2016 ACEEE Hot Water Forum – Heating Water with Integrated Heat Pumps

Modeling of Air-Source Integrated Heat Pumps

-simulation-driven design

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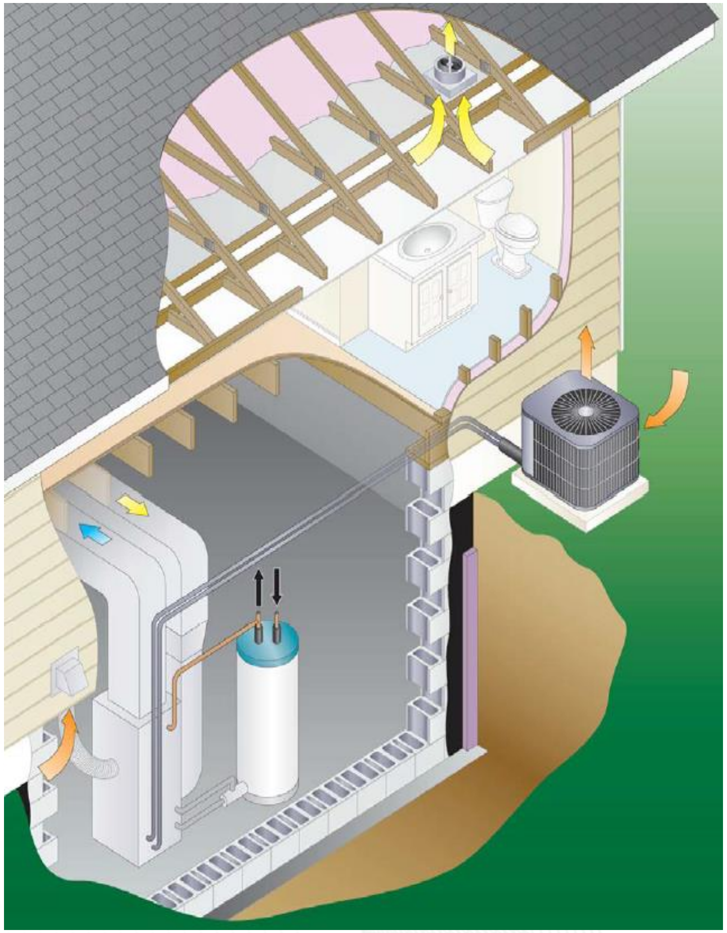
   – Operation modes and components

2. Modeling ASIHPs with ORNL Heat Pump Design Model (HPDM)
   – Component and system modeling
   – Building energy simulation

3. Simulation Case Studies

4. Summary

Conceptual Installation of ASIHP – 3-ton Rated Cooling Capacity



1.1 Reasons For Single-Unit ASIHP

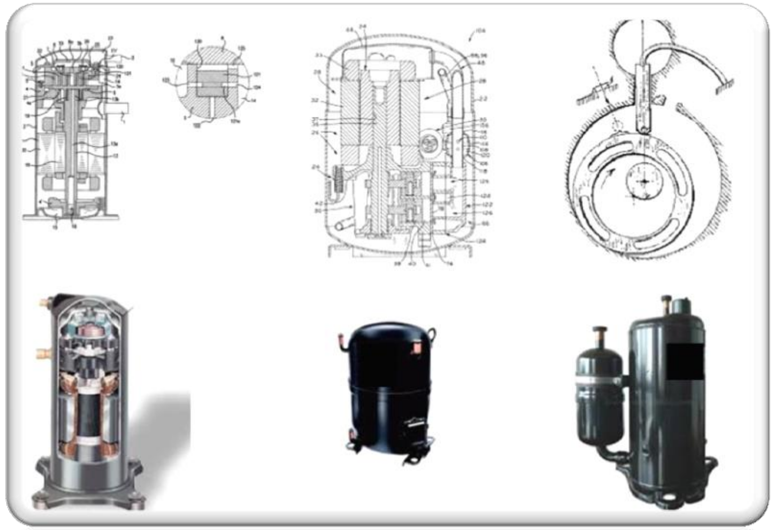
1. Maximize use of highly efficient but costly variable-speed compressor, blower, fan, and pump
   - Recover waste heat for water heating in cooling season
     - Dual useful outputs from single power input
   - Provide dedicated WH capability in shoulder months

2. Meet both high and lower capacity loads efficiently using speed modulation

Objective: Provide >50% annual energy savings for HVAC/WH functions

1.2 Various Components

Variable-Speed Flow Movers-compressors, fans and pumps



Air-to-refrigerant HXs

Water-to-refrigerant HXs

1.3 Multi Operation Modes Possible

Multiple operation strategies and component states, e.g. speed, HX states.

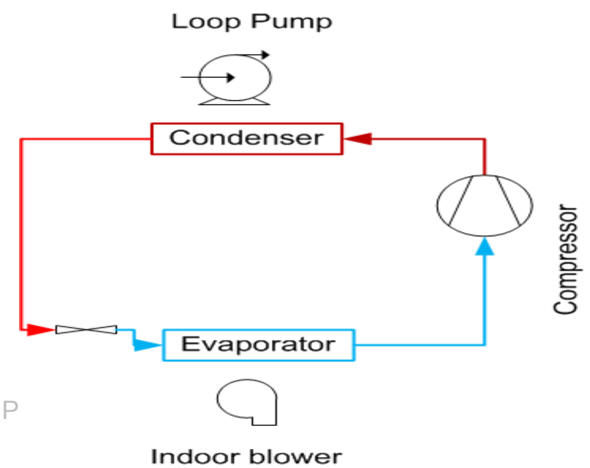
→Single-Function Modes:

1. Space cooling mode (SC)
2. Space Heating Mode (SH)
3. Dedicated Water Heating Mode (DWH)

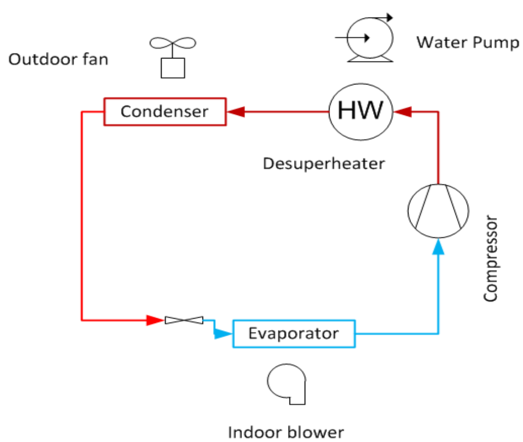
→Combined Modes:

4. SC + Water Heating Mode with Full Condensing (SCWH)
5. SC + Water Heating with Desuperheating (SCDWH)
6. SH + Water Heating with Desuperheating (SHDWH)

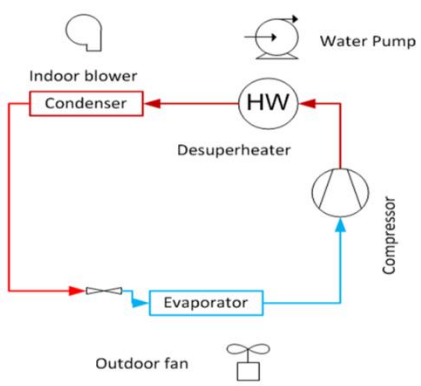
SCWH Mode



SCDWH Mode



SHDWH Mode



2.1 Variable-Speed Compressor Modeling

$$Y = C_1 + C_2 T_e + C_3 T_c + C_4 T_e^{\,2} + C_5 T_e T_c + C_6 T_c^{\,2} + C_7 T_e^{\,3} + C_8 T_c T_e^{\,2} + C_9 T_e T_c^{\,2} + C_{10} T_c^{\,3}$$

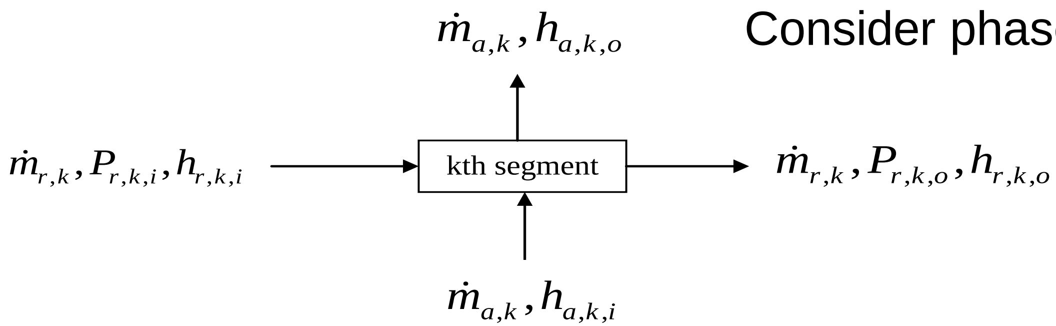
→10-coefficient AHRI compressor map at rated inlet superheat; Y represents the compressor mass flow and power use rates.

→Linear interpolation between speed levels.

→Mass flow rate adjustment for actual inlet superheat levels.

2.2 Advanced Heat Exchanger Modeling

- Segment-to-segment modeling approach



Consider phase change

Dry Coil Analysis Heat Transfer

$$\dot{Q}_{\max} = C_{\min}(T_{h,i} - T_{c,i})$$

$$\varepsilon = 1 - \exp(-NTU)$$

Wet Coil (Dehumidification) - Heat & Mass Transfer

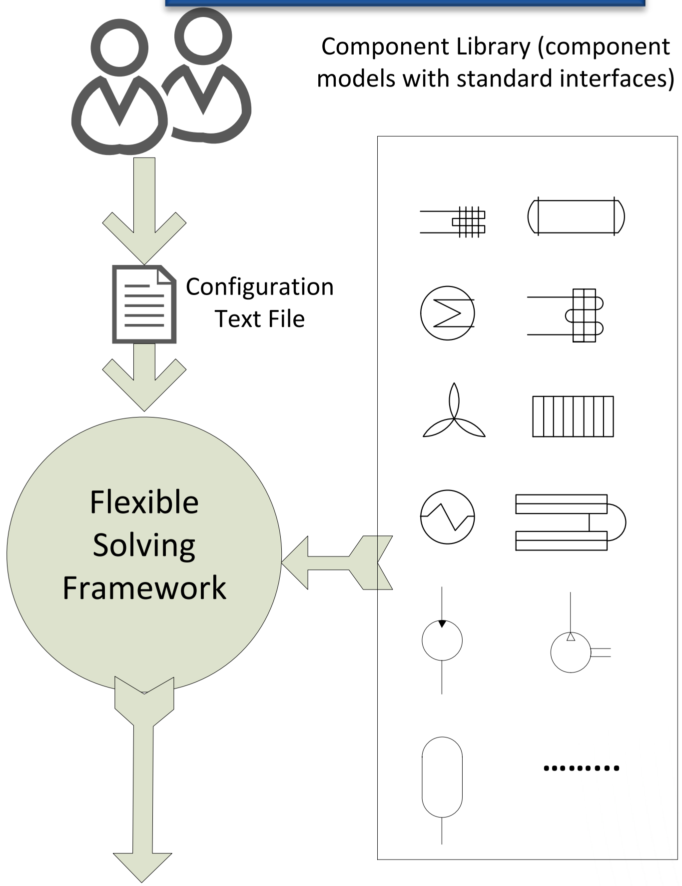
$$\dot{Q}_{\max} = \dot{m}_a(h_{a,i} - h_{s,evap})$$

$$\varepsilon^* = 1 - \exp(-NTU^*)$$

2.3 System Modeling - Component-Based Flexible Modeling Platform for Vapor Compression Systems

Component-Based

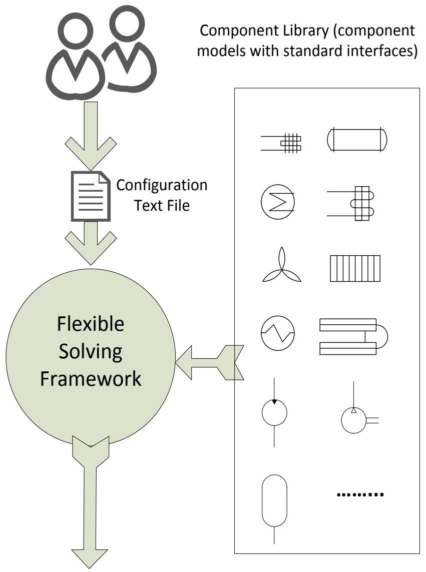
Plug-&-Play



Component models have standard interfaces to the solving framework, and generic connections to each other.

Automatically connect components into required system configuration by user input file.

2.4 Extensive Connectivity



ORNL Building Equipment Model

Generate Performance Curves

Curve-Fitting Program

EnergyPlus

Generate Performance Tables

Parametric Runs

TRNSYS 17

All connected.

3. Specific Issues Rated to AS-IHP Development

Four Simulation Case Studies

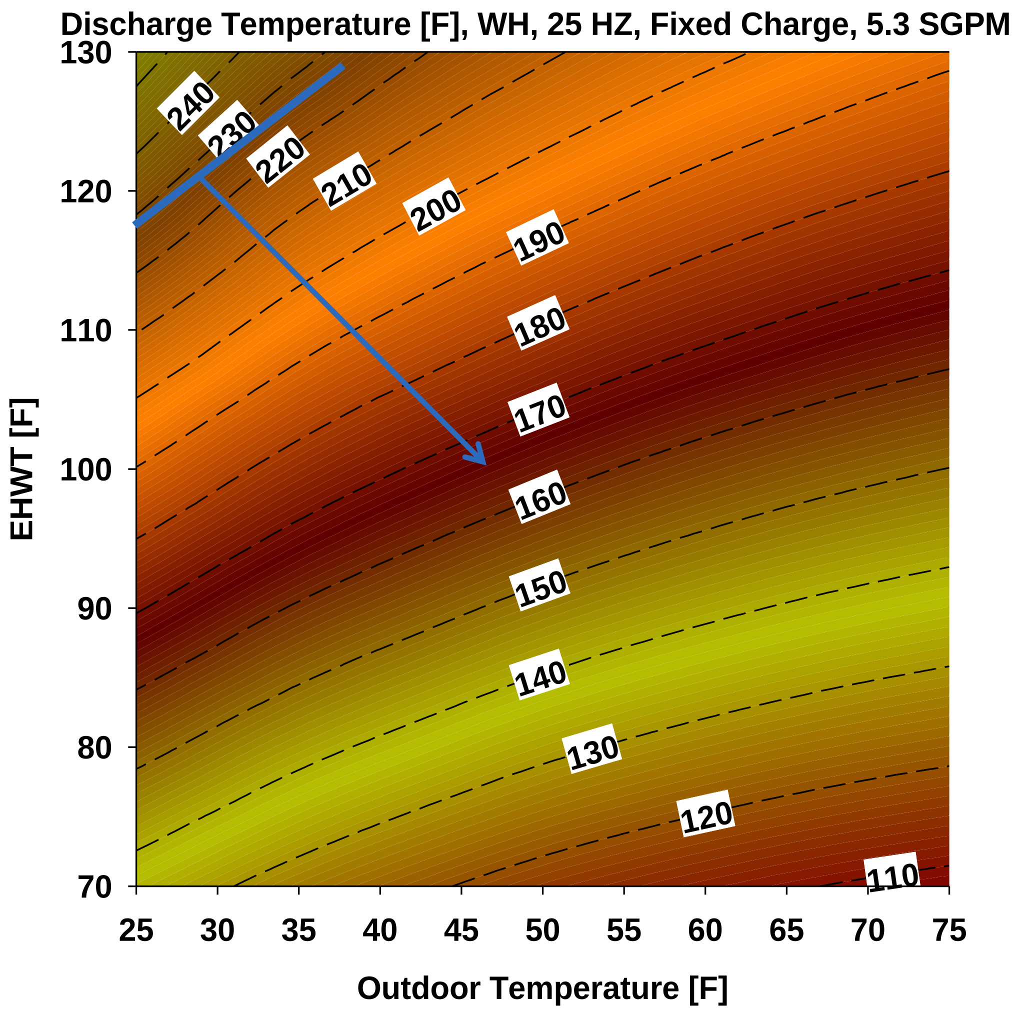
3.1 Convert Compressor Working Envelope to IHP Operation Constraints

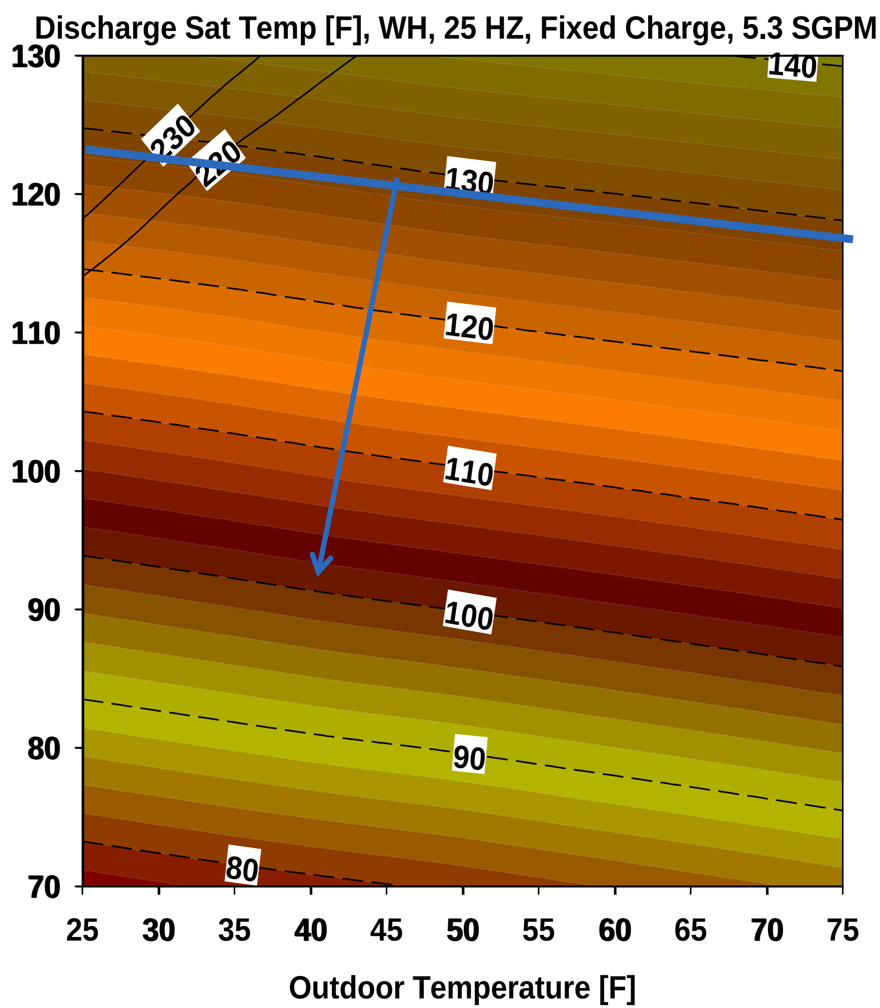
3.2 Optimize combined efficiency

3.3 Optimize efficiency with SHR constraint

3.4 Solving competing demands

3.1 Operation Constraints in DWH Modes



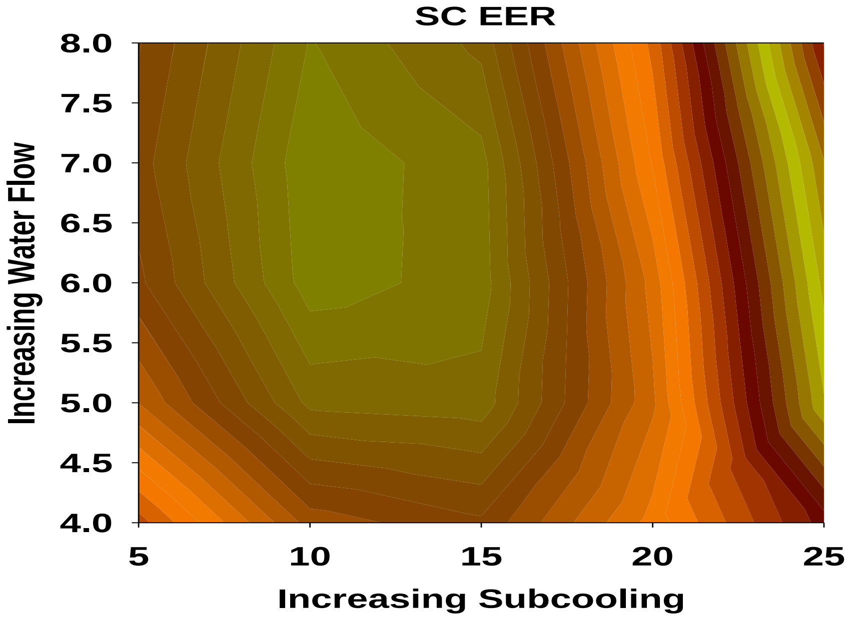


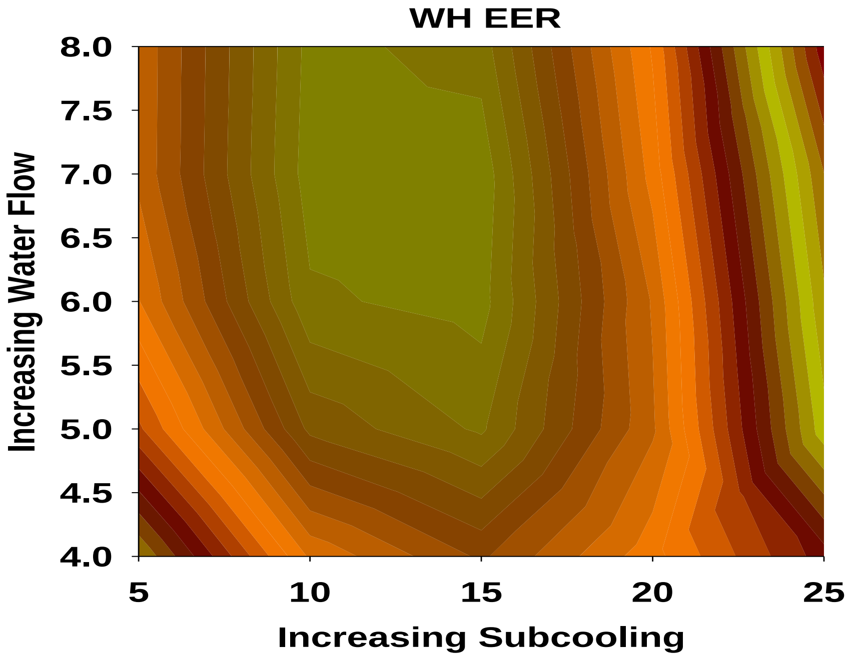
-Discharge temperature constraint

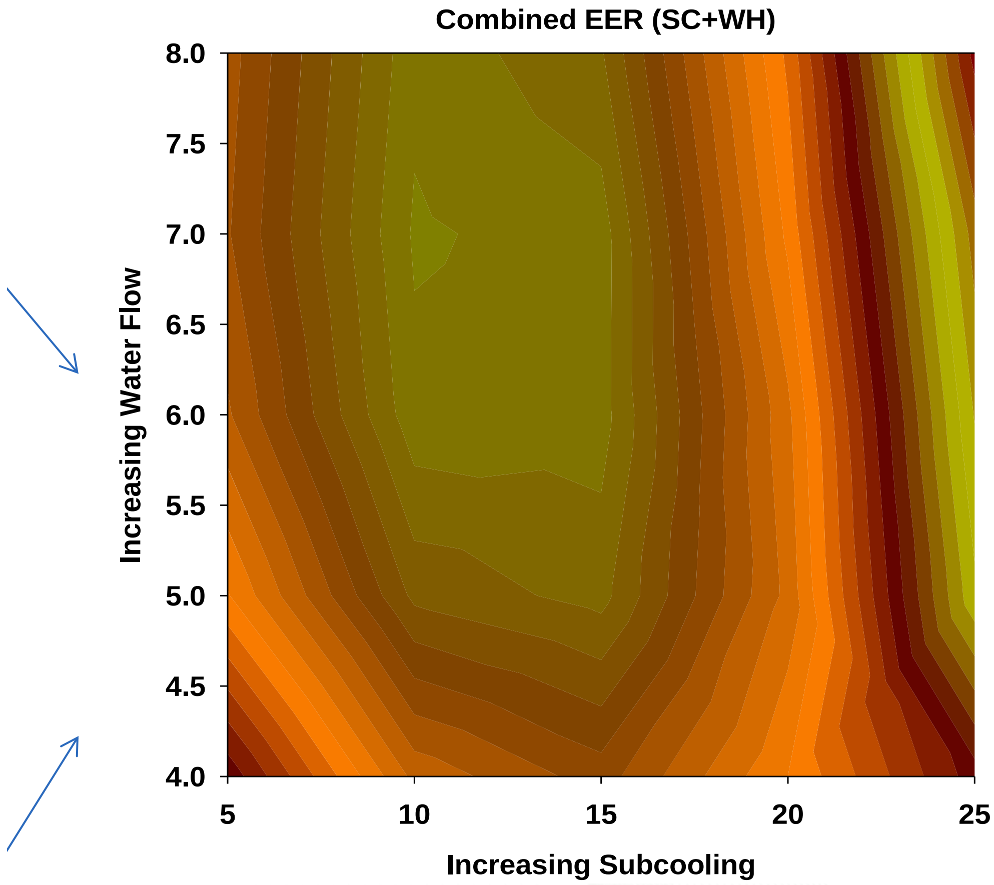
-Discharge saturation temp constraint

Convert compressor working envelope to equipment operation constraints.

3.2 Optimize Combined Efficiency







Total delivery efficiency is the target.

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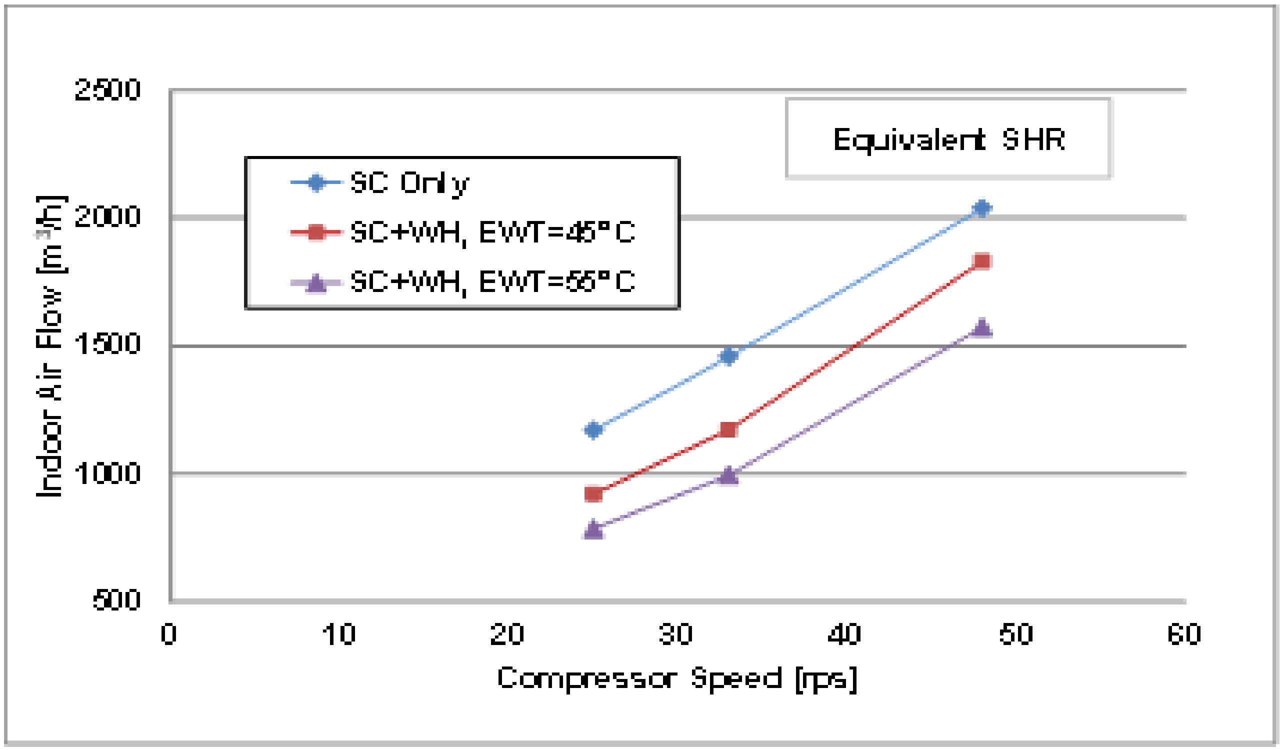
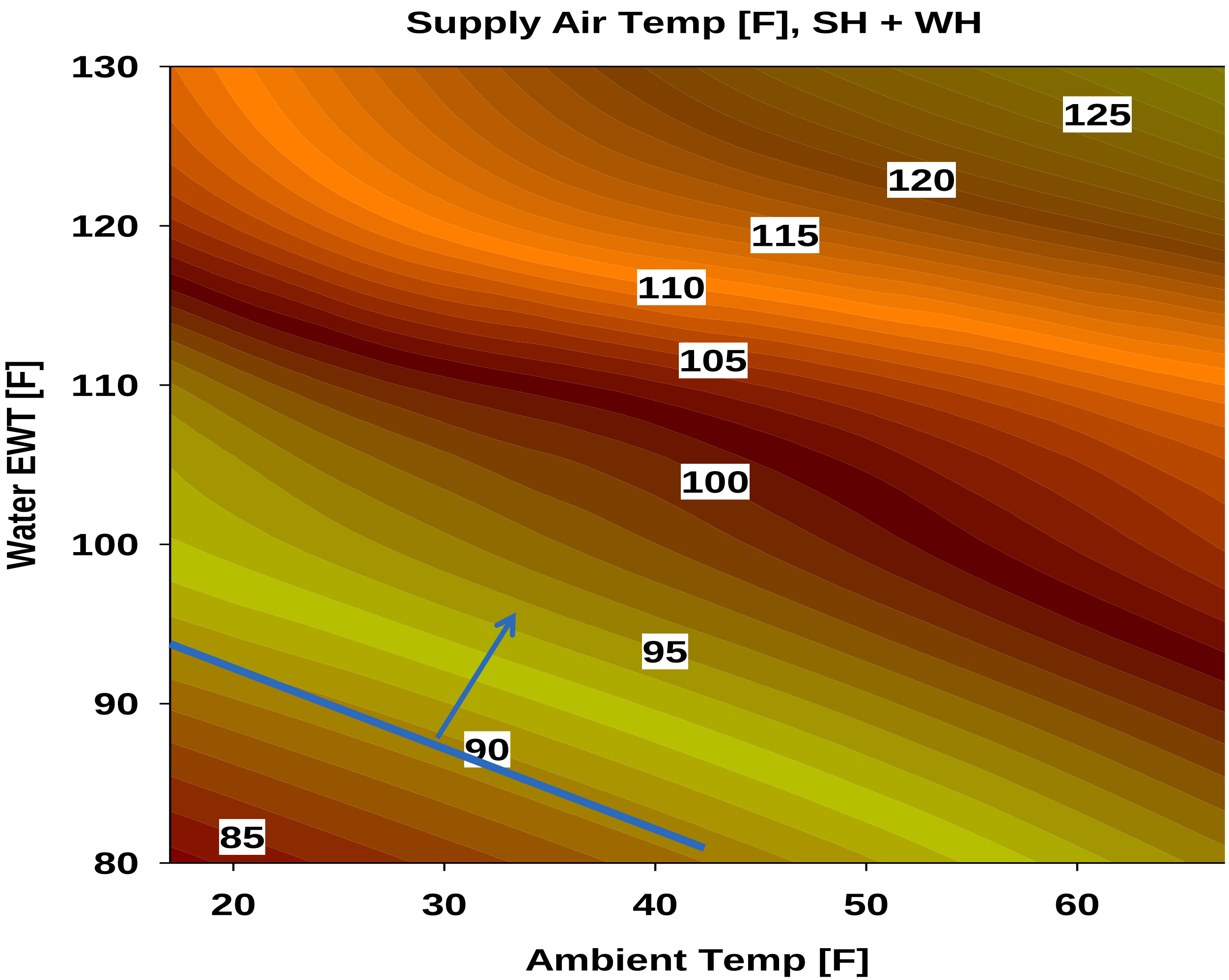
3.3 Optimize Efficiency with SHR constraint

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



Balance optimum efficiency with acceptable comfort.

3.4 Competing Demands of SHDWH Mode



-initial design at fixed compressor speed and water flow rate

WH function in SHDWH mode may take away too much heat from space heating.
-- increase compressor speed and lower water flow rate at low ambients to compensate

3.5.1 Predicted Annual Energy Savings in 5 U.S Locations (TRNSYS using HPDM performance maps) - 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**

Baseline: Electric Resistance WH; HP (13.0 SEER/8.0 HSPF)

3.5.2 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**

4. Summary

1. Simulations indicate ASIHP able to achieve annual energy savings > 50% in numerous US climate zones.

2. Demanding to design an ASIHP, e.g.

- operation constraints at different speed levels
- balance between efficiency & service/comfort requirements.
- competing demands of WH & space conditioning

An effective & flexible modelling tool is indispensable for the design process.

Discussion

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