

# US presentation: integrated heat pump (IHP) systems' status

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IEA HPT Annex 49 Workshop

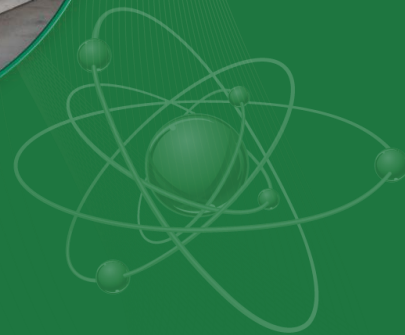
13<sup>th</sup> IEA Heat Pump Conference

April 26, 2021

Thanks to my US Annex 49 colleagues, Dr. Vance Payne of NIST and Dr. Reinhard Radermacher of Univ. of MD.

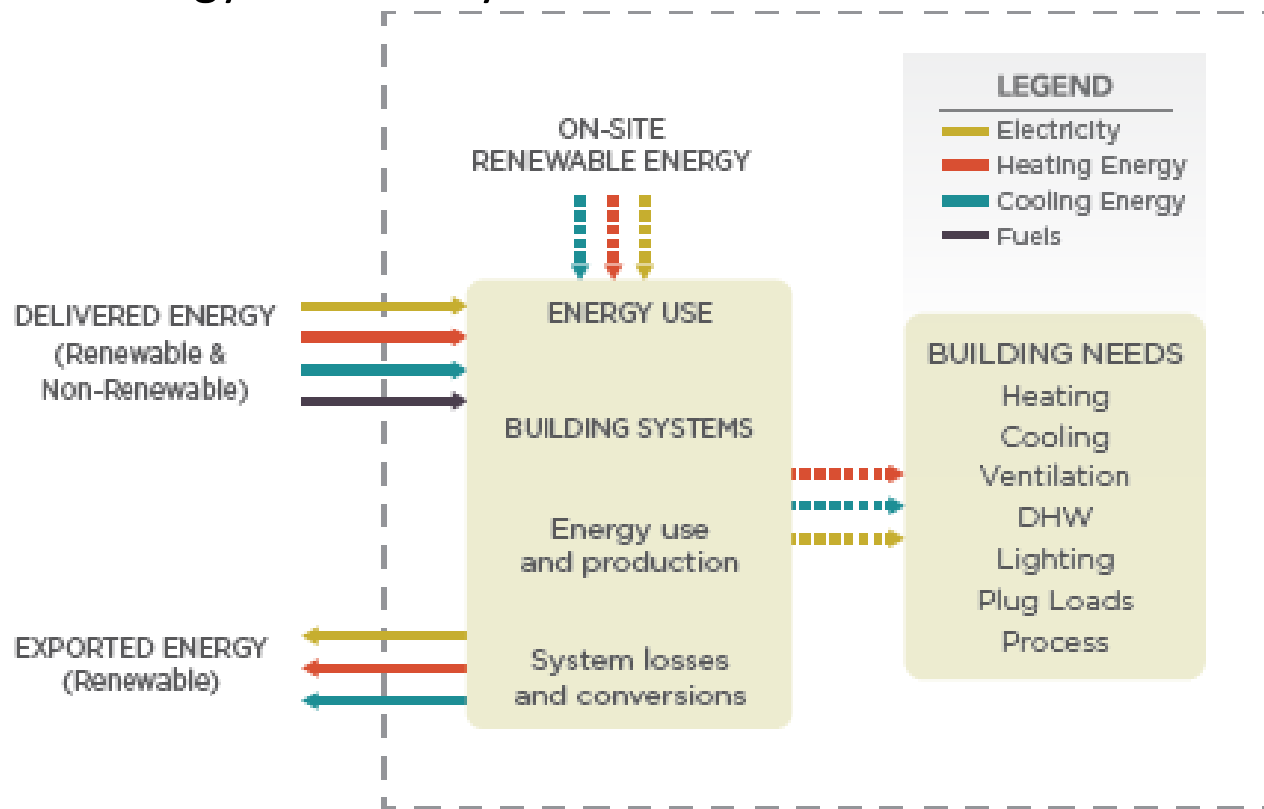
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# US DOE Definitions

- ZEB – An energy-efficient **building** where, on a source energy basis, the actual **annual delivered energy** is less than or equal to the on-site renewable **exported energy**
- Similar definitions for: zero energy campus, zero energy portfolio, and zero energy community



“A Common Definition for Zero Energy Buildings,”  
DOE/EE-1247, Sept. 2015

# *Mapping US contributions to Annex 49 tasks*

Task 1 – SOA Analysis (US report submitted early in 2019)

Task 3 – Technology Development and Field Monitoring

- NIST – Net Zero Energy Residential Test Facility (NZERTF)
  - Field evaluations of air-to-air air-source heat pump (ASHP) systems with different air circulation system designs
- Univ. of MD (UoMD) – development and evaluation of mobile personal comfort conditioning system, aka Roving Comforter (RoCo)
- ORNL – integrated (or multi-function) heat pump (IHP) systems
  - Field demo results for electric ground source product (GS-IHP)
  - Field test results for prototype electric air source IHPs (AS-IHP)
  - Development status of gas engine driven AS-IHP systems (small commercial and residential)

# Gas-engine-driven Air-Source Integrated Heat Pumps (GAS-IHP)

Commercial system field test, 2014-15:

- Test conducted in commercial building in Las Vegas, NV
- Two baseline comparison systems:
  - Electric rooftop AC unit (RTU) & electric WH
  - Electric RTU & gas WH
- Energy savings
  - Electric RTU/WH: 21.3%
  - Electric RTU/gas WH: 16.9%
- Simple payback (for \$6,000 cost premium)
  - Electric RTU/WH: 3.5 years
  - Electric RTU/gas WH: 3.7 years

- E. A. Vineyard, et al., “Field Demonstration of Gas Heat Pump Rooftop Unit with Waste Heat Recovery for Water Heating,” September 2015



Field test building: ~4150 m<sup>2</sup> total floor area  
~325 m<sup>2</sup> serviced by GAS-IHP field test unit  
(kitchen, training room, some warehouse space)

# ***GAS-IHP: Residential System***

Gas-engine driven – variable-speed AS-IHP; residential system ~17 kW cooling; ~20 kW heating; ~9 kW WH

- 1.1 cooling (@ 35C) and 1.3 heating (@ 8.3C) COPs; lab measured

Field tests in Las Vegas

- 8-13% source energy savings vs. 3.8 CSPF (13 SEER) electric heat pump baseline

Final prototype cost estimated at up to **\$15,000**

- **Severe market barrier; Southwest Gas estimated cost should be closer to \$8,000**

A. M. Momen, et al., Multi-Function Gas Fired Heat Pump, ORNL/TM-2015/701, Nov. 2015

2018-2019 value engineering project estimated ~44% cost reduction possible



Initial prototype

Engine

Compressor

Final prototype, 2015



Engine & compressor compartment

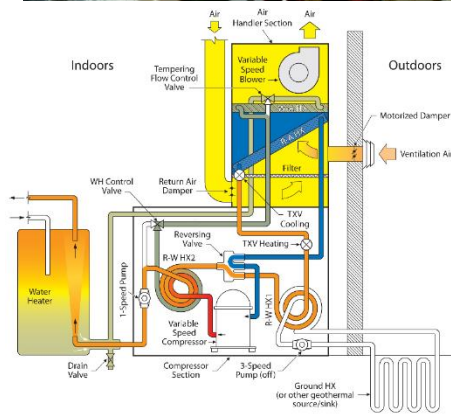
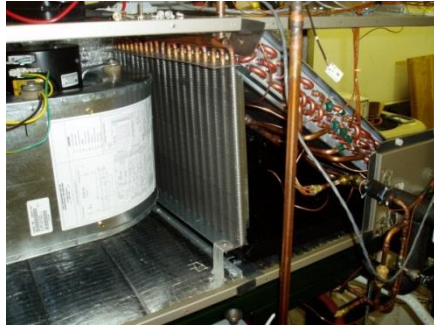


Overall system

# Electric Ground-Source Integrated Heat Pump (GS-IHP) - new product on market

- ClimateMaster (CM) development - Trilogy 45™ Q-mode™
  - Market introduction in late 2012
  - <https://www.climatemaster.com/Homeowner/side-links/products/product-details/trilogy>
- Field demonstration at two commercial/institutional building sites in 2015/16
  - Baxter, et al “Field Demonstration of Ground-Source Integrated Heat Pump,” ORNL/TM-2016/474, Sep 2016

ORNL lab prototype IHP concept



1st generation prototype GS-IHP



Partnership with CM to develop 1<sup>st</sup> gen field test prototype (tested 2010/2011)

- 52-59% predicted annual savings in various locations vs. baseline ASHP & electric WH

ClimateMaster develops new GS-IHP product



2<sup>nd</sup> gen prototype developed

- 2012/2013 field tests;
- documented in Annex 40 final report

Trilogy 45® Q-mode™ product

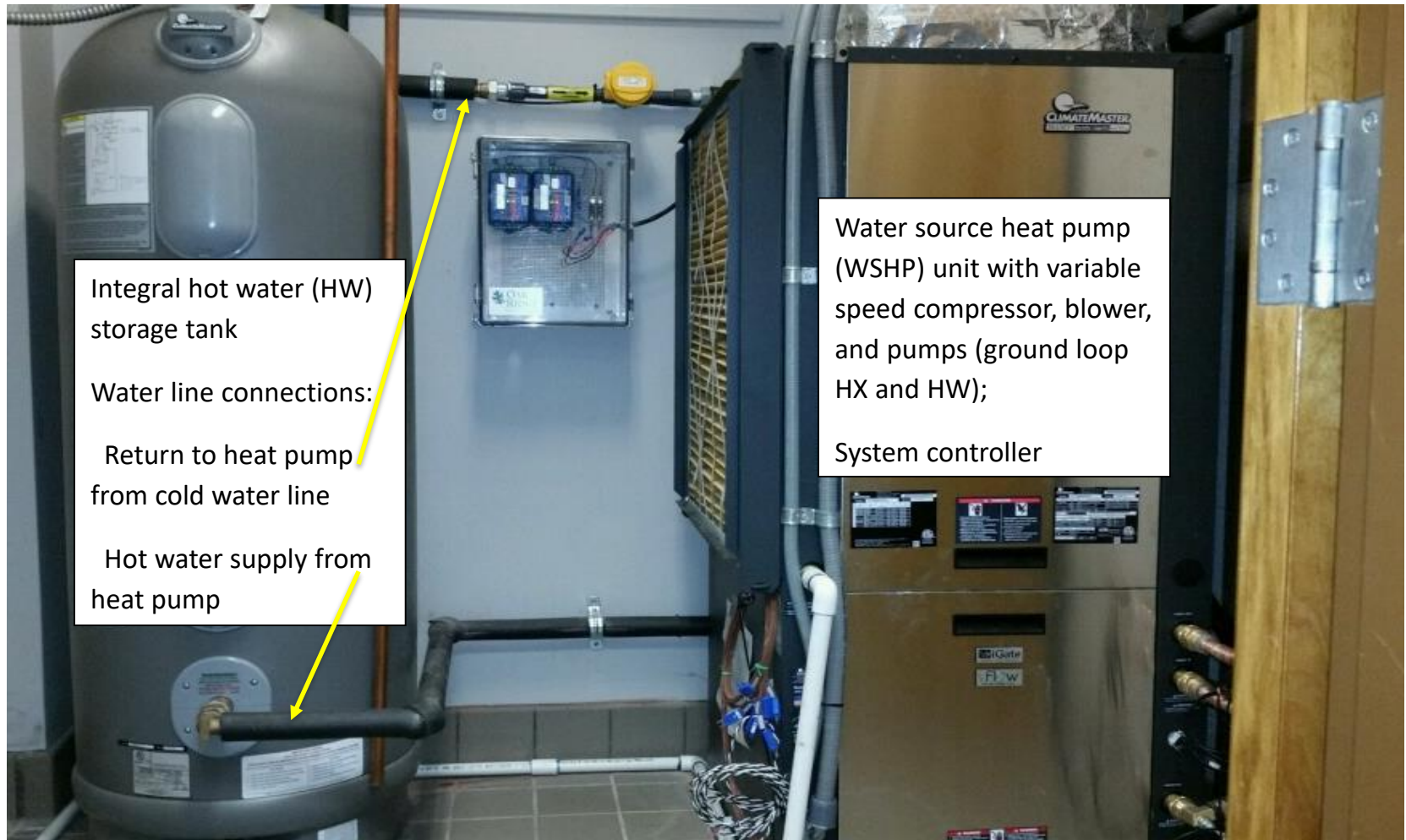
- Market introduction 2012
- 2015/2016 field demonstration



An LSB Industries, Inc. Company (NYSE: LXU)



# GS-IHP System description



# GS-IHP System description

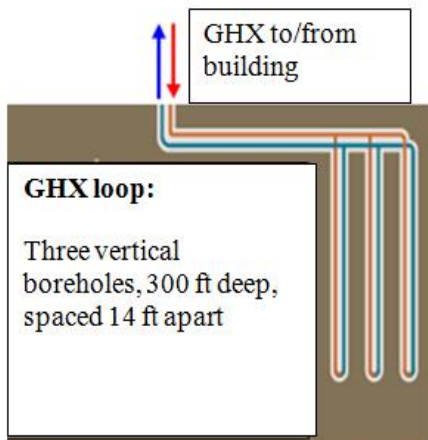
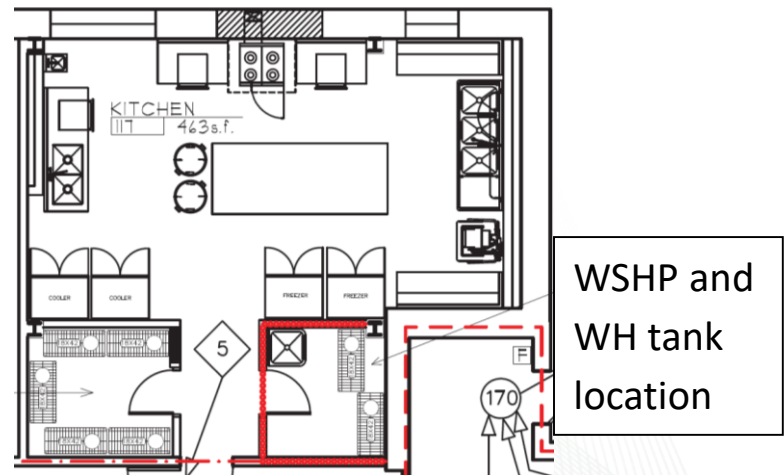
- Variable speed (VS) WSHP with 4 modes of operation:
  - Space heating (SH)
  - Space cooling (SC)
  - Space cooling + domestic water heating (SC+WH)
  - Dedicated domestic water heating (WH)
- VS compressor allows 1) constant WH output regardless of ground temp. and 2) a “boost” WH capacity mode when the SH demand is high to decrease the tank recovery time.
  - WH has priority unless space temp. falls below min. limit in winter

# Field Test Site 1



Knoxville, TN  
Day care center  
Kitchen  
Aerial view  
(Photo courtesy  
Google Maps)

Kitchen area layout



**GHX loop:**  
Three vertical  
boreholes, 300 ft deep,  
spaced 14 ft apart

# GS-IHP Field Test Unit vs. Baseline

## Aug. 2015-Aug. 2016 field performance, Knoxville

Parameters	GS-IHP (measured)	Baseline RTU/WH (estimated) <sup>c</sup>
Total space cooling (SC) delivered, kWh	16792	16792
SC energy use, kWh (GS-IHP savings vs. baseline)	2165 (46.3%)	4032
Average SC COP	7.73	4.15
Total space heating delivered, kWh	0.0	0.0
Water heating (WH)		
WH from heat pump to tank, kWh	2730	--
WH del. to kitchen, kWh	2106	2106
GS-IHP tank backup, kWh	1.5	--
Total WH energy use, kWh (GS-IHP savings vs. baseline)	646 (72.4%)	2340
Average WH COP or EF (WH COP/EF based on energy delivered to tank)	3.26 <sup>a</sup> (4.23)	0.90 (1.00)
Total system energy use (savings %)	2962 <sup>b</sup> (54.6%)	6519
Carbon eq. emissions (MT)	2.0	4.5

<sup>a</sup>Based on WH delivered to kitchen (includes tank and connecting line losses)

<sup>b</sup>Including misc. use for controls, etc.

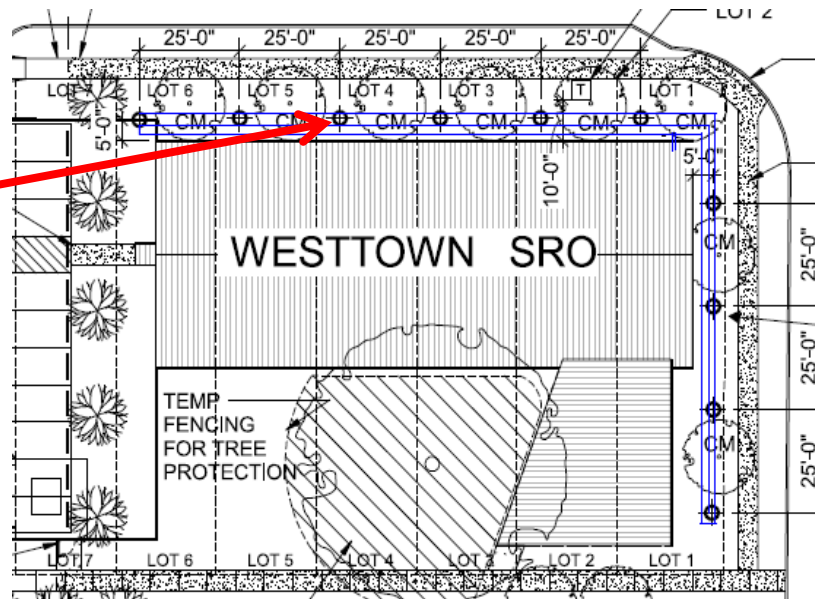
<sup>c</sup>Simulated based on same SC and WH loads

# Field Test Site 2



Oklahoma City, OK  
Homeless shelter dormitory  
Two GS-IHP units each serving 10  
dormitory units of ~23 m<sup>2</sup> each  
Two other non-integrated GSHPs  
serving building common areas and  
offices

GHX – ten vertical boreholes,  
each 152m deep and 7.6m  
apart



# GS-IHP Field Test Unit vs. Baseline

## Jan-Sept 2016 field performance, OK City

Parameters	GS-IHP (measured)	Baseline RTU/WH (estimated) <sup>c</sup>
Apr-Sept: space cooling (SC) delivered, kWh	12937	12937
SC energy use, KWh (GS-IHP savings)	1866 (49.7%)	3713
Average SC COP	6.93	3.48
Feb-Apr: space heating (SH) delivered, kWh	3455	3455
SH energy use, KWh (GS-IHP savings)	700 (51.2%)	1453
Average SH COP	4.94	2.38
May-Sept: Water heating (WH)		
WH energy delivered to tank, kWh	2761	2761
GS-IHP tank backup, kWh	19.1	--
Total WH energy use, kWh (GS-IHP savings)	622 (77.5%)	2761
Average WH COP <sup>a</sup>	4.44 <sup>a</sup>	1.00
Est. full year energy use (savings %)	8373 <sup>b</sup> (67.4%)	25,653
Est. full year carbon eq. emissions (MT)	5.7	17.7

<sup>a</sup>Based on WH delivered to tank (excludes tank loss; includes IHP-to-tank line losses)

<sup>b</sup>Including misc. use for controls, etc.

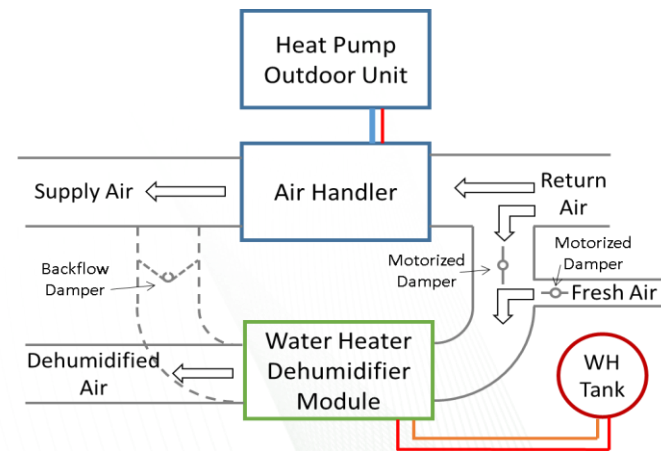
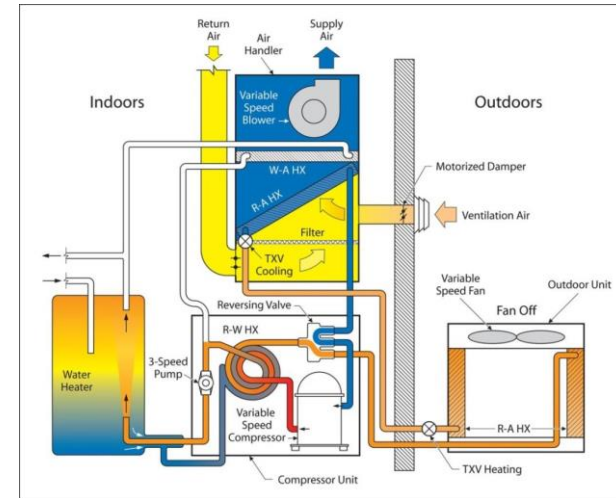
<sup>c</sup>Simulated based on same SC and WH loads

# Summary

- Site 1, Knoxville (full year data)
  - GS-IHP system demonstrated ~55% energy savings vs. simulated RTU/heat pump + electric storage WH baseline system meeting same loads at the Knoxville test location
  - up to ~80% monthly hourly peak kW reduction vs. base RTU/WH
  - ~8 year simple payback with “mature market” GS-IHP installed cost assumption
- Site 2, Oklahoma City (partial year data)
  - GS-IHP system demonstrated SH, SC, and WH energy savings of ~51%, ~50%, and ~77%, respectively, for actual test period
    - Full-year energy savings estimated at ~67%
  - Monthly hourly peak kW reduction ranged from about 40-70%

# Two electric AS-IHP concepts

- 1. integral single VS system
  - Space heating (SH)
  - Space cooling (SC)
  - Space cooling + domestic water heating (SC+WH)
  - Dedicated domestic water heating (WH)
  
- 2. two interconnected systems
  - VS ASHP unit for SH and SC
  - Separate WH/DH module
    - Dedicated WH function
    - Dedicated DH function (ideal for highly humidity locations)
  - Integrated via air distribution system



# Electric AS-IHP prototype field tests



223 m<sup>2</sup> test house  
(simulated occupancy based  
on Building America protocol)  
HDD → 1997 C-days  
CDD → 841 C-days

Field test systems



- Two prototypes developed and field tested
  - System 1, October 2014 through September 2015
  - System 2, October 2015 through September 2016
- No AS-IHP systems on market in US to date

# AS-IHP system 1 field test performance vs. Baseline

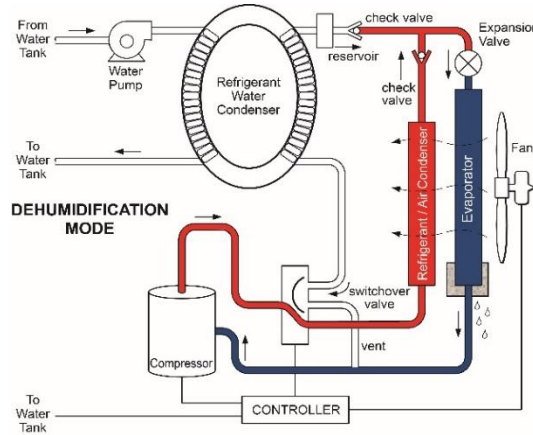
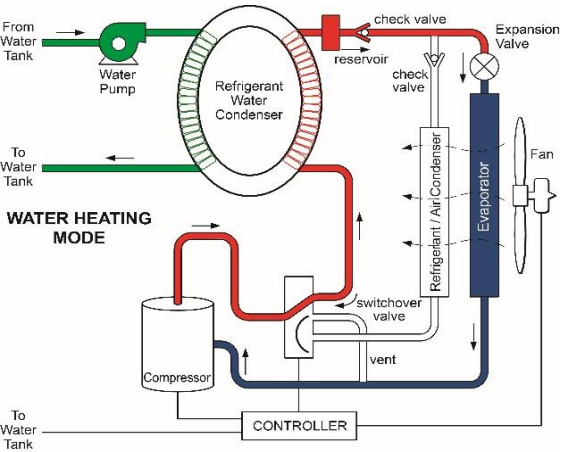
Parameters	AS-IHP 1 (2014-15 measured)	Baseline ASHP & electric WH (estimated) <sup>b</sup>
Total SC energy delivered, kWh	7,416	7,416
SC energy use, kWh (savings vs. baseline)	1,444 (55%)	3,244
Average SC COP	5.14	2.29
Total SH energy delivered, kWh	12,125	12,125
SC energy use, kWh (savings vs. baseline)	5,899 (20%)	7,360
Average SH COP	2.06	1.65
Total WH energy delivered to tank <sup>a</sup>	3,104	3,104
WH energy use, kWh (savings vs. baseline) <sup>a</sup>	1,199 (63%)	3,104
Average WH COP <sup>a</sup>	2.68	1.00
<b>Total energy use, kWh</b>	<b>8,542</b>	<b>13,708</b>
<b>AS-IHP total energy savings, %</b>	<b>38%</b>	<b>--</b>

<sup>a</sup>Based on WH delivered to tank (excludes tank loss; includes IHP-to-tank line losses)

<sup>b</sup>Estimated based previously measured Baseline ASHP seasonal COPs in same area and using measured test house loads

Baxter, V. D., et al., Advanced Variable Speed Air Source Integrated Heat Pump (AS-IHP) Development – Final Report, ORNL/TM-2015/525, Sept. 2015

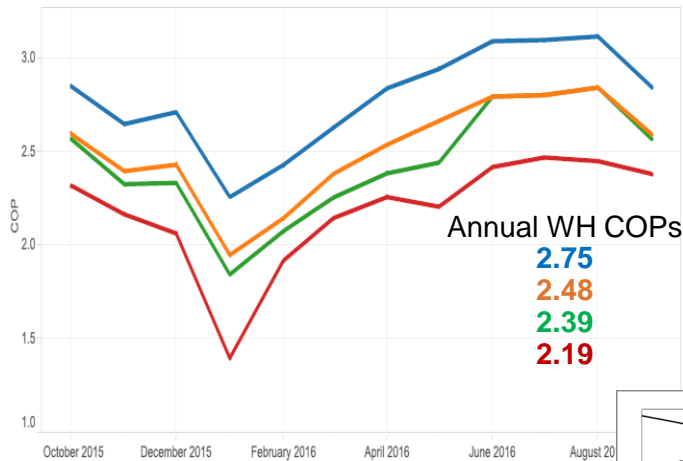
# Electric AS-IHP 2: WH/DH module



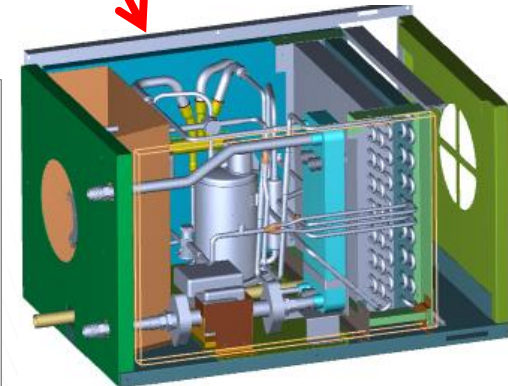
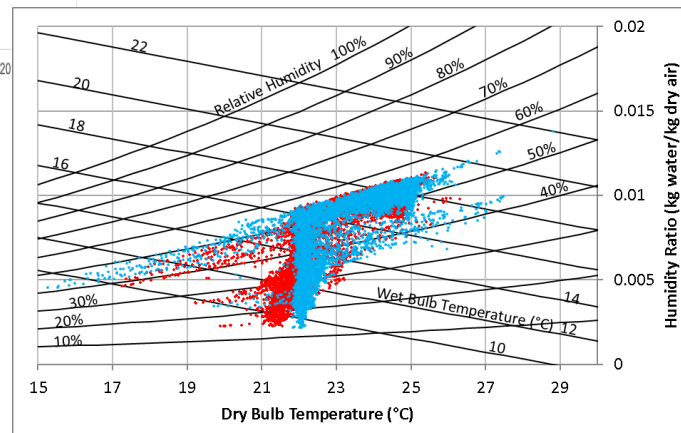
← Piping and general layout schematic



Photo & CAD schematic



WH results  
 ~10% line loss  
 (WH/DH-to-tank lines)  
 ~5% backup electric WH  
 ~10% tank loss to ambient



DH results  
 Average Hourly Temperature and Humidity for Floors 1 and 2  
 96% of hours between 21.7C and 24.4C  
 DH setpoint 55% RH  
 Average DH efficiency ~1.7 L/kWh

# AS-IHP system 2 field test performance vs. Baseline

Parameters	AS-IHP 2 (2015-16)	Baseline ASHP & electric WH <sup>b</sup>
Total SC energy delivered, kWh	9,189	9,189
SC energy use, kWh (savings vs. baseline)	2,201 (45%)	4,013
Average SC COP	4.17	2.29
Total SH energy delivered, kWh	11,651	11,651
SC energy use, kWh (savings vs. baseline)	5,225 (26%)	7,061
Average SH COP	2.23	1.65
Total WH energy delivered to tank <sup>a</sup>	2,739	2,739
WH energy use, kWh (savings vs. baseline) <sup>a</sup>	1,146 (58%)	2,739
Average WH COP <sup>a</sup>	2.39	1.00
<b>Total energy use, kWh</b>	<b>8,572</b>	<b>13,813</b>
<b>AS-IHP total energy savings, %</b>	<b>38%</b>	<b>--</b>

<sup>a</sup>Based on WH to tank (excludes tank loss; includes IHP-to-tank line loss and backup electric)

<sup>b</sup>Estimated based previously measured Baseline ASHP seasonal COPs in same area and using measured test house loads

Baxter, V. D., et al., Air Source Integrated Heat Pump Development – Final Report, ORNL/TM-2017/305, July 2017

# AS-IHP Summary

- Prototype field test results
  - Both systems demonstrated ~40% energy savings vs. baseline ASHP + electric storage WH baseline system for same loads at Knoxville research test house
  - Bulk of savings due to superior SC and WH efficiency compared to baseline
    - 4.2-5.1 Cooling SPF and 2.4-2.7 avg. seasonal WH COP
    - 45-55% SC energy savings; 55-63% WH savings
- Based on test results, best applications for AS-IHP should be those with thermal loads dominated by WH and SC
  - Commercial applications appear to be the best fit
    - Restaurants, commercial laundries, health/fitness centers, lodging facilities, etc.
    - HPWHs could fill this need almost as well and are simpler design