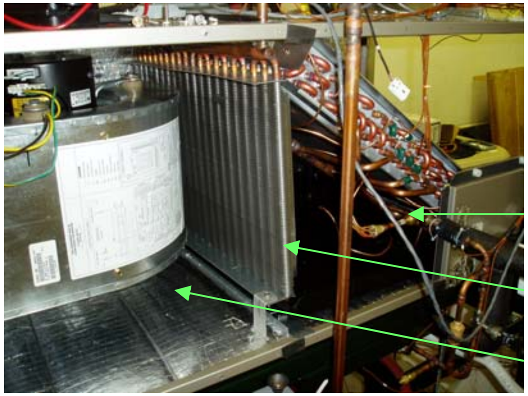
# AS-IHP Concept

- **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

ref/air HX

water/air HX

blower



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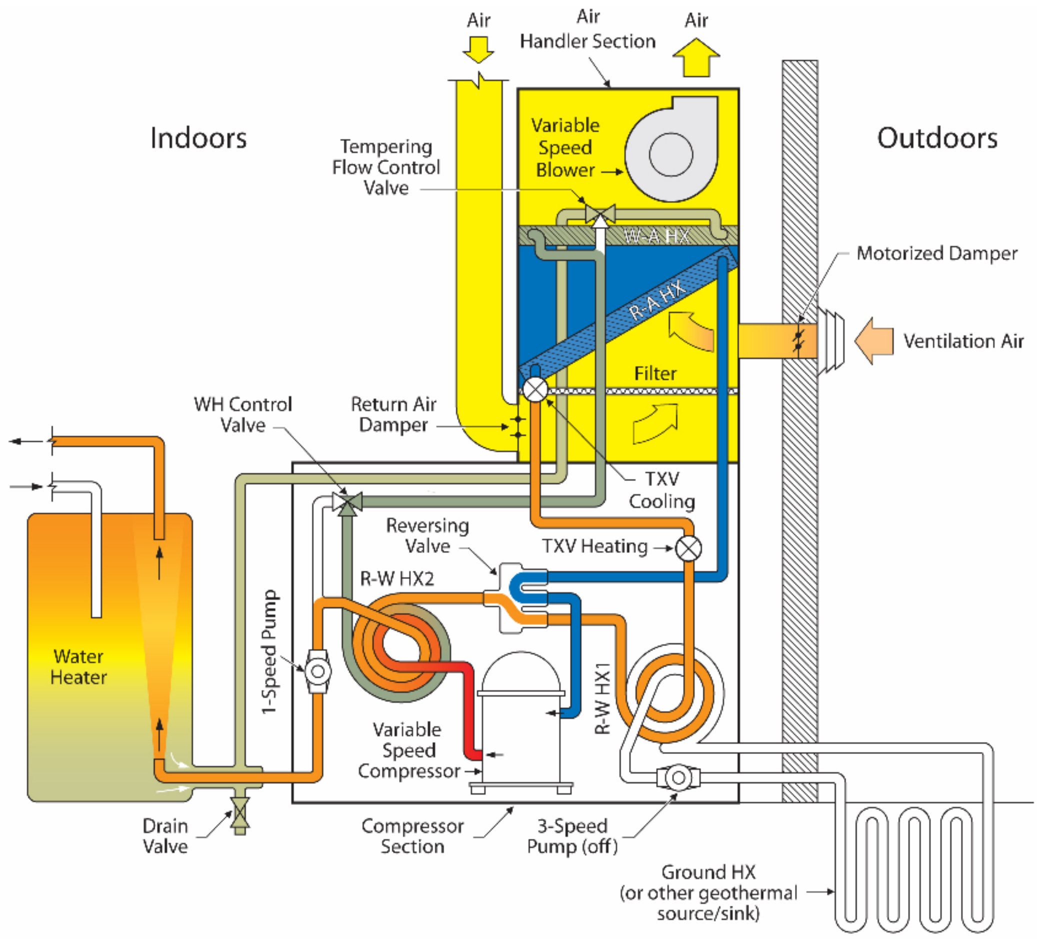
# GS-IHP Concept

- 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
- Cost could approach that of AS-IHP with enhanced GHX designs under development
  - e.g., solid-water-sorbent (SWS) to enhance GHX effectiveness as described in US contribution to Annex 29
  - GHX installed in house foundation excavation (FHX)




**GS-IHP system concept – dehumidification/ventilation/WH mode shown**

# IHP – System Simulation and Performance Analysis Approach

- Lab test data used to calibrate detailed heat pump system model
  - DOE/ORNL Heat Pump Design Model (HPDM)
- Calibrated HPDM used for design optimization and control assessments
  - Establish target compressor and blower speed ranges for major operation modes
    - initially for lab prototype system components (R-22 based)
    - added R-410A compressor map to HPDM and re-optimized design and speed/control relationships for R-410A based systems (both air source and ground source IHPs)

# IHP – Performance Analyses

- Detailed annual performance assessments and initial estimate of installed cost & payback vs. baseline system
  - Baseline system – individual systems to deliver same energy services
    - air-source heat pump + electric storage water heater + stand alone dehumidifier + whole-house ventilation system
    - current or proposed minimum efficiency levels
- Calibrated HPDM linked to TRNSYS simulation engine
  - Enables sub-hourly analysis of IHP annual performance
    - using optimized R-410A based design
  - Confirmed ~50% or greater energy savings potential in most locations for both AS-IHP and GS-IHP
    - Exceptions: AS-IHP in Chicago (~45% savings) and Phoenix (~49% savings)
    - poor heat pump SH and WH efficiency and high reliance on back up electric resistance during extreme cold weather periods in Chicago
    - SC efficiency not quite high enough during extreme hot weather periods in Phoenix to achieve 50% savings
- Estimated performance on following slides



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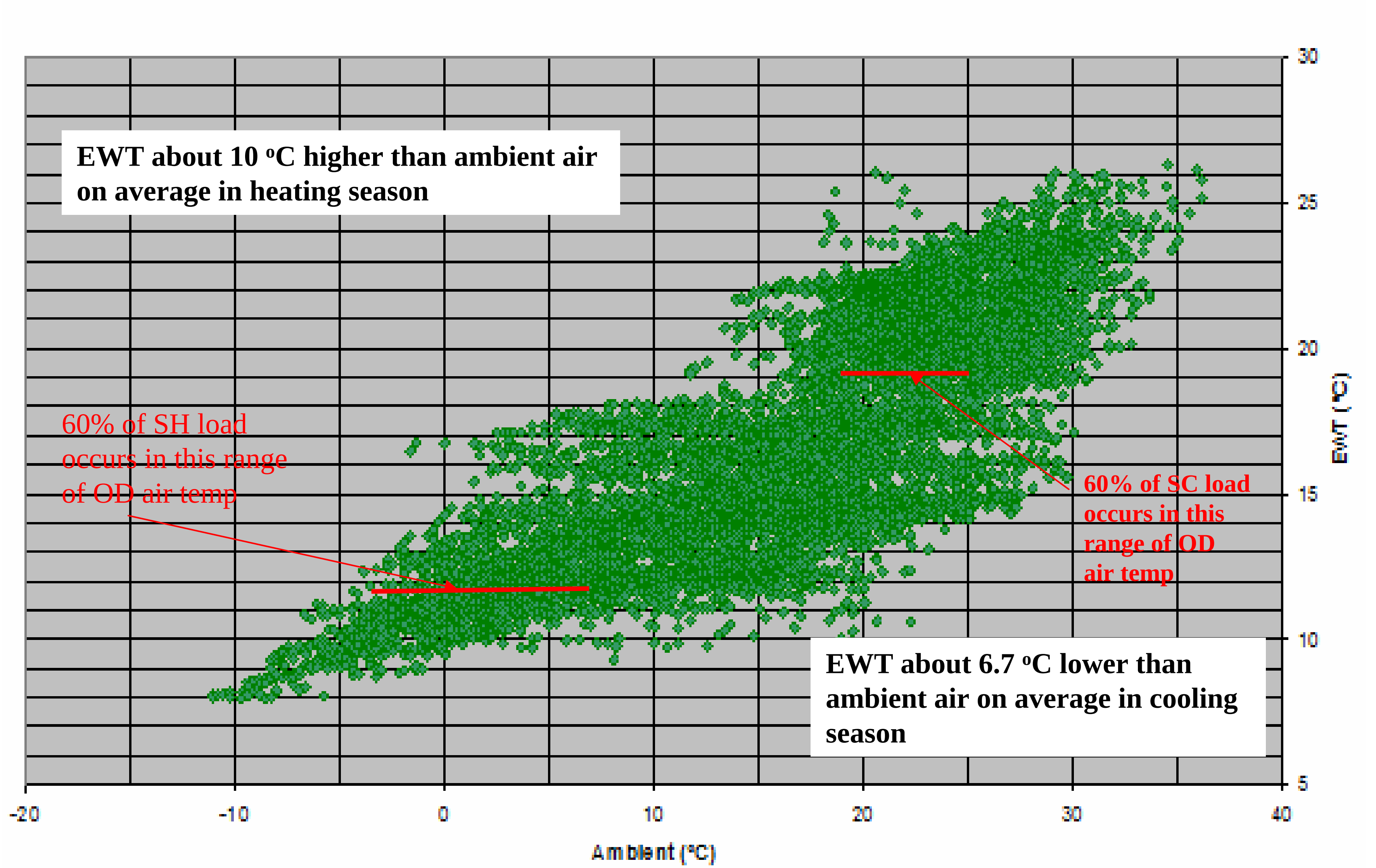
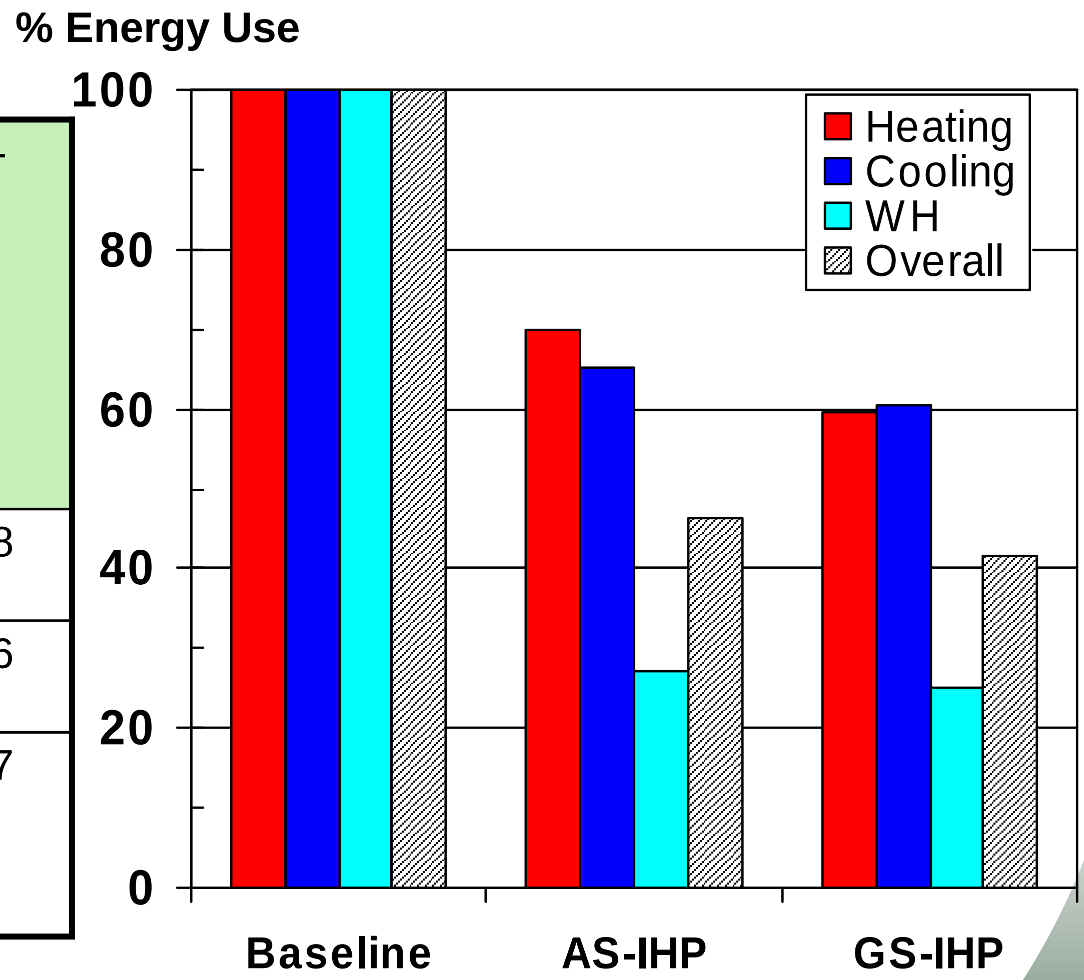
# IHP – Performance Analyses; GS Entering Water Temp (EWT) vs. OD Air Temp, Atlanta, GA



# IHP – Performance Comparison in 167m² NZEH in Atlanta, GA

## Efficiency Equivalent

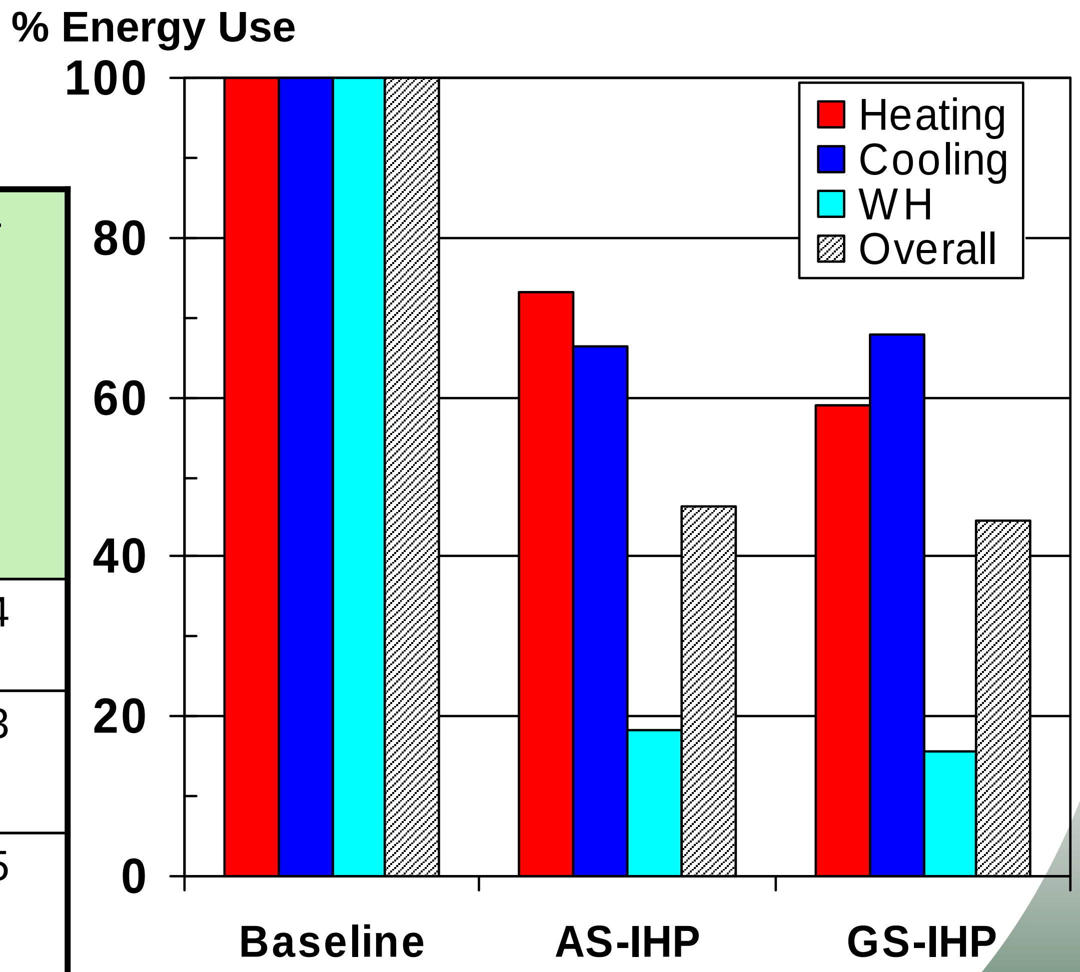
| | Baseline (air/air heat pump + electric resistance water heater) | AS-IHP | GS-IHP |
|---|---|---|---|
| HSPF (W/W) | 2.67 | 3.82 | 4.48 |
| CSPF (W/W) | 3.49 | 5.34 | 5.76 |
| WH Energy Factor (W/W) | 0.89 | 3.30 | 3.57 |



# Loads and Energy Consumption by Operational Mode for IHPs in Atlanta, GA, from TRNSYS/HPDM Simulation – Example Detailed Results

| Loads (167 m$^2$ NZEH) | | Equipment | | | | |
|---|---|---|---|---|---|---|
| | | Baseline | AS-IHP | | GS-IHP | |
| Source | kWh | Energy use, kWh ($I^2r$) | Energy use, kWh ($I^2r$) | Energy reduction compared to baseline | Energy use, kWh ($I^2r$) | Energy reduction compared to baseline |
| Atlanta | | | | | | |
| Space Heating | 4775 | 1789 (51) | 1251 | 30.1% | 1066 | 40.4% |
| Space Cooling | 5735 | 1643 | 1073 | 34.7% | 996 | 39.4% |
| Water Heating | 3032 | 3402 | 924 (142) | 72.8% | 855 (144) | 74.9% |
| Dedicated DH | 158 | 208 | 82 | 60.4% | 73 | 64.9% |
| Ventilation fan | - | 189 | 20 | 89.6% | 17 | 90.9% |
| Totals | 13701 | 7230 | 3349 | 53.7% | 3007 | 58.4% |
| Humidifier water use | 499 kg | | 618 kg | | 647 kg | |

# IHP – Performance Comparison in 167m² NZEH in Houston, TX




## Efficiency Equivalent

| | Baseline (air/air heat pump + electric resistance water heater) | AS-IHP | GS-IHP |
|---|---|---|---|
| **HSPF (W/W)** | 2.73 | 3.73 | 4.64 |
| **CSPF (W/W)** | 3.48 | 5.24 | 5.13 |
| **WH Energy Factor (W/W)** | 0.89 | 4.84 | 5.75 |



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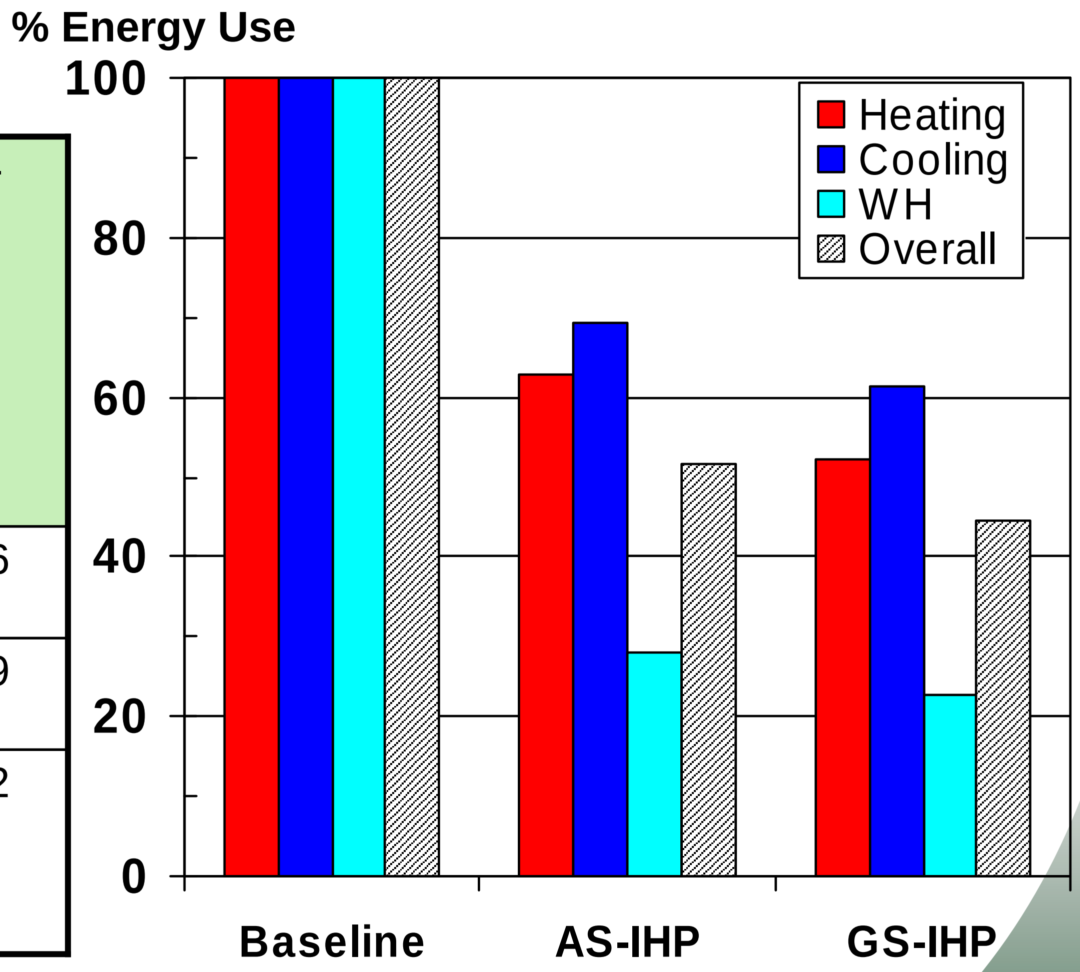
# IHP – Performance Comparison in 167m² NZEH in Phoenix, AZ

## Efficiency Equivalent

| | Baseline (air/air heat pump + electric resistance water heater) | AS-IHP | GS-IHP |
|---|---|---|---|
| **HSPF (W/W)** | 2.95 | 4.70 | 5.66 |
| **CSPF (W/W)** | 2.94 | 4.25 | 4.79 |
| **WH Energy Factor (W/W)** | 0.89 | 3.56 | 4.42 |



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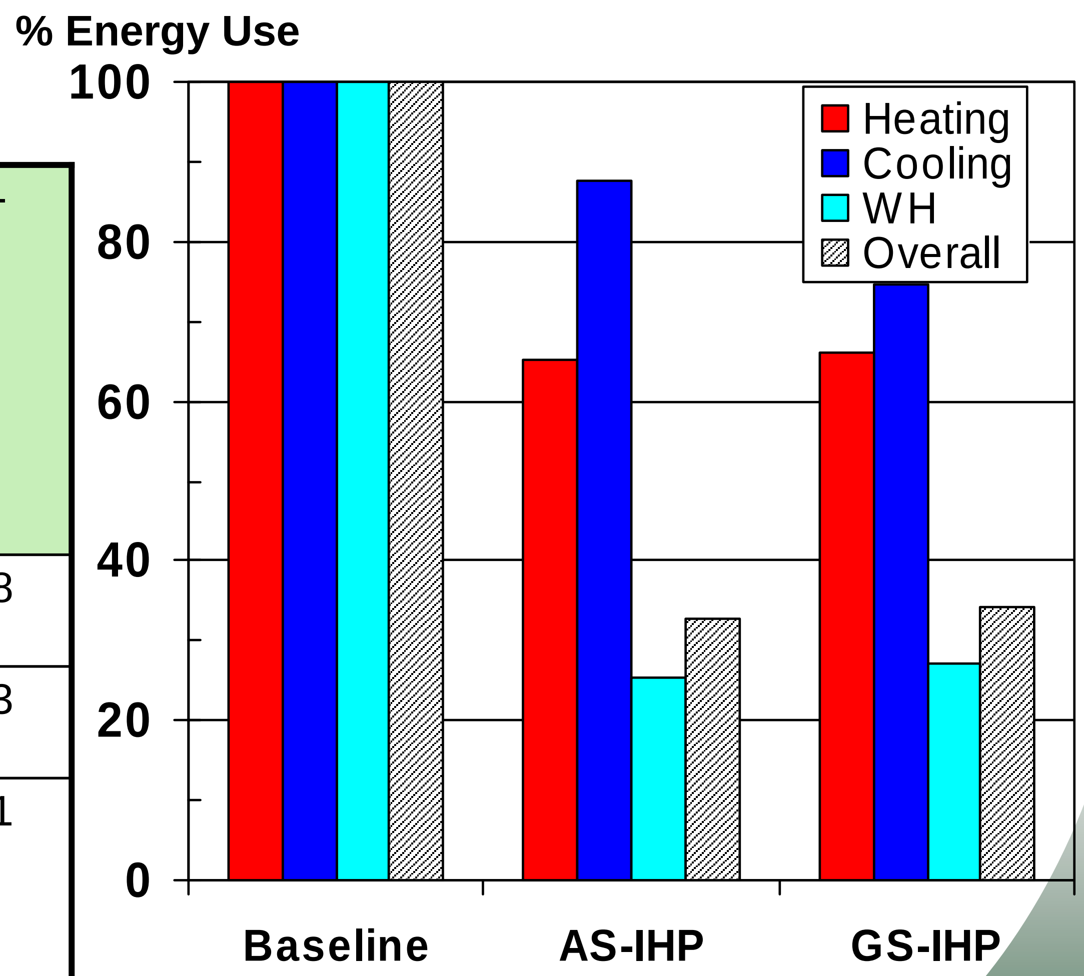
# IHP – Performance Comparison in 167m² NZEH in San Francisco, CA

## Efficiency Equivalent

| | Baseline (air/air heat pump + electric resistance water heater) | AS-IHP | GS-IHP |
|---|---|---|---|
| **HSPF (W/W)** | 3.09 | 4.75 | 4.68 |
| **CSPF (W/W)** | 3.38 | 3.83 | 4.63 |
| **WH Energy Factor (W/W)** | 0.90 | 3.55 | 3.31 |



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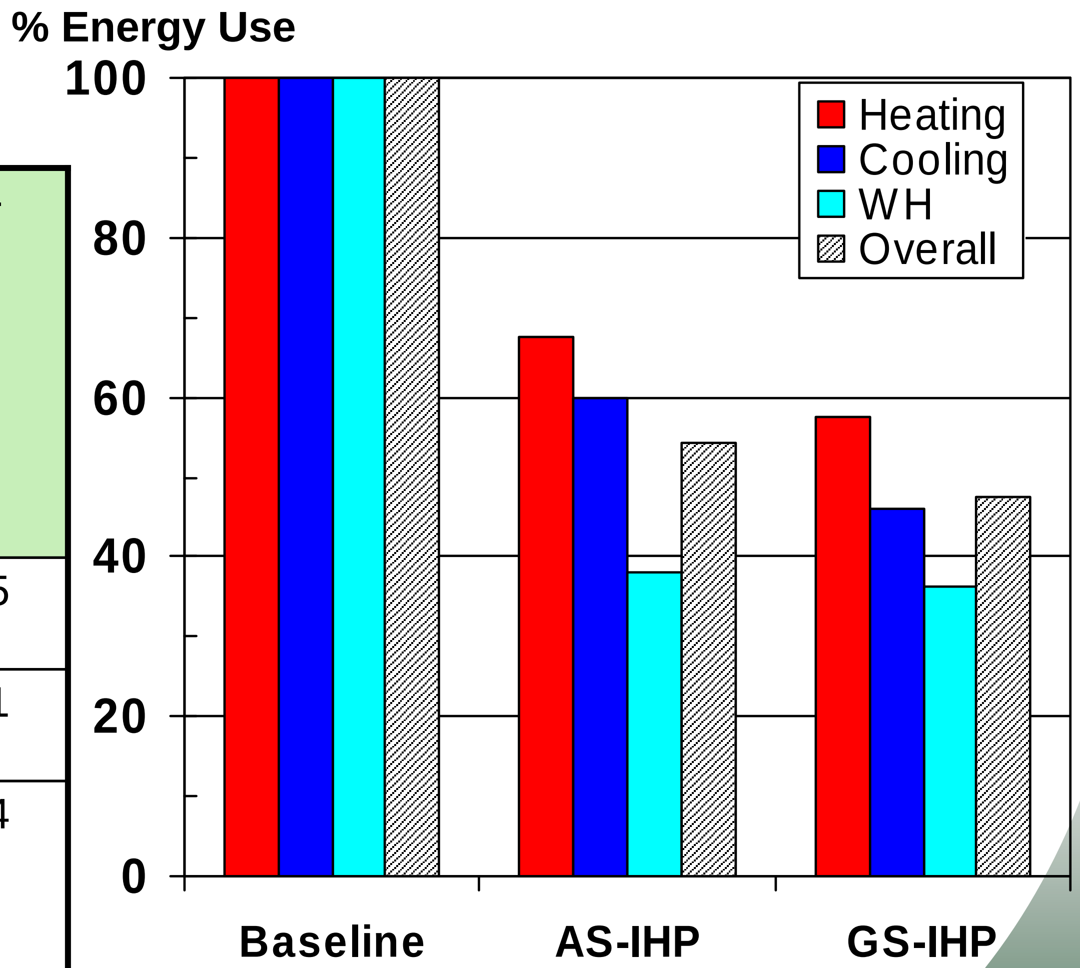
# IHP – Performance Comparison in 167m² NZEH in Chicago, IL

## Efficiency Equivalent

| | Baseline (air/air heat pump + electric resistance water heater) | AS-IHP | GS-IHP |
|---|---|---|---|
| **HSPF (W/W)** | 2.10 | 3.10 | 3.65 |
| **CSPF (W/W)** | 3.50 | 5.85 | 7.61 |
| **WH Energy Factor (W/W)** | 0.89 | 2.32 | 2.44 |



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# IHP – Conclusions To-Date and Future Directions

- IHP system simulations show significant performance enhancement compared to current baseline equipment system for net zero energy houses (ZEH) in range of US climate types
  - AS-IHP; 46% (Chicago) to 67% (San Francisco) improvement
  - GS-IHP; 52% (Chicago) to 66% (San Francisco) improvement
    - very mild ambient temperatures favor air source systems in San Francisco
- Significant summer peak electric demand reduction also
  - AS-IHP; 20% (Phoenix) to 60% (Chicago) at utility peak time
  - GS-IHP; 45% (Phoenix) to 70% (Chicago) at utility peak time
- Initial estimates of simple payback vs.. baseline *in net ZEH*
  - AS-IHP;  5 (Houston) – 10 (Phoenix) years
  - GS-IHP;  6.5 (Chicago) – 14 (Phoenix) years (*with vertical bore GHX*)
    - with successful cost reduction efforts (SWS enhanced GHX, FHX concept, etc.) costs could be about equal to those of AS-IHP



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# IHP – Conclusion To-Date and Future Directions, Contd.

- All R&D so far focused on net ZEH application
  - that market is vanishingly small at present
- During next 1-2 years, we will be working with two manufacturer to develop initial products based on IHP concept
  - One for AS-IHP and one for GS-IHP; GS-IHP development at more advanced stage
    - AS-IHP: evaluating potential product configurations and potential markets; if outcome positive will begin prototype lab development/testing by late 2008 with initial field tests beginning mid-late 2010; 2$^{nd}$ round field test/demonstration of ~10 pre-production units planned to begin mid-late 2011
    - GS-IHP: prototype development/testing underway; initial field testing planned to begin by December 2009; 2$^{nd}$ round pre-production test/demonstration planned to begin late 2010
  - Both approaches will be modifications of ZEH IHP design described in this presentation – to meet needs of current housing market and specific manufacturer capabilities
    - Probably eliminate some functions – demand dehumidification to be option
    - Possibly use less expensive components
    - Final compromises to be determined