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PNNL Lab Homes

A Platform for Efficiency and Smart Grid Technology Demonstrations

Presented at the Northwest Public Power Association
Northwest Communications & Energy Innovations Conference

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Welcome to the PNNL Lab Homes…

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LAB HOMES

Demonstrating tomorrow's efficient and smart technologies.

Goal is to demonstrate an intelligent, energy efficient, and grid responsive home retrofit over a period of 5 to 7 years which achieves 50% whole-house energy savings.

Lab Homes Partners

- Initial Partners
  - DOE/BTO/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)

Lab Homes Characteristics

- Specified to represent existing manufactured and stick-built housing
  - 3 BR/2BA 1493-ft^2 double-wide, factory-built to HUD code.
  - All-electric with 13 SEER/7.7 HSPF heat pump central HVAC + alternate Cadet fan wall heaters throughout
  - R-22 floors, R-11 walls & R-22 ceiling with composition roof
  - 195.7-ft^2 (13% of floor) window area
  - Wood siding
  - Incandescent lighting
  - Bath, kitchen, whole-house exhaust fans
  - Carpet + vinyl flooring
  - Refrigerator/range/washer/dryer/dishwasher
  - All electric
- Modifications include end-use metering, sensors, weather station, and three electric vehicles charging stations

Lab Homes Floor Plan

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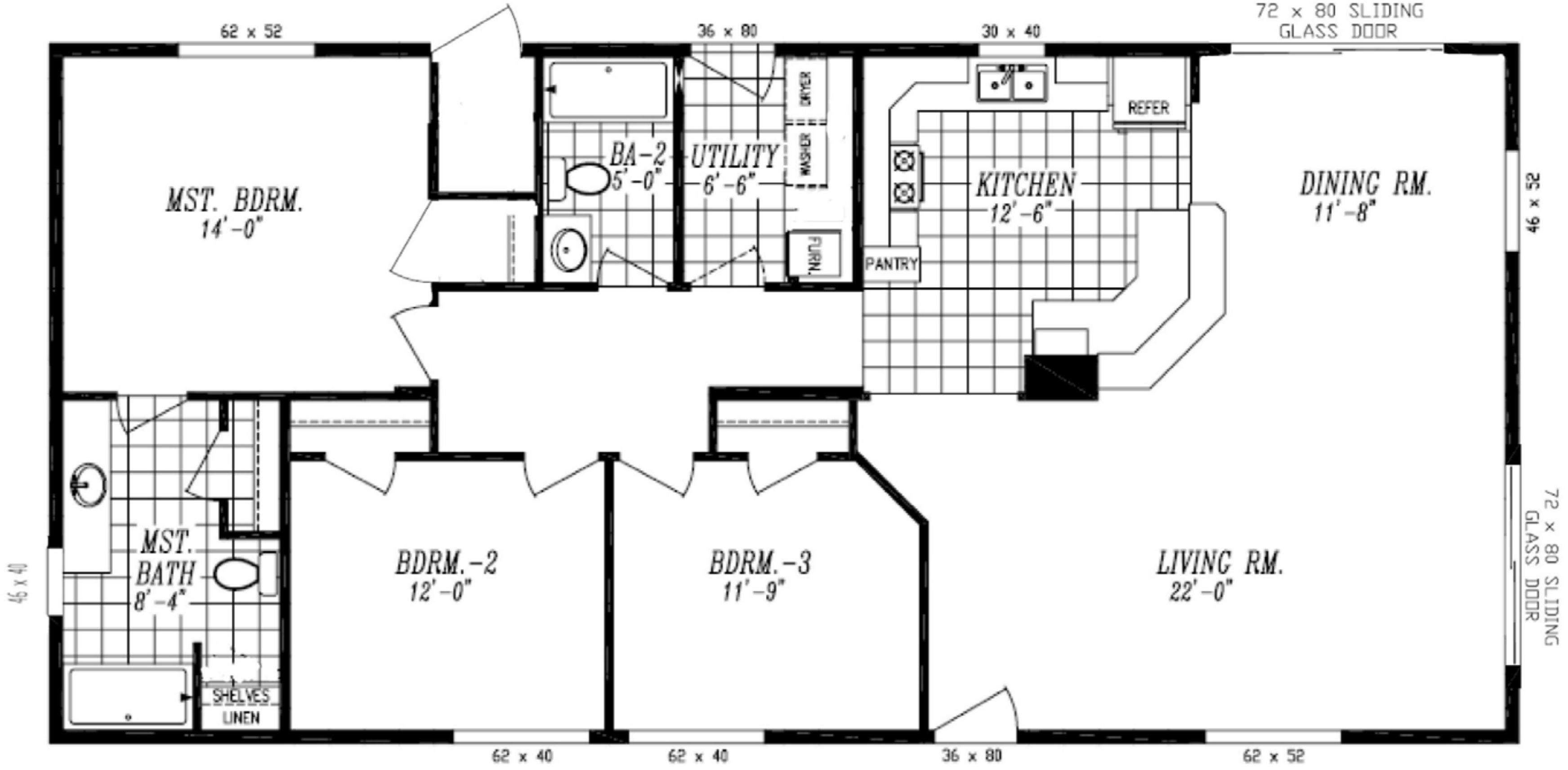

Metering and Monitoring Characteristics

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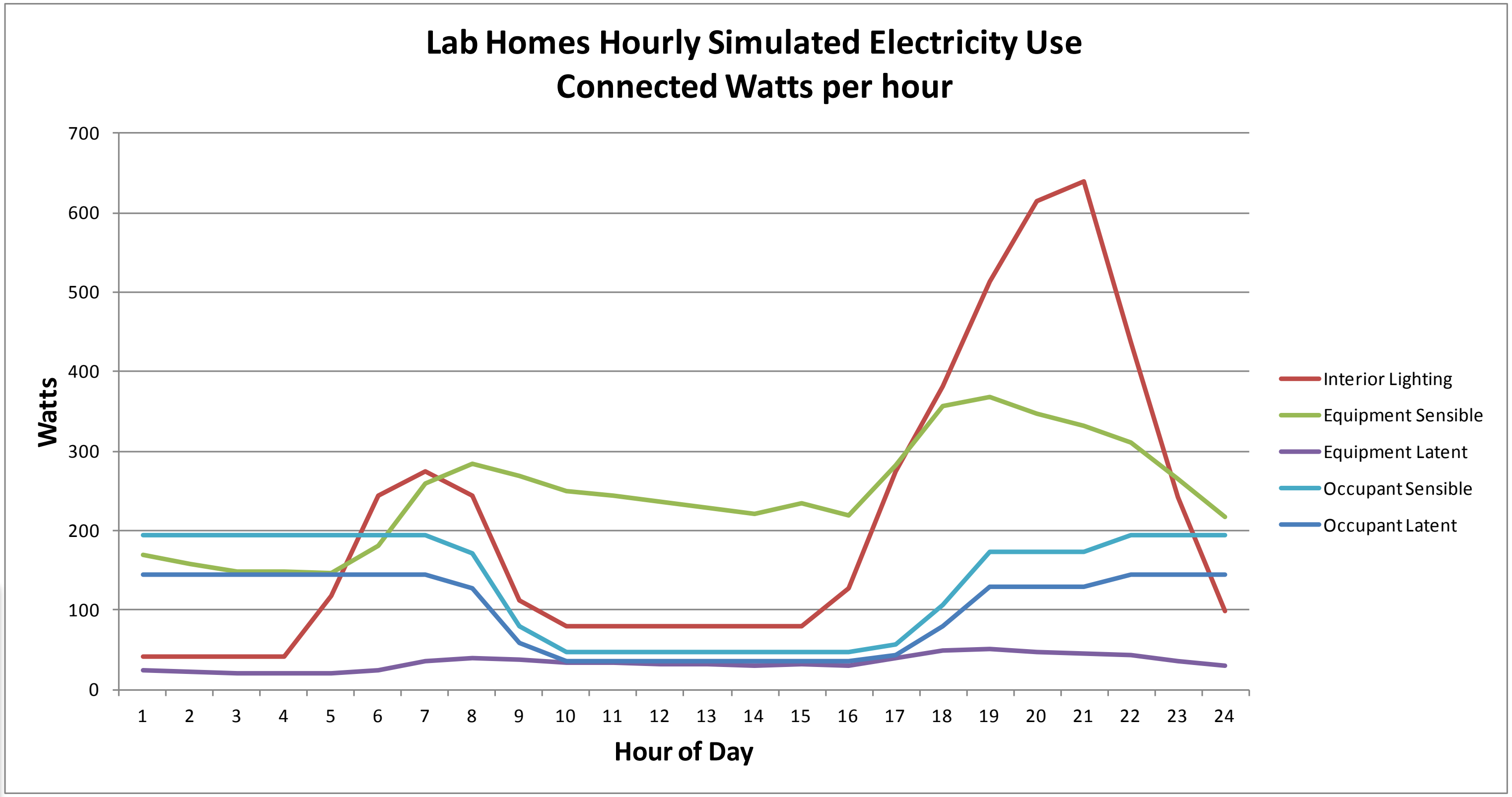
- Energy metering
  - 42 individually monitored breakers with ½ controllable and whole house
  - Itron smart billing meter
- Temperature and relative humidity
  - 15 interior room temperature thermocouples
  - 22 interior and exterior glass surface temperature thermocouples
  - 2 room relative humidity sensors
  - 2 mean radiant temperature sensors
- Water and environment
  - Controllable water flows at fixtures
  - Solar insolation (pyranometer) inside home
  - Site weather station
- Data collection via 2 Campbell Scientific data loggers/home
  - 1 minute, 15 minute, and hourly

Per Home!

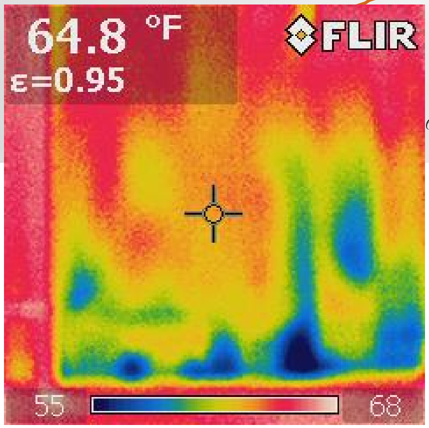
Occupancy Simulation

- Simulation in accordance with Building America house simulation protocol

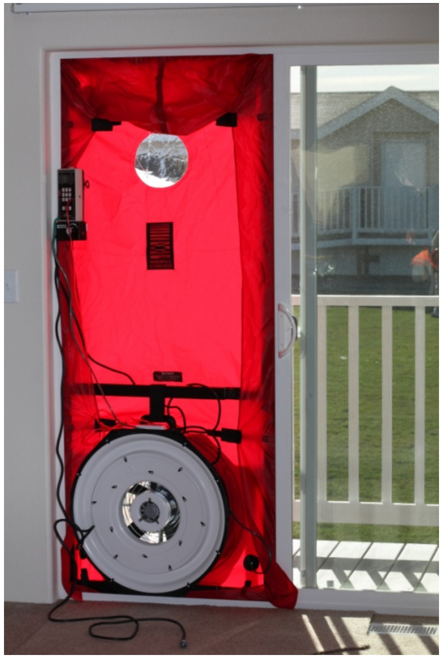


60W light bulb simulating adult occupant

Initial Null Testing



- Building construction comparison
  - Homes' air leakage (CFM air flow @50Pa) was within 6.2%
  - Homes' duct leakage (CFM air flow @50Pa) was within 2%, similar distribution performance
  - Heat pumps demonstrated similar ΔT across coil and air handler flows 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@25	477.4	30.4	478.5	30.5
CFM@50	638.5	27.8	681.1	26.7
ACH50	3.07	0.13	3.28	0.13
ACH_n^*	0.14	0.01	0.15	0.01
*n = 21.5, based on single story home in zone 3, minimal shielding				

Highly Insulating Windows Experiment

First Experiment – Highly Insulating Windows

- Joint funding by BPA & DOE
- Evaluate impact on energy consumption and thermal comfort of highly insulating (R-5) windows
  - Jeld Wen triple pane, argon/krypton filled, vinyl frame windows with triple low-E 366 coating on two inside faces
  - Compared to “typical” double pane, aluminum frame, clear glass windows
  - No window treatments in either home
  - Heat pump (only) as heating/cooling system

	Baseline Home Windows		Highly Insulating Windows	
	Windows	Patio Doors	Windows	Patio Doors
U-factor	0.68	0.66	0.20	0.20
SHGC	0.7	0.66	0.19	0.19
VT	0.73	0.71	0.36	0.37

Summary of Energy Savings of R5 Windows

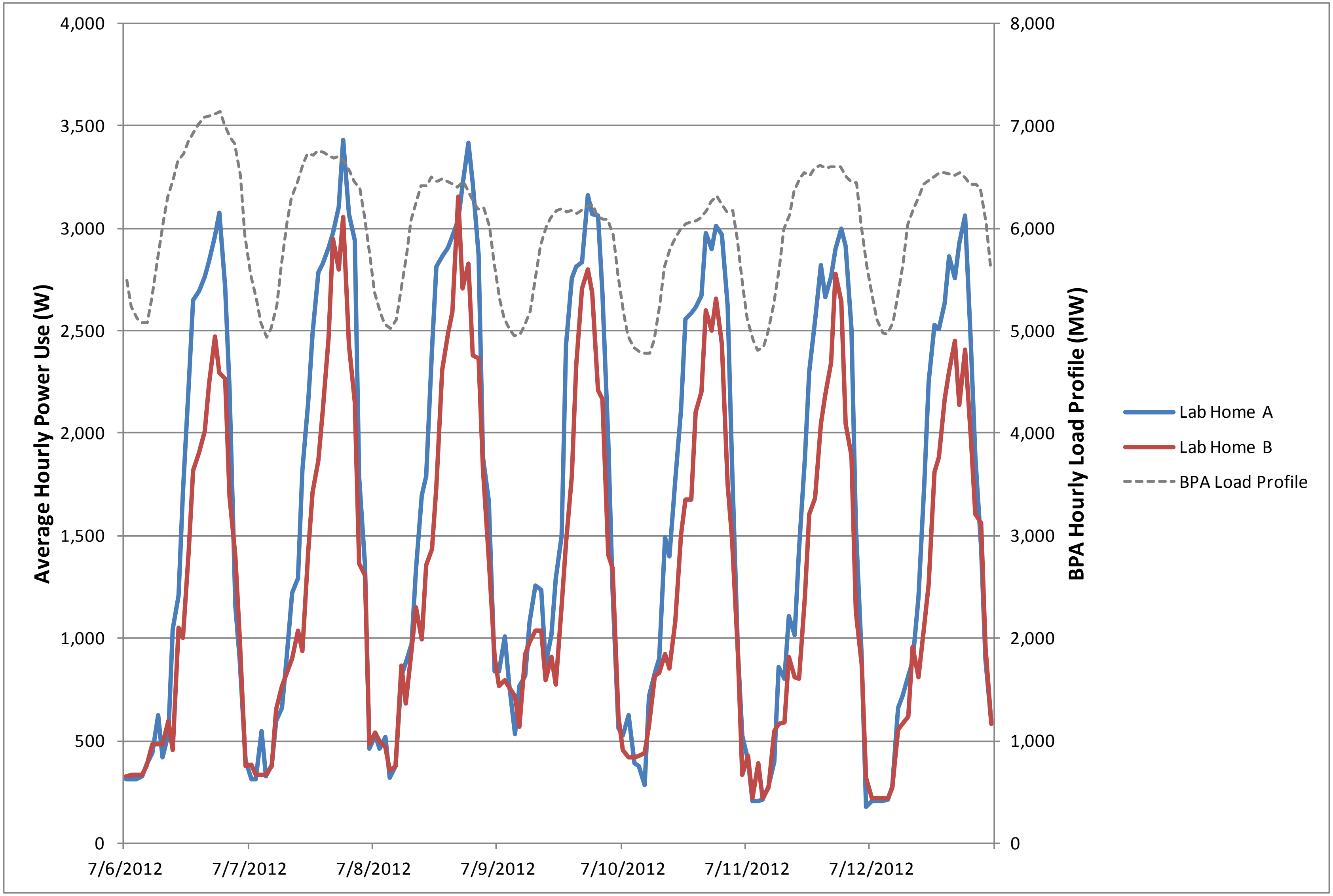
- The side-by-side assessment in the PNNL Lab Homes demonstrates that highly insulating (R5)/low SHGC (0.19) windows:
  - Save an average of 12.2% on whole-house energy use annually
    - 11.6 ± 1.53% in the heating season
    - 18. 4 ± 2.06% in the cooling season
  - Reduce peak demand in the summer
    - 24.7 ± 0.1% in cooling season, which aligns with the region's peak power period

Average Daily Energy Savings

		Average Daily Energy Use (Wh)	Average Daily Energy Savings (Wh)	Average Daily Energy Savings (%)
Heating Season	Lab Home A (Baseline)	47,599	5,821 ± 1,054	11.6 ± 1.53
	Lab Home B (Experimental)	41,896		
Cooling Season	Lab Home A (Baseline)	35,572	6,518 ± 842	18.4 ± 2.06
	Lab Home B (Experimental)	29,055		
Model	Lab Home A (Baseline)	28,537	1,370	13.2
	Lab Home B (Experimental)	24,784		

- Modeled performance used EnergyPlus to extrapolate tested performance to entire year.

Peak Load Reduction

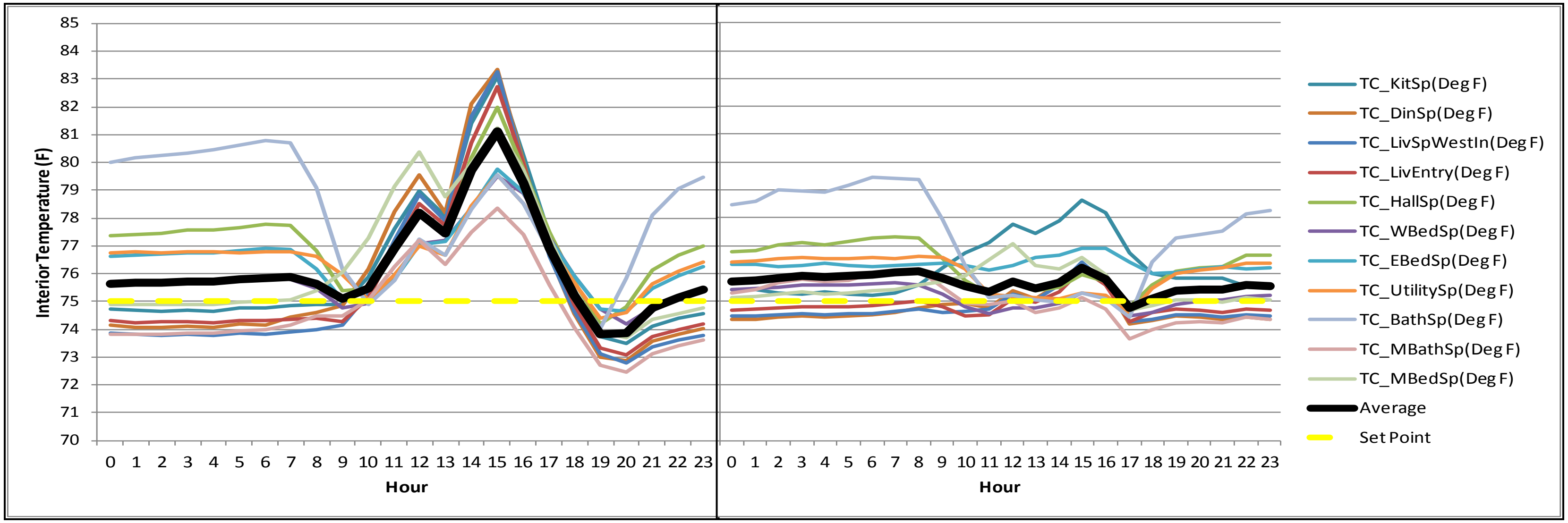


Summary Thermal Comfort Results

- The side-by-side assessment in the PNNL Lab Homes demonstrates that highly insulating (R5) windows:
  - Improve thermal comfort through more consistent interior temperatures and higher surface glass temperatures
  - Decrease the risk of condensation and mold issues in regions with high humidity

Lab Home A (single-pane)

Lab Home B (highly Insulating)



Cost Effectiveness of R5 Windows

- Long payback periods of 23-35 years compared to today's ENERGY STAR windows
  - Windows cost data highly variable
  - Costs will change, savings will not
- Cost effectiveness could be improved through:
  - Improvements in manufacturing and/or market penetration
  - Valuation of non-energy benefits, e.g. occupant comfort
  - Optimized duct design and downsized HVAC systems to reduce HVAC costs

Current (FY13) Experiments

- Evaluate the performance and demand response (DR) of the Gen II GE GeoSpring™ HPWH under a number of operating configurations in Lab Homes

- Evaluate impact on energy consumption and thermal comfort of low-E storm windows

- Develop and test a laboratory testing protocol of selected non-intrusive load monitoring (NILM) technologies

- Evaluation of Smart Grid appliances and control strategies

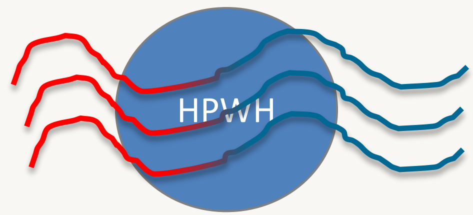
HPWH Experiment: Motivation

- Heat pump water heaters (HPWH) can provide up to 62% energy savings over electric resistance water heaters.[1]
- 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.

[1] 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)

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		**Exterior**	
	Summer	Winter	Summer	Winter
HP COP	2.3 – 2.5		3-5	1
DHW Energy Savings	2,500 kWh/yr		1,650 kWh/yr	0
Impact on Space Energy Use	-0 to 200 kWh/yr	+800 to 2,200 kWh/yr	0	
Total Savings	300 to 2,600 kWh/yr		1,650 kWh/yr	

[3] Ecotope; 2011

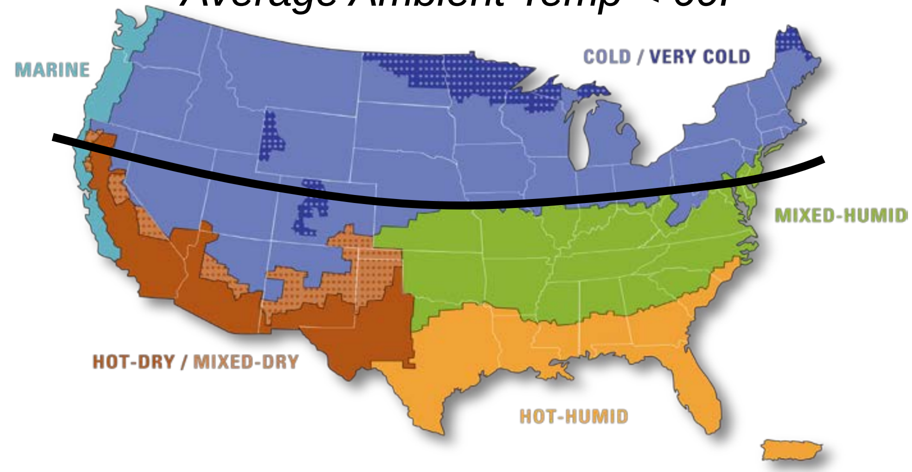
HPWHs with Exhaust Ducting

- 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 • Unconditioned	dBA < 65
Tier 2	2.0	Tier 1 plus: • Minimal use of electric heating elements • Freeze protection • Exhaust ducting option • Compressor shut-down/notification • 10 year Warranty • Condensate Mgmt	• Conditioned • Semi-conditioned • Unconditioned	dBA < 60
Tier 3	2.4	Tier 2 plus: • Intake ducting option • Air Filter Mgmt	• Conditioned • Semi-conditioned • Unconditioned	dBA < 55

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

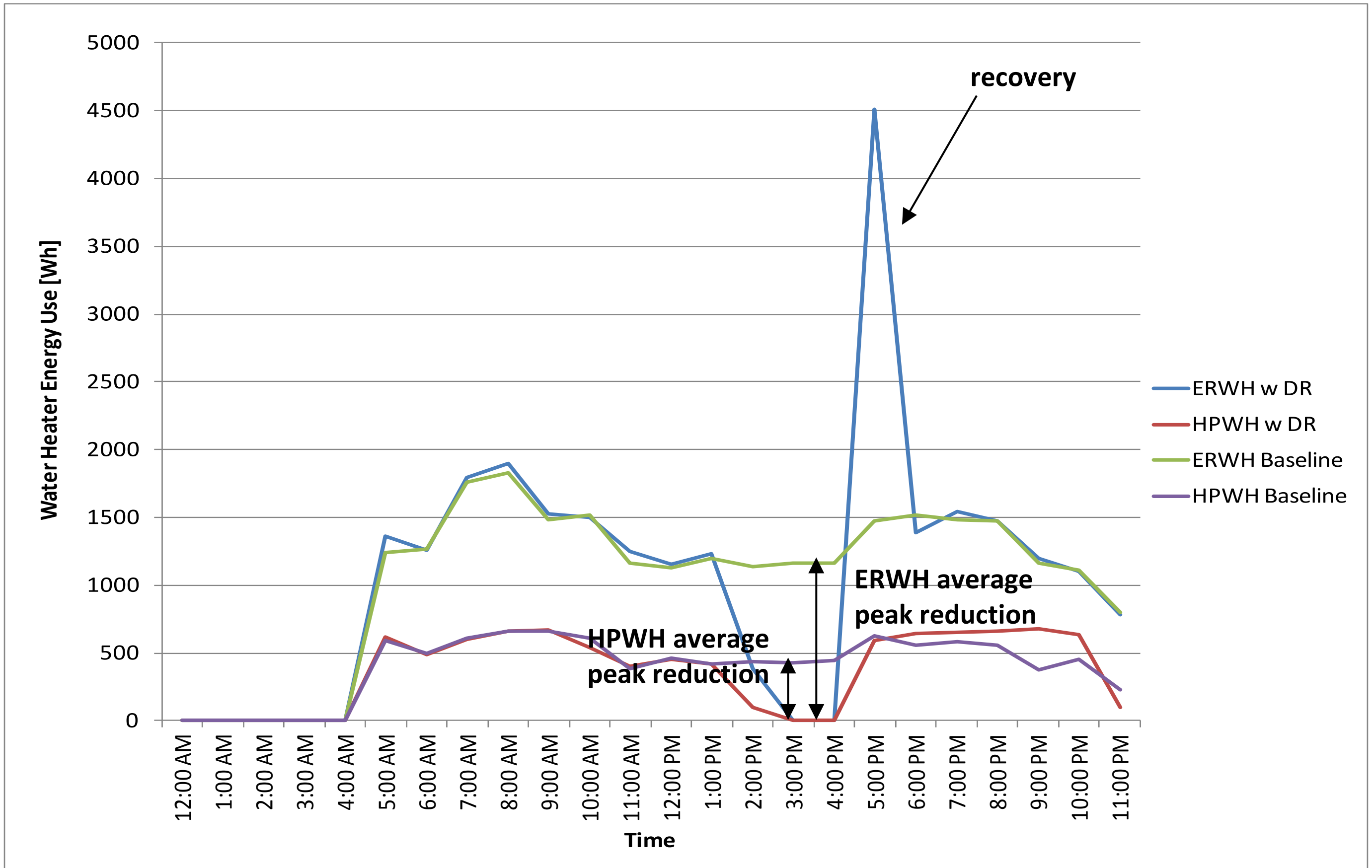
Northern Climates
≥ 4000 HDD and
Average Ambient Temp < 60F



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

HPWH Demand Response Characteristics

- Many utilities currently employ electric resistance water heaters to shave peak load by turning off the water heater.
- PNNL has also demonstrated the potential of using HPWHs to manage load (INC & 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.”



HPWH Experimental Design

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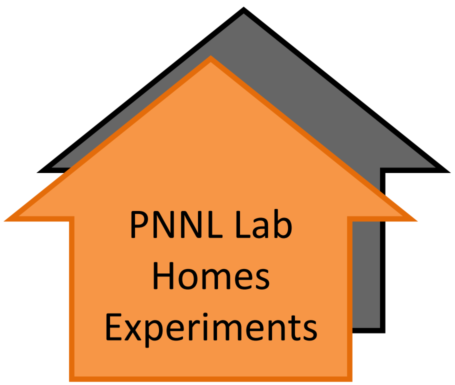
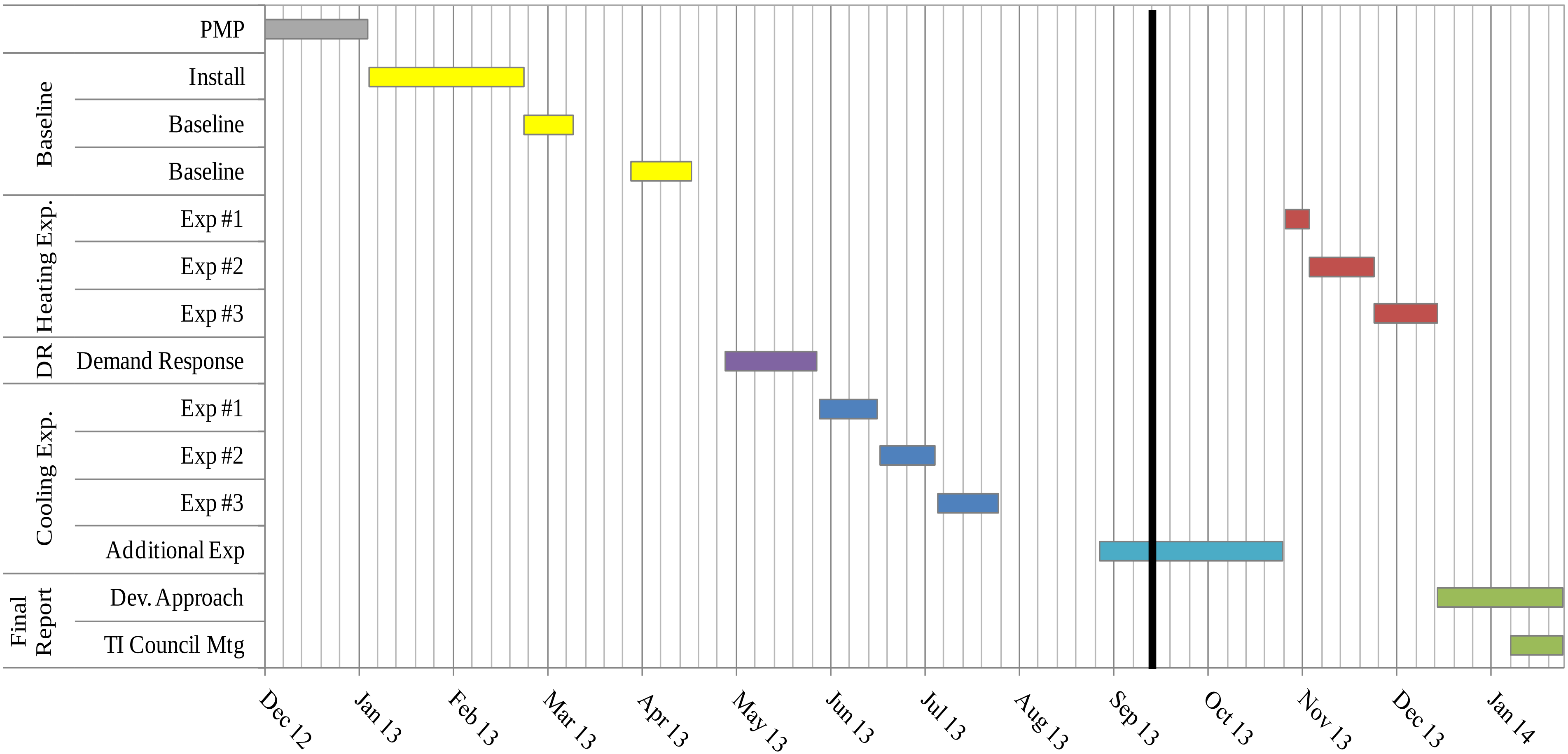
- Highly controlled, side-by-side comparison of HPWHs installed in conditioned space in a number of configurations and as a demand response asset



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

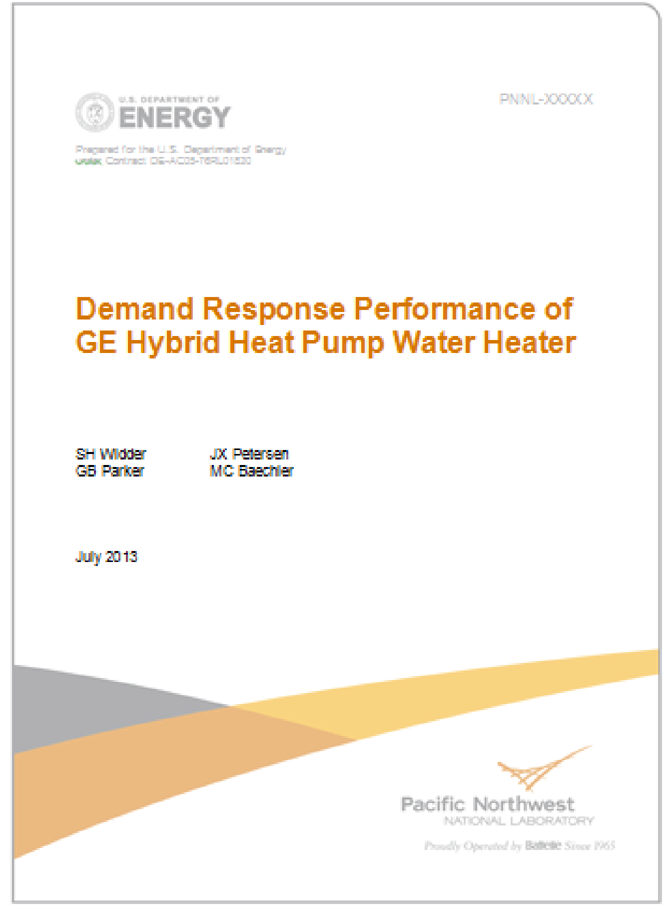
- This information is necessary to support regional efficiency and manufactured housing programs and encourage more widespread adoption of HPWH nationally

HPWH Experiment Status



Demand Response Results

Deliverable	Status	Expected Date Available
Report Summarizing DR Findings (includes descriptive graphs & tabulated summary data)	Complete	Available Now
Clean 1-min data of WH kW, kVA, water flow, and inlet & outlet temps for all experiments	In Progress	Mid-Late September 2013
Efficiency Experimental Results	Cooling Season Data Analysis Underway	December 2013


U.S. DEPARTMENT OF ENERGY

PNNL-XXXXX

Demand Response Performance of GE Hybrid Heat Pump Water Heater

SH Widder
GB Parker
JX Petersen
MC Baechler

July 2013

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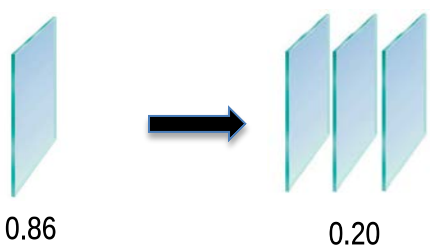
Available at: labhomes.pnnl.gov/resources

Low-E Storm Window Experiment

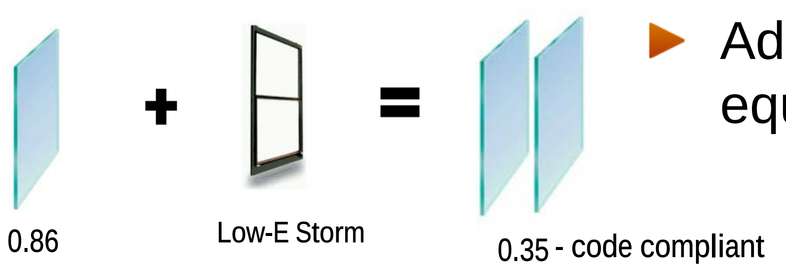
- Windows are 'holes' in a building's thermal barrier not typically addressed by home energy retrofits due to high cost of window replacement

2009 IECC Requirements for Climate Zone 5	
Wall Insulation	R-20
Ceiling Insulation	R-38
Window Insulation	~R-3

- Low-E coatings are a thin metal or metallic oxide particles which are applied to the glazing surface to **reduce radiant heat transfer** and increase **glass temperatures**



- Replacing single pane with high efficiency, low-E primary window can reduce heat loss **up to 40%**



- Adding low-E storm on top of single pane is equivalent to **code compliant window**

Low-E Storm Window Installation

- Low-E storm windows are easy to install and cost ~25% as much as primary window replacement.

Low-E Storm Window Preliminary Results

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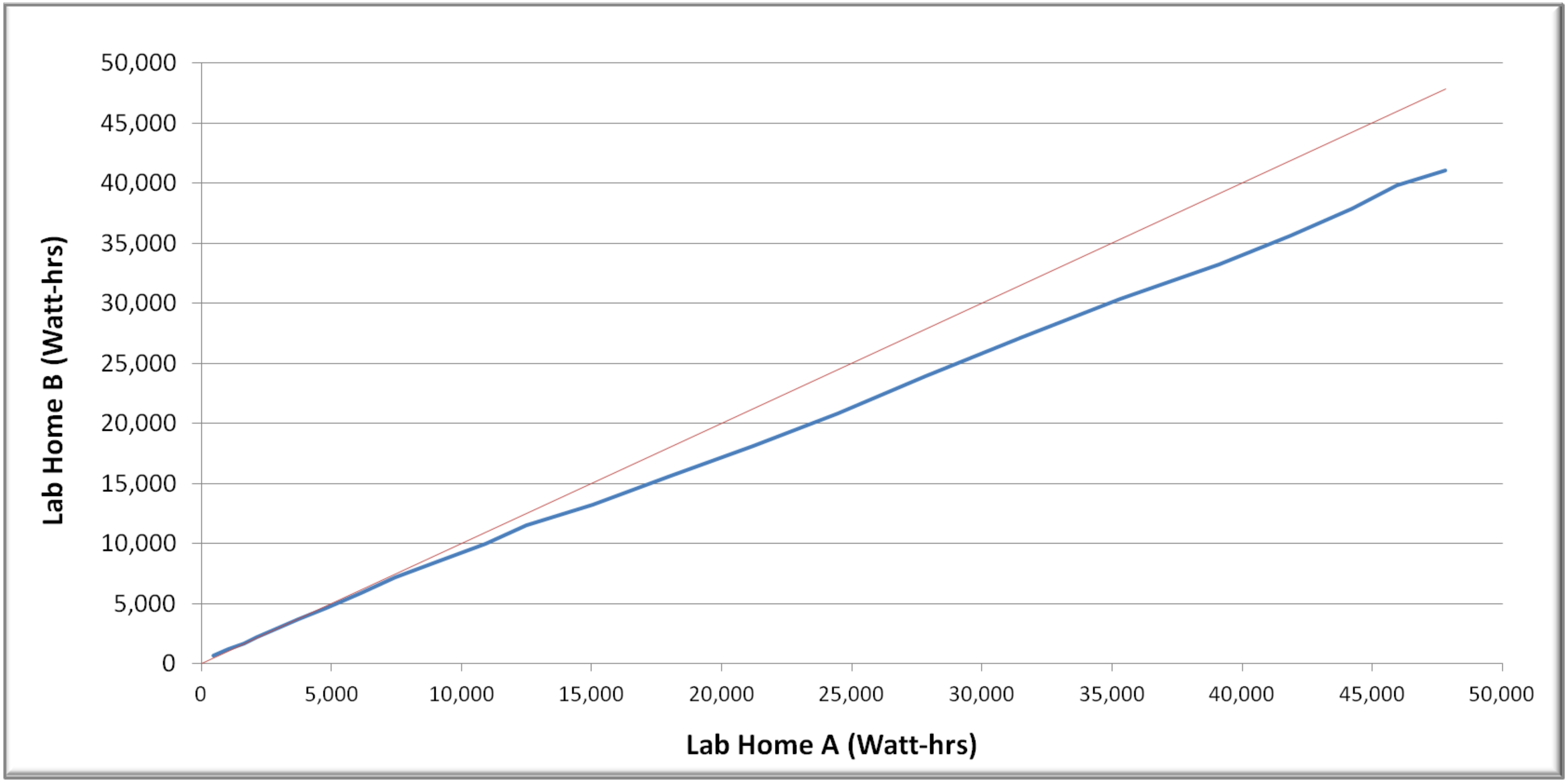
- Preliminary results indicate ~10% savings on a whole house basis, ~14% HVAC energy savings.



- Full report available February 2014

Maximum Savings Coincident with Peak Energy Use in Home

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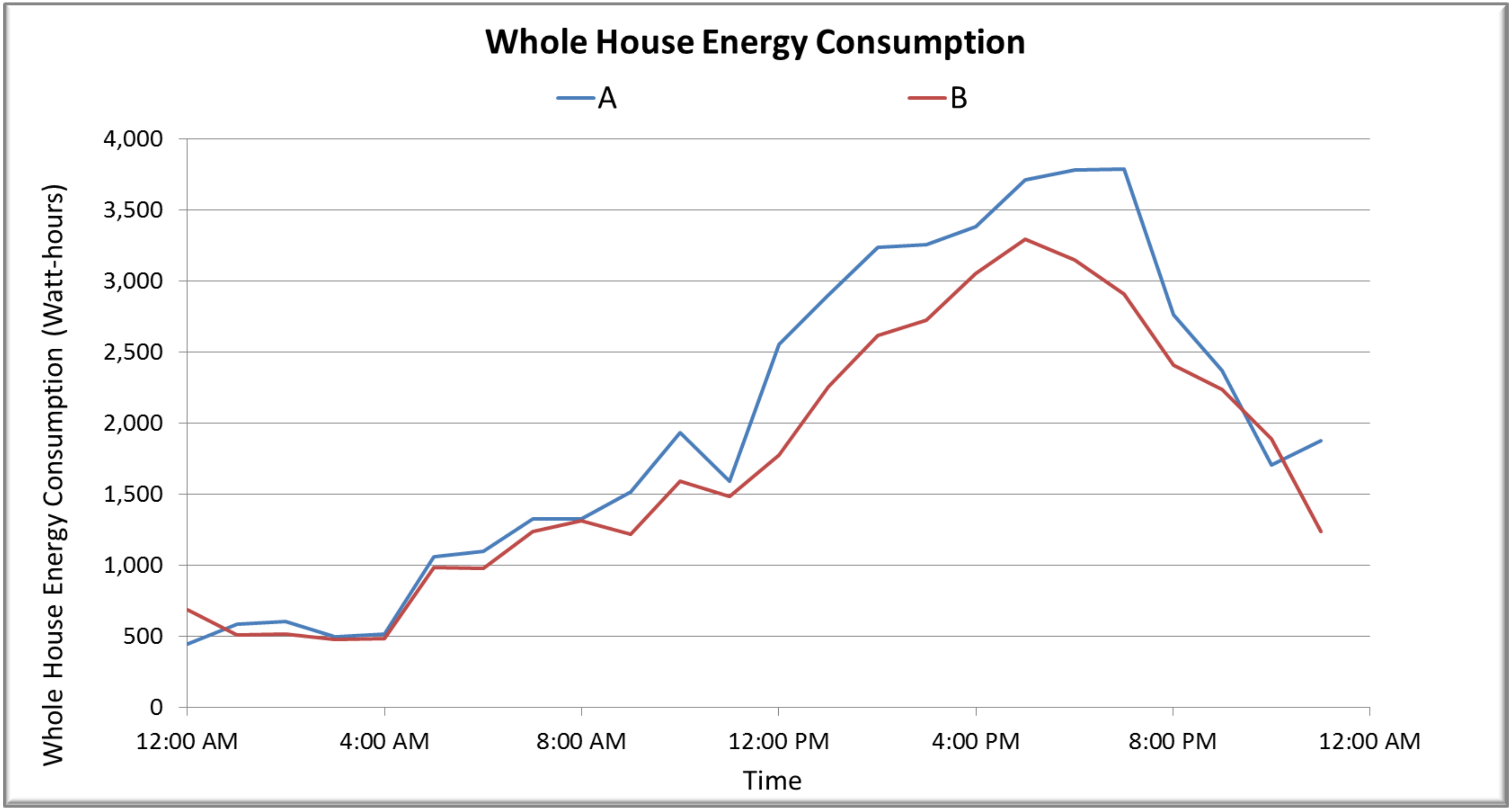

Non-Intrusive Load Monitoring (NILM)

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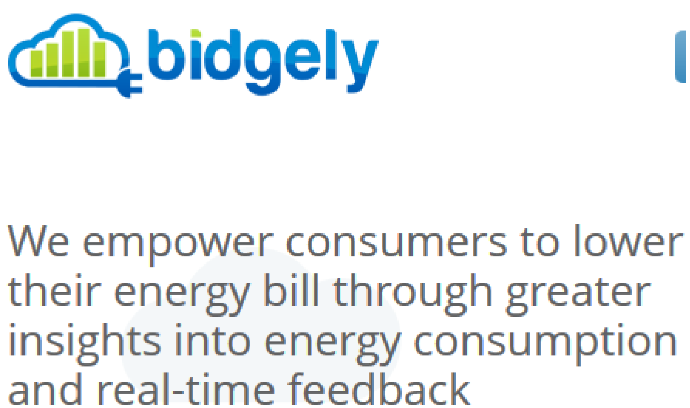
- NILM is a process for analyzing changes of voltage and current going into a residence to understand what appliances are used in the house as well as their individual energy consumption.

- NILMs can provide more cost-effective sub-metered energy information, which may increase penetration rates of energy retrofits, identify program opportunities, provide predictive maintenance for HVAC systems, and help encourage behavior change in homeowners.

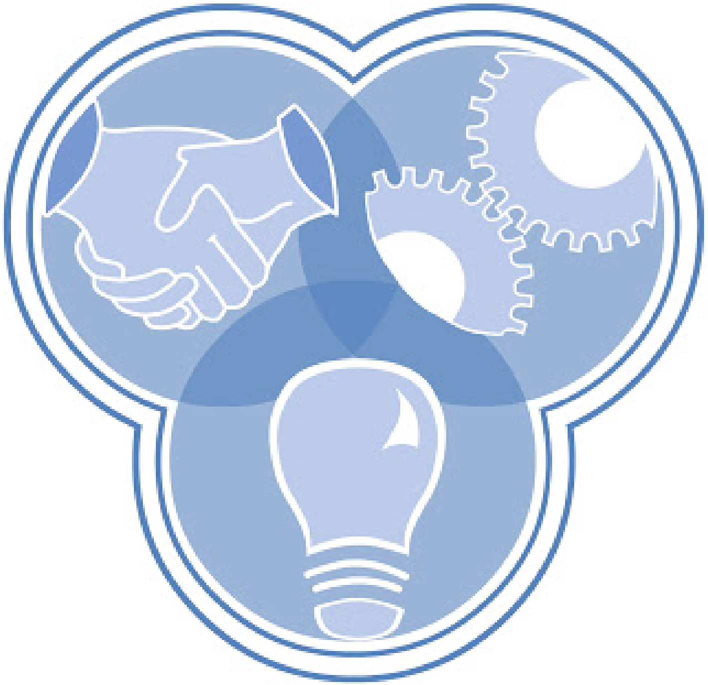
- Lab and field testing are needed to validate and confirm the accuracy of these devices, particularly their ability to differentiate and measure loads in a real-world environment.



Smart Grid Technology

- Smart Grid and demand response technologies that have been/are being evaluated in the PNNL Lab Homes:
  - GE Nucleus and suite of smart-enabled appliances
  - PNNL-developed VOLTTRON™ universal Smart Grid controller

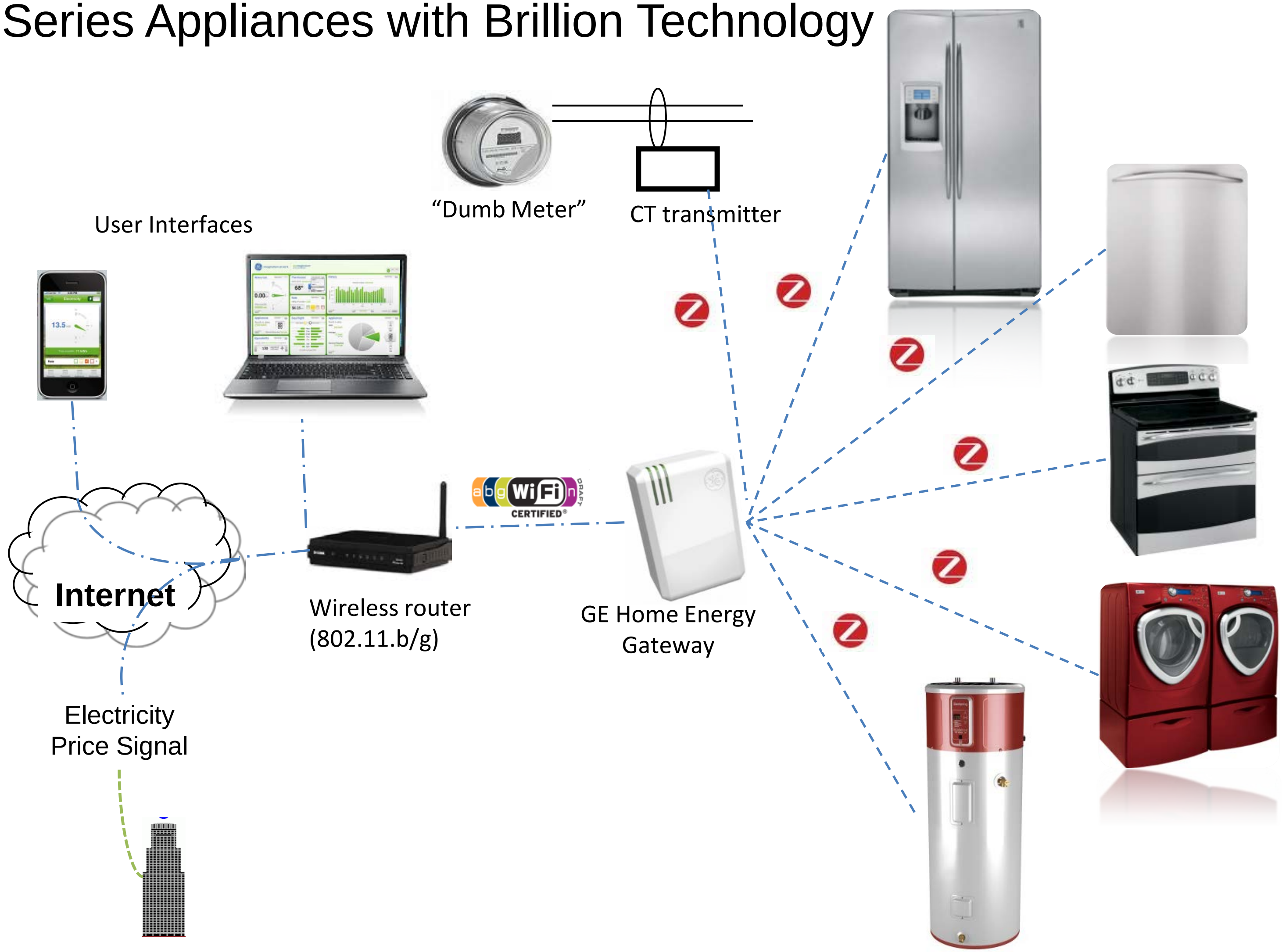
- Interaction between demand response or “smart” features and energy efficiency not well understood in practice.
  For example:
  - HPWH ability to perform demand response.
  - Home energy management systems that typically focus on utility control (demand response = DR) or homeowner control (energy efficiency = EE), but not both.



- Understanding impact of DR on EE and EE on DR can help maximize value proposition for both homeowners and utilities.

GE Smart Appliance Approach

- GE's Home Management System, Featuring Nucleus with GE ProfileTM Series Appliances with Brillion Technology



Load Scheduling

- **Problem**:
  - High-energy residential and commercial loads often synchronize, leading to peak energy demand.
  - Plug-in hybrid cars may introduce a synchronized load due to similar consumer behavior. Consider a neighborhood where individuals return from work between 5pm and 6pm and plug-in hybrid cars for charging.
  - Value to utilities is tremendous. Translating value to consumers is less apparent.

- **Concept**:
  - Utilize mobile agents to communicate load behavior and develop a scheduled sharing of energy. The scheduled consumption both reduces peak energy demand and provides forecasting information. Three potential strategies to achieve load goal
    - Global price signal
    - Individual price signal
    - Cooperative

PNNL's Volttron Smart-Grid Integration Platform

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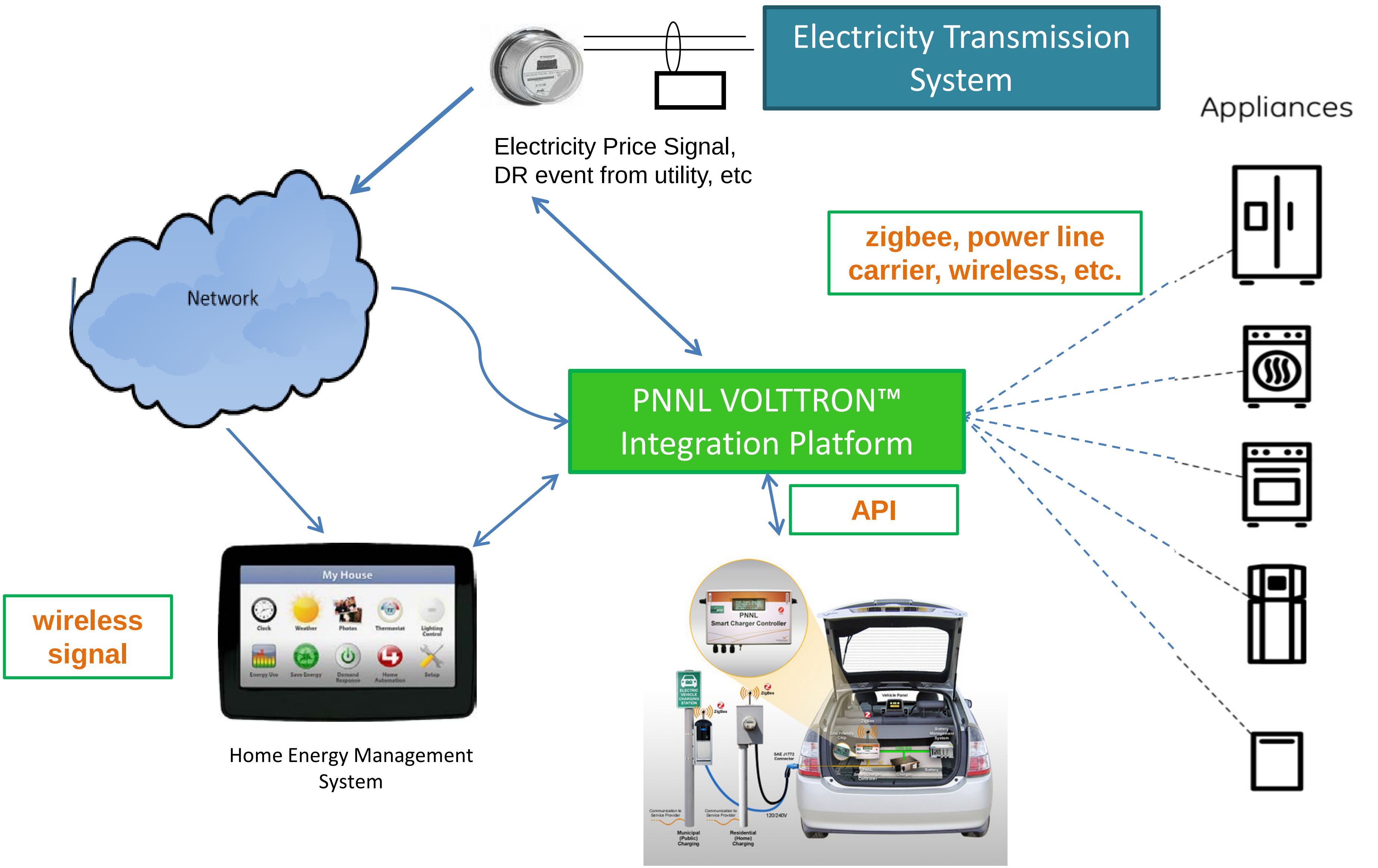


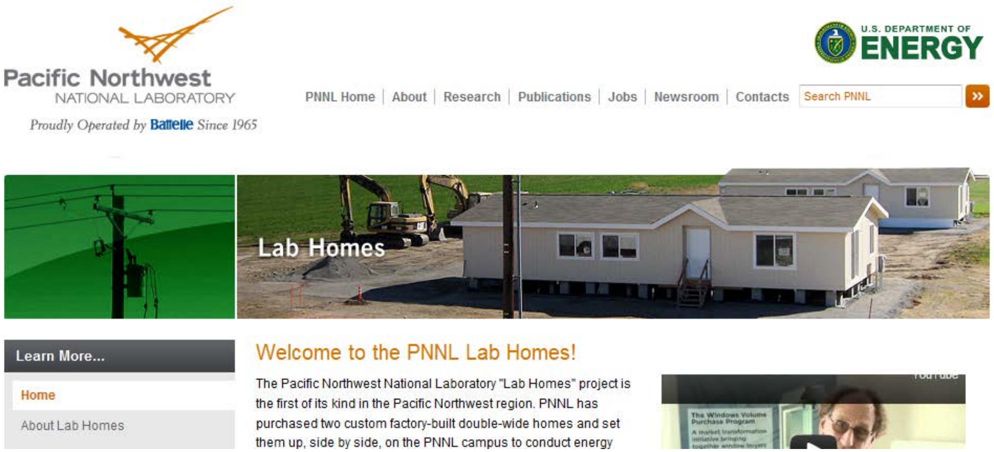
Future Research Agenda

- FY14 planned research will evaluate grid-smart appliances & smart electric vehicle charging stations; CO_2-driven heat pump water heaters (EE & DR).
- Future potential research may include efficient enclosures, innovative HVAC technologies, and solar-thermal/PV.
- **What can we evaluate in the Lab Homes that would help your programs?**

The "multiple (5) outdoor refrigerator" experiment

For more info….

- Visit our website:
  - http://labhomes.pnnl.gov/



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  - Joe Petersen
  - Greg Sullivan, Efficiency Solutions
  - Jake Knox
  - Nathan Bauman
  - Vrushali Mendon
  - Marye Hefty

Thank You!

Questions?

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What Should the PNNL Lab Homes Evaluate Next?

Back Up Slides

Thermal Experiments

Experiment	Lab Home A Configuration	Lab Home B Configuration	Purpose of Experiment
#1: HP vs. ER	50-gallon electric resistance*	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

* Electric resistance baseline will be GE Hybrid HPWH in ER only mode.

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)

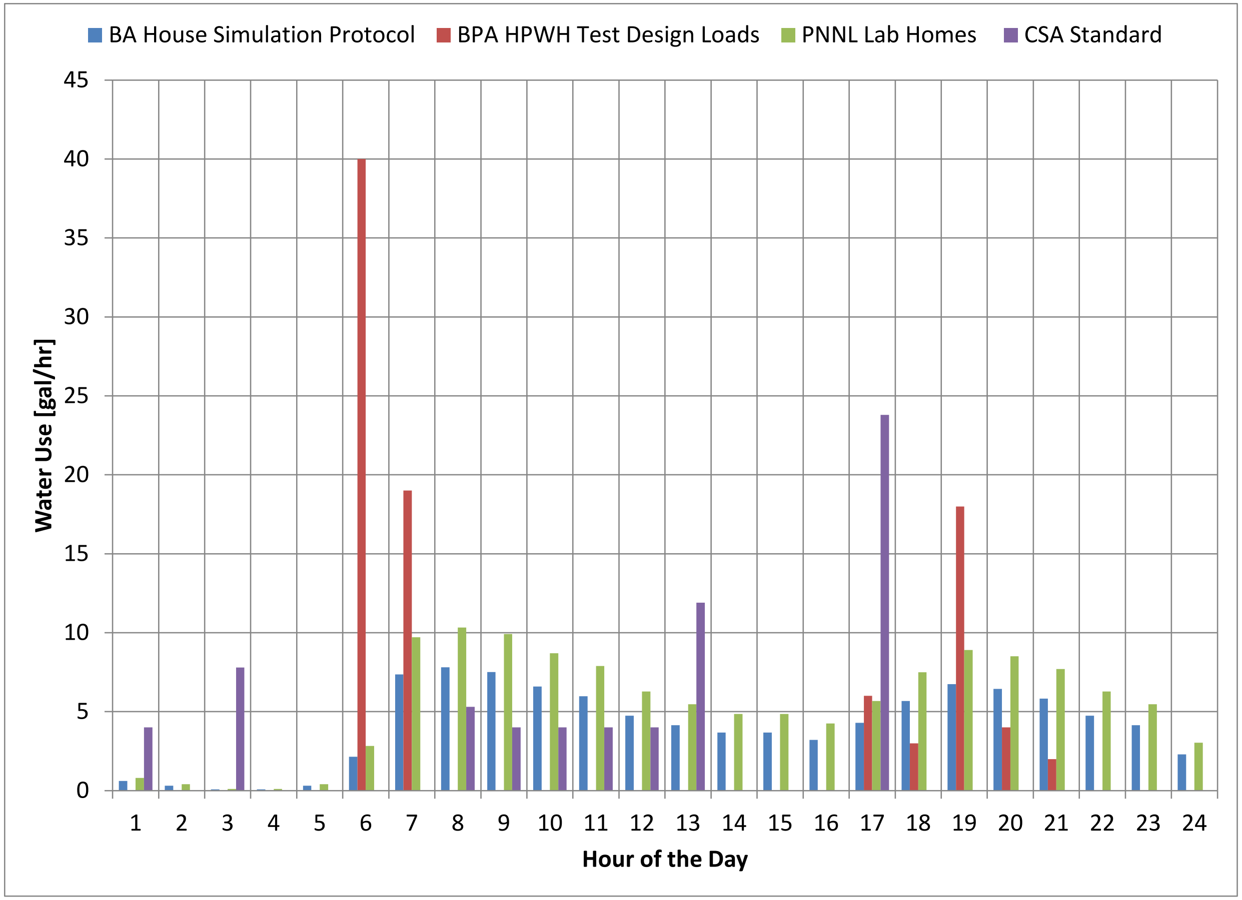
Data Files

- Power, water flow, and temperature data are provided for each DR related tests, including: baseline, peak curtailments; INC balancing events, and DEC balancing events.
- A data file, in csv (comma separated value) format, with 1-minute data for the following variables is available at labhomes.pnnl.gov for other researchers or interested parties to perform their own additional analysis:
  - Total electric real power to each water heater (kW), 1 minute average.
  - Total electric apparent power to each water heater (kVA), 1 minute average.
  - Hot water flow rate out of the water heater (gallons per minute), 1 minute average.
  - Temperature of the cold water supply into the water heaters (°F), 1 minute average.
  - Temperature of the water at the outlet of the water heaters (°F), 1 minute average.

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

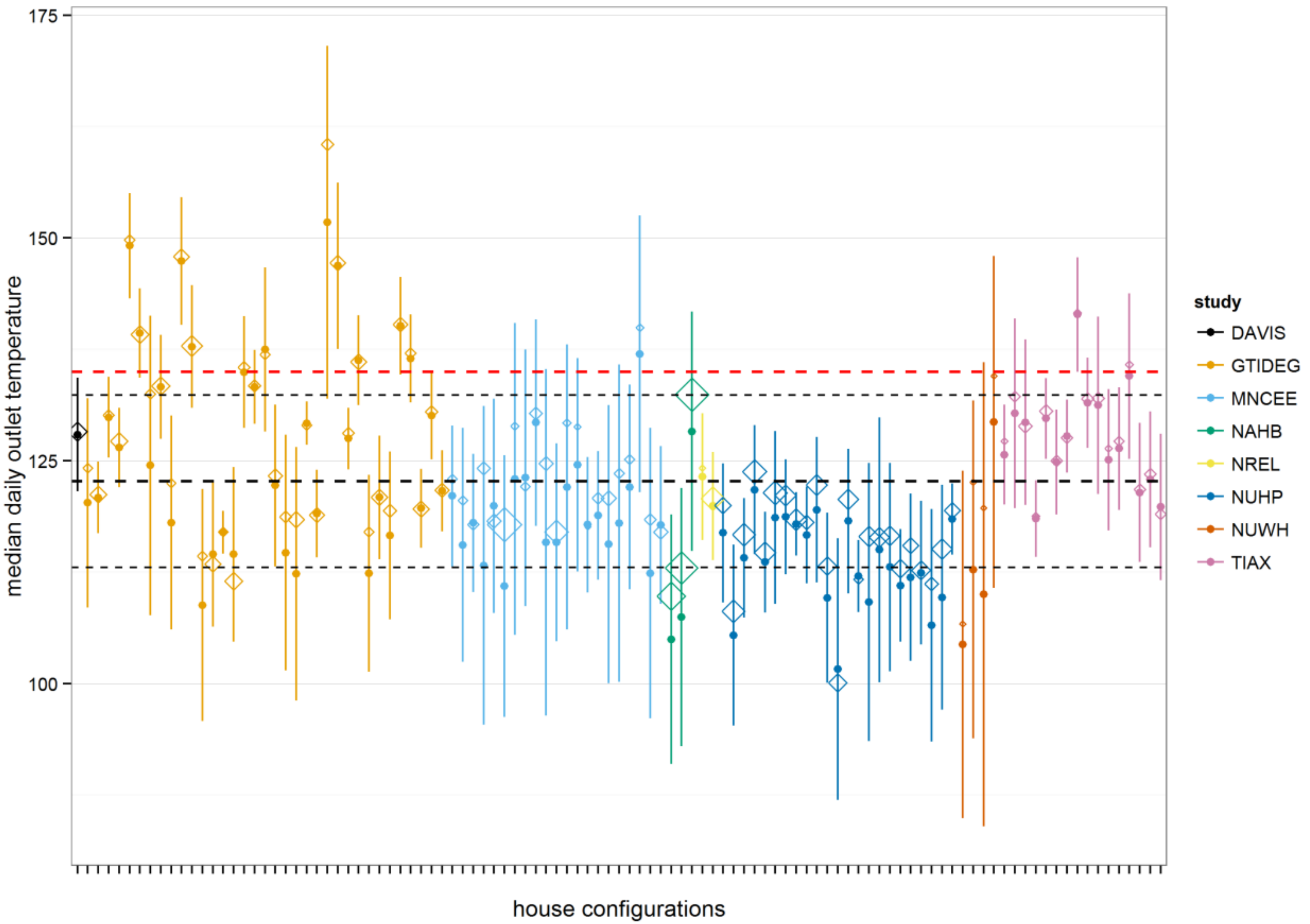
[1] Lutz and Melody; 2012



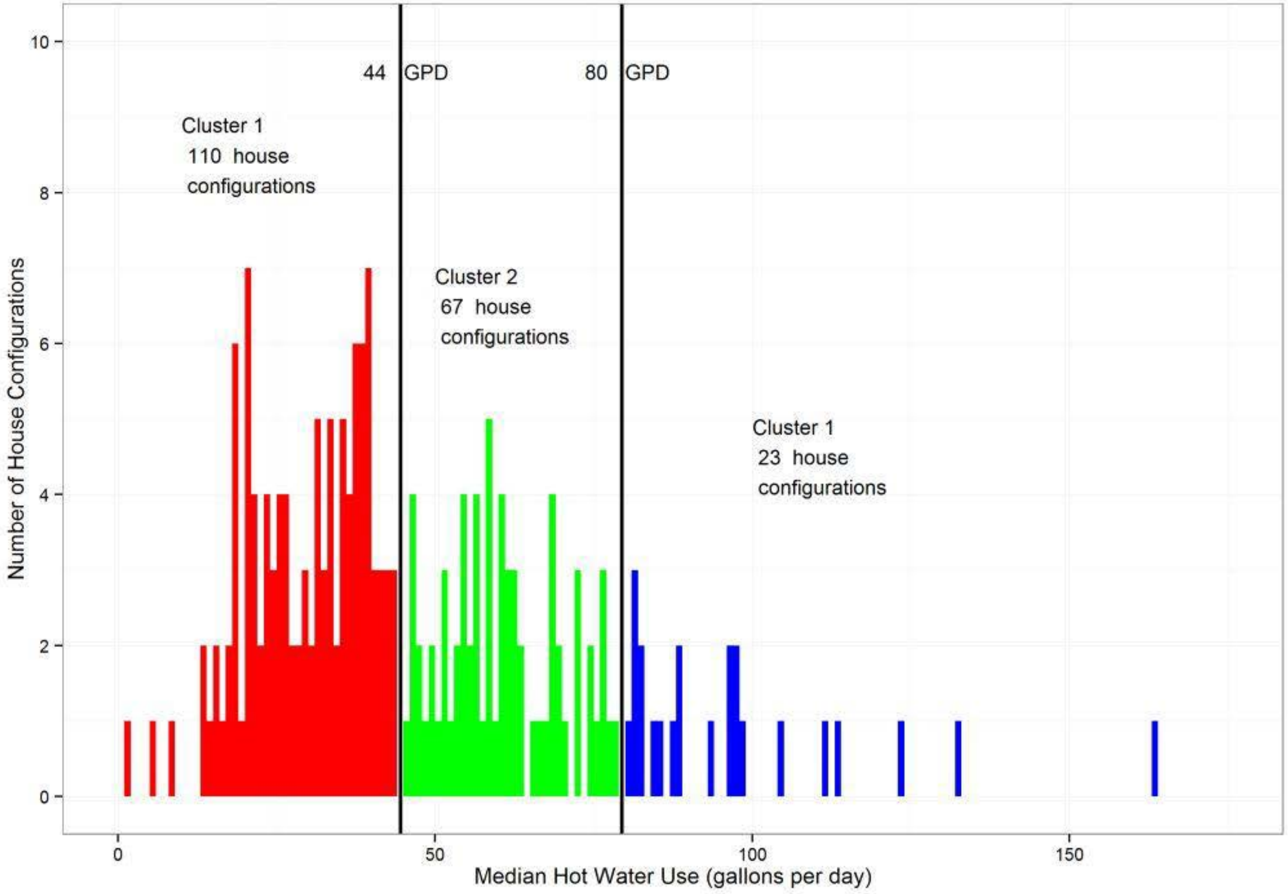
Profile	Daily Hot Water Use *[gal/day]*
Building America House Simulation Protocol	97 (6 people)
BPA Evaluation	90 (4 people)
Canadian Test Standard	68.8 ("high usage")
PNNL Lab Homes	130

LBNL Draw Profile Meta-analysis

- 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

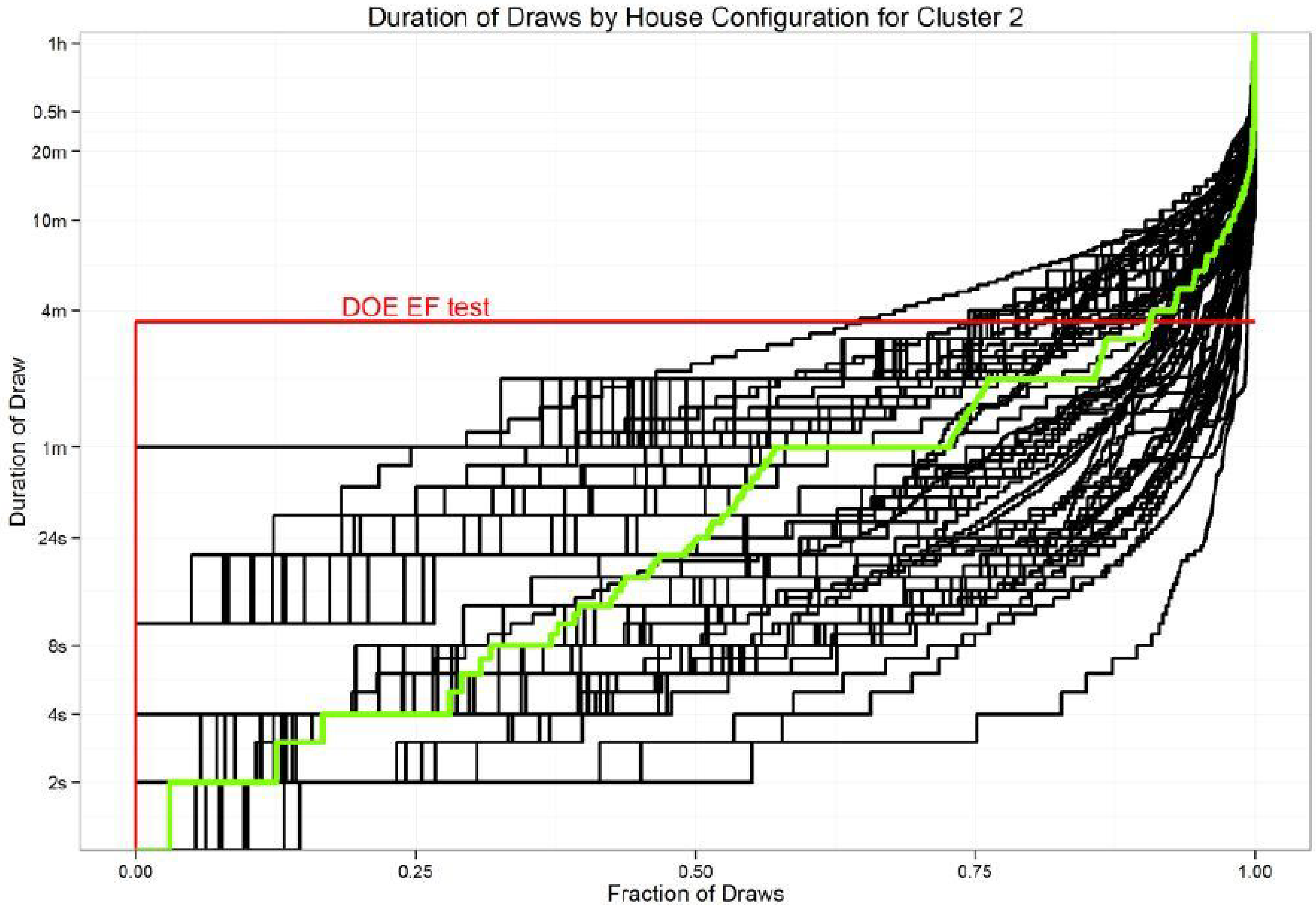


Figure 14 **Cumulative Distribution of Draws by Duration for House Configurations in Cluster 2**

LBNL Draw Profile Meta-analysis

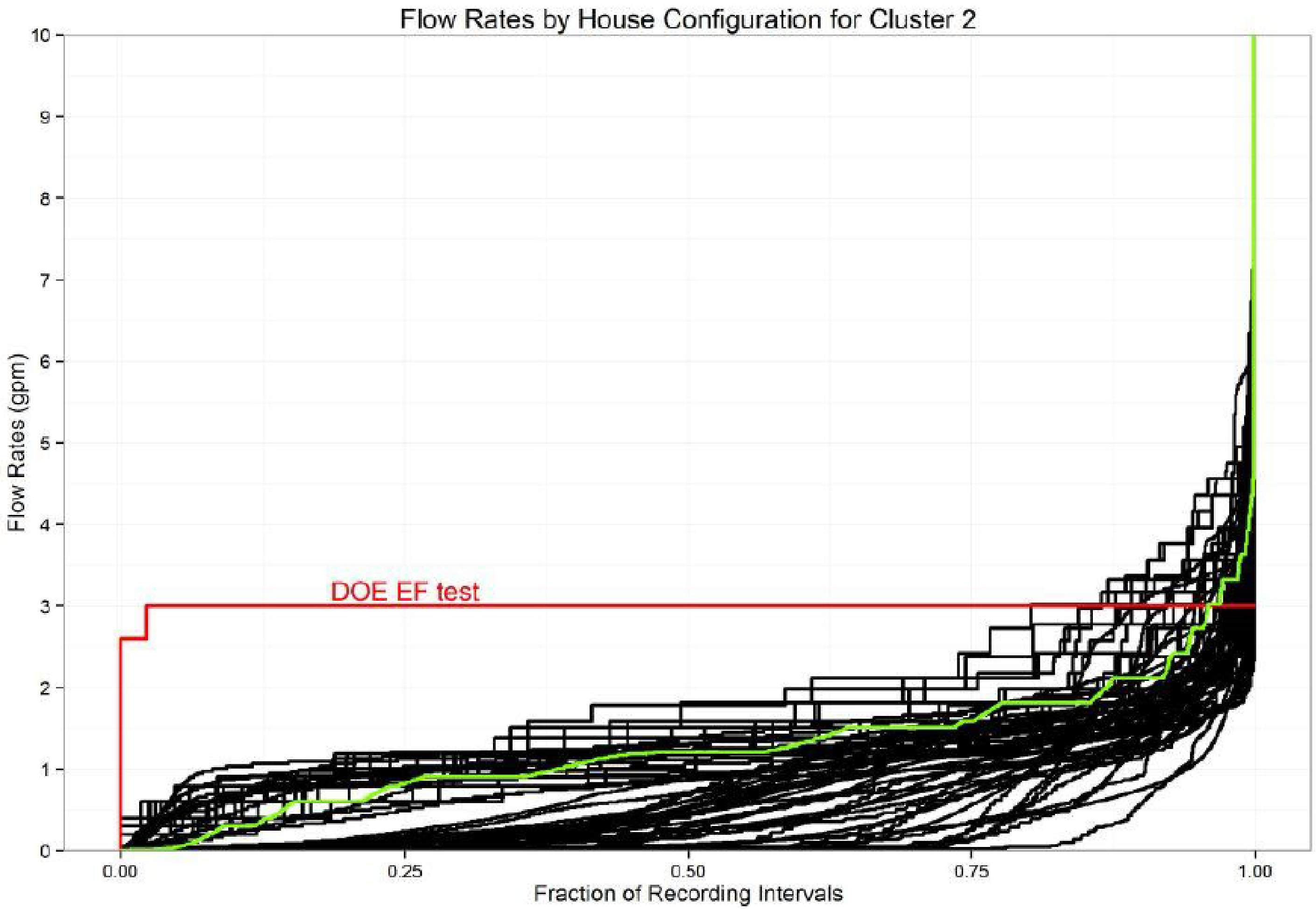
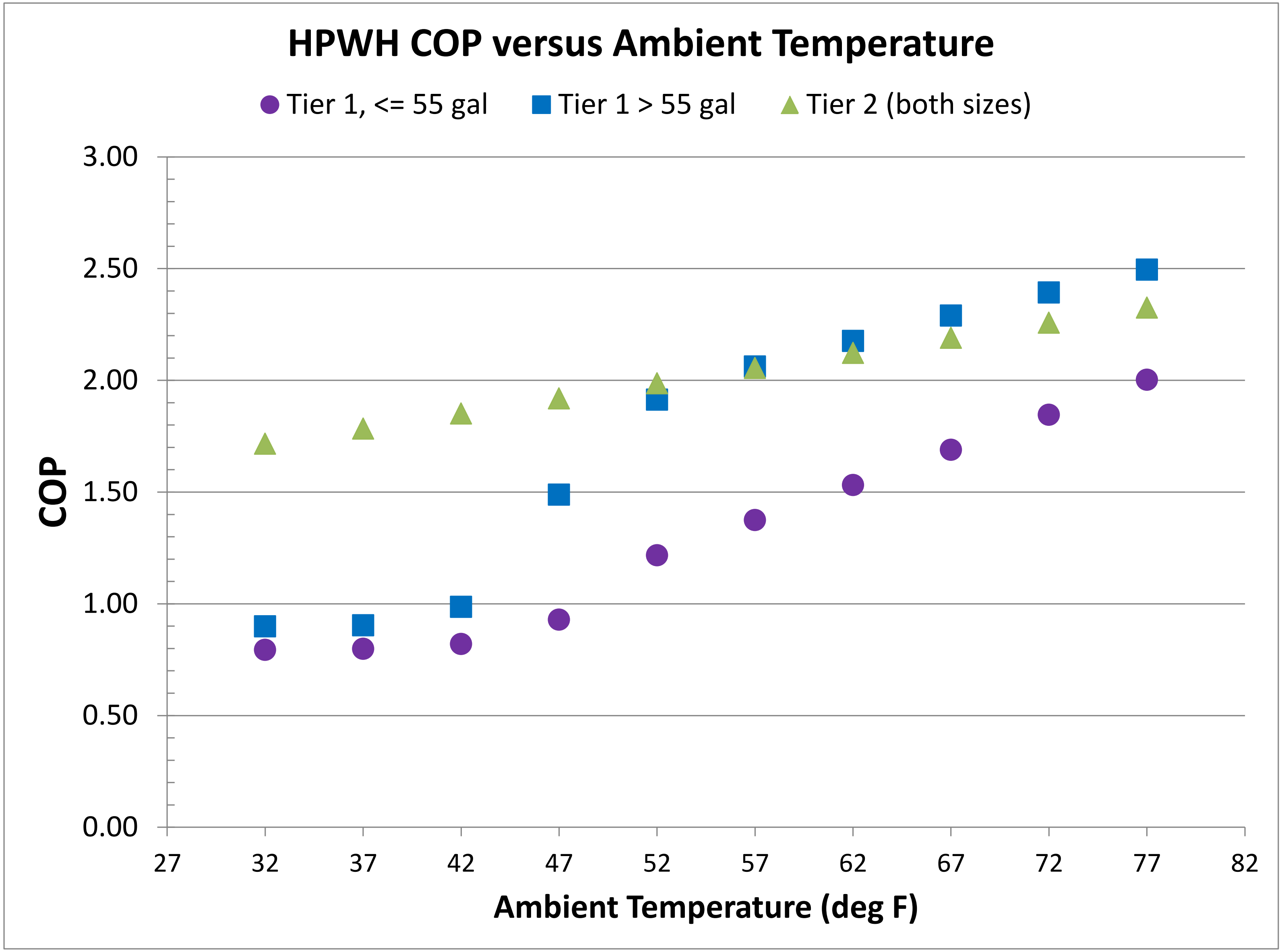


Figure 20 **Cumulative Distribution of Intervals by Flow Rate for House Configurations in Cluster 2**

Prior Lab Testing (Ecotope, 2011)



RTF Overall Savings Estimates

- 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

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

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

Cooling System Interaction

- 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

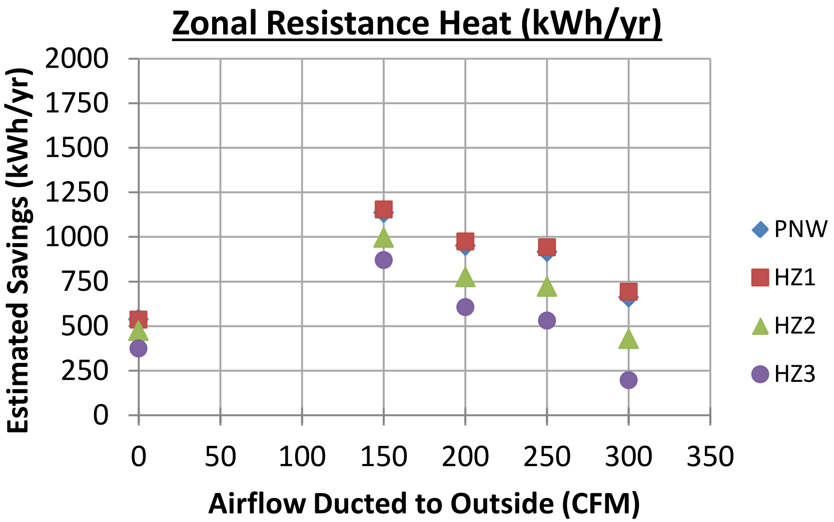
Zonal Resistance Heat (kWh/yr)				
CFM	PNW	HZ1	HZ2	HZ3
300	662	692	428	197
250	917	942	722	531
200	994	1016	825	666
150	1145	1163	1009	884
0	538	537	474	374

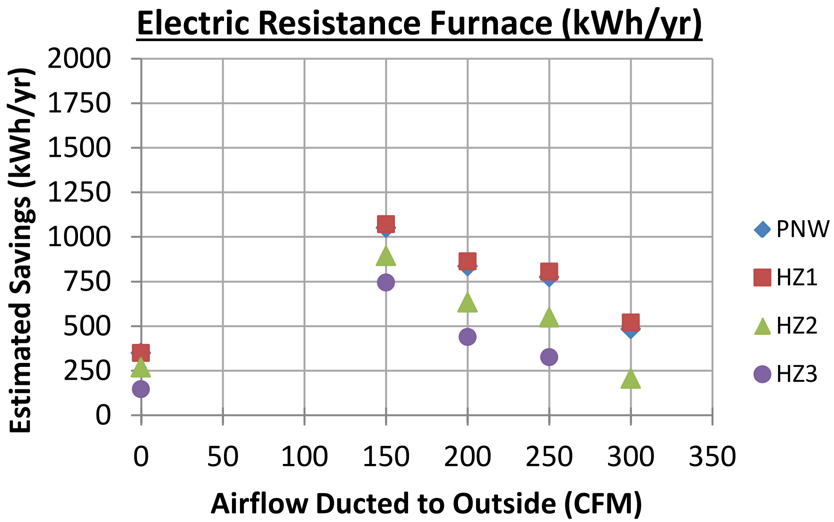
Electric Resistance Furnace (kWh/yr)				
CFM	PNW	HZ1	HZ2	HZ3
300	484	520	206	-70
250	776	806	549	327
200	884	909	690	506
150	1063	1083	907	761
0	349	350	270	147

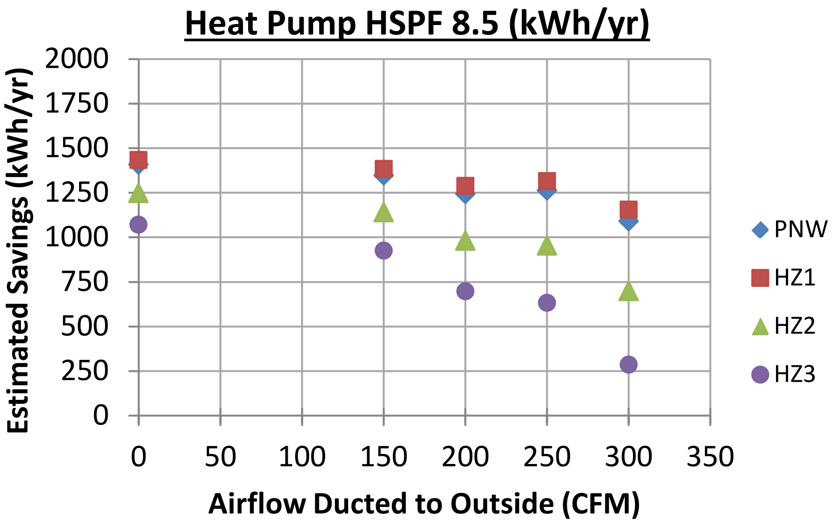
Heat Pump HSPF 8.5 (kWh/yr)				
CFM	PNW	HZ1	HZ2	HZ3
300	1090	1155	698	284
250	1263	1314	952	632
200	1267	1311	1014	744
150	1352	1387	1149	935
0	1407	1433	1248	1071

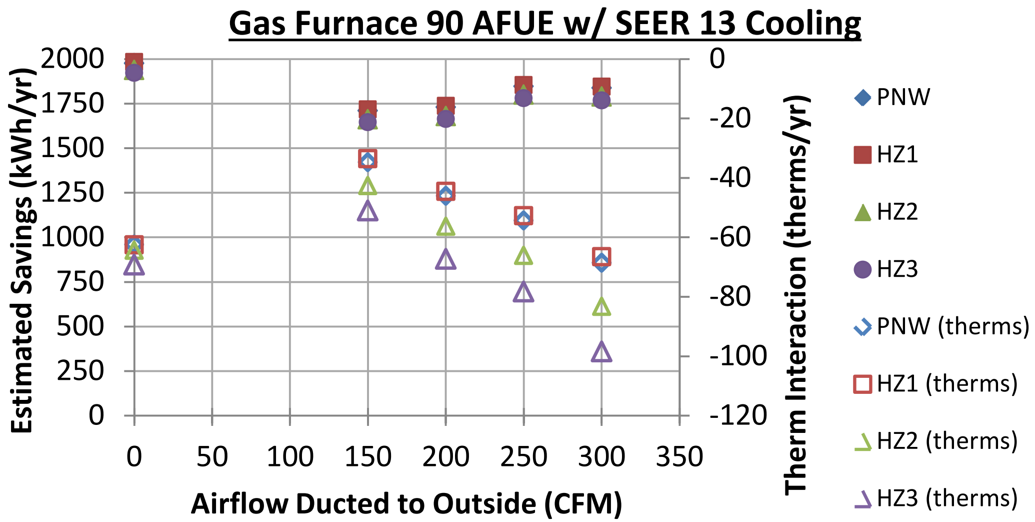
Gas Furnace AFUE 90 (kWh/yr)				
CFM	PNW	HZ1	HZ2	HZ3
300	1829	1837	1778	1756
250	1839	1847	1791	1771
200	1726	1734	1675	1657
150	1706	1714	1656	1640
0	1970	1976	1930	1914

PNW Modeling: DHW Savings with Combined Interaction









BPA Demand Response Product Characteristics

Product details

	DR Product 1 Within-hour load decrease for non-spinning balancing reserves (INC)	DR Product 2 Within-hour load increase for non-spinning balancing reserves (DEC)	DR Product 3 Heavy load hour to light load hour shift for oversupply	DR Product 4 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) 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 (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): $7.68 kW/month	VERBS rate (FBS-based): $2.07 kW/month	OMP cost estimate: $40-50 MW/hour	Demand charge for LF customers: $9.62 kW/month
Future Comparative Cost	Combustion gas turbine: $17.63 kW/month	TBD - no current market-ready alternative	TBD - no current market-ready alternative	Combustion gas turbine: $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

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

HPWH DR Testing Schedule

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

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	