Development of a Variable-Speed Residential Air-Source Integrated Heat Pump

Keith Rice, Bo Shen, Jeffrey Munk, Moonis Ally, and Van Baxter, ORNL

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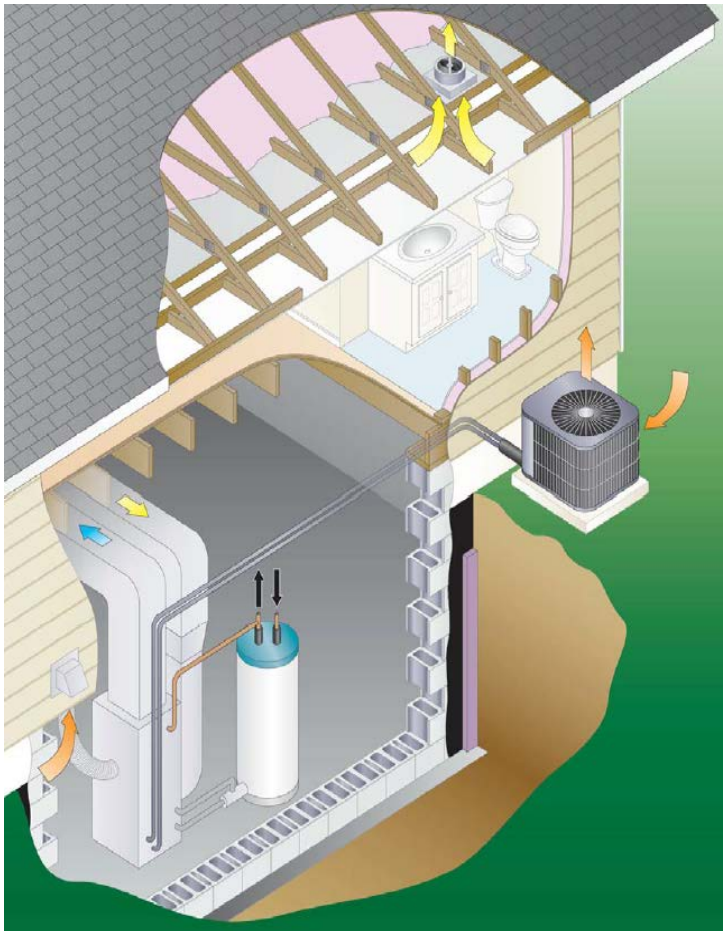
General Motivation

- 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 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 (AS-IHP) designs under development with industry partners
    - Two-unit design, for both new and retrofit market, is the subject of another paper presented later at the conference
    - Single-unit variable-speed design is the focus of this paper

Conceptual Installation of AS-IHP



Conceptual AS-IHP Packaging Approach

Specific Motivation For Single-Unit VS Design

- To make maximum year-round use of highly efficient but more costly variable-speed compressor, blower, fan, and pump
  - To enable waste heat recovery for WH in cooling season
    - Not free heat due to elevated condensing temperatures
    - But dual useful outputs from single power input
  - To provide dedicated WH capability in shoulder months
  - To maintain comfort conditions in cooling, heating, and shoulder seasons
- To meet both high and lower capacity loads efficiently using speed modulation
- To provide >50% annual energy savings for HVAC/WH functions

Prototype Design

- 10.6 kW (3-ton) Nominal Cooling Capacity
- Full Condensing (FC) and Desuperheating (DS) Water Heating
  - Parallel Condensers when FC
  - Series Condensers when DS
- Modulating Brushless Permanent Magnet (BPM) Components
  - Rotary Compressor, Blower, Fan, and Pump
- Dual Electronic Expansion Valves (EEVs)
- R-410A Refrigerant
- Patented Refrigerant Charge Management

Main Operating Modes

- Space Cooling
  - Enhanced DH option
- Combined Space Cooling and WH (heat recovery)
  - Enhanced DH Option
- Combined Space Cooling and Desuperheating
- Dedicated WH
- Space Heating
- Combined Space Heating and Desuperheating

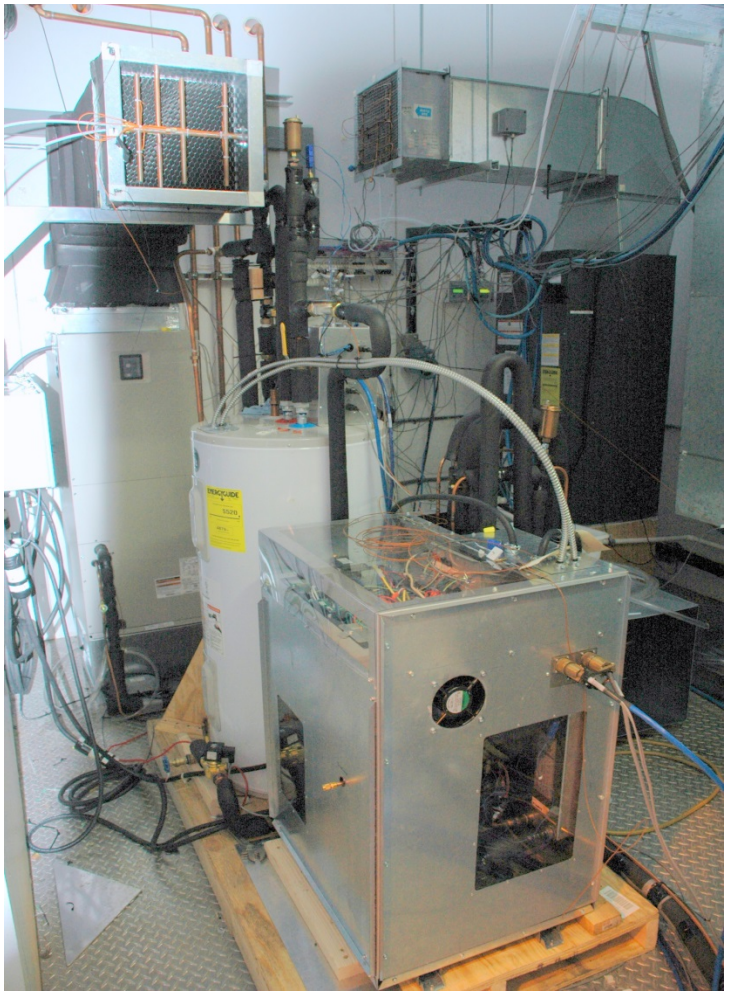
WH/DH Unit –Tube-In-Tube WH HX Used in First Prototype

Refrigerant-Outside, Water-Inside Double-Walled Fluted Tube Hx

AS-IHP Unit – Hardware Configuration

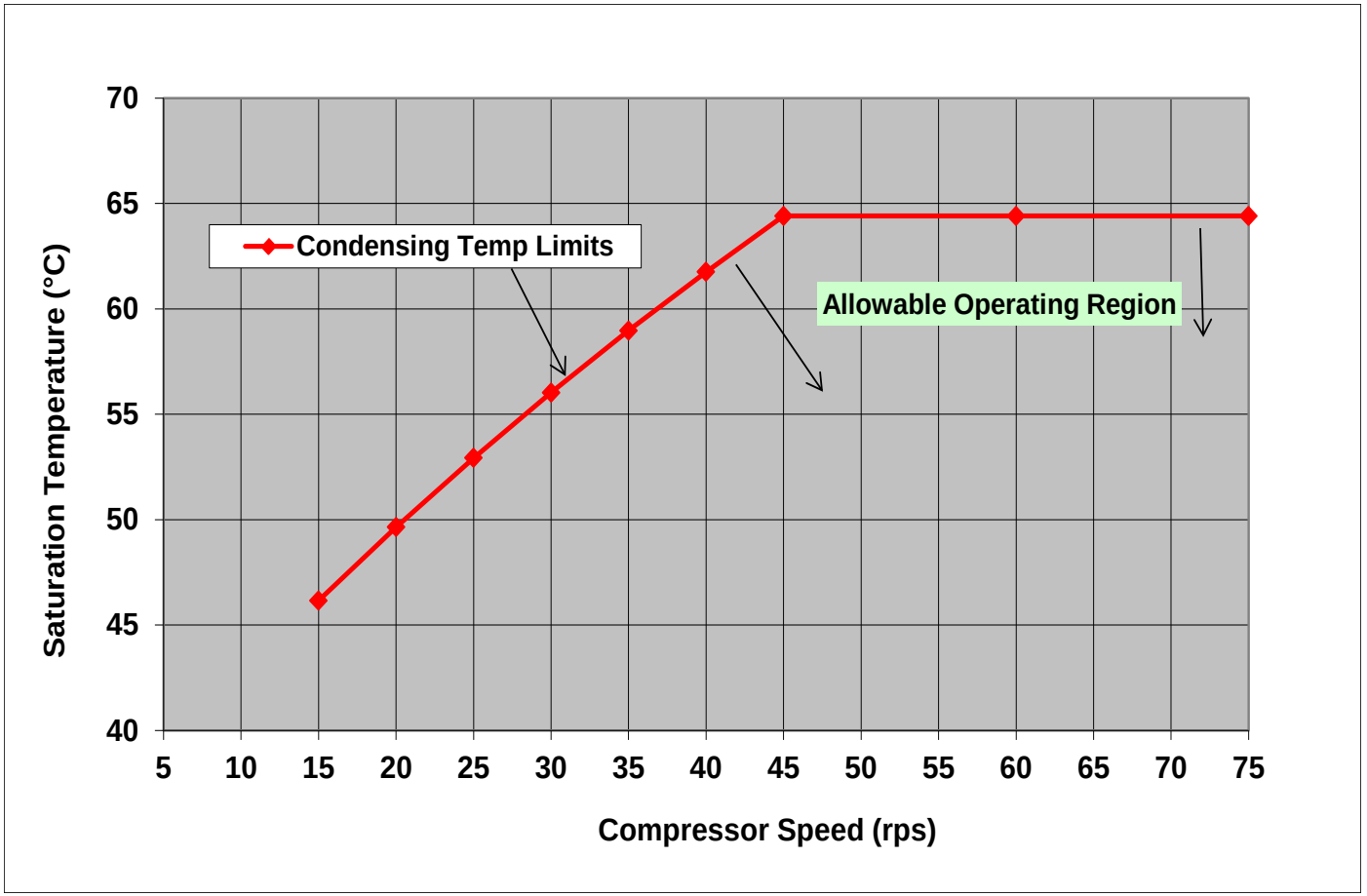
First Lab-Tested Prototype

Second Lab-Tested Prototype



AS-IHP Unit – WH Design Constraints

Example of Condensing Temperature Limits Versus Compressor Speed

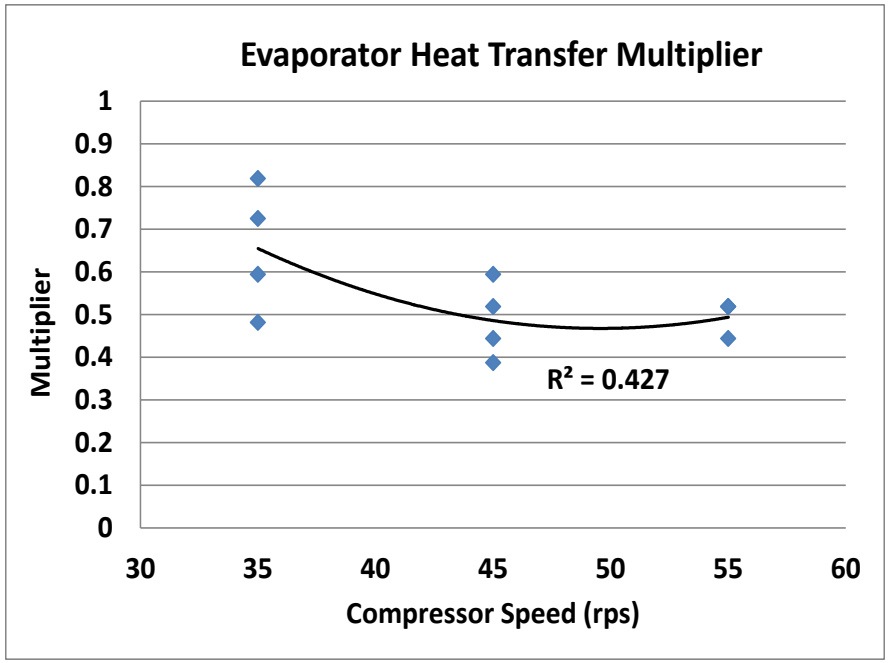


AS-IHP Unit – Lab S-S Test Conditions

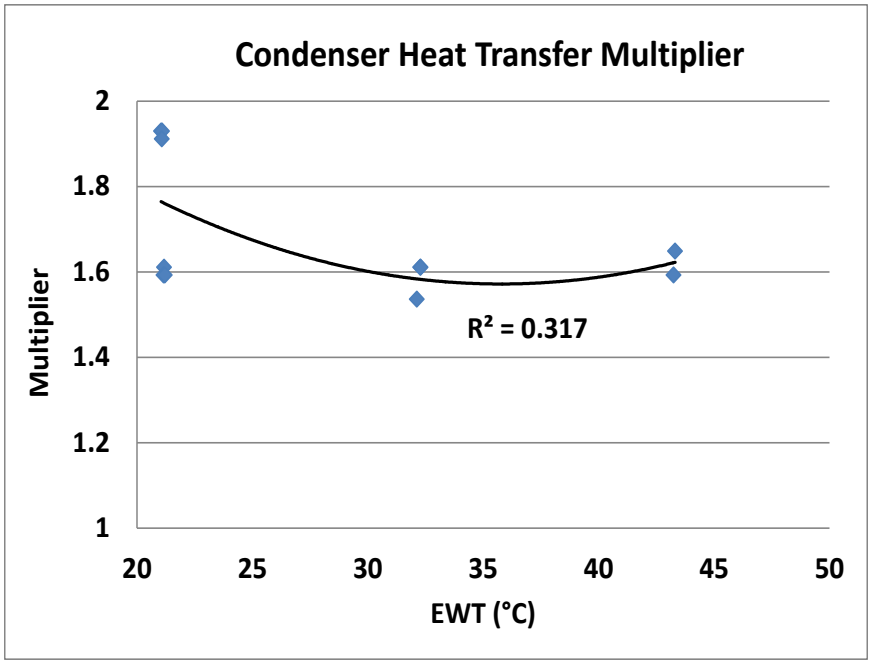
- Space Conditioning at Standard VS Ratings Conditions and Speeds
  - w/o and with desuperheating, EWTs from 21 to 60°C
- Combined SC+ WH Operation at Similar Conditions/Speed
  - EWTs from 21 to 48.9°C
- Dedicated WH from 8.3 to 25°C, 36 and 45 rps
  - EWTs from 21 to 48.9°C

Calibration of HX Models in SC+WH Mode in First Prototype

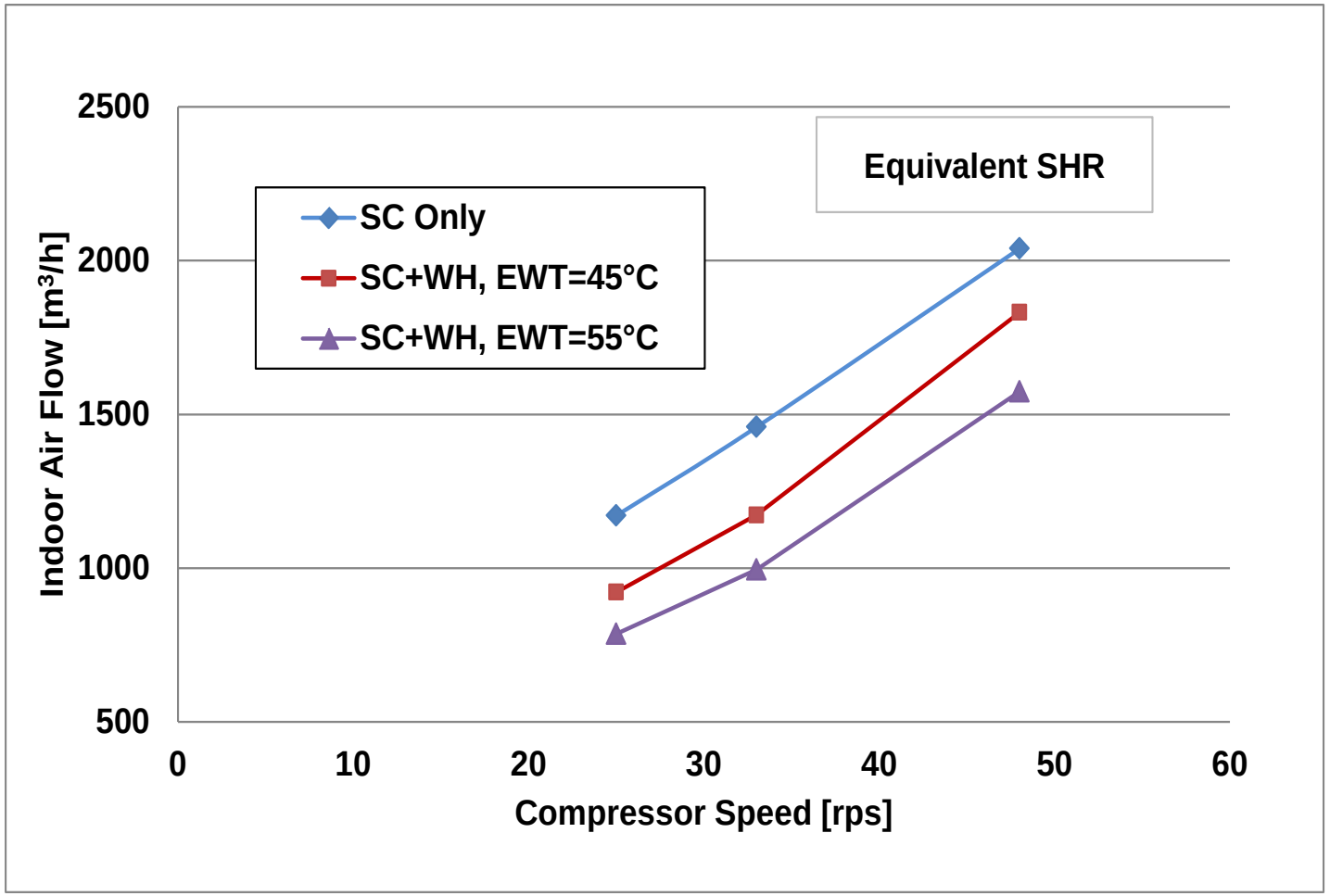
Air-to-Refrig. Evaporator



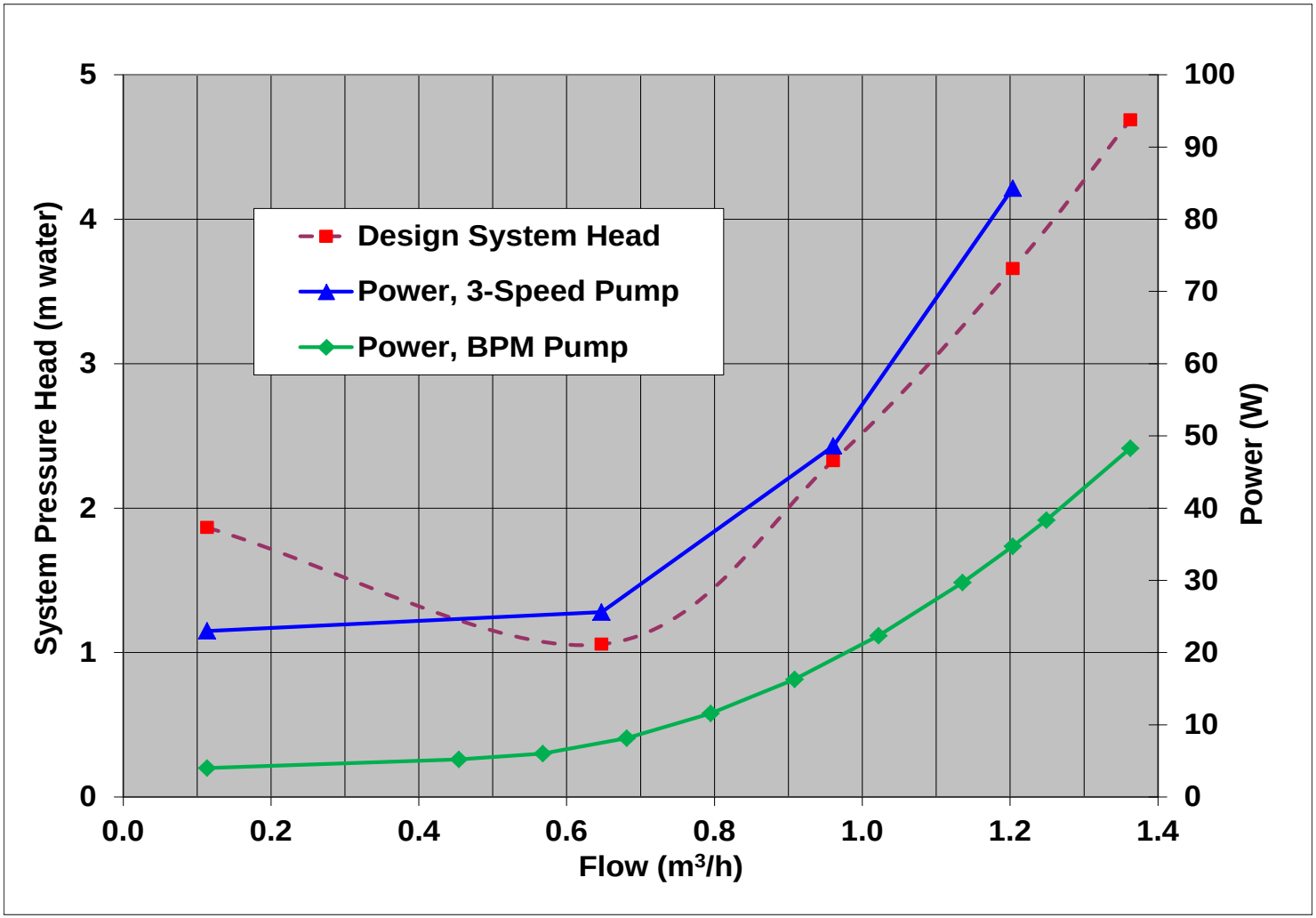
Water-to-Refrig. Condenser



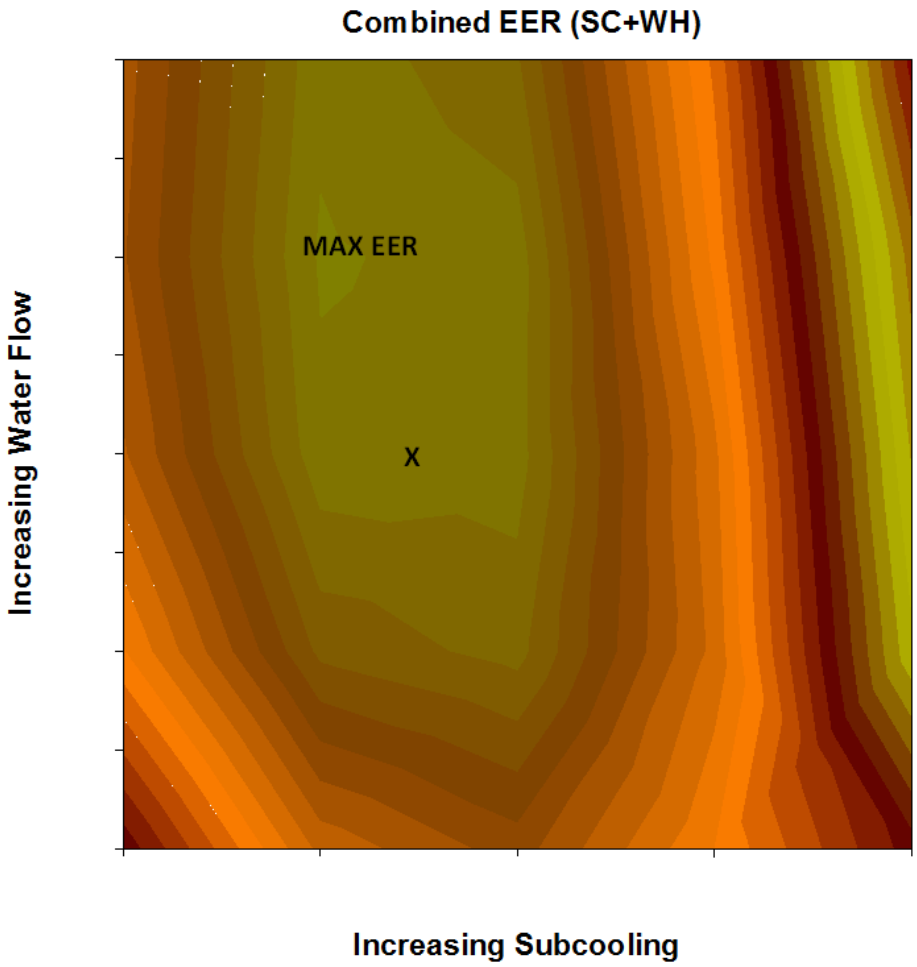
Indoor Airflow Needs to be Reduced When in Combined SC+WH Mode For = SHR Control



Power Comparisons versus Flow Between 3-Speed Induction and BPM Pump for Design Head Requirements



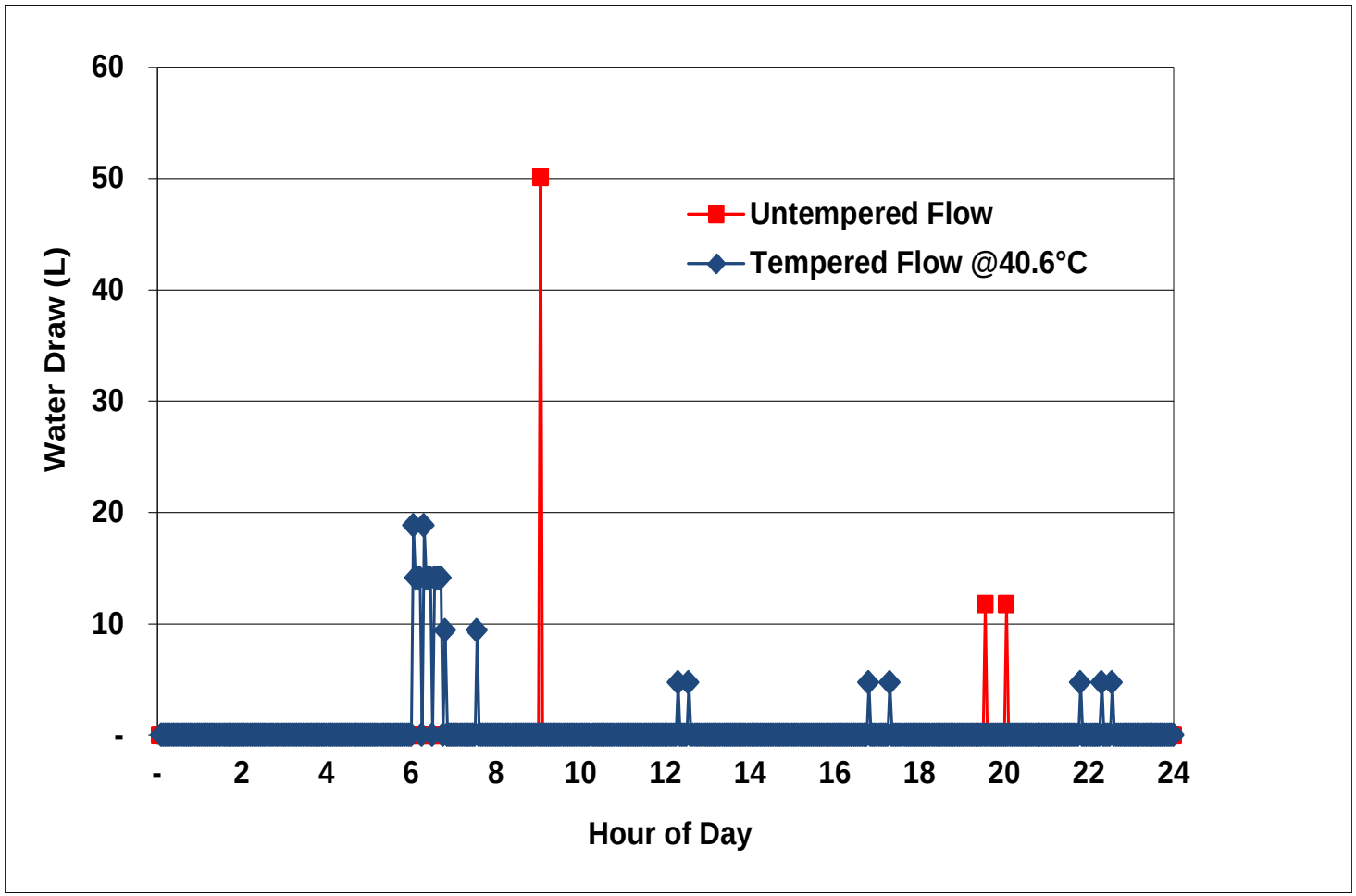
Optimal Water Flow Vs Cond. Subcooling for BPM Pump and Brazed Plate HX in Second Prototype Design



Annual Performance Simulations

- Mapped AS-IHP performance with ORNL HPDM
  - Using calibrated models over wide range of air/water inlet conditions
  - For modes of SC, SC+WH, Dedicated WH, SH, and SH+ DS
  - Using BPM Compressor, Blower, Fan, and Pump
- Linked with TRNSYS house/weather project and type 534 WH tank module
  - 3-min time steps and nominal 50ºC WH set point
  - Prescribed daily hot water draw schedule (shown next)
- 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

Assumed Daily Hot Water Draw Schedule from DHW Tank, ~243 L/day



Predicted WH Savings in 5 U.S Locations

Location	% WH Energy Savings Versus Electric WH with 0.90 EF
Atlanta	70.0
Houston	75.7
Phoenix	72.2
San Francisco	69.4
Chicago	62.4
US average	**69.9**

Predicted Annual Energy Savings in 5 U.S Locations

For 242 m^2 (2600 ft^2) well-insulated house

Location	% Energy Savings Versus Baseline HP w Electric WH
Atlanta	53.3
Houston	54.7
Phoenix	46.7
San Francisco	60.9
Chicago	46.0
US average	**52.3**

Summary and Next Step

- Prototype AS-IHP Units Developed and Lab Tested
  - Provided basis for calibrated performance models and annual savings predictions
    - Average savings potential of >50% predicted for tested unit in range of suitable U.S. climates
- Fully Variable-Speed Space Conditioning
  - Maximizes efficiency in cooling and heating seasons
  - Allows overspeed operation at cold ambients to minimize backup resistance heat
- Provides efficient high-capacity WH operation over wide range of conditions
  - multiple modes of WH are predicted to provide average WH energy savings of 70%
  - while staying within the allowed compressor operation envelope
- Field tests on a 3rd generation prototype design begun in spring of 2014