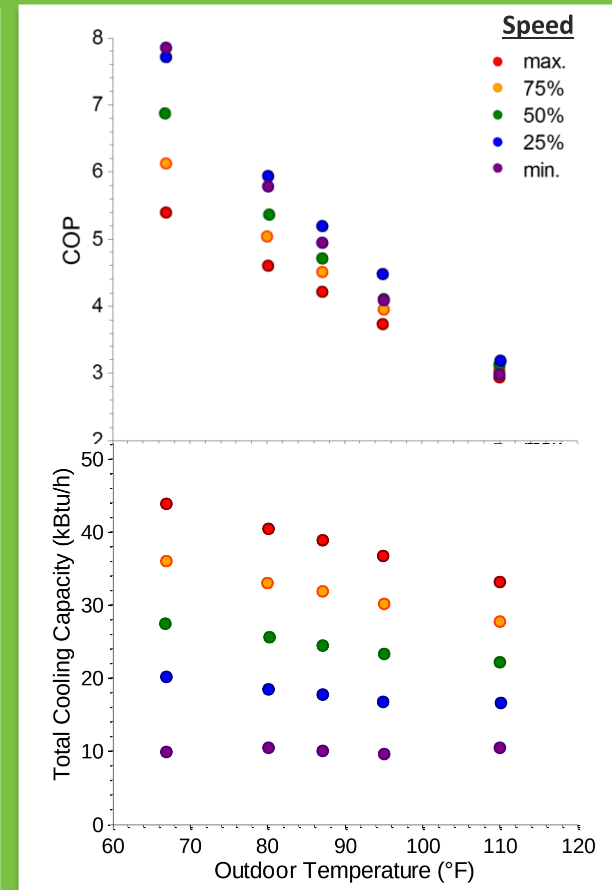
HVAC Performance Maps

2014 Building Technologies Office Peer Review



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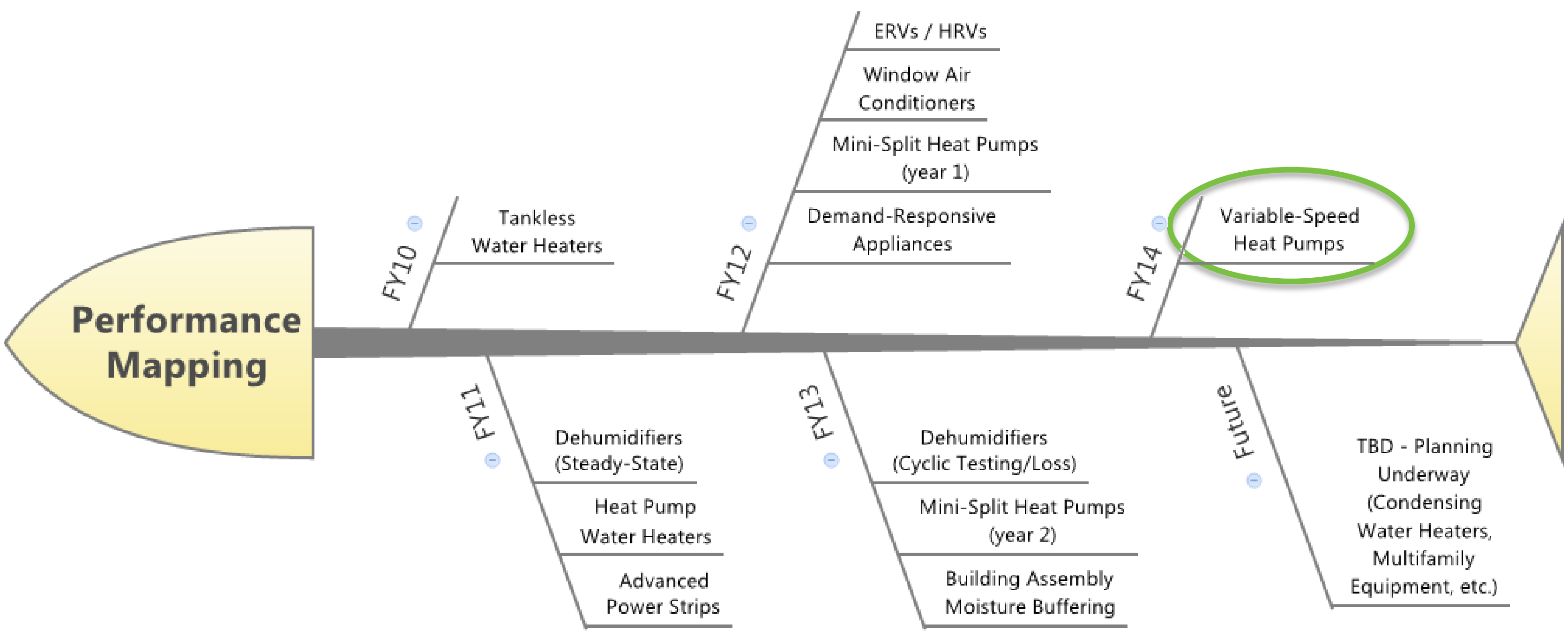
Performance Mapping at NREL

NREL develops and validates model inputs for certain types of residential products, for use in whole-building simulation tools.

Often, the available data is insufficient to completely specify these inputs. In those cases, additional investigation is required.

We term this data development effort "Performance Mapping."



Project Summary

Timeline:

Start date: 11/15/2013

Planned end date: 9/30/2014

Key Milestones

1. 1st Heat Pump characterization complete; 3/31/14
2. Technical Report - measured performance and simulation guidance for all units; 8/28/14

DOE Budget:

FY2014 Project: $340,000

Total future DOE $: TBD

Target Market/Audience:

- Residential whole-home efficiency programs (Federal, utility and private)
- Building simulation tools
- Building scientists and researchers
- Homeowners & HVAC contractors

Key Partners: *(FY2014)*

- Ingersoll-Rand
- Carrier
- Lennox International
- Oak Ridge National Laboratory

Project Goal:

Through laboratory evaluation, this project will develop detailed datasets, termed "*performance maps*," of certain types of heat pumps.

Performance enables impact:

1. Developing & validating technology models for building energy simulation tools
2. Creating generalized and product-specific model inputs
3. Identifying product improvement opportunities

Building America and similar programs rely on performance maps to estimate product energy use and delivered capacity in a whole-building context, across varying climates and conditions.

Purpose and Objectives

Problem Statement: Gaps exist in our ability to accurately predict energy use and delivered capacity of efficient products when installed in real buildings and operated under various conditions. To address these gaps, technology models must be created and validated. Then model inputs, representing actual products, must be developed.

Typically, **publically-available product data is insufficient to meet these needs**.

Project Goal: NREL's **Performance Maps project develops EnergyPlus model inputs**, termed "*performance maps*," used to accurately estimate energy use and delivered capacity of the product across the full range of real-world operating conditions. Building America and similar **programs rely on performance maps** in order to accurately evaluate product energy use and cost-effectiveness in a whole-building context.

In FY2014, this project will develop performance maps of residential variable speed heat pumps (VSHPs).

Target Market and Audience: Building America program, industry teams, similar home energy efficiency researchers and programs.

Project Impact – FY14, Variable Speed Heat Pumps

Performance mapping projects seek to **enable high impact**:

1. Develop & validate technology models for building energy simulation tools *(mathematical framework – what are the right equations to best represent this type of product?)*
2. Creating product-specific model inputs *(what parameters describe this specific product?)*
3. Identifying opportunities to improve field performance *(how will interactions with other systems impact overall product/technology performance in real buildings?)*

Impact is achieved in two ways:

Market Transformation

1. Efficient products become broadly accessible in building energy tools
2. Tool use informs benefits, cost savings from efficient products in real buildings
3. Perceived barriers to efficient product adoption are reduced

Product Innovation

1. Field performance improvement opportunities are distributed to manufacturers, efficiency stakeholders
2. Products are modified to address these opportunities
3. Improved products outperform their competitor products, earning market approval

4. Market penetration of higher efficiency products grows
5. Minimum efficiency standards can be increased

Approach

Approach:

1. Study the technology's simulation tool model
2. Identify performance map parameters, data requirements
3. Select a laboratory methodology to collect necessary performance map data
4. Conduct performance mapping on representative products, at a comprehensive set of operating conditions and compressor loads
5. Generate model inputs and validate EnergyPlus model using experimental data – publish to public and simulation tools
6. Identify and pursue product innovation path opportunities

Key Issues: Control strategies incorporated in variable speed systems make it challenging to collect steady-state performance in a laboratory.

Variable-Speed Heat Pump Model

Key Model Outputs:

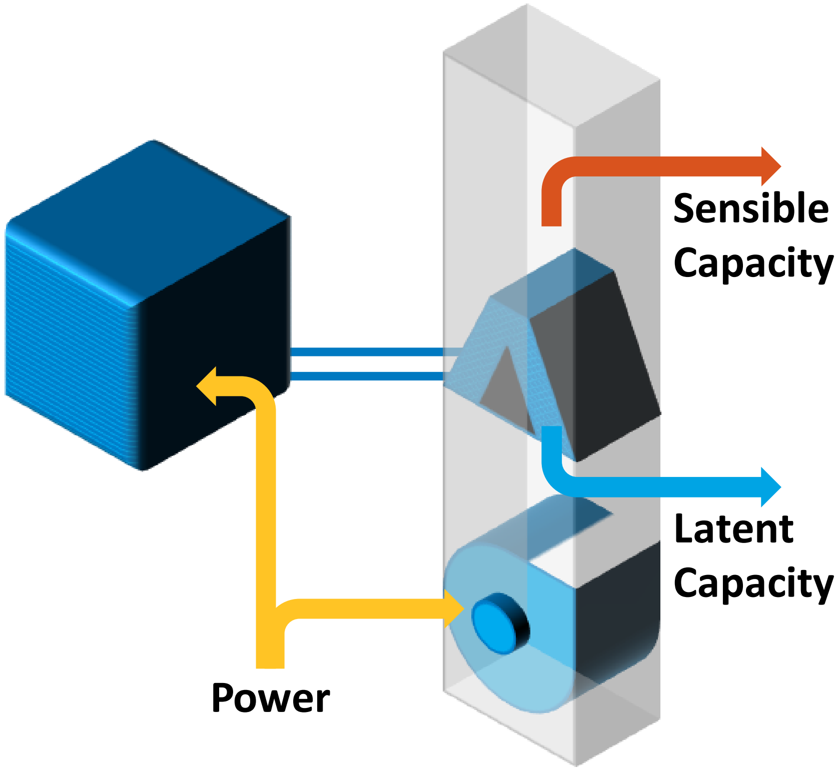
- Power consumption
- Sensible & latent capacity

E+ Model Inputs (Single Speed):

- Rated value inputs
  - Capacity, COP, SHR
- Biquadratic performance curve coefficients
  - Capacity, COP

E+ Model Inputs (Variable Speed):

- Number of speeds (*up to 10*)
- Single speed inputs for each speed modeled



Key Assumptions:

- Equipment perfectly matches the building load
- Performance in between speeds is determined through linear interpolation

Key Questions:

- How many speeds are required to accurately simulate variable speed units?
- Is linear interpolation in between speeds accurate?
- How does capacity turndown affect latent performance?
- How does system vary airflow as speed reduces?

Approach

Industry Practice (Publically Available Data)

- Manufacturer expanded data tables are not appropriate for developing model inputs [1]

EVAP. AIR	CONDENSER ENTERING AIR											
	75 (23.9)				85 (29.4)				95 (35)			
EWB °F (°C)	ID SCFM	Capacity MBtuh Total	Capacity MBtuh Sens‡	Total Sys. KW	ID SCFM	Capacity MBtuh Total	Capacity MBtuh Sens‡	Total Sys. KW	ID SCFM	Capacity MBtuh Total	Capacity MBtuh Sens‡	Total Sys. KW
25VNA036A**30 Outdoor Section With FE4ANI												
57 (13.9)		35.99	35.99	1.83		34.03	34.03	2.12		32.35	32.35	2.46
62 (16.7)		36.04	36.04	1.83		34.09	34.09	2.12		32.40	32.40	2.46
63 (17.2)††	1325	36.10	29.46	1.83	1240	34.19	27.82	2.12	1200	32.33	26.63	2.46
67 (19.4)		39.00	30.83	1.79		36.98	29.12	2.07		35.00	27.90	2.41
72 (22.2)		43.06	24.31	1.74		40.86	23.02	2.02		38.71	22.00	2.36

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25VNA036A**30 Outdoor Section With FE4ANI												
57 (13.9)		14.31	14.31	0.60		13.73	13.73	0.74		13.07	13.07	0.89
62 (16.7)		14.31	14.31	0.60		13.75	13.75	0.74		13.11	13.11	0.89
63 (17.2)††	500	14.40	11.66	0.60	500	13.68	11.34	0.74	500	12.89	11.01	0.90
67 (19.4)		15.61	12.20	0.57		14.82	11.88	0.71		13.97	11.56	0.87
72 (22.2)		17.18	9.66	0.53		16.40	9.38	0.67		15.48	9.05	0.83

- Model-derived, with previously identified limitations and large uncertainty
- Only two speeds (min & max) provided – 25 operating conditions

[1] Cutler, D.; Winkler, J.; Kruis, N.; Christensen, C.; Brendemuehl, M., *Improved Modeling of Residential Air Conditioners and Heat Pumps for Energy Calculations*. 46 pp.; NREL Report No. TP-5500-56354, 2013. http://www.nrel.gov/docs/fy13osti/56354.pdf

Building America VSHP Performance Mapping

	Compressor Speed (%)	Outdoor T_DB (°F)		Indoor - Sealevel T_DB (°F)	T_WB (°F)	W (grains)	RH (%)	T_DP (°F)	Set Points Outdoor T_DB (°C)	Set Points Indoor T_DB (°C)	T_DP (°C)	W (grains)
1		67							19.4			
2		75							23.9			
3		82							27.8			
4		87	Indoor Rated	80	67	78.1	51.1	60.4	30.6	26.7	15.8	97.8
5		95							35.0			
6		100							37.8			
7		110							43.3			
8		67							19.4			
9		80							26.7			
10		87	Indoor Pt. 2	76	65.8	78.4	58.5	60.4	30.6	24.4	15.8	97.9
11		95							35.0			
12		110							43.3			
13		67							19.4			
14	100	80							26.7			
15		87	Indoor Pt. 3	76	62.3	62.0	46.4	54.0	30.6	24.4	12.2	77.4
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20		87	Indoor Pt. 4	70	60.2	62.0	56.8	54.0	30.6	21.1	12.2	77.4
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- 150 test conditions

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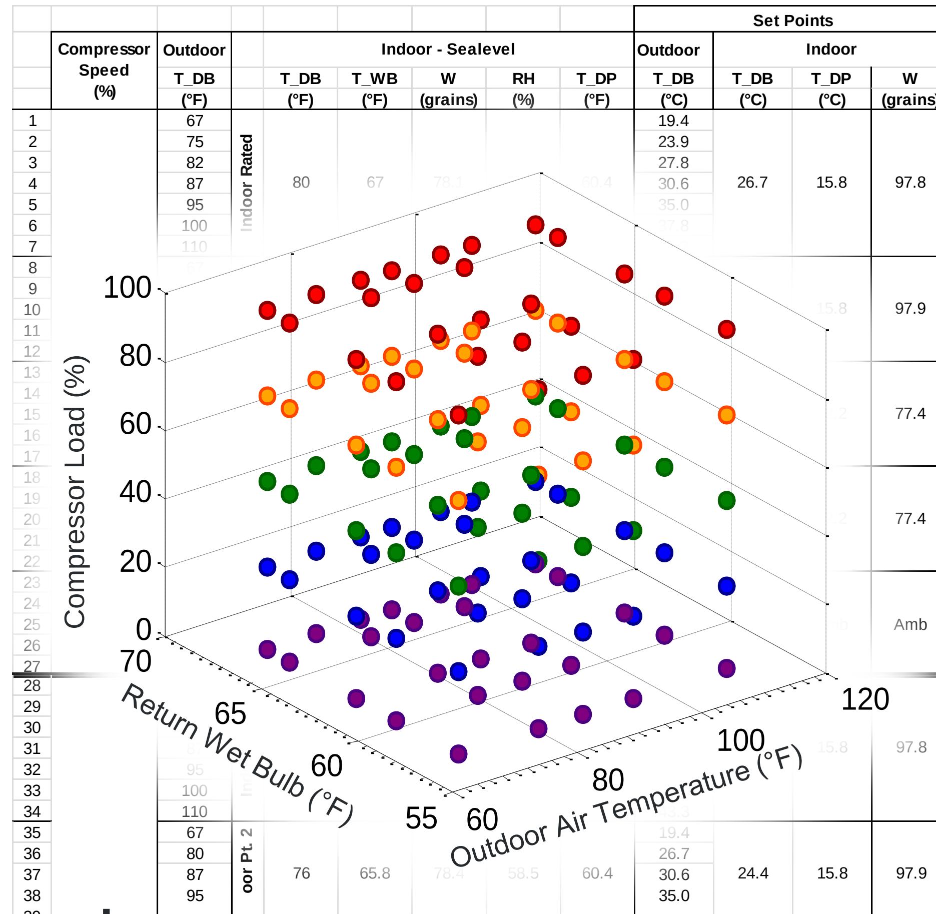
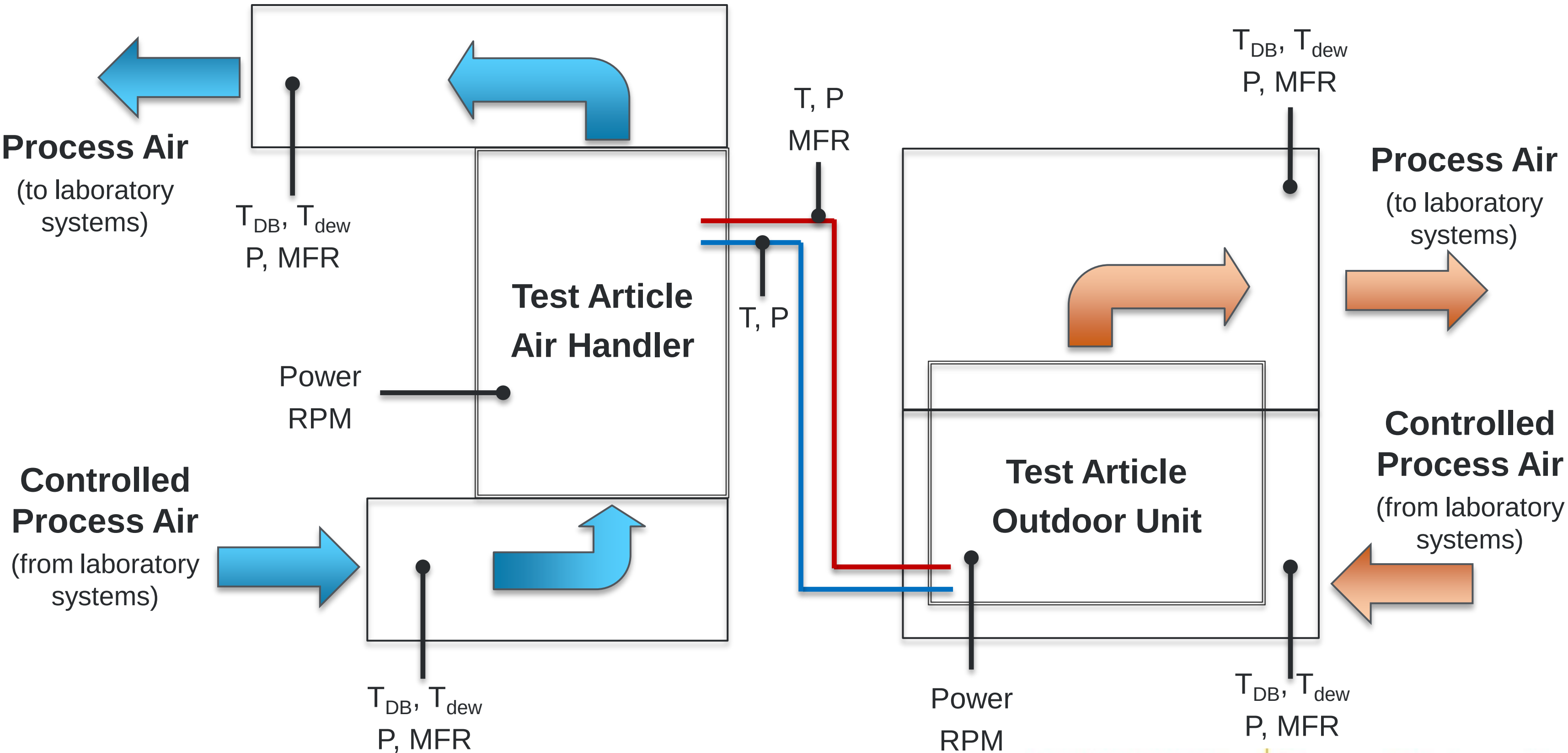
Building America VSHP Performance Mapping



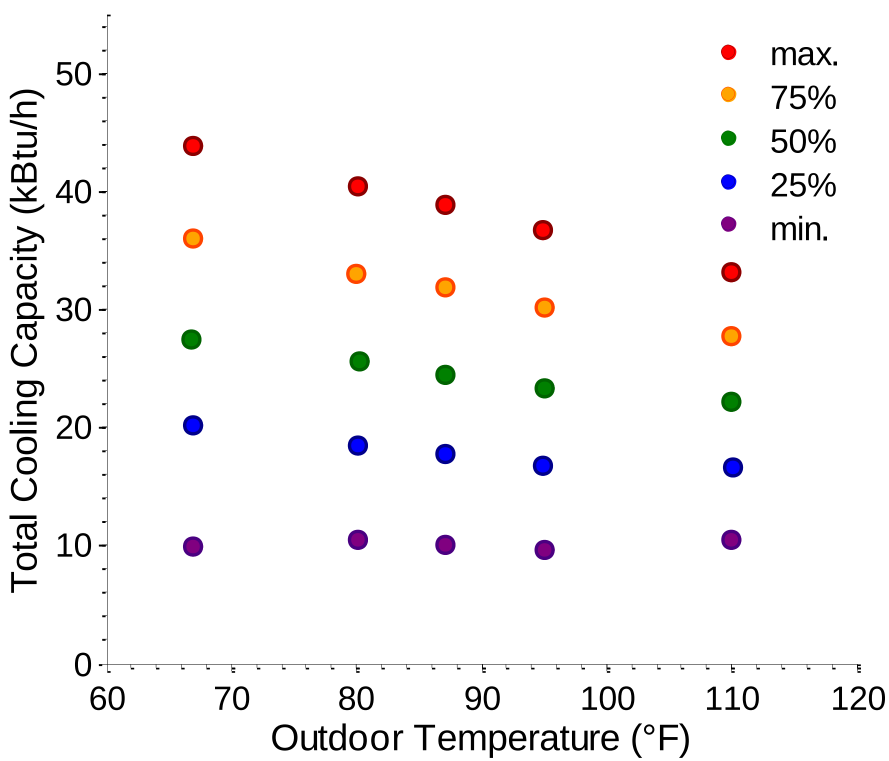
- 150 test conditions

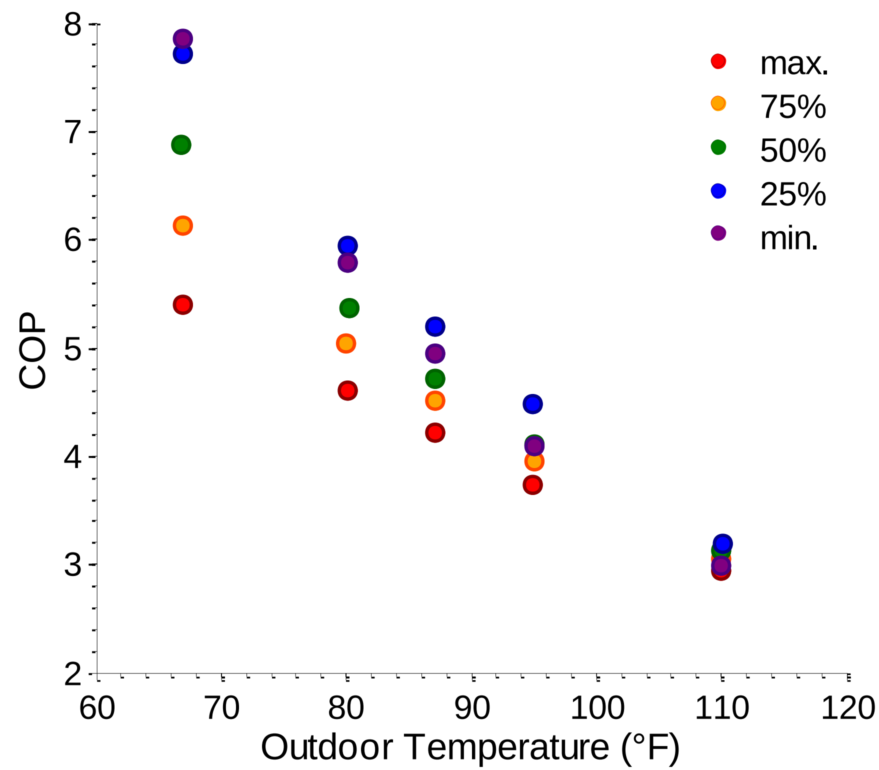
Schematic

Distinctive Characteristic: *NREL's unique* laboratory approach allows rapid adjustment of operating condition, expediting performance mapping data collection. It permits 150 test points in less than 3 weeks test time, resulting in a more comprehensive performance map than would be reasonably feasible via other methods.



Interim Results





- 76°F DB, 65.5°F WB indoor test condition (1 of 5 tested conditions)
- First test article maintained latent performance by proportionally reducing airflow. This could be good for low-load homes, but may affect air mixing at supply registers.

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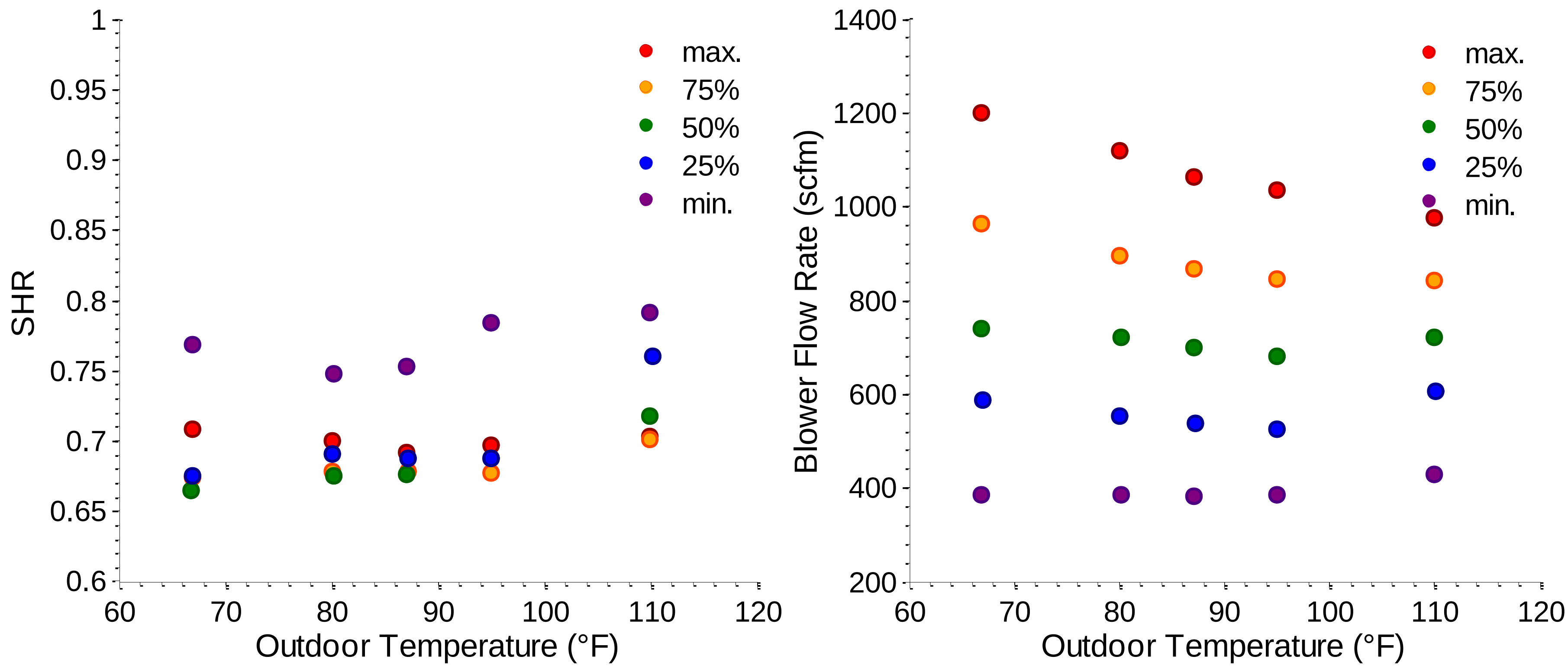

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Progress and Accomplishments

Lessons Learned: Simulation Model for variable-speed systems may be more complex than necessary to simulate residential central variable speed systems.

Accomplishments: NREL's FY14 HVAC Performance Maps project has met all project milestones on time & on budget. On track for successful completion.

Market Impact: Variable Speed Heat Pump Performance Mapping has been underway for 4 months. Market Impact will occur in the future.

Project Integration and Collaboration

Project Integration: This project is being executed with direct, regular communication with manufacturer partners – results, opportunities and impacts are shared with each prior to publication.

Partners, Subcontractors, and Collaborators:
- Manufacturer partners – technical support and discussion of product performance, collaboration on product improvement *(Partners)*
- ORNL and BA Teams – discussion of issues and opportunities, experience from prior field studies *(Partners)*

Communications: This work has not been presented.

Next Steps and Future Plans

Next Steps and Future Plans:

- Adjustments to the EnergyPlus model will be made, if necessary
- Performance Maps will be incorporated into BEopt, and available to public for use in other tools (EnergyGauge, OpenStudio, Home Energy Scoring Tool, etc.)
- Simulation studies will investigate regional, market opportunities and constraints
- Collaboration with manufacturers will lead to next-generation products addressing any opportunities identified through performance mapping

Project Impact – Prior Year Example, HPWHs

FY2011 – Performance Mapping – Residential Heat Pump Water Heaters (HPWHs)

Project Description: Five integrated HPWHs were performance mapped in NREL's Advanced HVAC Systems Laboratory. Project was co-funded by DOE and BPA. Results and improvement opportunities were documented in a technical report. http://www.nrel.gov/docs/fy11osti/52635.pdf

Market Impacts:

1. In FY11, NREL shared results with each manufacturer. Several **manufacturers improved their products based on our data and recommendations**. Improved controls and efficiency are evident in later field studies.
2. In FY11, NREL's work contributed to **BPA's successful efforts to offer the new integrated HPWH products as an efficiency measure** in the Pacific Northwest. http://www.aceee.org/files/pdf/conferences/hwf/2012/6B-Bedney-Final.pdf

> **"Our region has made great headway into offering HPWHs to end users. And there is no way that that would have happened without your laboratory testing. You've done a tremendous work in supporting our regional efforts. … The lab testing proved that at least two of the products had the potential to save energy in our climate zones and that HPWHs were reliable."**
>
> ***- Kacie Bedney, BPA Technology Innovations Program Manager***

3. HPWH performance maps demonstrated that the **existing EnergyPlus HPWH model was not satisfactory for simulating residential HPWHs**. In FY12, the NREL Analysis team developed a new model based on performance map findings. http://www.nrel.gov/docs/fy12osti/54848.pdf

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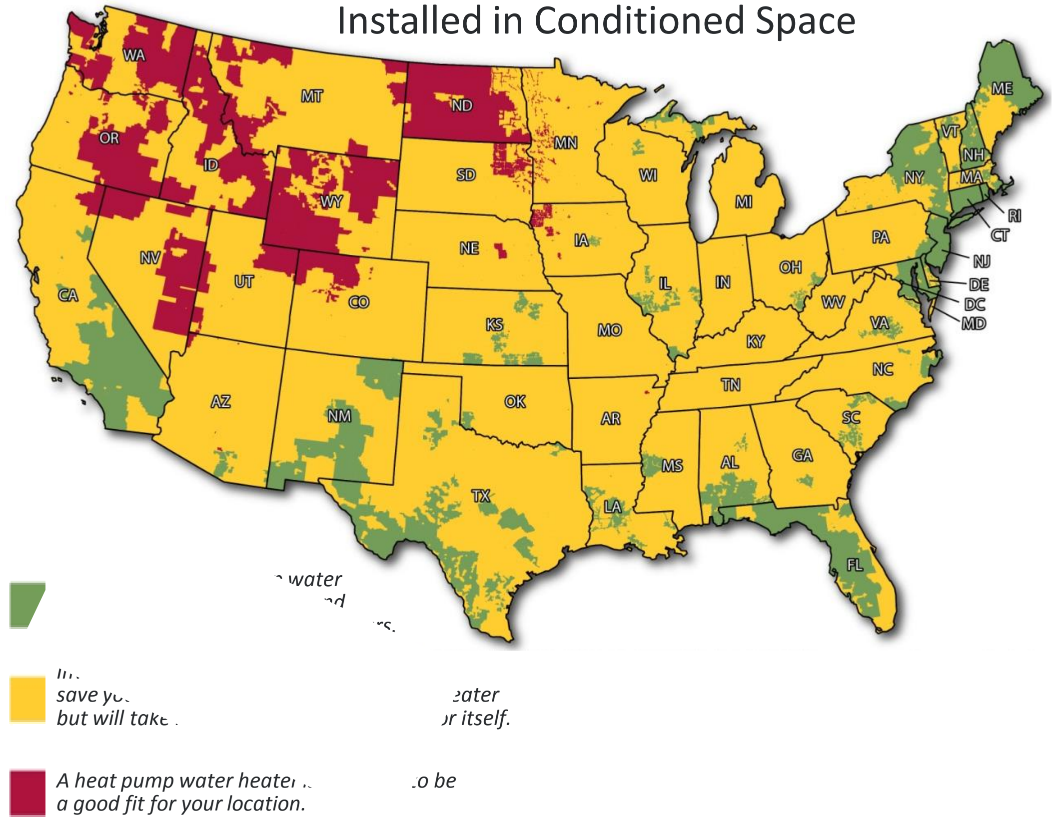
Project Impact – Prior Year Example, HPWHs

Ensuing Research:

4. In FY12-13, NREL used simulation tools to **perform a national technology assessment** that identifies regional impacts of HPWH technology from policy-, utility- and homeowner-centered perspectives. *http://www.nrel.gov/docs/fy12osti/51433.pdf* & *http://www.nrel.gov/docs/fy13osti/58594.pdf*
5. In FY13, NREL developed algorithms and patent-pending methods for **advanced control of HPWHs for enhanced hot water delivery and energy efficiency**.
6. In FY13 and FY14, NREL is investigating **HPWH Installation** to enhance whole-building efficiency.
7. In FY13 and FY14, NREL has **collaborated with two HPWH manufacturers to support next-generation HPWH product innovation.**

Estimated HPWH Payback
Installed in Conditioned Space



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REFERENCE SLIDES

Project Budget

Project Budget: $340,000 – FY2014
Variances: None. Project is being executed to plan.
Cost to Date: $170,000

Budget History					
FY2013 (past)		FY2014 (current)		FY2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	340,000	0 *	0	0

Additional Funding: * Modest in-kind cost share from partners:
Manufacturer partners – wholesale pricing on test articles, technical support
ORNL and Building America Teams – discussion on opportunities & prior findings from field monitoring of similar systems

Project Plan and Schedule

Project start date: 11/15/2013   Project planned completion date: 9/30/2013

Key Milestones:

- Complete performance mapping of first test article, 3/31/2014
- Deliver Technical Report on performance mapping results and simulation guidance, 8/29/2014

Project is on schedule and expected to complete successfully

Project Schedule												
Project Start: November, 2013		Completed Work										
Projected End: September, 2014		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed										
		Milestone/Deliverable (Actual) use when met on time										
	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Monthly Status Reports												
Q2 Milestone: Complete Performance Mapping on first test article												
Current/Future Work												
Q3 Milestone: Monthly Status Reports												
Q4 Milestone: Technical Report (Deliverable)												