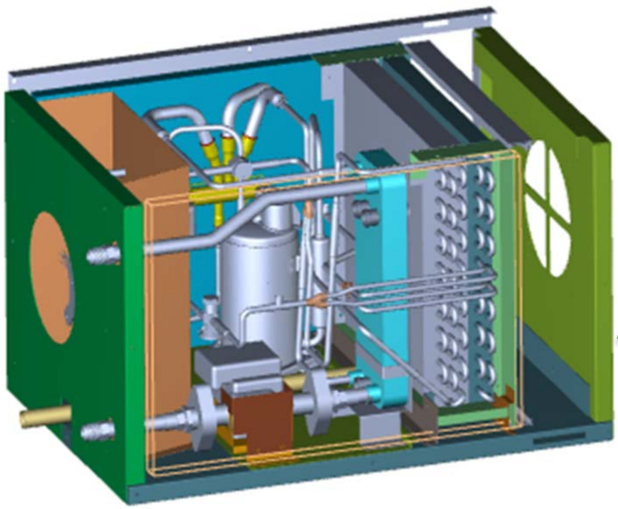
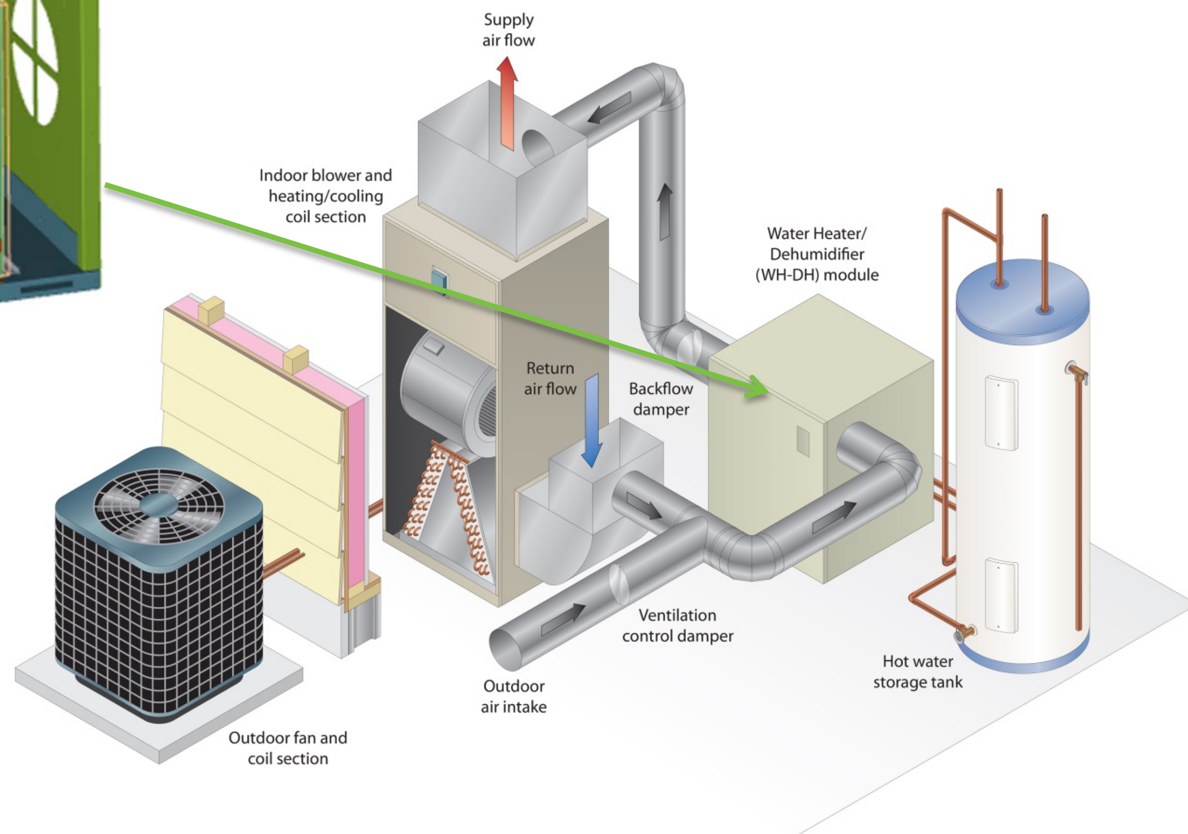
AS-IHP System Development

2017 Building Technologies Office Peer Review





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Project Summary

Timeline:

Start date: 10/1/2007

Planned end date: 9/30/2017

Key Milestones

1. Air-Source Integrated Heat Pump (AS-IHP) system prototype field test completed; 11/15/2016
2. Draft final project report; 2/28/2017

Budget:

Total Project $:

- DOE: $2845k
- Cost share: ~ 50% of DOE funding

Key Partners:

Lennox International Inc.

LENNOX

Project Outcome:

- Developed prototype **"retrofit ready"** advanced HVAC/WH system.
- Demonstrated **year-round dedicated space relative humidity (RH) and ventilation** control (important for homes with tight envelopes).
- Demonstrated system energy savings potential of approximately 30-40% for space heat/cool plus water heating.

Purpose and Objectives

Problem Statement: New energy efficient HVAC&WH technologies are needed by 2020 to enable BTO to meet its goals to reduce building energy use intensity by 30% by 2030 and ultimately by 50% (2016-2020 MYPP, page 15). This project focuses on a technology based on the integrated heat pump (IHP) concept.

Target Market and Audience:

- Regional solution for mixed/hot humid zones
  - Residential electric space heat and cool and water heater (WH) market of ~0.88 quads with technical potential savings of ~0.43 quads/year in 2030.

Progress and Accomplishments

Accomplishments:

- Close collaboration with partner to develop and verify performance of energy efficient HVAC/WH system prototype with dedicated space RH and ventilation control capability suitable for **retrofit** or new construction markets.
  - Novel heat pump water heating and dehumidification (WH/DH) module developed: HPWH performance plus dedicated RH and ventilation control.
  - **Retrofit ready**: WH/DH can be co-located with WH tank if remote from air handler and still retain at least the dual function (WH+space conditioning) IHP benefits along with dedicated space RH and ventilation control.
  - Demonstrated **excellent space RH control** (51-55% RH band) during entire field test year (*important* need for tight, efficient building envelopes in humid climate zones).
  - Maintained minimum ventilation per ASHRAE 62.2 during field test.
  - Demonstrated space heating and cooling and WH energy savings of ~18%, 38%, and 58%, respectively at field test site.

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Progress and Accomplishments

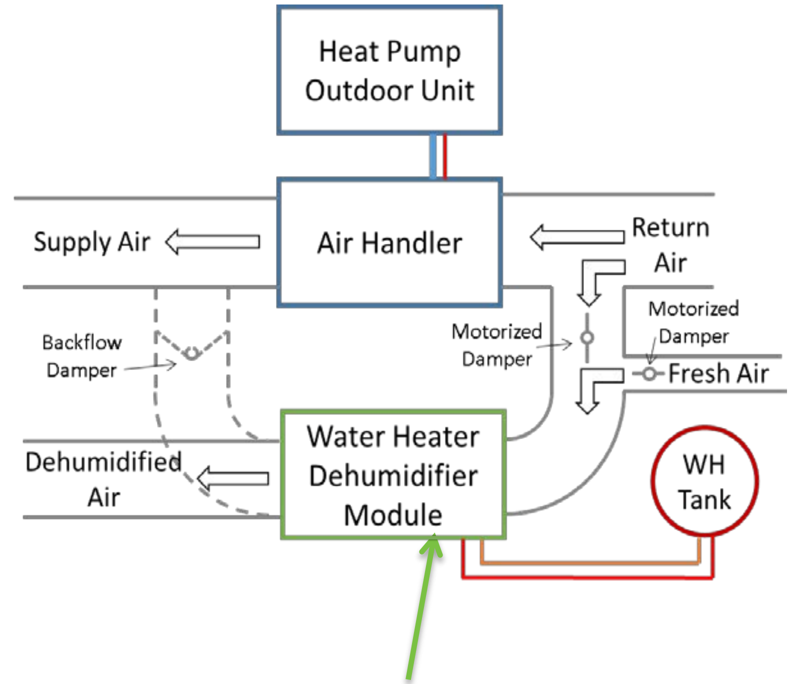
Market Goals:

- Intermediate: WH/DH product available 2-3 years after project completion
- Long-term: AS-IHP (WH/DH+ASHP) the go-to solution for home retrofit applications in warm/humid areas of US and export markets.

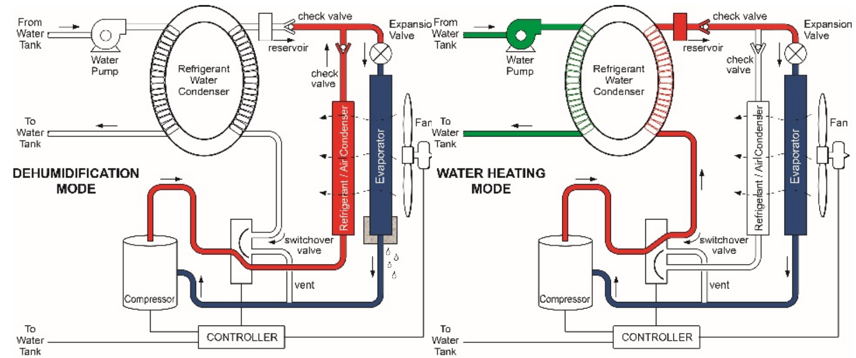
Lessons Learned: A field test step is critical in such development projects. It helps identify building integration issues that need resolution to facilitate ultimate development of a viable product for the building HVAC/WH market. For the subject project these included issues related to efficient operation of the WH/DH module in both its dehumidification and WH modes.

Approach: AS-IHP System Development

- Lennox embodiment of IHP concept
  - ASHP for space conditioning
  - Separate heat pump WH/DH module:
    - Space dehumidification, DH
    - Water Heating, WH
    - Ventilation air treatment, V
- ASHP component is an existing product
- WH/DH module primary focus for development efforts.
  - 3 cycles of WH/DH prototypes
    - ORNL used detailed heat pump model (HPDM) to conduct system optimization analyses.
    - Lennox built prototypes for testing by Lennox and ORNL; started from their whole house DH unit platform.
    - Final field test.



WH/DH module process diagrams: US Patent 6,689,574 B2



General issue: Resource limitations (time line)

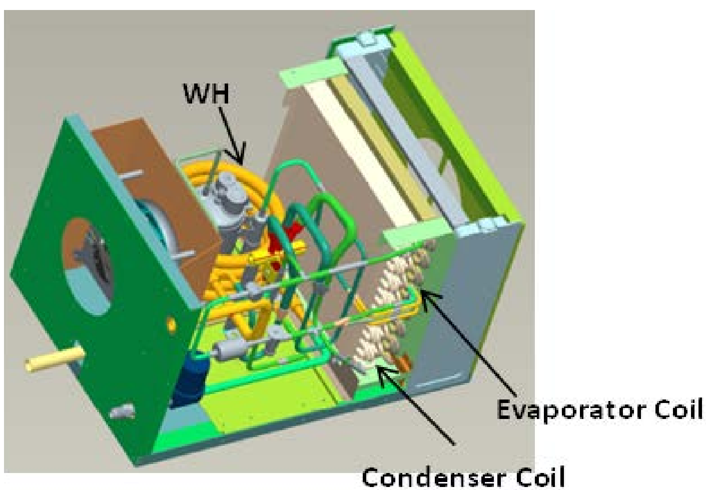
Approach: WH/DH Unit Development

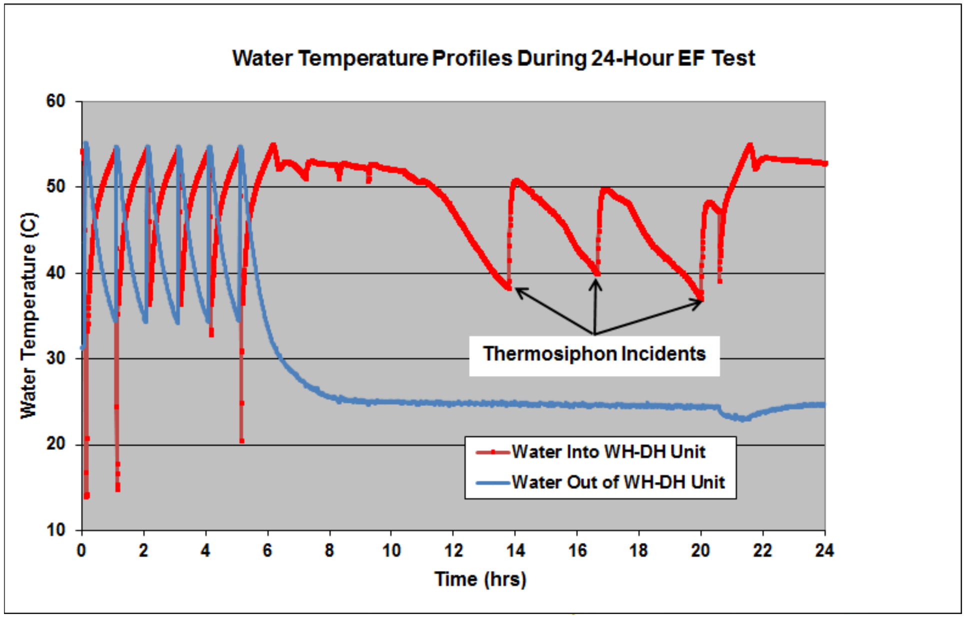
First generation WH/DH

- Target performance (Energy Star: DH energy factor, EF ≥1.85; WH EF ≥2)
  - DH EF achieved; EF ~2 @ std. conditions of 80F/60%RH & <75 pints/d capacity

Key issues:

- Lennox blower tests indicated unit capable of only 240 cfm air flow vs. 300 cfm per ORNL design analyses (air inlet & outlet too small).
- WH mode EF only ~1.9 (WH mode heat losses too high)
  - Tank water recirculation during off periods result in extra WH/DH operation.
  - More insulation needed internally and on connecting lines.





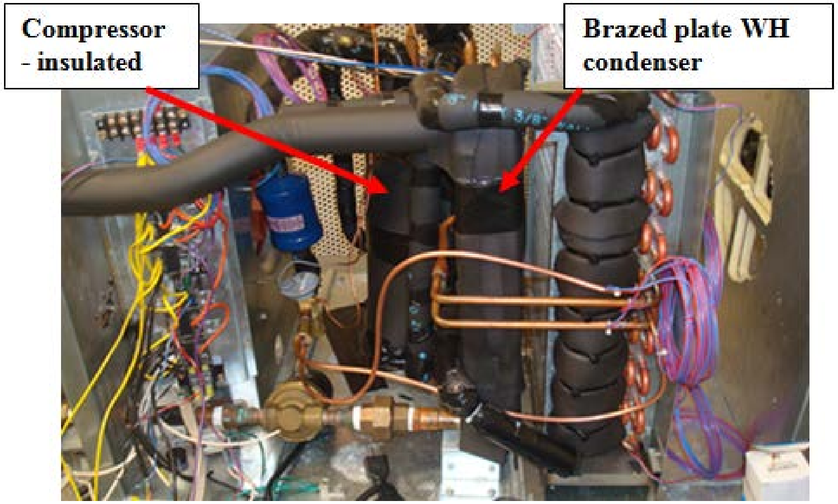
Approach: WH/DH Unit Development

2nd generation WH/DH

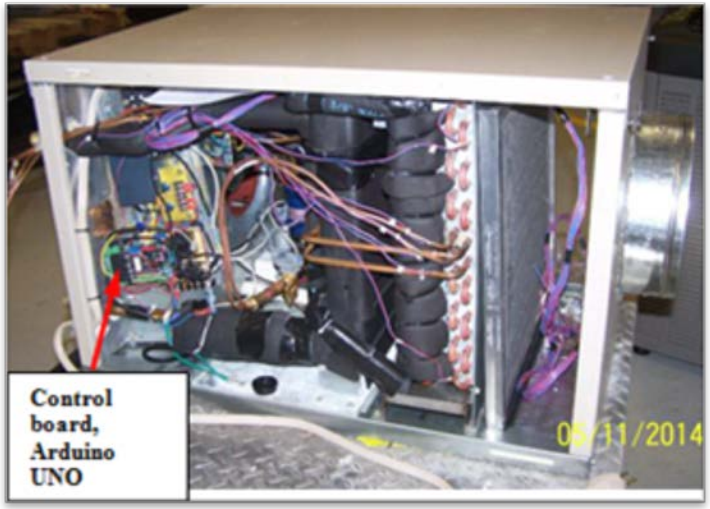
- Increased air connection size to 10”; switched to brazed plate WH condenser; further insulated all “hot” components.
- WH EF target achieved, ~2.05.
  - Still significant heat losses in connecting lines between tank and module.
- DH EF improved from ~2 to ~2.2 L/kWh.

3rd generation, field test WH/DH prototype

- Improved insulation for WH condenser and added solid state controller.



2nd generation WH/DH

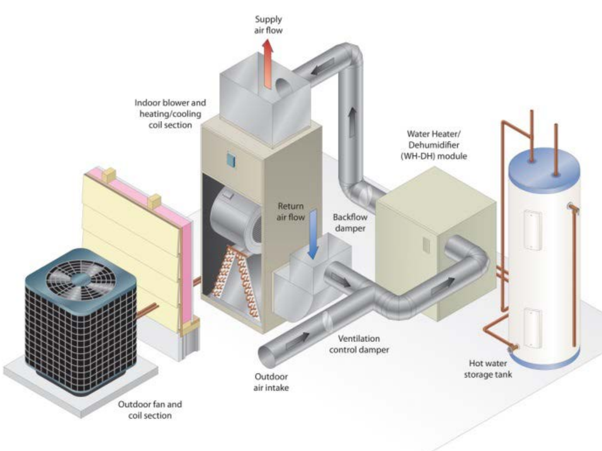


Field test WH/DH prototype

Approach: Field Test

Distinctive Characteristics:

Field tested in unoccupied research house in Knoxville, TN beginning August 2015. Controlled but realistic internal and hot water loads determined via Building America Analysis Spreadsheet and Domestic Hot Water Event Generator.



Key issues:

1. Condensate re-evaporation from WH/DH evaporator during ventilation.
2. Line heat losses during WH operation.

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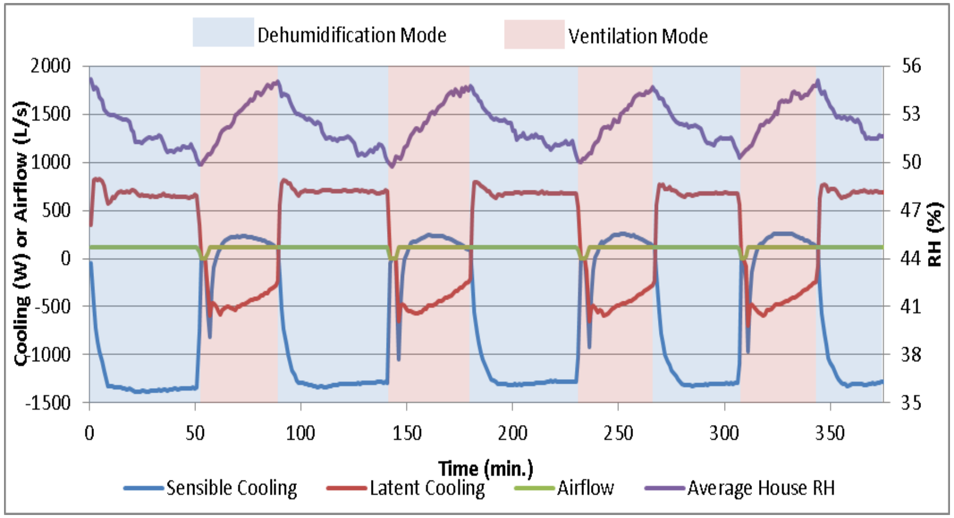
Re-evaporation Issue

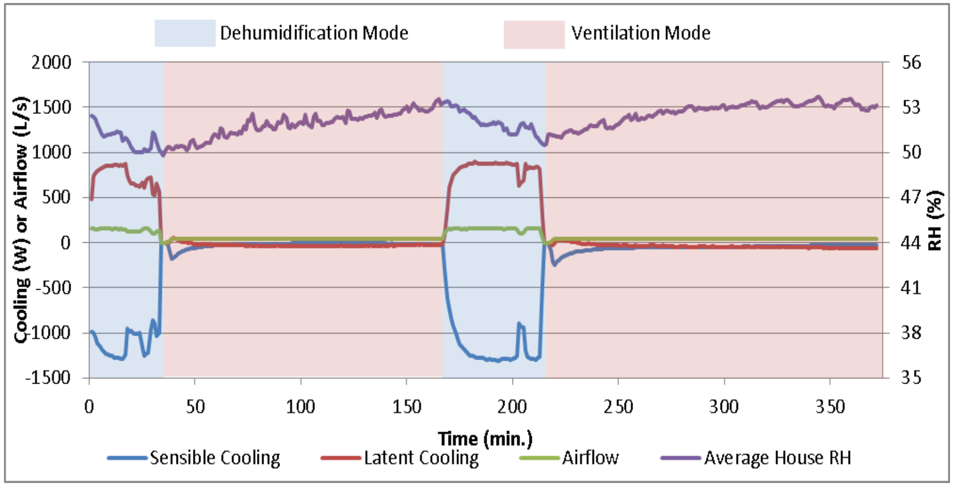
Initial WH/DH control approach: Entering air to WH/DH was combination of indoor and outdoor air.

Equal airflow (300 ft^3/min) used in DH, WH, and ventilation (V) modes to ensure sufficient V flow (top plot).

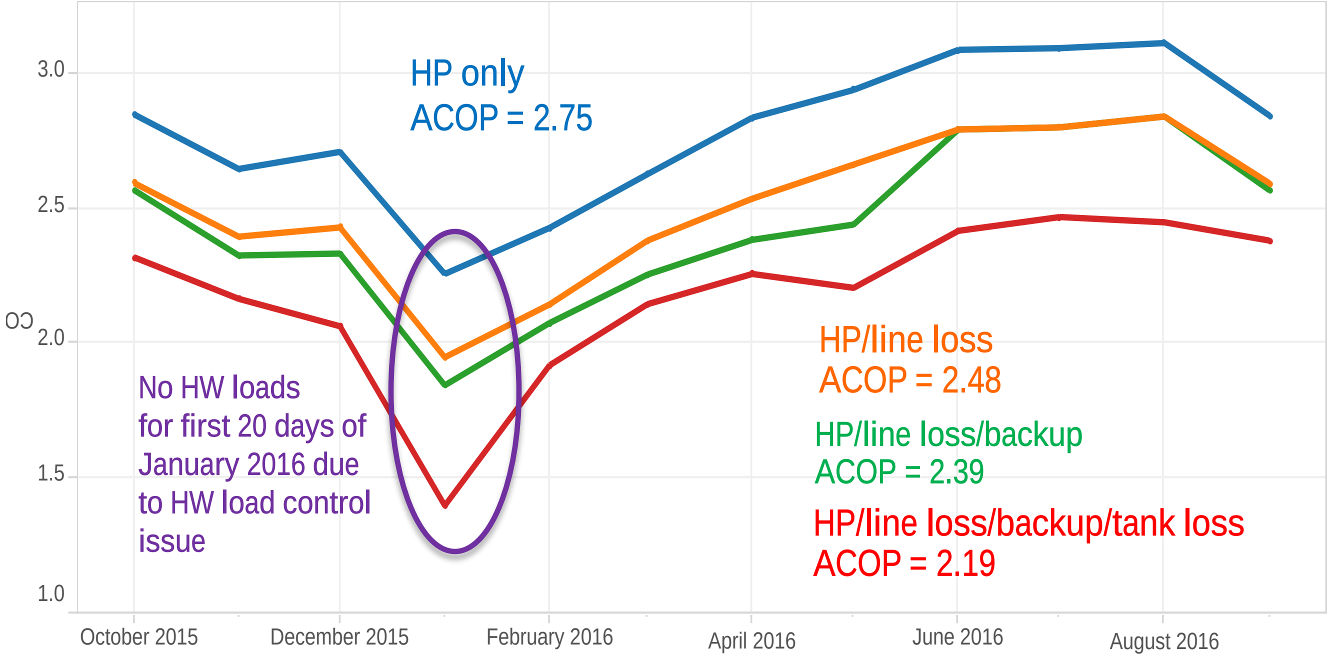
Revised control: In late June 2016, we installed a damper to close the space return air inlet and reduced air flow to minimum required (46 ft^3/min) for V mode: achieved reduced DH runtime and cycle frequency (bottom plot).

Planned: Internal damper mechanism designed and being fabricated to block part of evaporator during V mode. Plan to conduct tests later this spring.





WH Mode Line Heat Loss Issue



Note:
ACOP → average WH COP for 10/15 – 9/16; Includes Jan. 2016 no-load period

Heat losses from lines connecting WH/DH to storage tank accounted for ~10% of total WH energy use during Knoxville field test. To minimize this impact the line length and diameter should be minimized and line insulation maximized to extent possible in any given installation.

Backup electric WH element power accounted for ~5% of total WH energy use in field test.

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AS-IHP Overall Performance; 10/2015 thru 9/2016

	Baseline performance estimates		AS-IHP	Savings over baseline	
	Bin calculation*	Prior 13 SEER ASHP test results†		Bin calculation*	Prior 13 SEER ASHP test results†
Space heating, kWh (SCOPh)	5889 (1.98)	7061 (1.65)	5225 (2.23)	11%	26%
Space cooling and dehumidification, kWh (SCOPc)	3214 (2.86)	4013 (2.29)	2201 (4.17)	32%	45%
Water Heating, kWh (WH tank losses excluded)	2739	2739	1146	58%	58%
TOTAL, kWh	11842	13813	8572	**28%**	**38%**

Baseline: 13 SEER ASHP + 0.9 EF WH + 1.4 EF DH

Average savings estimates for field test site:

SH: ~18%; SC: ~38%; WH: ~58% **Total: ~33%**

Impact of WH/DH on ASHP performance ~200 kWh additional energy use; relatively small impact for target climate zones.

Note: For baseline using same ASHP as field test system, est. total savings are ~15%.

*Baseline ASHP SCOPs calculated using binned test year weather data.

†Baseline ASHP SCOPs average of measured values in 2011-2012 (same area).

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AS-IHP: General Project Resource Limitation Impacts

FY 08-09 – Design and preliminary assessment phases; no issues

FY 10-15 – WH/DH prototype build/test phases and field test preparation

- Lennox personnel and physical resources focused on qualifying existing product lines to meet impending increases in minimum SEER and HSPF requirements.
- ORNL staff focused on three other heat pump CRADA projects.
- Acquisition and preparation of new research house for field test (initial leased site returned to owner when lease expired).
  - We own the new site.

Overall impact: Approximately 5 years added to project duration

Project Integration and Collaboration

Project Integration: System and WH/DH development based on close collaboration with CRADA partner, Lennox. This ensures feedback from partner to ORNL regarding practical cost/manufacturability issues and technical/design/performance issue feedback from ORNL to partner for incorporation into eventual production design.

Partners, Subcontractors, and Collaborators:
Lennox International Inc., DOE/BTO RBI co-funded field test with ET

Communications: AS-IHP and WH/DH designs have been presented at ASHRAE, 2014 IEA Heat Pump, and ACEEE conferences. Field test results will be presented at the 2017 IEA Heat Pump Conference in May 2017 being held in Rotterdam, Netherlands.

Next Steps and Future Plans

Next Steps and Future Plans:

- Complete field test analyses and project report/conference paper.
- Present results at May 2017 conference.
- Complete tests of redesigned WH/DH module with internal damper mechanism.
- Commercial product launch timing uncertain:
  - Currently lower priority for Lennox vs. efforts to qualify mainline products for potential Low-GWP refrigerant conversion.
    - Maybe 2-3 years before commercial development.
  - Quickest approach at this time may be to license technology to other manufacturer(s).
    - Proposal submitted to DOE FOA 1632 under “Scale-up” area using this approach (project not “encouraged” for full proposal).
    - Other opportunities to be investigated.

REFERENCE SLIDES

Project Budget

Project Budget: DOE: 2845k, partner in-kind cost share ~50-60% DOE level
Variances: Schedule delays as noted
Cost to Date: ~2742k (through January 2017)
Additional Funding: Field tests co-funded with Residential Integration program

Budget History			
FY2008 – FY 2016 (past)		FY 2017 (current)	
DOE	Cost-share	DOE	Cost-share
$2805k	50-60%	$40k	50-60%

Project Plan and Schedule

- Project original initiation date: 10/1/2007
- Project planned completion date: 9/30/2017
- Schedule and Milestones: see below
- Significant delays due to competing priorities for ORNL and Lennox
- FT results to be presented in May
- Project final report to be completed by end of FY17

Project Schedule		
Project Start: October 2007		Completed Work
Projected End: September 2017		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned) use for missed
		Milestone/Deliverable (Actual) use when met on time

	FY2015				FY2016				FY2017			
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												
Complete FT proto dev (orig - FY11)												
Initiate FT (orig FY11)												
Complete proto AS-IHP FT (orig - FY12)												
Current/Future Work												
Complete final WH/DH tests												
Complete draft final project report												
Submit final project report												