Development of an Air-Source Heat Pump Integrated with a Water Heating / Dehumidification Module

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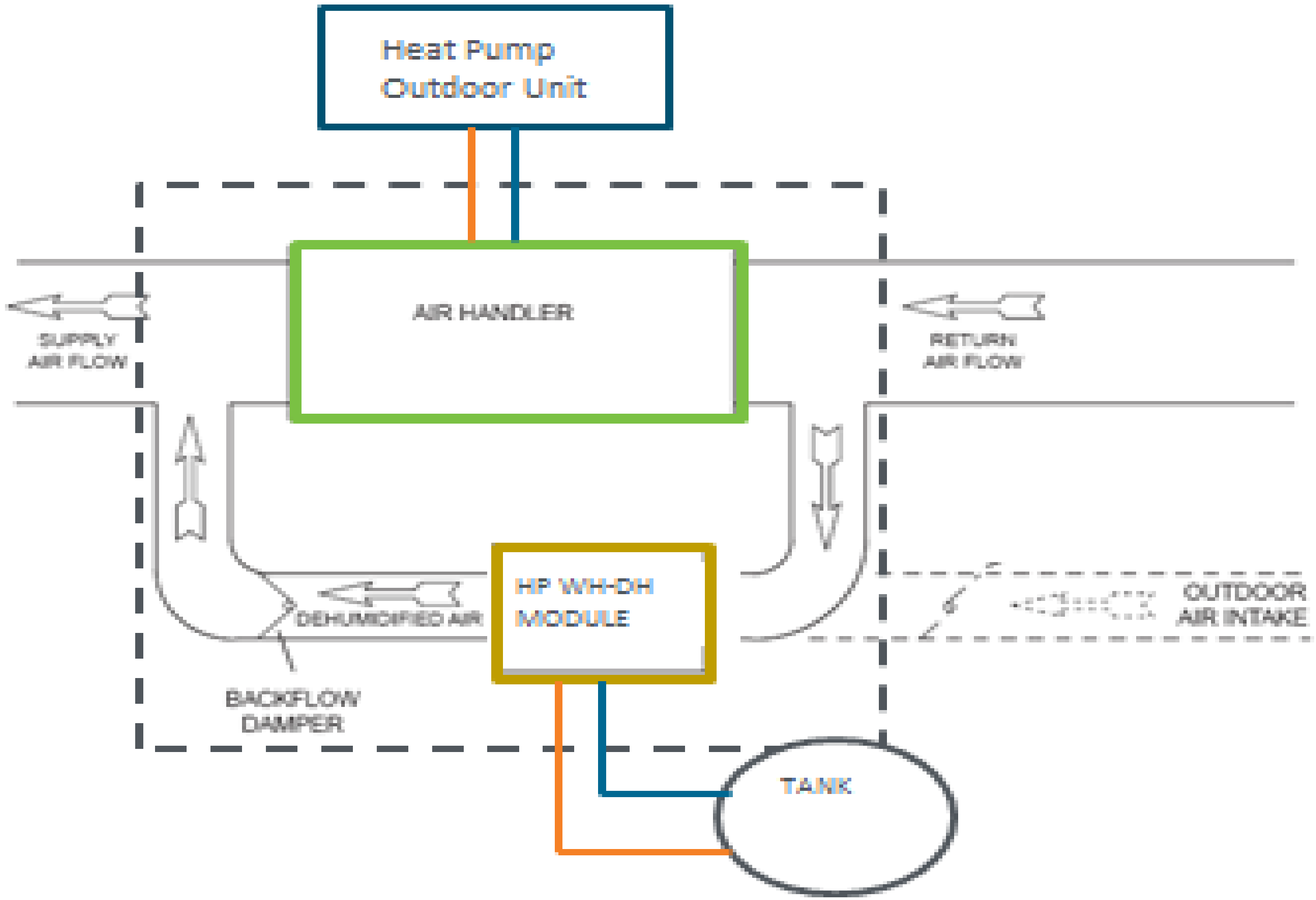
General Motivation

- Strategic Focus of U.S. DOE Buildings Technology Office
  - Maximize energy efficiency of U.S. buildings
  - Reduce building energy consumption 50% by 2030 vs 2010 levels
    - Sub goal for HVAC – 20% reduction by 2030
    - Sub goal for water heating (WH) – 60% reduction by 2030
  - Relative to current minimum efficiency equipment
- Develop integrated heat pumps (IHPs) to help meet these goals
  - Ground-source IHP unit recently introduced to U. S. market
  - Air-source IHP designs under development with industry partners
    - Single-unit design is the subject of another paper at conference
    - <u>Two-unit design, for both new and retrofit market, is the focus of this paper</u>

Two-Unit IHP Concept

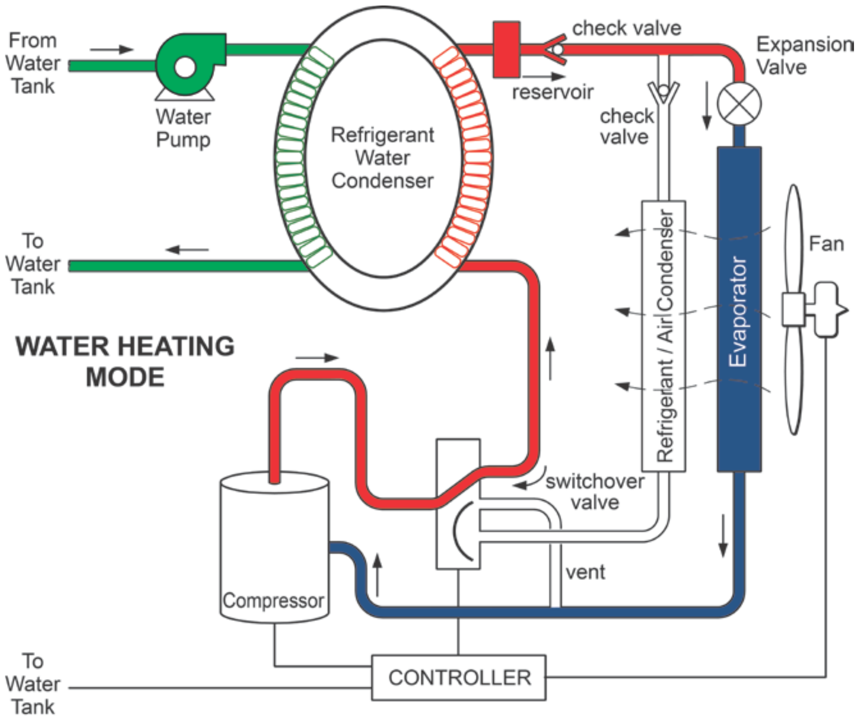


Specific Motivation For Two-Unit Design

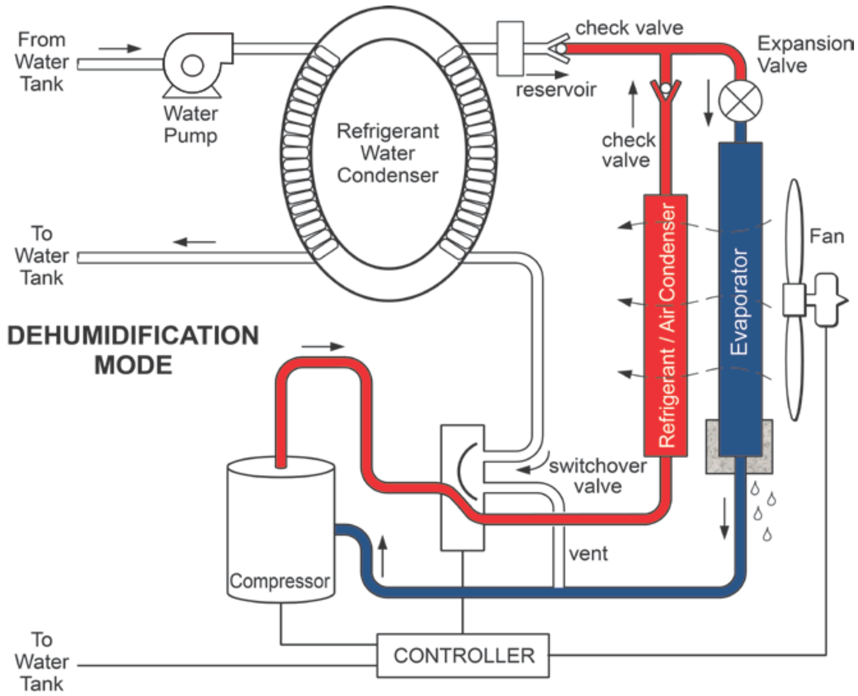
- Forecast Trend is for Sensible Loads to be Reduced more than Latent
  - Dedicated WH-DH unit provides on-demand WH and humidity control
    - Independent operation separates and simplifies controls compared to all-in-one designs
    - Provides two useful outputs in warmer shoulder and summer months
    - Central duct connection circulates conditioned air throughout the house
    - Also provides conditioning for ventilation air
- Close matching of lower WH loads possible with smaller single-speed compressor
- Design can be applied to retrofit/upgrade and new applications
  - Using standard electric WHs and wide range of multi-capacity central heat pumps

WH/DH Unit – Mode Configurations

Water Heating Mode



Dehumidifier Mode



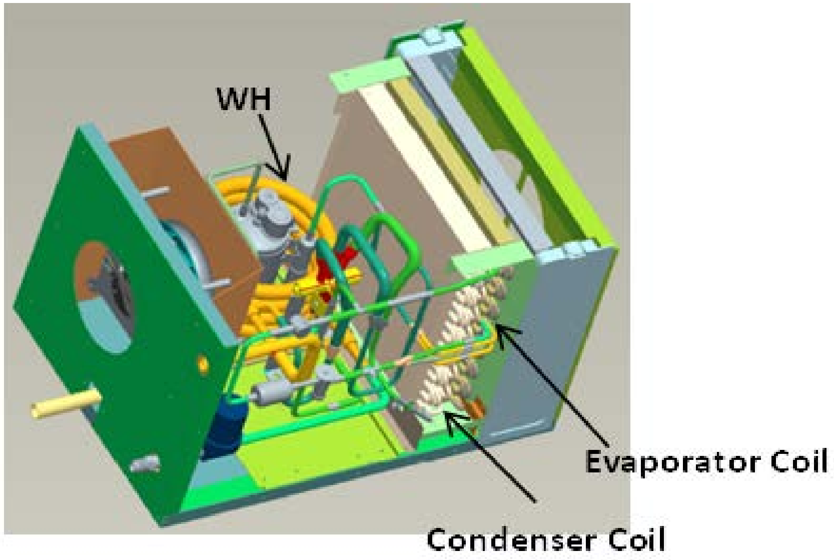
WH/DH Unit – Tube-In-Tube WH HX

Refrigerant-Outside, Water-Inside

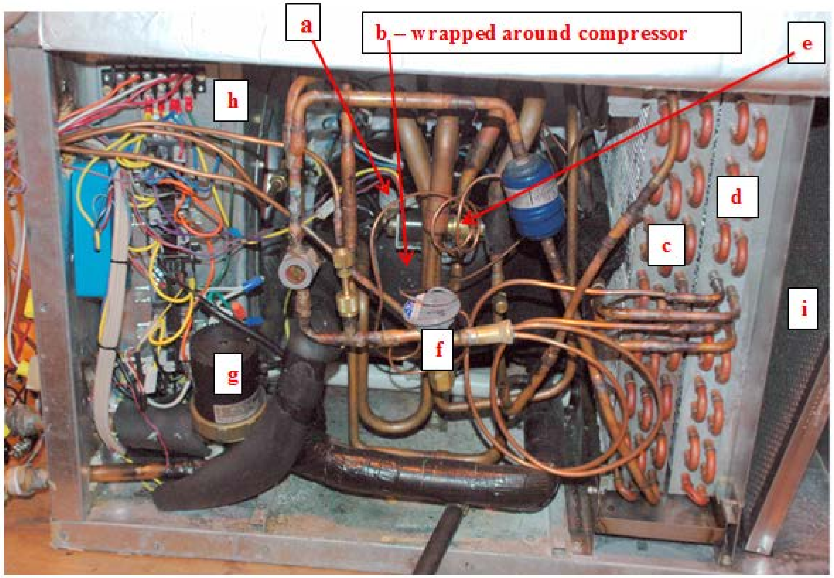
Double-Walled Fluted Tube Hx

WH/DH Unit – Hardware Configuration

CAD Representation

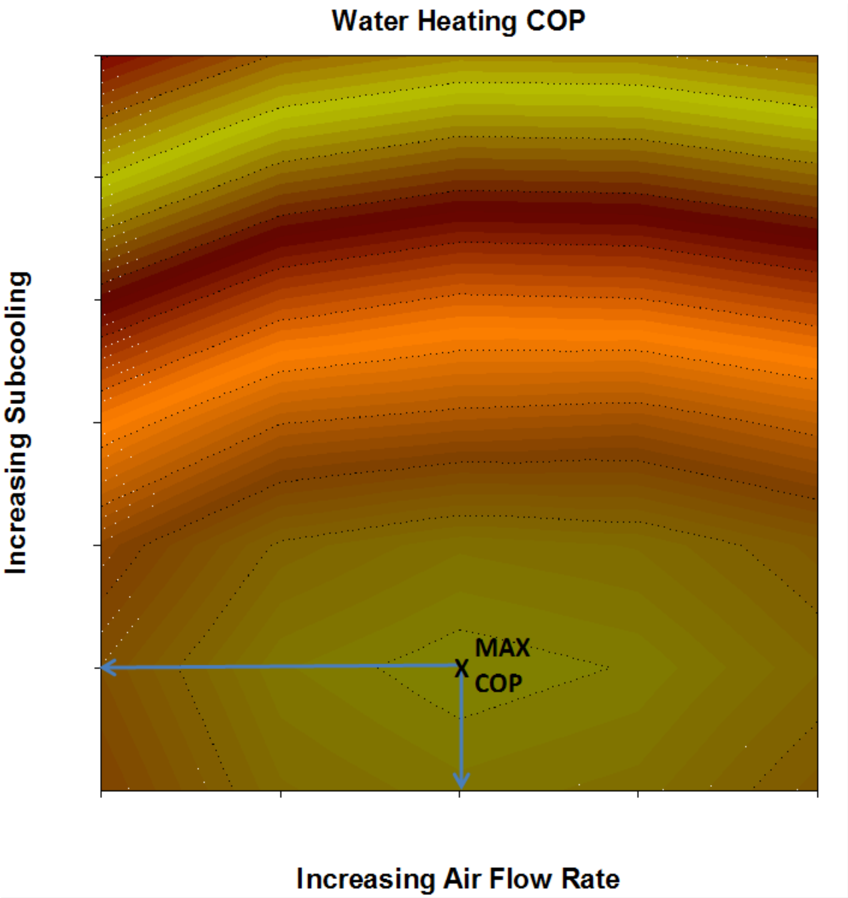


Lab-Tested Prototype

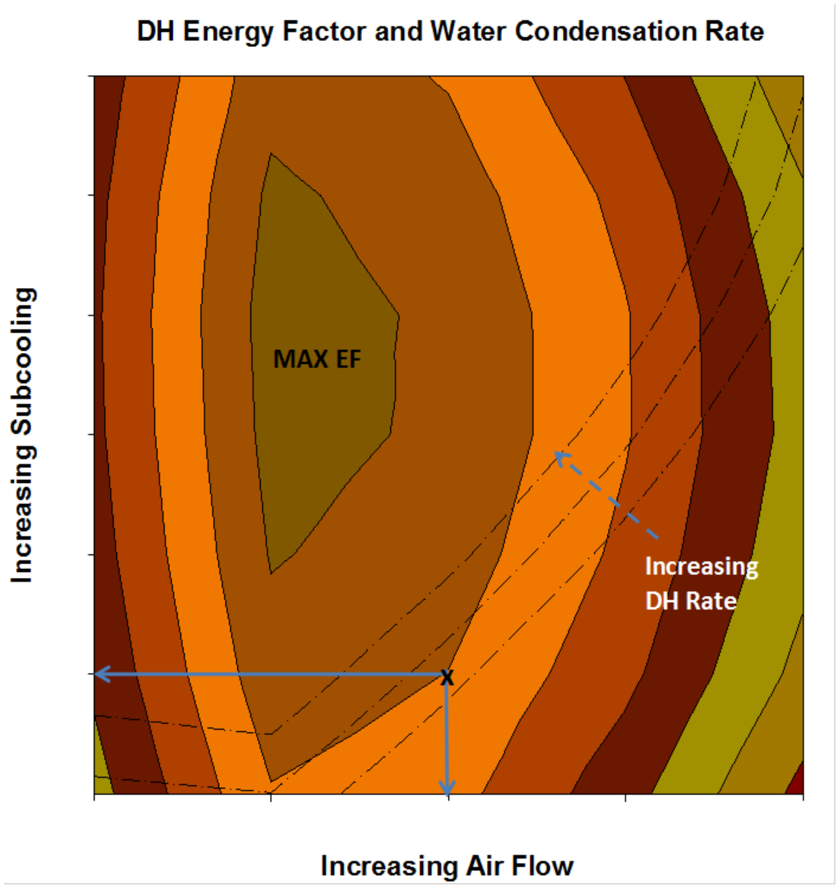


WH/DH Unit – Design Point Optimizations

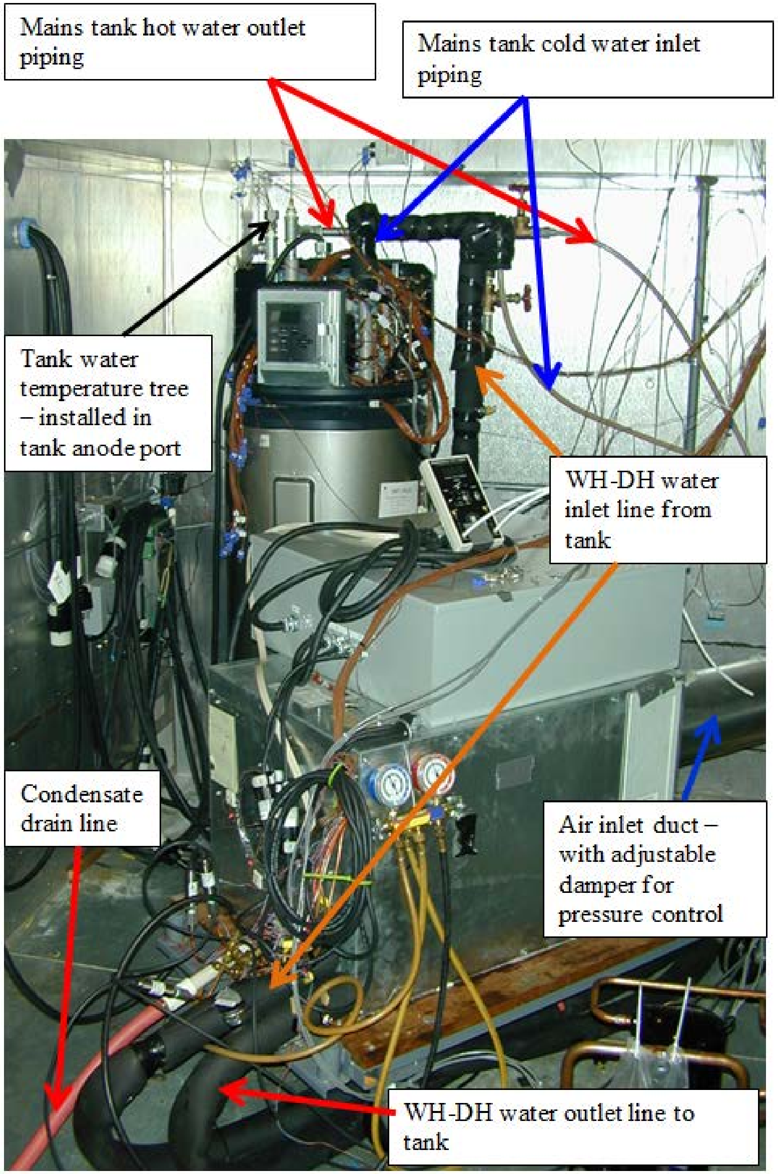
Water Heating Mode



Dehumidification Mode



WH/DH Unit – Installed in Test Chamber

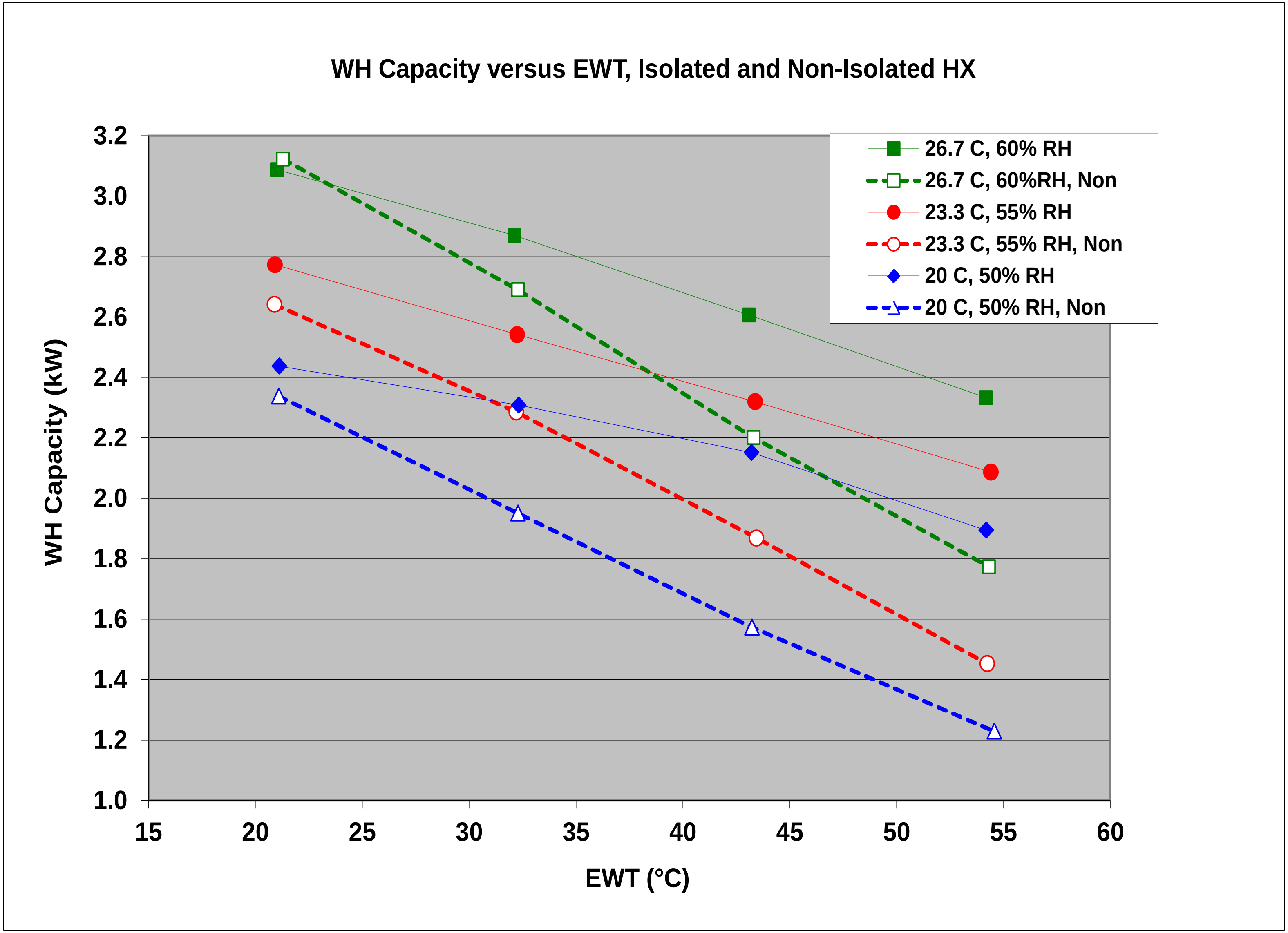


WH/DH Unit – Lab S-S Test Conditions

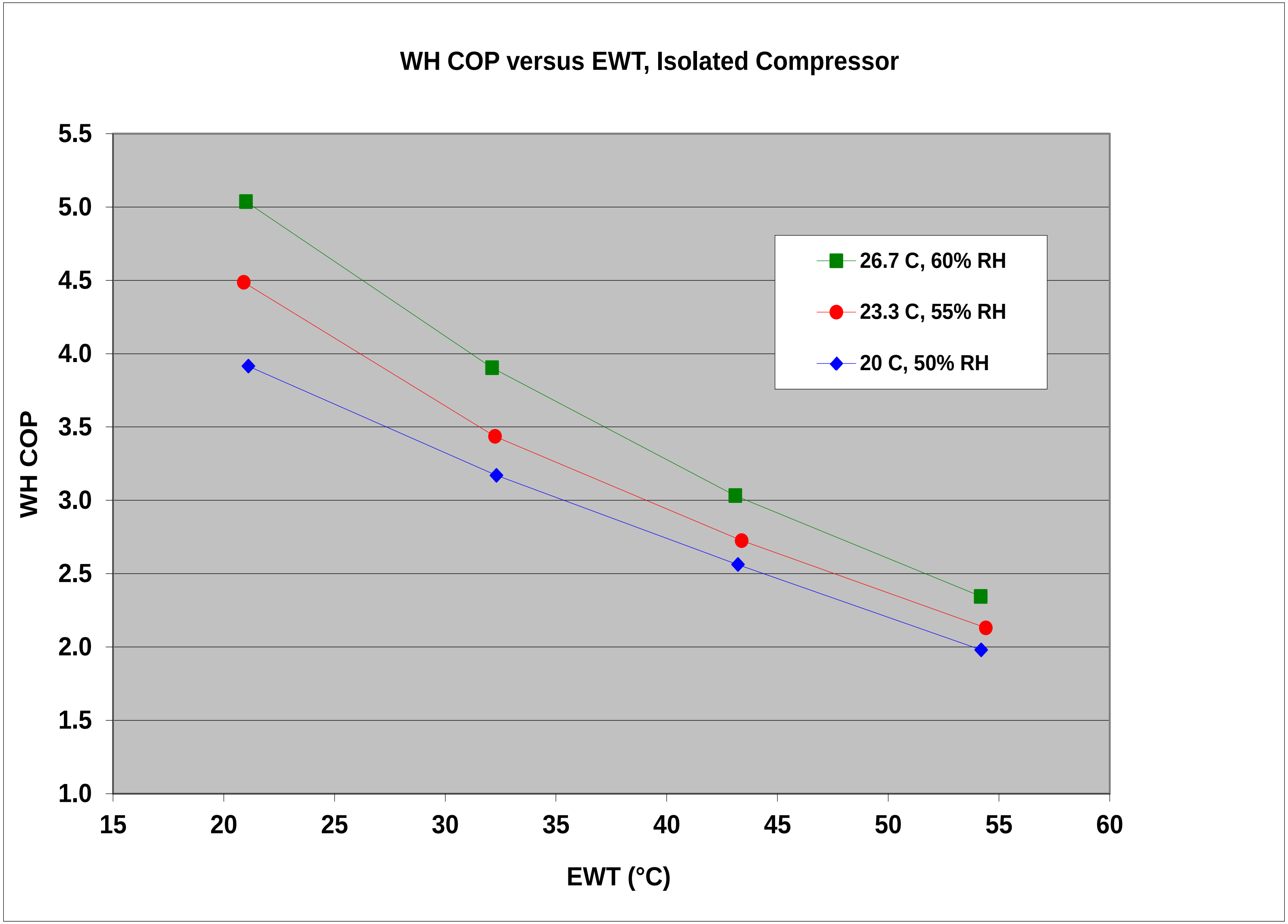
Test Matrix for DH Mode		
Test #	Test Condition	
	Inlet DB, °C	RH %
1	26.7	60
2	26.7	55
3	26.7	50
4	23.3	55
5	23.3	60
6	23.3	50
7	20.0	60
8	20.0	55
9	20.0	50

Test Matrix for WH Mode			
Test #	Test Condition		
	Inlet DB, °C	RH %	EWT °C
1	20.0	50	21.1
2	20.0	50	32.2
3	20.0	50	43.3
4	20.0	50	54.4
5	23.3	55	21.1
6	23.3	55	32.2
7	23.3	55	43.3
8	23.3	55	54.4
9	26.7	60	21.1
10	26.7	60	32.2
11	26.7	60	43.3
12	26.7	60	54.4

Lab Test Results – S-S WH Capacity



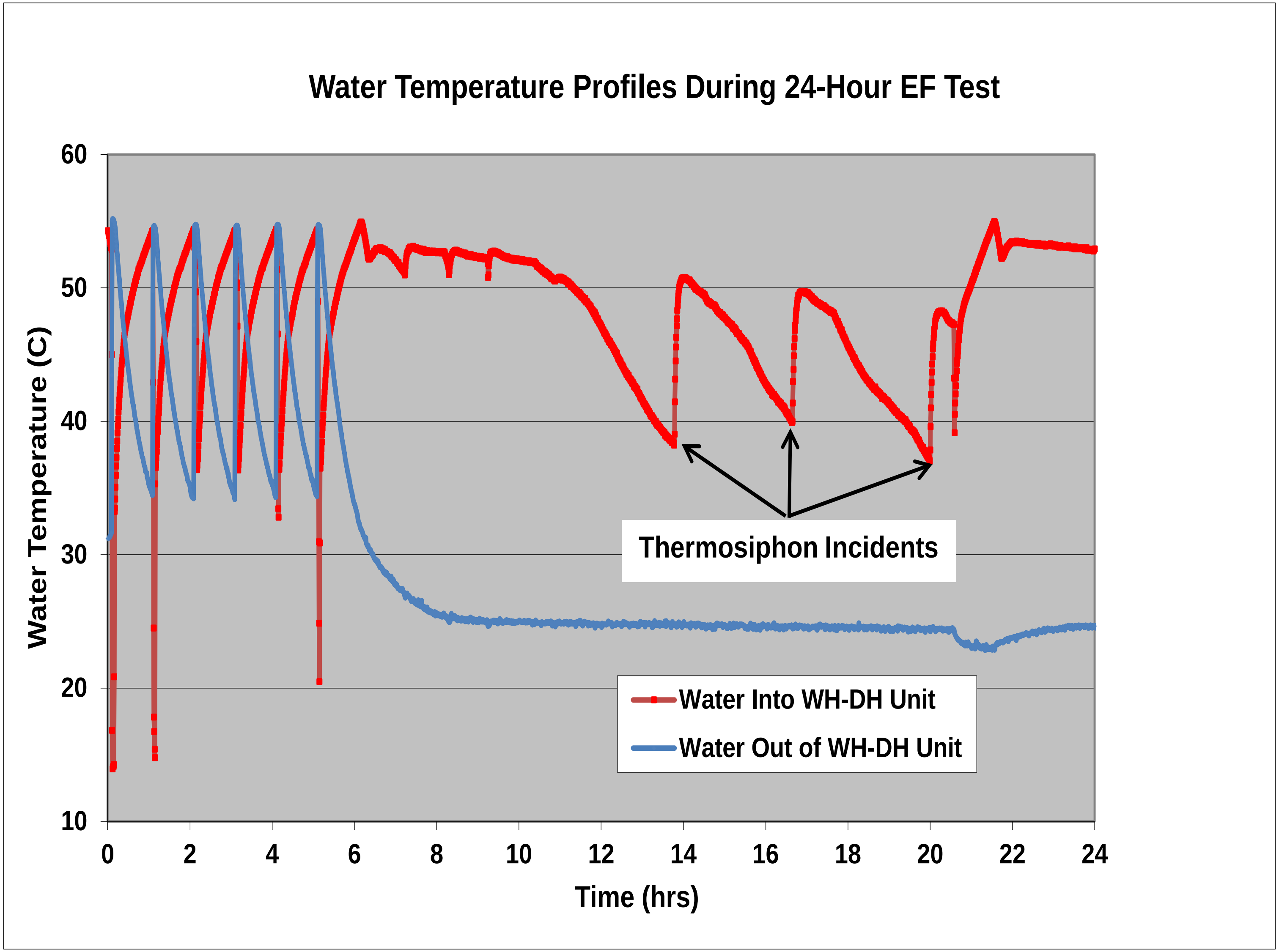
Lab Test Results – S-S WH COP



Energy Factor (EF) Test Results

- Dehumidifier EF Ratings Test per ANSI/AHAM DH-1-2008
  - 6 hrs at 26.7C / 60% RH
  - Avg. EF from 2 tests of 2.08 and capacity of 1.47 L/hr
- DOE 24 hr Water Heater EF Test
  - Ambient air at 19.7C / 50% RH
  - 6 equal draws of 40.6 L over 3 min, 1 hour apart, followed by recovery / cool down in hours 6-24
  - Initial EF results of ~ 1.5 with significant heat losses
    - Subsequent tests with added insulation, isolation from airflow, and adjusted set points raised EF to 1.78
  - Next identified multiple thermosiphon events during cool down period
    - Elimination of these events by valving off inlet water line increased EF to 1.92

Lab Results – 24 Hr WH EF Test



Annual Performance Simulations

- Mapped S-S WH and DH performance with ORNL HPDM
  - Using calibrated models over wide range of air/water inlet conditions
  - Derated WH-DH unit to 20% lower airflow rate based on blower testing against expected external back pressure of central duct system
    - Dropped WH performance ~ 3.3% and DH EF by 1.2%
- Linked with TRNSYS house/weather project and type 534 WH tank module
  - 3-min time steps and nominal 50ºC WH set point
- Paired WH-DH unit with two-capacity central air-source HP
  - 5.4 CSPF / 2.67 HSPF of same design capacity as baseline unit
- Compared versus baseline all-electric suite of min eff equipment
  - 3.8 CSPF / 2.3 HSPF HP, 0.9 EF WH, and 1.4 EF DH

Predicted Annual Energy Savings By Mode

Energy Use by Mode; 242 m^2 Tight, Well-Insulated House			
	1-Speed Base	2-Speed w WH-DH Unit, 113 L/s	
Operation Mode	Energy Use kWh (I^2R)	Energy Use kWh (I^2R)	Reduction from Base (%)
Atlanta			
space heating	2311	1965	15.0%
resistance heat	(18)	(31)	
space cooling	1741	1059	39.2%
water heating	3380	1553	54.1%
resistance heat	(3380)	(488)	
dedicated DH	319	299	6.2%
ventilation fan	189	202	-6.9%
totals	7941	5079	36.0%
Houston			
space heating	995	906	9.0%
resistance heat	(0)	(3)	
space cooling	3035	1975	34.9%
water heating	2813	1169	58.5%
resistance heat	(2813)	(246)	
dedicated DH	1154	1035	10.3%
ventilation fan	189	179	5.6%
totals	8187	5264	35.7%
Chicago			
space heating	6214	4915	20.9%
resistance heat	(916)	(669)	
space cooling	740	402	45.6%
water heating	4218	2122	49.7%
resistance heat	(4218)	(906)	
dedicated DH	154	154	0.0%
ventilation fan	189	169	10.5%
totals	11514	7762	32.6%

Summary and Recent Work

- Novel Prototype WH-DH Unit Developed and Tested
  - Provided basis for calibrated performance models and annual savings predictions
    - Average savings potential of ~35% predicted for tested unit in range of suitable U.S. climates
    - EF performance goals met for DH function and approached for WH mode
      - Heat losses from tube-in-tube HX found to be significant
- Recent Prototype Improvement
  - Enlarged both airflow openings and gained 40% more ext. static capability
  - Replacement of tube-in-tube with double-walled brazed plate HX
    - lighter weight, more compact, reduced thermal capacitance, easily insulated
  - "Risers" added to significantly reduce thermosiphon losses
  - Energy Factors increased: DH 2.08 → 2.12, WH 1.92 → 2.0
- Would like to conduct field test beginning later in 2014