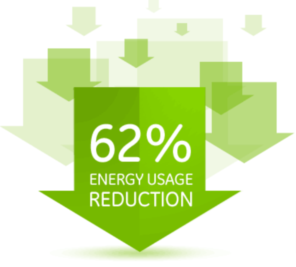
# Building America Program Review

April 24-25, 2013

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy






# Evaluation of Ducted GE Hybrid Heat Pump Water Heater in PNNL Lab Homes

**Sarah Widder**

# Project Partners



## Key PNNL Staff:

- Sarah Widder, Engineer, Principal Investigator
- Viraj Srivastava, Engineer, Demand Response Lead
- Vrushali Mendon, Engineer, Energy Modeling
- Nathan Bauman, Engineer, Metering

## Partners:

- Brady Peeks, Engineer/Manufactured Homes; Northwest Energy Works
- Jonathan Smith/Scot Shaffer, Engineers/Software & Hardware; GE Appliances
- Greg Sullivan, Principal/Metering & Analysis; Efficiency Solutions
- Valerie VanSchramm, CPS Energy

## Co-Funders:

- Bonneville Power Administration, Emerging Technologies Program
- DOE, Office of Electricity

# Lab Homes Partners

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- Initial Partners
  - DOE/BT/Building America-ARRA
  - DOE/BT/Windows and Envelope R&D
  - Bonneville Power Administration
  - DOE/OE
  - PNNL Facilities
  - Tri Cities Research District
  - City of Richland
  - Northwest Energy Works
  - WSU-Extension Energy Program
  - Battelle Memorial Institute (made land available)

# Primary Problem or Opportunity:
## National Energy Savings from HPWHs

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- Water heaters account for 18% of energy used in homes, or 1.8 Quads of energy use annually.[1]
- Electric resistance water heaters make up 41% of all residential water heaters in the U.S.[1]
- Heat pump water heaters (HPWH) can provide up to 62% energy savings over electric resistance water heaters.[2]
- 50% market penetration of HPWHs would result in savings of approximately 0.08 Quads annually.

[1] EIA; 2009 Residential Energy Consumption Survey

[2] Based on the DOE test procedure and comparison of an electric tank water heater (EF=0.90) versus a heat pump hot water heater (EF=2.35)

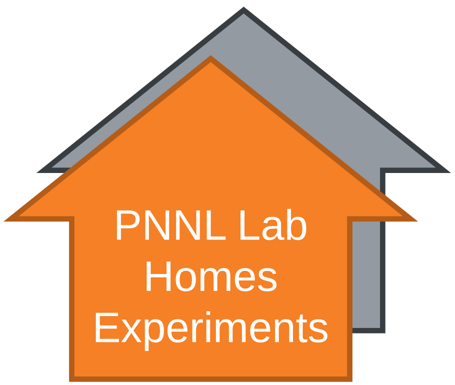
# Primary Problem or Opportunity:
## Lack of Market Penetration

- Currently, market adoption and utility program incentives of HPWHs are limited due to lack of understanding and field data regarding:
  - Impact on space conditioning energy consumption and occupant comfort.
  - Impact on demand response programs.
  - Durability in harsh water conditions.

# Primary Problem or Opportunity:
## The Role of This Research Project



- Evaluation of HPWHs in a highly controlled environment will help achieve market penetration of HPWHs through creation of a detailed data set that will comprehensively describe the performance of HPWHs installed in conditioned space in a number of configurations and as a demand response asset.

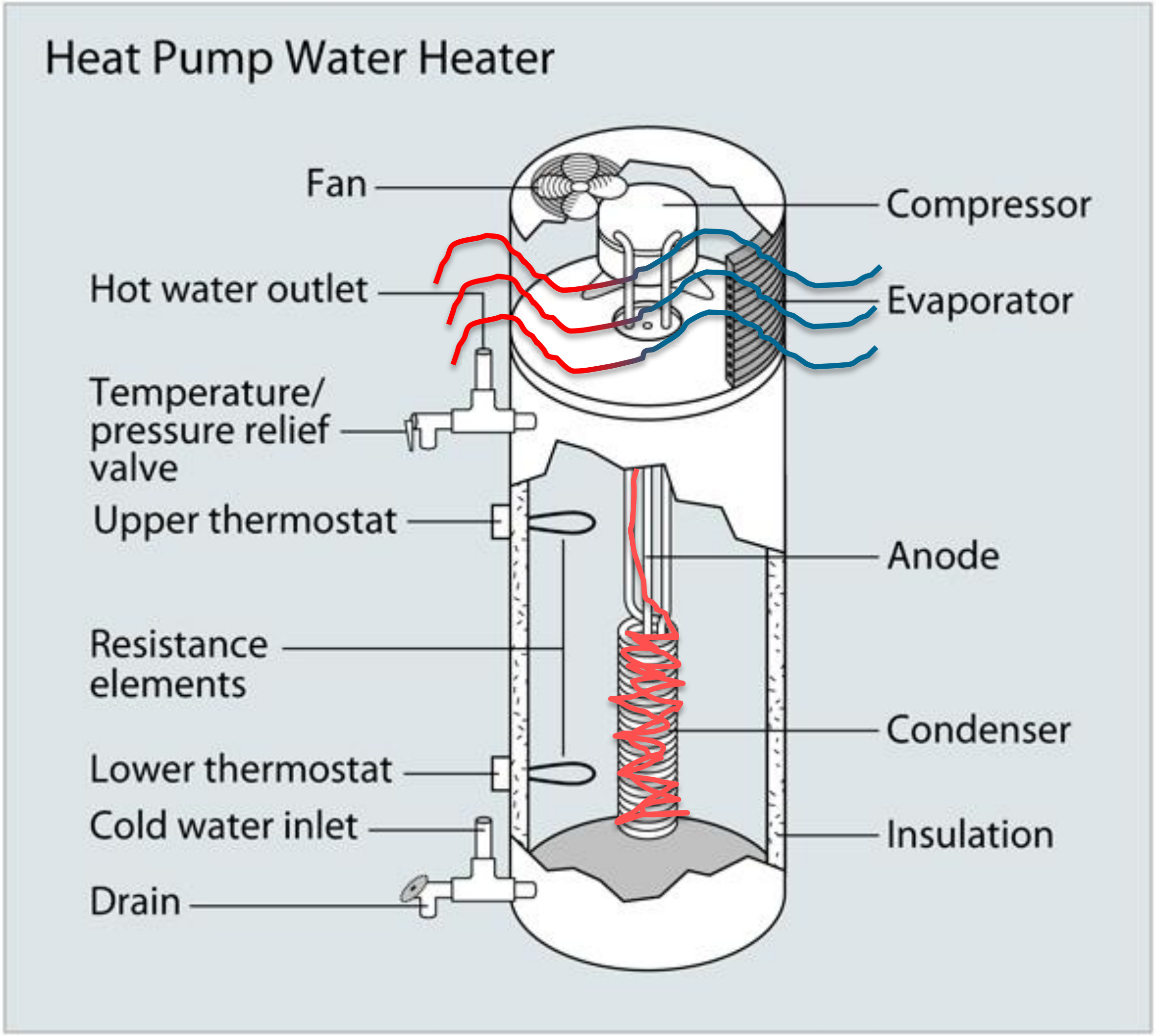



| Experiment | Whole House Power/Energy Use *[kWh or kW]* | HVAC Power/Energy Use *[kWh or kW]* | HPWH Power/Energy Use *[kWh or kW]* | Temperature/ RH at Several Interior Locations* *[°F/%]* |
|---|---|---|---|---|
| **Impact of exhaust ducting** | Whole house energy savings | Incremental HVAC systems energy use/savings | Impact of ducting and exhaust fan on HPWH efficiency | Impact of exhaust ducting on occupant comfort |
| **Impact of supply and exhaust ducting** | Whole house energy savings | Incremental HVAC system energy use/savings | Impact of supply ducting and supply air temp on HPWH efficiency | Impact of supply and exhaust ducting on occupant comfort |
| **Demand response characteristics** | Whole house power reduction during DR events | N/A | HPWH power reduction during DR events | *Tank temperature decrease during DR events |

- This information is necessary to support regional efficiency and manufactured housing programs and encourage more widespread adoption of HPWH nationally.

# Overview of Technology: HPWHs

- HPWHs work by transferring heat from the ambient air to the water in the tank.
- This process provides more energy to the water than it uses in electricity.
  - Tested Energy Factors (EF) for HPWHs available on the market range from 1.7 to 2.4.[3]




[3] Ecotope; 2011

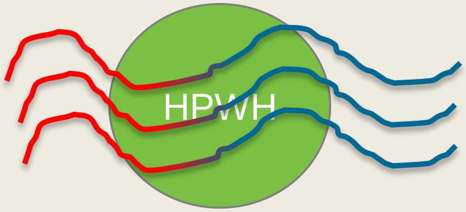
Source: U.S. DOE; energysavers.gov

# Overview of Technology: HPWHs in Conditioned Space



- HPWHs installed in interior space will use conditioned indoor air to heat water.
  - Benefit during cooling
  - Penalty during heating
  - May affect comfort

- Performance of HPWHs installed outside will have reduced performance.
  - Most HPWH compressors do not operate below 40-45 F.[3]




| | Interior | |
|---|---|---|
| | **Summer** | **Winter** |
| HP COP | 2.3 – 2.5 | |
| DHW Energy Savings | 2,500 kWh/yr | |
| Impact on Space Energy Use | -0 to 200 kWh/yr | +800 to 2,200 kWh/yr |
| Total Savings | 300 to 2,600 kWh/yr | |

[3] Ecotope; 2011

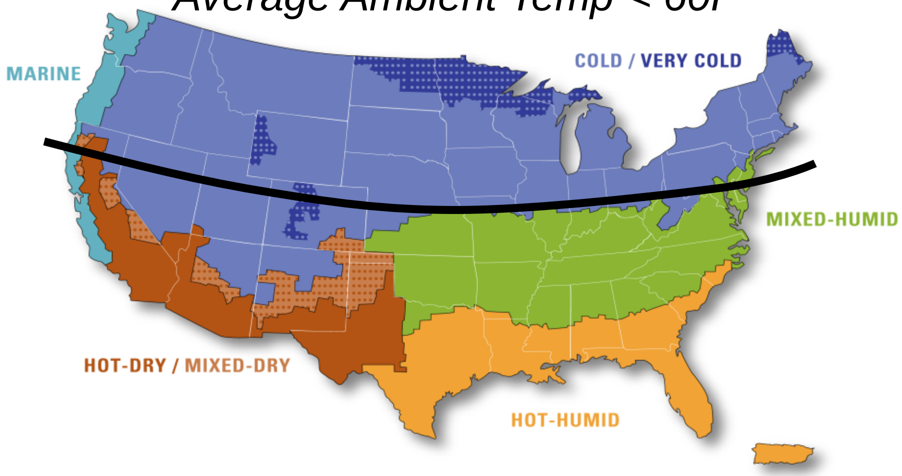
# Overview of Technology: HPWHs with Exhaust Ducting

- Modeling has found ducting exhaust to effectively mitigate some adverse space conditioning impacts in Northern Climates.
  - Resulted in NEEA Northern Climate HPWH Specification requiring exhaust ducting for Tier 2 products.

| | Minimum Northern Climate EF* | Minimum "Northern Climate" Features | Minimum supported installation locations | Sound levels** |
|---|---|---|---|---|
| **Tier 1** | **1.8** | • ENERGY STAR compliance | • Semi-conditioned<br>• Unconditioned | dBA < 65 |
| **Tier 2** | **2.0** | Tier 1 plus:<br>• Minimal use of electric heating elements<br>• Freeze protection<br>• Exhaust ducting option<br>• Compressor shut-down/notification<br>• 10 year Warranty<br>• Condensate Mgmt | • Conditioned<br>• Semi-conditioned<br>• Unconditioned | dBA < 60 |
| **Tier 3** | **2.4** | Tier 2 plus:<br>• Intake ducting option<br>• Air Filter Mgmt | • Conditioned<br>• Semi-conditioned<br>• Unconditioned | dBA < 55 |

* see Appendix A for details on definition and calculation method.
** see Appendix D for details on measurement method.

**Northern Climates**
*≥ 4000 HDD and*
*Average Ambient Temp < 60F*




- **Requires data to verify model assumptions and findings.**

# Overview of Technology: Supply Ducting

- Newton's 2nd Law
  - Reduced impact with exhaust ducting relies on buffering from semi-conditioned spaces.
  - Will result in depressurization with respect to outside.
    - This may be a problem for small homes (e.g., manufactured homes) and homes in high radon areas.

- NEEA Tier 3 Spec requires optional supply ducting and Northwest Energy Efficient Manufactured Home (NEEM) Specification may require similar.
  - No products are currently available with this configuration.
  - Ducting directly from outside will result in decreased HPWH performance.

- Need to verify performance of HPWH with supply ducting to crawlspace.

# Overview of Technology:
## HPWH Demand Response Characteristics

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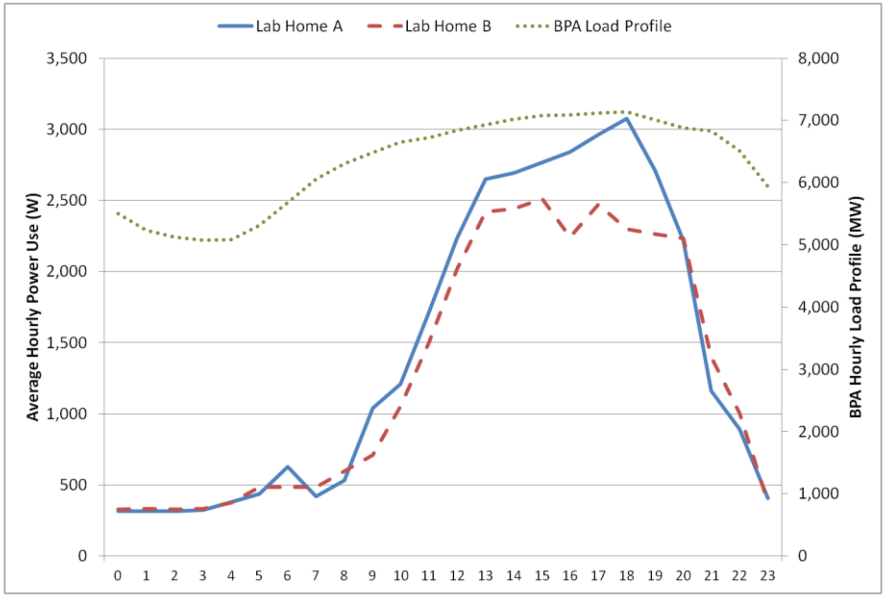


- Many utilities currently employ electric resistance water heaters to shave peak load by turning off the water heater (INC).
- PNNL has also demonstrated the potential of using HPWHs to increase load (DEC) for areas with high renewable penetration and to provide additional balancing and ancillary (voltage regulation) services.
- Need to understand demand response characteristics of HPWHs as compared to electric resistance water heaters, including “dispatchable kW,” “thermal capacity,” and “response time.”

# Overview of Technology:
## HPWH Durability in Hard Water

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- Utilities and consumers are concerned about lifetime of HPWHs in areas with hard water
  - HPWHs typically have anode rods installed to neutralize hard water and delay tank corrosion.
  - Information is not widely available for what ranges of hard water conditions anode rods are designed for or how they affect HPWH lifetime and cost effectiveness.

### *GE Hybrid Water Heater Warranty.*

All warranty service provided by our Authorized Servicer Network. To schedule service, call 888.4GE.HEWH (888.443.4394). Please have serial number and model number available when calling for service.

Staple your receipt here. Proof of the original purchase date is needed to obtain service under the warranty.

***What Is Not Covered:***

- Service trips to your home to teach you how to use the product.
- Improper installation, delivery or maintenance.
- Failure of the product if it is abused, misused, altered, used commercially or used for other than the intended purpose.
- Use of this product where water is microbiologically unsafe or of unknown quality, without adequate disinfection before or after the system.
- Replacement of house fuses or resetting of circuit breakers.
- Damage to the product caused by accident, lightning, fire, flood or acts of God.
- Incidental or consequential damage caused by possible defects with this appliance, its installation or repair.
- Product not accessible to provide required service.
- If product removed from original installation location.
- Damages, malfunctions or failure caused by the use of repair service not approved by GE.
- Damages, malfunctions or failure caused by the use of unapproved parts or components.
- Damages, malfunctions or failure caused by operating the heat pump water heater with the anode rod removed.
- Damages, malfunctions or failure resulting from operating the heat pump with an empty or partially empty tank.
- Damages, malfunctions or failure caused by subjecting the tank to pressure greater than those shown on the rating label.
- Damages, malfunctions or failure caused by operating the heat pump water heater with electrical voltage exceeding those shown on the rating label.
- Water heater failure due to the water heater being operated in a corrosive atmosphere.

*EXCLUSION OF IMPLIED WARRANTIES—Your sole and exclusive remedy is product repair as provided in this Limited Warranty. Any implied warranties, including the implied warranties of merchantability or fitness for a particular purpose, are limited to one year or the shortest period allowed by law.*

# Vision of Success



- Clear guidance on the optimal installation of HPWHs in all climates and configurations.
- Adoption of HPWHs as a fully-approved measure in BPA service territories and into other utility incentive programs, particularly in cold climates and areas with hard water.
- Consideration of HPWHs for High-Performance Manufactured Homes (HPMHs) in the Pacific Northwest that go beyond the current Northwest Energy Efficiency Manufactured Home (NEEM) specifications.
- Adoption of HPWHs into utility demand response product portfolios.
- HPWHs are installed as “standard” technology for electrically-heated homes across the nation and contribute to 50% energy saving solutions in new and existing homes.

# Business Plan Linking Research to Industry/Market

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## Research results will:

| | | |
|---|---|---|
| Present data to Regional Technical Forum | Present results to research community and builders | Provide installation guidance in BASC |
| **Justify and/or support modification of Northern Climate Spec and PNW Incentives** | **Inform HPWH models and enable Northern Climate Tier 3 product with supply ducting** | **Provide industry with installation best practices** |

# Key Metrics for Each Year of Funding Anticipated

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## 2013

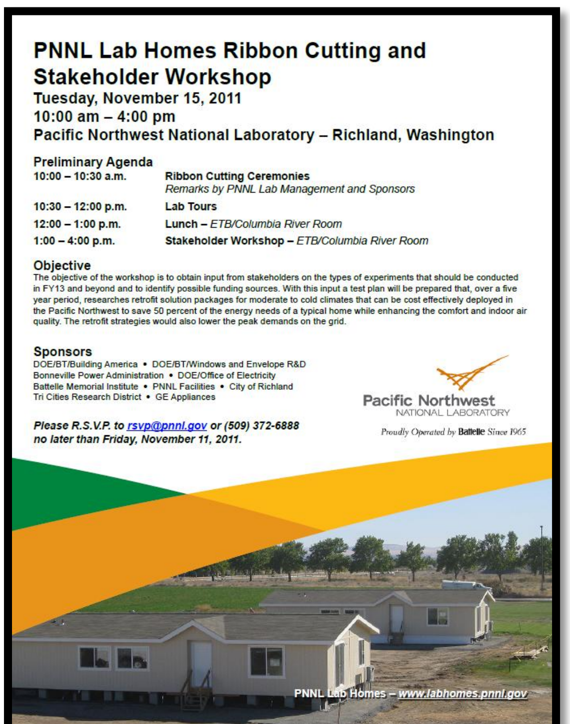
- Verification and documentation of energy savings, load-balancing potential, and performance of:
  - energy and occupant comfort impacts of new HPWHs without ducting, with exhaust ducting, and with supply and exhaust ducting,
  - HPWH demand response capabilities, and
  - HPWH performance in hard water conditions.
- Development of specifications for HPWH appropriate for adoption into utility incentive programs, particularly in cold climates and areas with hard water.
- Production of data set to inform HPWH model calibrations.

## Beyond

- Development of climate- and housing type-specific guidance for HPWH installation to maximize savings in all climate zones and configurations.
- Collaboration with manufacturers to develop market-ready supply ducted units, as appropriate.

# 2011 Primary Accomplishments

- Sited and commissioned PNNL Lab Homes
- Held Road-mapping Workshop



**PNNL Lab Homes Ribbon Cutting and Stakeholder Workshop**
**Tuesday, November 15, 2011**
**10:00 am – 4:00 pm**
**Pacific Northwest National Laboratory – Richland, Washington**

**Preliminary Agenda**

| | |
|---|---|
| **10:00 – 10:30 a.m.** | **Ribbon Cutting Ceremonies**<br>*Remarks by PNNL Lab Management and Sponsors* |
| **10:30 – 12:00 p.m.** | **Lab Tours** |
| **12:00 – 1:00 p.m.** | **Lunch –** *ETB/Columbia River Room* |
| **1:00 – 4:00 p.m.** | **Stakeholder Workshop –** *ETB/Columbia River Room* |

**Objective**
The objective of the workshop is to obtain input from stakeholders on the types of experiments that should be conducted in FY13 and beyond and to identify possible funding sources. With this input a test plan will be prepared that, over a five year period, researches retrofit solution packages for moderate to cold climates that can be cost effectively deployed in the Pacific Northwest to save 50 percent of the energy needs of a typical home while enhancing the comfort and indoor air quality. The retrofit strategies would also lower the peak demands on the grid.

**Sponsors**
DOE/BT/Building America • DOE/BT/Windows and Envelope R&D
Bonneville Power Administration • DOE/Office of Electricity
Battelle Memorial Institute • PNNL Facilities • City of Richland
Tri Cities Research District • GE Appliances

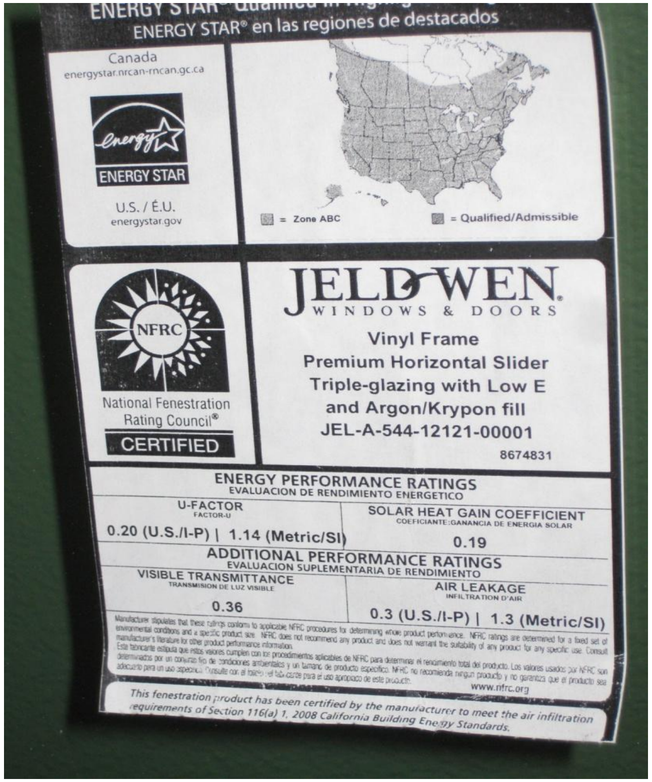
***Please R.S.V.P. to rsvp@pnnl.gov or (509) 372-6888 no later than Friday, November 11, 2011.***

Pacific Northwest NATIONAL LABORATORY
*Proudly Operated by Battelle Since 1965*

PNNL Lab Homes – www.labhomes.pnnl.gov

## Highly Insulating Windows Experiment

- Side-by-side assessment in the PNNL Lab Homes demonstrated that highly insulating windows:
  - Save approximately 13% on whole house energy use
  - Reduce peak demand 25% in the summer
  - Improve thermal comfort through more consistent interior temperatures and higher surface glass temperatures
  - May decrease the risk of condensation and mold issues in regions with high humidity
  - Still have long PBPs - from 23 to 55 years.
- Cost effectiveness could be improved through reduced costs, valuation of non-energy benefits, and accounting for system-level savings (e.g., downsized HVAC systems and optimized duct design).



# Research Adjustments Based on Past Findings

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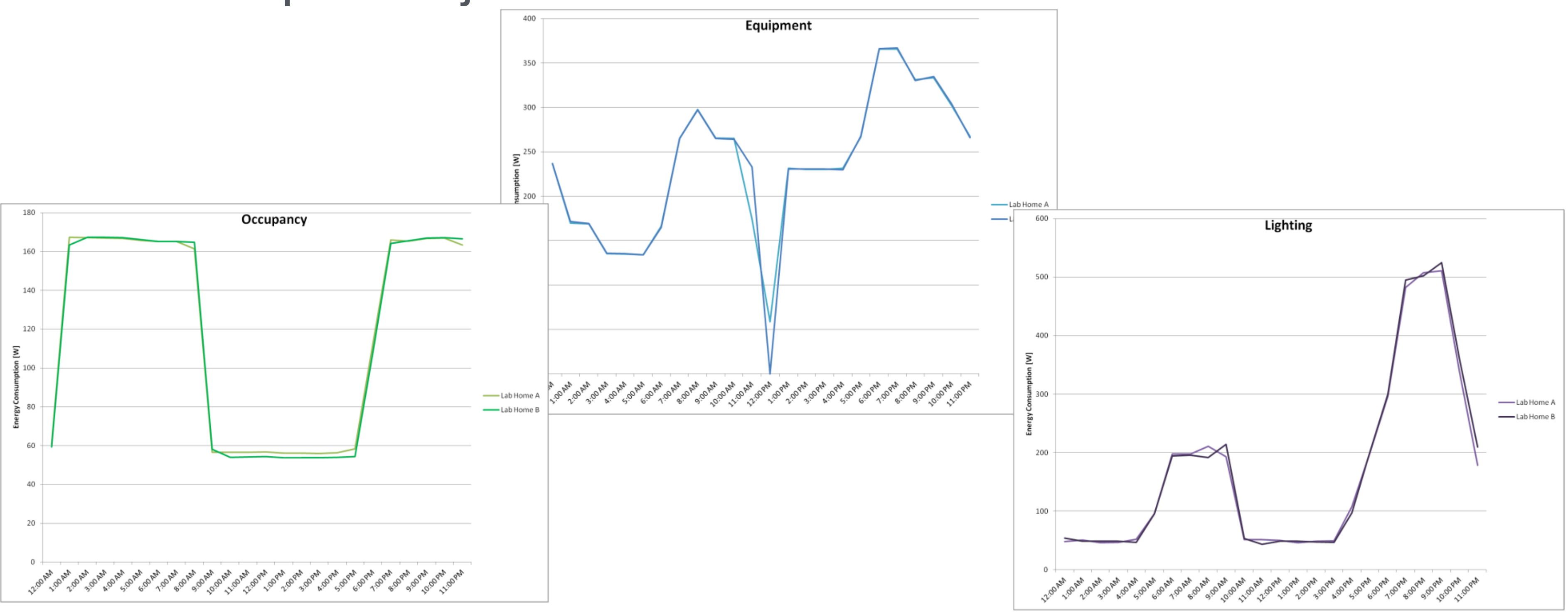
- Despite budget and schedule implications of changing terms of cooperation with GE, the experimental plan and scope have not changed.
- It is important to check data daily to ensure quality and make quick adjustments.



# 2013 Strategy to Achieve Research Goals: Steps

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**Modify Lab Homes**

- Install two second-generation GE GeoSpring Hybrid HPWHs in the conditioned space of the two PNNL Lab Homes, which will allow for side-by-side comparison of the HPWHs in various configurations with identical simulated occupancy patterns to isolate the performance and effects of the HPWHs from all other variables.

**Coordinate**

- Coordinate with existing and ongoing verification efforts by PGE, BPA, GTI, EPRI, NEEA, NREL and others to better understand HPWH interaction with the conditioned space and validate models, such as BeOpt, to better predict HPWH performance in different climates.

**Conduct Experiments**

- 3 Thermal Experiments, 1 DR Experiment, 1 Hard Water Evaluation
- Ongoing QA/QC of data and experimental set up

# Technical Underpinnings Targeted: #1 - #3: Thermal Experiments

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| Experiment | Lab Home A Configuration | Lab Home B Configuration | Purpose of Experiment |
|---|---|---|---|
| #1: HP vs. ER | 50-gallon electric resistance[5] | 50-gallon GE Hybrid HPWH | Characterize performance and interaction with HVAC for HPWH as compared to ER baseline |
| #2: Ducted vs. Unducted | 50-gallon GE Hybrid HPWH with no ducting | 50-gallon GE Hybrid HPWH with exhaust ducting | Characterize performance of ducted HPWH vs. identical unducted HPWH to isolate the impact of ducting on whole-house and HVAC energy consumption, thermal comfort, and HPWH performance |
| #3: Fully Ducted vs. Unducted | 50-gallon GE Hybrid HPWH with no ducting | 50-gallon GE Hybrid HPWH with supply ducting (from crawl) and exhaust ducting | Characterize interaction of HPWH on infiltration and house pressurization for fully ducted and unducted scenarios and impact using tempered crawlspace air as supply air |

[5] Electric resistance baseline will be GE Hybrid HPWH in ER only mode.

# Technical Underpinnings Targeted #4: Demand Response Experiments



- Evaluate demand response characteristics of this smart-grid−enabled HPWH compared to electric resistance baseline during variety of demand response events:

| Exp Name | Experiment Description | Time | Duration | Purpose of Experiment |
|---|---|---|---|---|
| **AM Load Shift** | Turn off heating elements | 7:00 AM | 3 hours | Evaluate HPWH load shedding potential (dispatchable kW and thermal capacity) as compared to electric resistance baseline to manage peak load |
| **PM Load Shift** | Turn off heating elements | 2:00 PM | 3 hours | Evaluate HPWH load shedding potential (dispatchable kW and thermal capacity) as compared to electric resistance baseline to manage peak load |
| **EVE Load Shift** | Turn off heating elements | 6:00 PM | 3 hours | Evaluate HPWH load shedding potential (dispatchable kW and thermal capacity) as compared to electric resistance baseline to manage peak load |
| **INC Balancing** | Turn off heating elements | 2:00 AM; 8:00 AM; 2:00 PM; 8:00 PM | 30 minutes | Evaluate HPWH potential to provide balancing reserves for (dispatchable kW and thermal capacity) as compared to electric resistance baseline |
| **DEC Balancing** | Set tank temp to 135 F | 2:00 AM | 30 minutes | |
| **DEC Balancing V2** | Turn on ER in Lab Home A; HP only in Lab Home B | 2:00 AM | 30 minutes | N/A; HPWHs should stay in appropriate mode throughout test (Lab Home A = ER; Lab Home B = HP) |

# Technical Underpinnings Targeted
## #5: Hard Water Experiments

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- PNNL will work with GE and CPS Energy in San Antonio, Texas, to evaluate HPWH performance and durability in hard water conditions.  This research question is of particular interest to CPS Energy, who would like to incentivize HPWHs due to their ideal climate but is concerned about the effect of the local hard water on the units.
  - Phase I: Literature review and manufacturer interviews to better characterize problem and current building science knowledge.
  - Phase II: Conduct any necessary additional data collection to fill identified gaps in understanding.  This may include deploying HPWHs to San Antonio (contingent on outyear funding).

# 2013 Research Goals and Metrics

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**Thermal Experiments:**

- Quantification of the tradeoffs between space conditioning impact and HPWH performance and identification of the optimal installation of HPWHs in conditioned space, which minimizes whole house energy use and does not adversely affect occupant comfort.
  - Whole house, HVAC, DHW energy use, and thermal comfort impacts in each configuration.

**Hard Water Evaluation:**

- Characterization of current understanding of HPWH longevity in regions with hard water.

**Demand Response Experiments:**

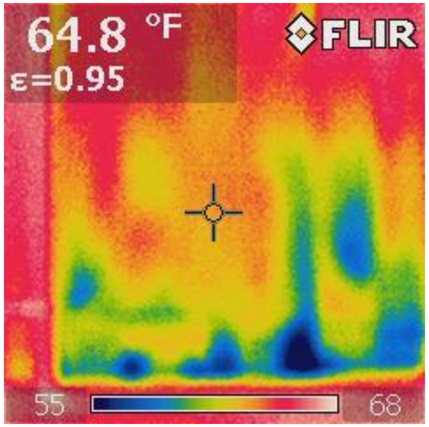
- Evaluation of HPWH demand response characteristics for load shedding and balancing reserve events.
  - Dispatchable kW, inherent capacity reduction, response time and duration, delivered hot water temp.

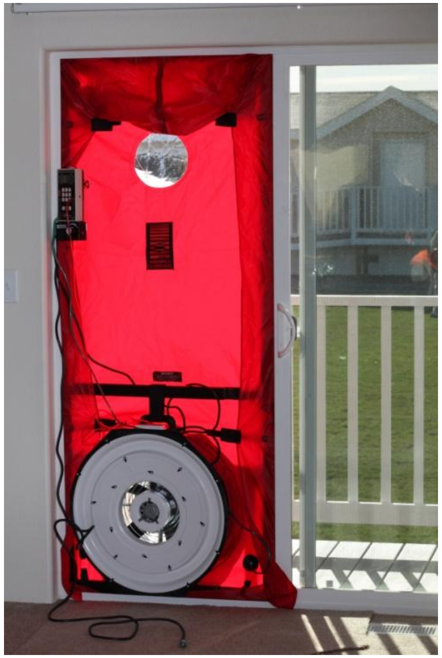
# Questions?

# Back Up Slides

# Null Testing

- Building construction comparison
  - Homes' air leakage (CFM air flow @50Pa) was within 5%
  - Homes' duct leakage (CFM air flow @50Pa) was within 2%, similar distribution performance
  - Heat pumps' performance similar ΔT across coil and air handler flow within 6%
  - Ventilation fans' flows within 2.5%
  - Thermal conductivity with IR camera shows settling of R-11 batt insulation in 2x6 wall cavity in both homes.



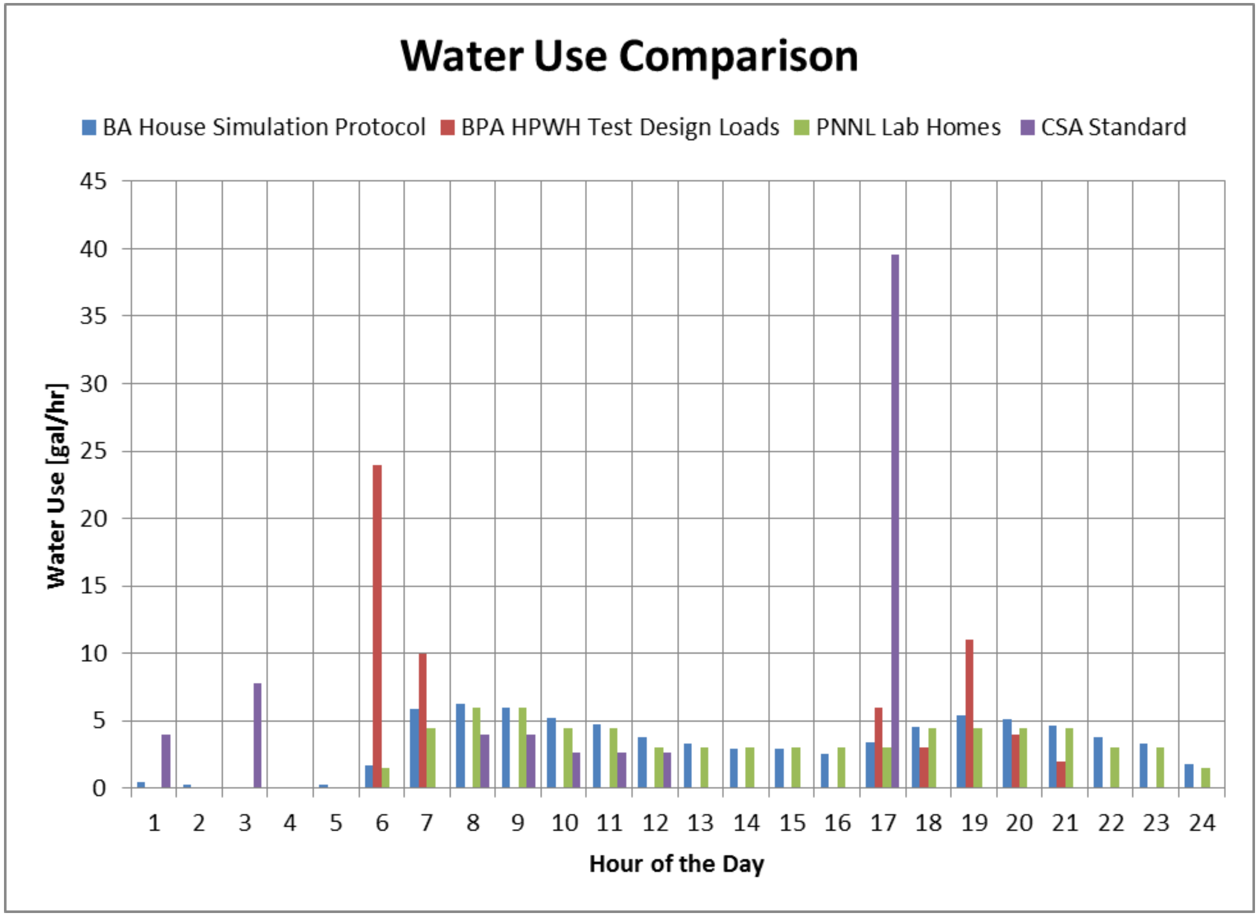



| SUMMARY DATA | | | | |
|---|---|---|---|---|
| | Baseline Home | | Experimental Home | |
| | Average Value | +/- Error | Average Value | +/- Error |
| **CFM@50** | 783 | 27 | 824 | 27 |
| **ACH50** | 3.77 | 0.1285 | 3.965 | 0.13 |
| **$ACH_n$*** | 0.18 | 0.01 | 0.18 | 0.01 |
| *n = 21.5, based on single story home in zone 3, minimal shielding | | | | |

# Hot Water Draw Profile

- LBNL Meta-analysis[1] of 159 homes found:
  - 122.7 F average tank set point
  - Majority of draws between 1 and 1.5 gpm
  - Majority of draws between 1 and 4 minutes in length
  - "High," "medium," and "low" daily water draws of 29.38, 60.52, 98.04 gal/day

[1] Lutz and Melody; 2012




| Profile | Daily Hot Water Use *[gal/day]* |
|---|---|
| Building America House Simulation Protocol | 78.51 (4 people) |
| BPA Evaluation | 81 gal/day (3 people) |
| Canadian Test Standard | 67.2 gal/day |
| PNNL Lab Homes | 69.28 (3 people) |

# LBNL Draw Profile Meta-analysis

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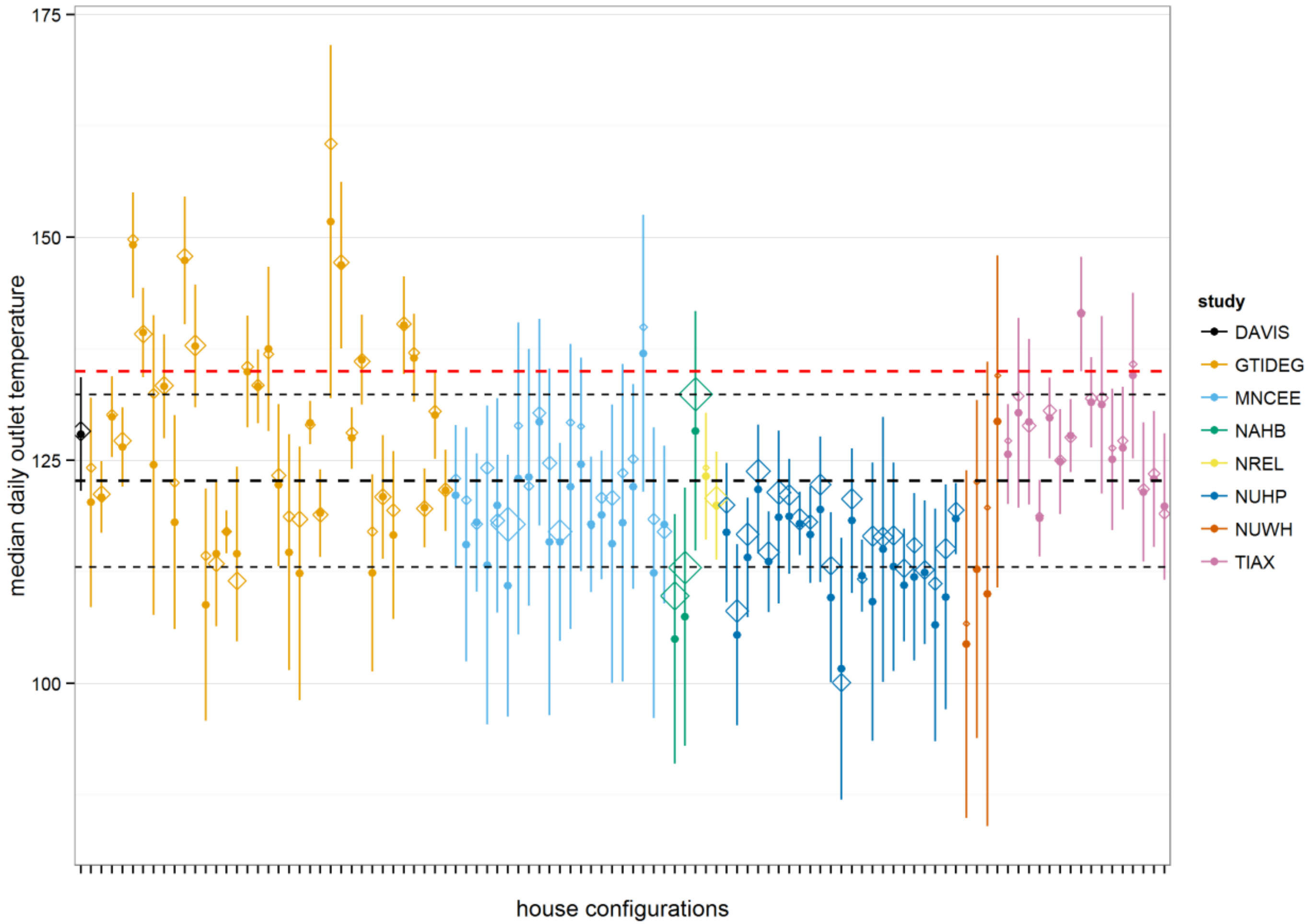
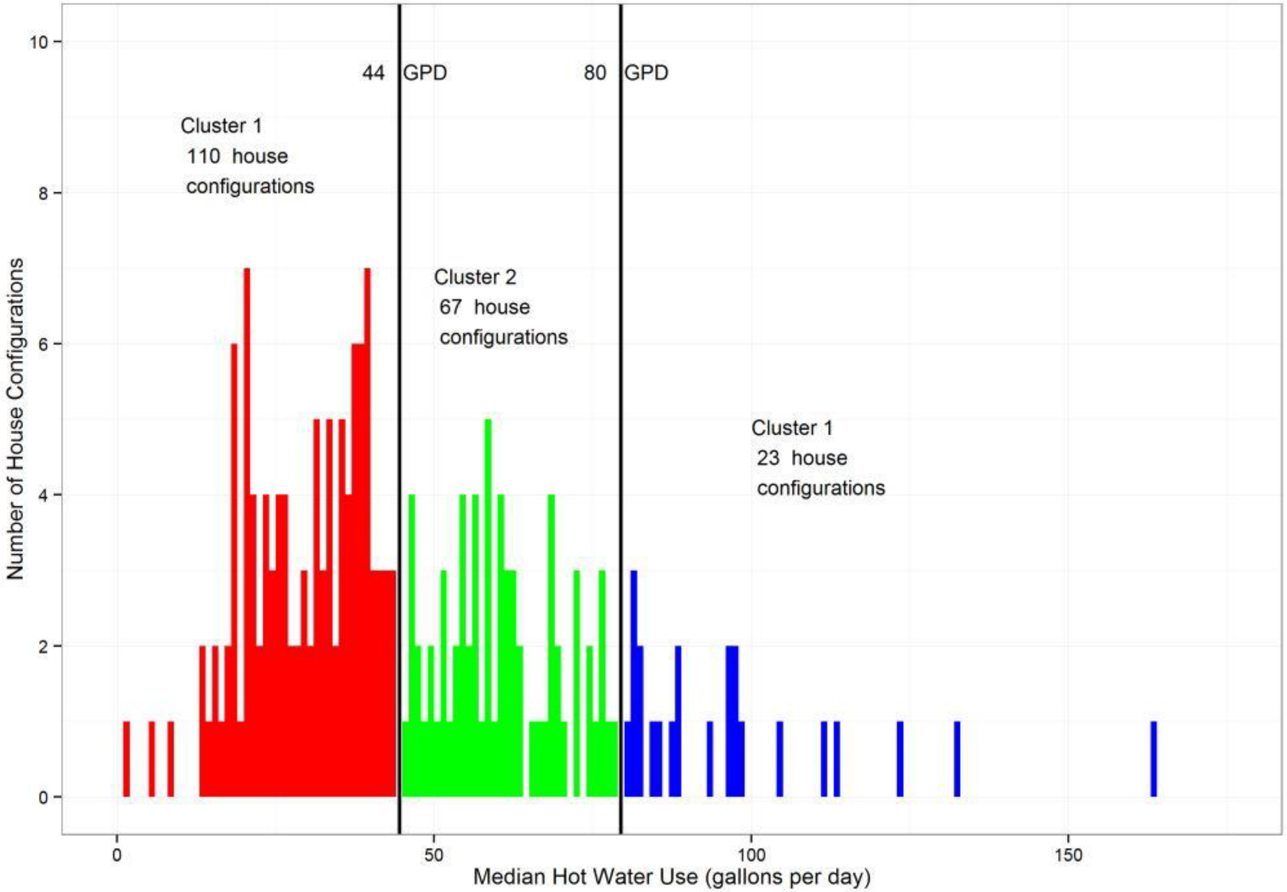
- Median Daily Outlet Temp = 122.7F



# LBNL Draw Profile Meta-analysis






| Cluster | House Configurations | Median Daily Volume (gallons) | | | Average Daily Draws |
|---|---|---|---|---|---|
| | | Minimum | Average | Maximum | |
| 1 | 110 | 1.52 | 29.38 | 43.23 | 45.22 |
| 2 | 67 | 45.25 | 60.52 | 78.66 | 66.48 |
| 3 | 23 | 80.74 | 98.04 | 163.21 | 86.37 |

# LBNL Draw Profile Meta-analysis

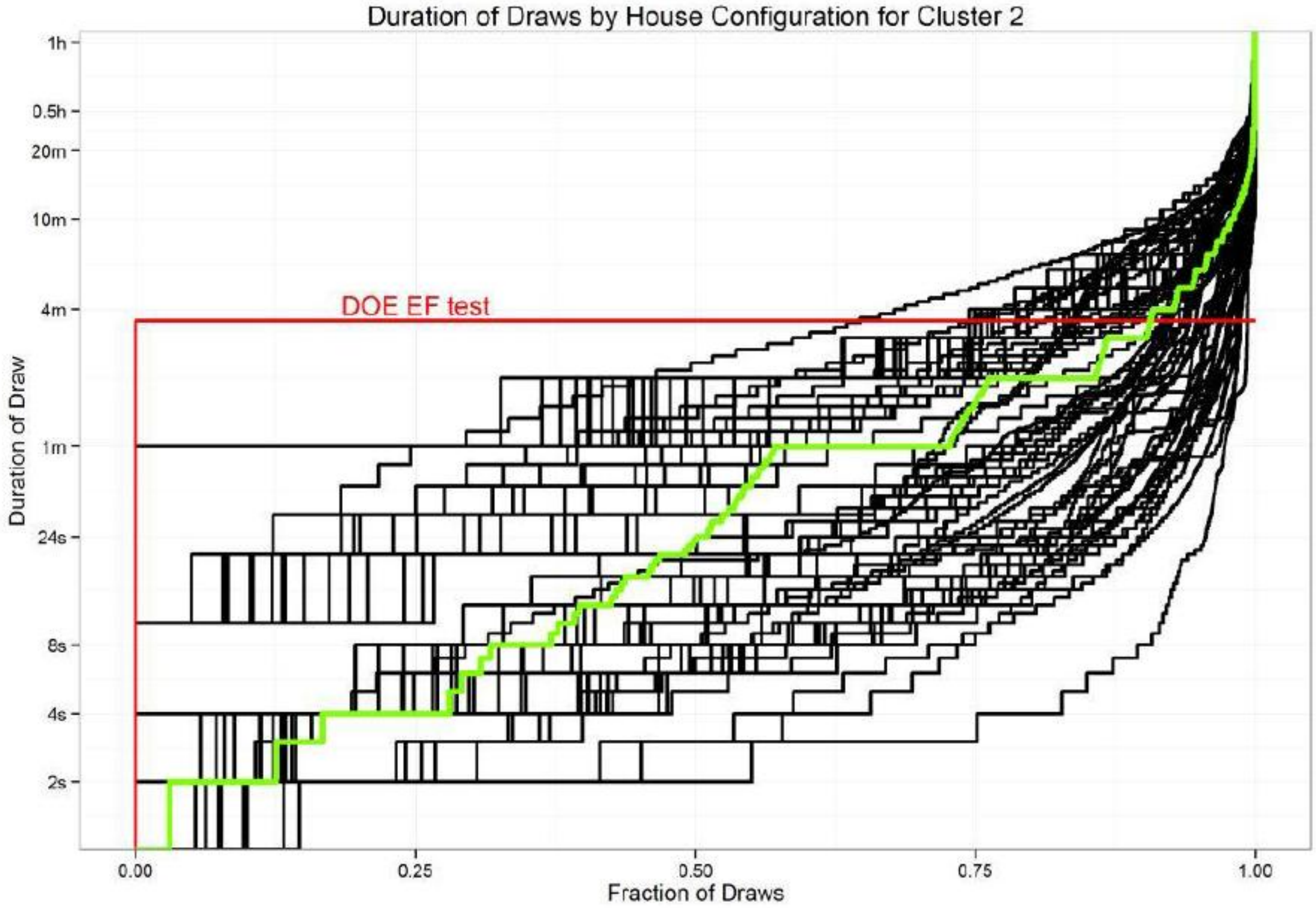



**Figure 14** **Cumulative Distribution of Draws by Duration for House Configurations in Cluster 2**

# LBNL Draw Profile Meta-analysis

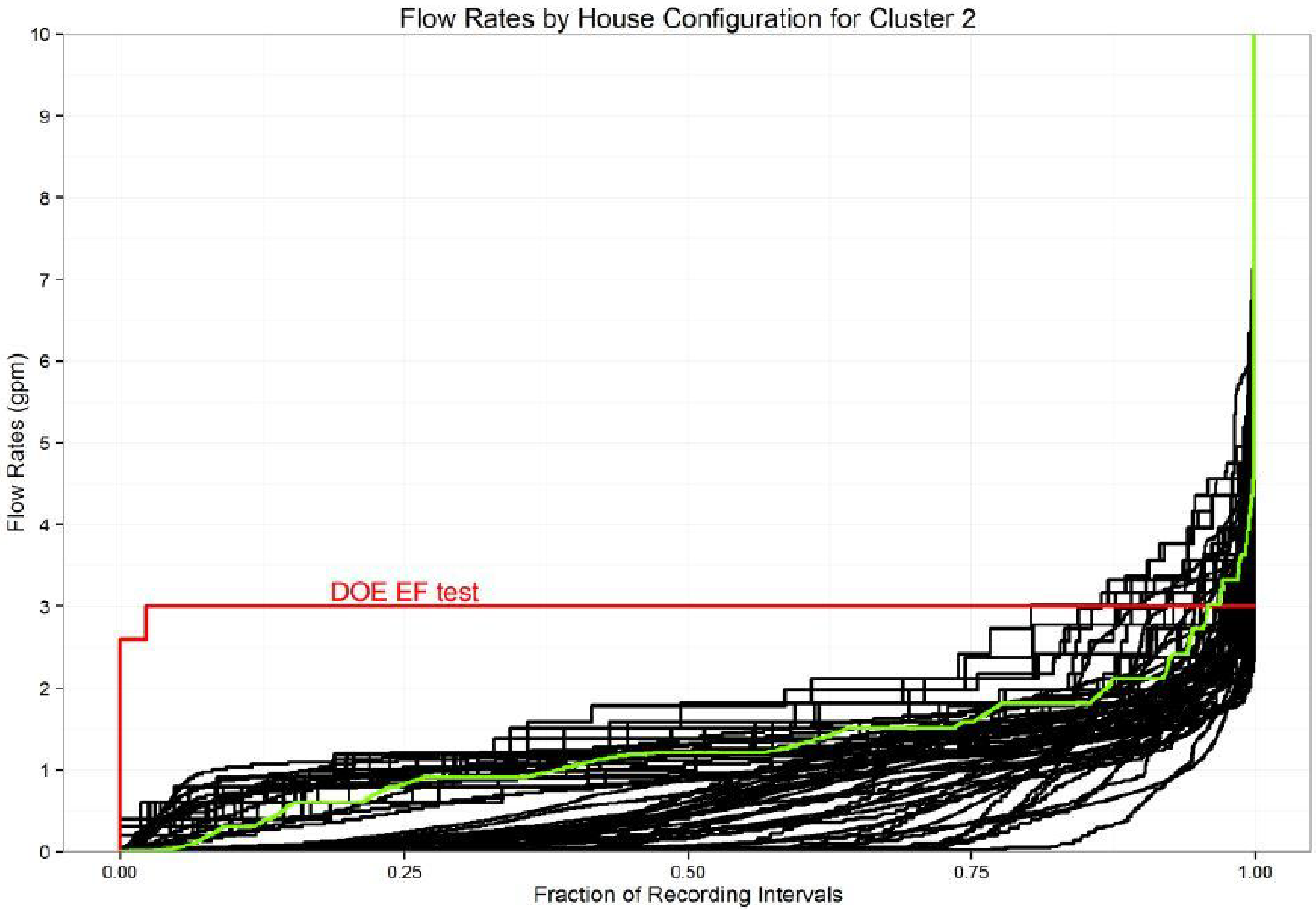
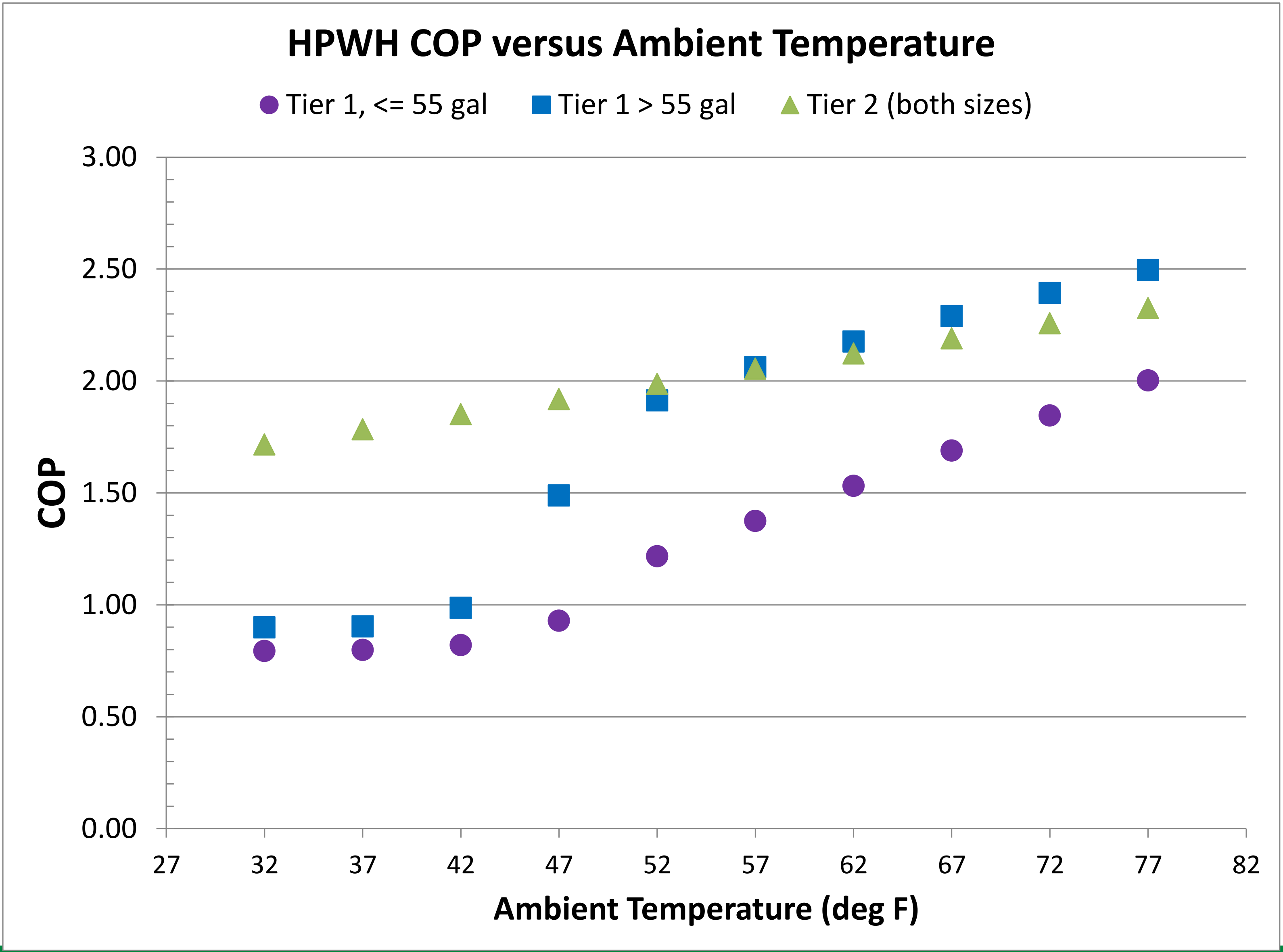



**Figure 20 Cumulative Distribution of Intervals by Flow Rate for House Configurations in Cluster 2**

# Prior Lab Testing (Ecotope, 2011)



# RTF Overall Savings Estimates

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- Impact on house heating + cooling system depends on climate, exhaust airflow, and HVAC system type
- Combining DHW energy savings with heating + cooling impact produces the overall energy savings estimate
- 5 scenarios in 4 climates considered on next slide:
  - Interior non-ducted (0 cfm flow to outside)
  - 4 levels of exhaust ducting to outside
    - 150, 200, 250, and 300 cfm

# Heating System Interaction

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| Zonal Resistance Heat (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | -1283 | -1252 | -1514 | -1764 |
| 250 | -1029 | -1003 | -1222 | -1431 |
| 200 | -839 | -817 | -1006 | -1184 |
| 150 | -664 | -646 | -799 | -943 |
| 0 | -1415 | -1415 | -1479 | -1597 |

| Electric Resistance Furnace (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | -1464 | -1428 | -1741 | -2036 |
| 250 | -1173 | -1143 | -1399 | -1641 |
| 200 | -953 | -927 | -1146 | -1349 |
| 150 | -751 | -730 | -906 | -1072 |
| 0 | -1608 | -1606 | -1688 | -1830 |

| Heat Pump HSPF 8.5 (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | -790 | -731 | -1142 | -1542 |
| 250 | -617 | -572 | -888 | -1195 |
| 200 | -491 | -454 | -701 | -961 |
| 150 | -379 | -351 | -539 | -741 |
| 0 | -609 | -590 | -731 | -892 |

| Gas Furnace AFUE 90 (therms/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | -68 | -66 | -83 | -98 |
| 250 | -54 | -53 | -66 | -78 |
| 200 | -46 | -44 | -56 | -67 |
| 150 | -35 | -33 | -42 | -51 |
| 0 | -62 | -62 | -64 | -68 |

- **CFM is airflow ducted to outside (“0” corresponds to no ducting)**
- **Negative values are a heating system debit**

# Cooling System Interaction

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- None for houses without cooling system (Zonal Resistance and Electric Furnace)
- Cooling savings for ducted installations nearly negligible but not so for nonducted ones

| Heat Pump SEER 13 (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | 20 | 20 | 20 | 20 |
| 250 | 18 | 18 | 18 | 18 |
| 200 | 17 | 17 | 17 | 17 |
| 150 | 16 | 16 | 16 | 16 |
| 0 | 153 | 153 | 153 | 153 |

| Gas Furnace w A/C: SEER 13 (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | 19 | 19 | 19 | 19 |
| 250 | 18 | 18 | 18 | 18 |
| 200 | 17 | 17 | 17 | 17 |
| 150 | 16 | 16 | 16 | 16 |
| 0 | 152 | 152 | 152 | 152 |

- **CFM is airflow ducted to outside ("0" corresponds to no ducting)**
- **Positive values are a cooling system benefit**

# Analysis Outputs: Combined Savings Tables

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

| Zonal Resistance Heat (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | 662 | 692 | 428 | 197 |
| 250 | 917 | 942 | 722 | 531 |
| 200 | 994 | 1016 | 825 | 666 |
| 150 | 1145 | 1163 | 1009 | 884 |
| 0 | 538 | 537 | 474 | 374 |

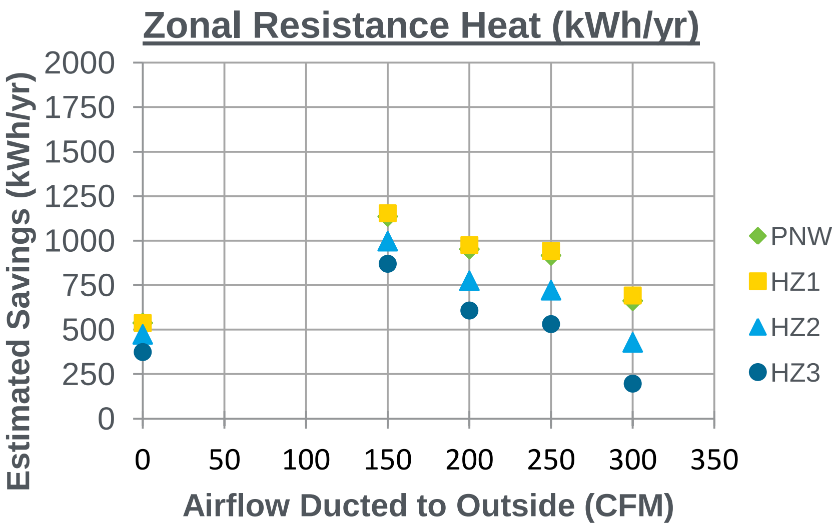
| Electric Resistance Furnace (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | 484 | 520 | 206 | -70 |
| 250 | 776 | 806 | 549 | 327 |
| 200 | 884 | 909 | 690 | 506 |
| 150 | 1063 | 1083 | 907 | 761 |
| 0 | 349 | 350 | 270 | 147 |

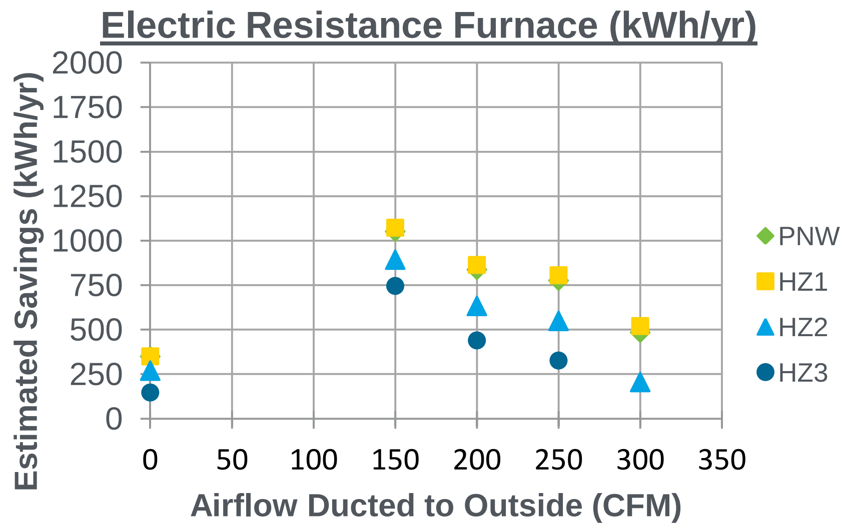
| Heat Pump HSPF 8.5 (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | 1090 | 1155 | 698 | 284 |
| 250 | 1263 | 1314 | 952 | 632 |
| 200 | 1267 | 1311 | 1014 | 744 |
| 150 | 1352 | 1387 | 1149 | 935 |
| 0 | 1407 | 1433 | 1248 | 1071 |

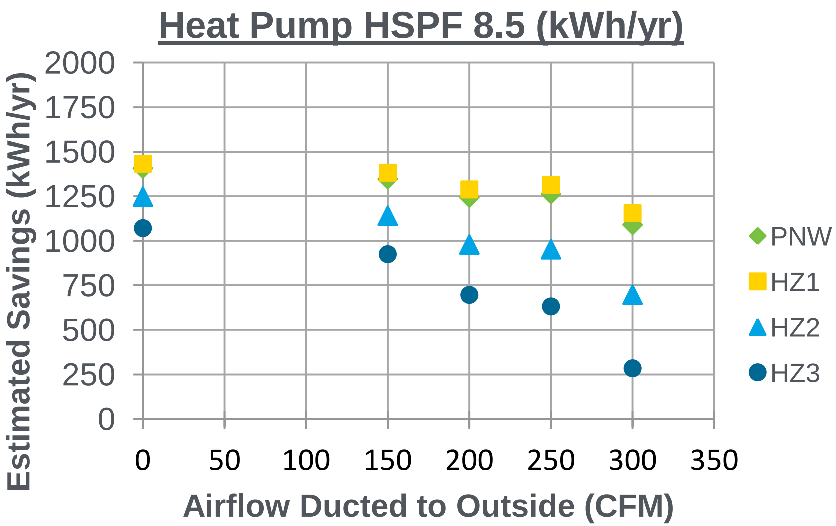
| Gas Furnace AFUE 90 (kWh/yr) | | | | |
|---|---|---|---|---|
| CFM | PNW | HZ1 | HZ2 | HZ3 |
| 300 | 1829 | 1837 | 1778 | 1756 |
| 250 | 1839 | 1847 | 1791 | 1771 |
| 200 | 1726 | 1734 | 1675 | 1657 |
| 150 | 1706 | 1714 | 1656 | 1640 |
| 0 | 1970 | 1976 | 1930 | 1914 |

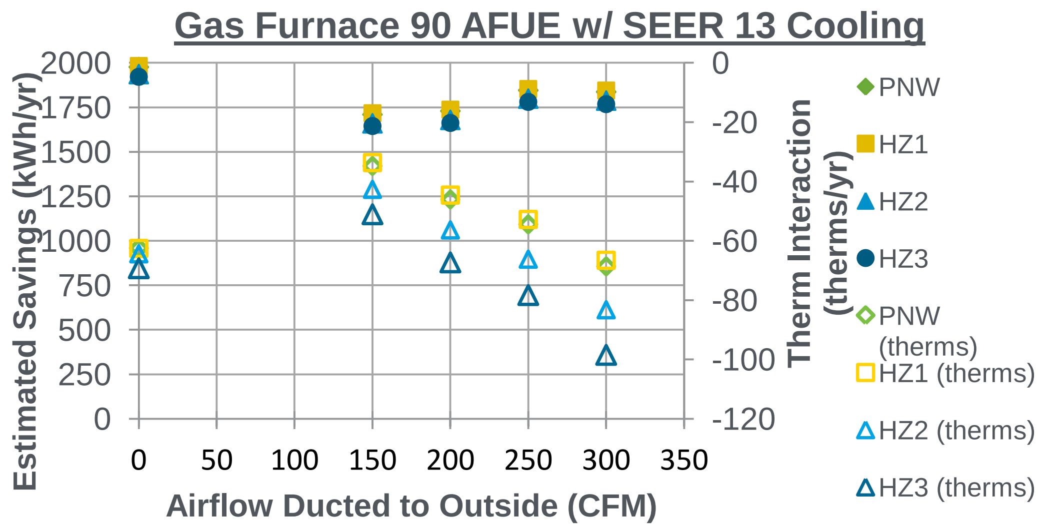
# PNW Modeling: DHW Savings with Combined Interaction





# BPA Demand Response Product Characteristics

## Product details

| | DR Product 1<br>Within-hour load decrease for non-spinning balancing reserves (INC) | DR Product 2<br>Within-hour load increase for non-spinning balancing reserves (DEC) | DR Product 3<br>Heavy load hour to light load hour shift for oversupply | DR Product 4<br>Load decrease for capacity/peak shifting with BPA and utility dispatch |
|---|---|---|---|---|
| Primary Use | Additional balancing reserves for wind integration | Additional balancing reserves for wind integration | Oversupply mitigation | Transmission and distribution congestion management and deferrals, utility peak avoidance |
| Dispatched By | BPA | BPA | BPA | Contractually separate dispatch by BPA and participating utility |
| Expected Beneficiaries | Variable energy resources (VERs) | Variable energy resources (VERs) | Variable energy resources (VERs) | BPA Transmission, participating utility |
| Dispatch Period | 10 minutes | 10 minutes | 60 minutes | Within-hour (BPA)<br>Day-ahead (utility) |
| Seasonality | Year-round | Year-round | March - July | Year-round |
| Duration | Up to 90 minutes | Up to 90 minutes | Up to 6 hours | Up to 4 hours |
| Maximum Hours Annual Usage | 300 | 180 | 480 | 300 |
| Expected Cost FY13-15 | $6-7 kW/month | $1-3 kW/month<br>(as add-on to DR Product 1) | $4-5 kW/month | $4-5 kW/month |
| Expected Cost at Scale | $3-5 kW/month | TBD - no current full-scale programs | TBD - no current full-scale programs | $3-5 kW/month |
| Current Comparative Cost | VERBS rate (FBS-based):<br>$7.68 kW/month | VERBS rate (FBS-based):<br>$2.07 kW/month | OMP cost estimate:<br>$40-50 MW/hour | Demand charge for LF customers:<br>$9.62 kW/month |
| Future Comparative Cost | Combustion gas turbine:<br>$17.63 kW/month | TBD - no current market-ready alternative | TBD - no current market-ready alternative | Combustion gas turbine:<br>$17.63 kW/month |
| Estimated expected BPA Benefit | 100% | 100% | TBD - based on project-specific expected benefits analysis | TBD - based on project-specific expected benefits analysis |
| Estimated expected Utility Benefit | 0% | 0% | TBD - based on project-specific expected benefits analysis | TBD - based on project-specific expected benefits analysis |

Notes:

- Cost estimates based on benchmarking and market research with DR providers
- Initial cost allocation estimates based on assessment of each product by DR Cost Allocation Team comprised of Power and Transmission Rates staff
- Actual cost allocation for each project will be determined by analyzing its expected benefits; if expected benefits are not clear upfront, costs will be allocated based on principles determined by the IRTP Cost Allocation Team and approved by the ASF

# Schedule Table

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

| Task | | Description | Task Alias | Subtask Alias | Start | Finish | Days |
|---|---|---|---|---|---|---|---|
| 1 | | Project Management Plan (PMP) | | PMP | 12/1/2012 | 1/4/2013 | 34 |
| 2 | A | Modify Lab Homes and Install Equipment | Baseline | Install | 1/4/2013 | 2/24/2013 | 51 |
| 2 | B | Baseline Testing | | Baseline | 2/24/2013 | 3/12/2013 | 16 |
| 3 | B | Baseline Testing | | Baseline | 3/31/2013 | 4/20/2013 | 20 |
| 3 | A | Heating Season Exp #1 (ER v. HPWH) | Heating Exp. | Exp #1 | 11/1/2013 | 11/9/2013 | 8 |
| 3 | B | Heating Season Exp #2 (Exhaust Duct) | | Exp #2 | 11/9/2013 | 11/30/2013 | 21 |
| 4 | | Heating Season Exp #3 (Supply&Exhaust) | | Exp #3 | 11/30/2013 | 12/21/2013 | 21 |
| 5 | | Demand Response | DR | Demand Response | 5/1/2013 | 5/31/2013 | 30 |
| 6 | A | Cooling Season Exp #1 (ER v. HPWH) | Cooling Exp. | Exp #1 | 6/1/2013 | 6/20/2013 | 19 |
| 6 | B | Cooling Season Exp #2 (Exhaust Duct) | | Exp #2 | 6/21/2013 | 7/9/2013 | 18 |
| 7 | A | Cooling Season Exp #3 (Supply&Exhaust) | | Exp #3 | 7/10/2013 | 7/30/2013 | 20 |
| 7 | B | Sensitivity Experiments | | Additional Exp | 9/1/2013 | 10/31/2013 | 60 |
| 8 | | Final Report | Final Report | Dev. Approach | 12/21/2013 | 1/31/2014 | 41 |
| 9 | | TI Council Meeting Presentation | | TI Council Mtg | 1/14/2014 | 1/31/2014 | 17 |

**PNNL HPWH DR Testing Schedule**

| Day | Date | Exp | Signal 1 | Time | Duration | Signal 2 | Time | Duration | Signal 3 | Time | Duration | Signal 4 | Time | Duration | Mode to Return to after event(s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | TBD | AM Load Shift | Turn off heating elements | 7:00 AM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 2 | TBD | AM Load Shift | Turn off heating elements | 7:00 AM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 3 | TBD | AM Load Shift | Turn off heating elements | 7:00 AM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 4 | TBD | PM Load Shift | Turn off heating elements | 2:00 PM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 5 | TBD | PM Load Shift | Turn off heating elements | 2:00 PM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 6 | TBD | PM Load Shift | Turn off heating elements | 2:00 PM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 7 | TBD | EVE Load Shift | Turn off heating elements | 6:00 PM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 8 | TBD | EVE Load Shift | Turn off heating elements | 6:00 PM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 9 | TBD | EVE Load Shift | Turn off heating elements | 6:00 PM | 3 hours | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | Lab Home A = ER; Lab Home B = HP |
| 10 | TBD | INC Balancing | Turn off heating elements | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | Lab Home A = ER; Lab Home B = HP |
| 11 | TBD | INC Balancing | Turn off heating elements | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | Lab Home A = ER; Lab Home B = HP |
| 12 | TBD | INC Balancing | Turn off heating elements | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | Lab Home A = ER; Lab Home B = HP |
| 13 | TBD | DEC Balancing | Set tank temp to 135 F | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | N/A; HPWHs should stay in appropraite mode throughout test (Lab Home A = ER; Lab Home B = HP) |
| 14 | TBD | DEC Balancing | Set tank temp to 135 F | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | |
| 15 | TBD | DEC Balancing | Set tank temp to 135 F | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | |
| 16 | TBD | DEC Balancing V2 | Turn on ER in Lab Home A; HP only in Lab Home B | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | N/A; HPWHs should stay in appropraite mode throughout test (Lab Home A = ER; Lab Home B = HP) |
| 17 | TBD | DEC Balancing V2 | Turn on ER in Lab Home A; HP only in Lab Home B | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | |
| 18 | TBD | DEC Balancing V2 | Turn on ER in Lab Home A; HP only in Lab Home B | 2:00 AM | 30 minutes | Turn off heating elements | 8:00 AM | 30 minutes | Turn off heating elements | 2:00 PM | 30 minutes | Turn off heating elements | 8:00 PM | 30 minutes | |