New Construction Hybrid-Ductless Heat Pump Study

(Resistance is Futile)

Bruce Carter, Tacoma Power

Michael Lubliner, WSU Energy Program

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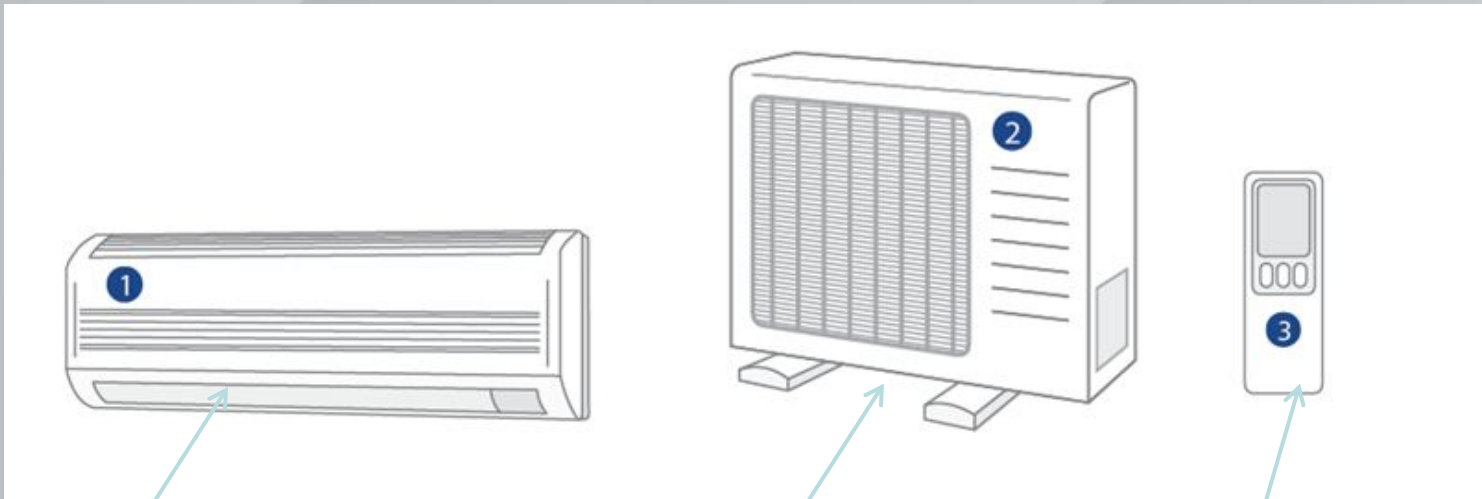
Sponsored by the BPA E3T Program and U.S. DOE Building America BA-PIRC

What is a Ductless Heat Pump (DHP)?



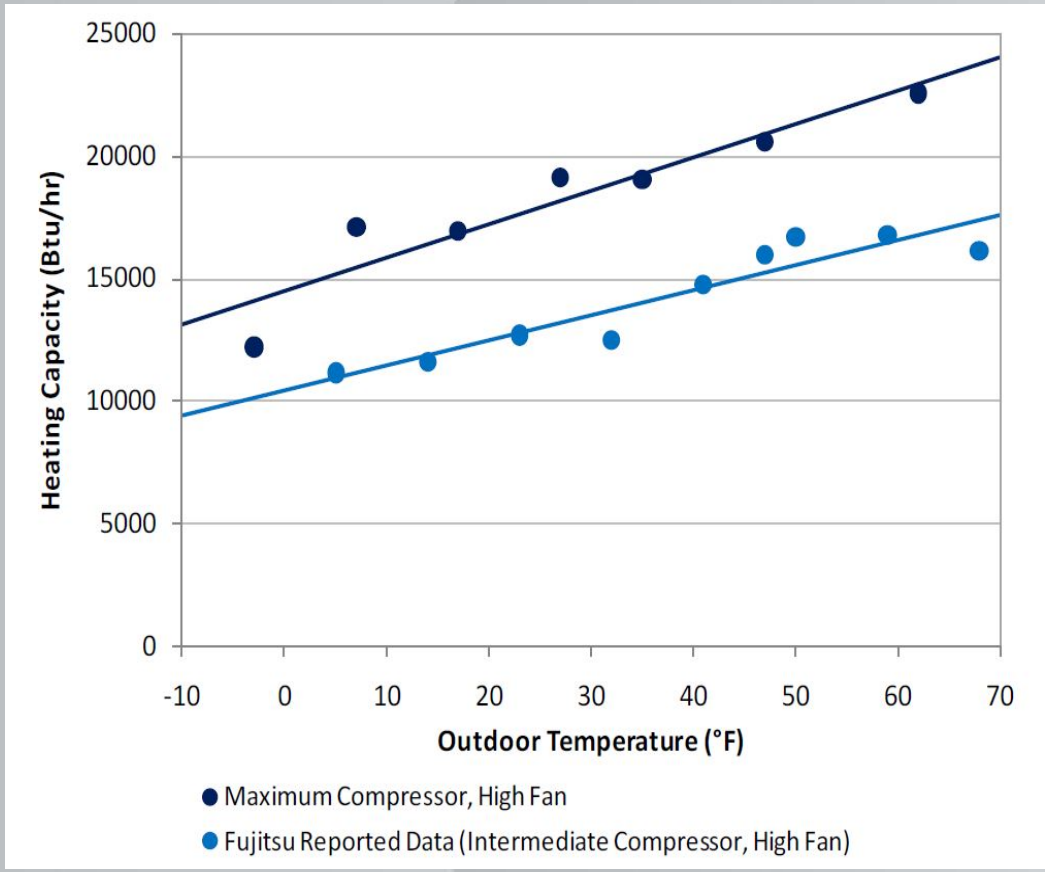
1. Fan coil (indoor)

2. Compressor (outdoor)

3. Remote

DHP Performance

- Unlike central heat pumps, DHPs have outstanding cold weather performance, requiring no supplemental heat.
- They also maintain COPs above 2 even at extreme cold temperatures.



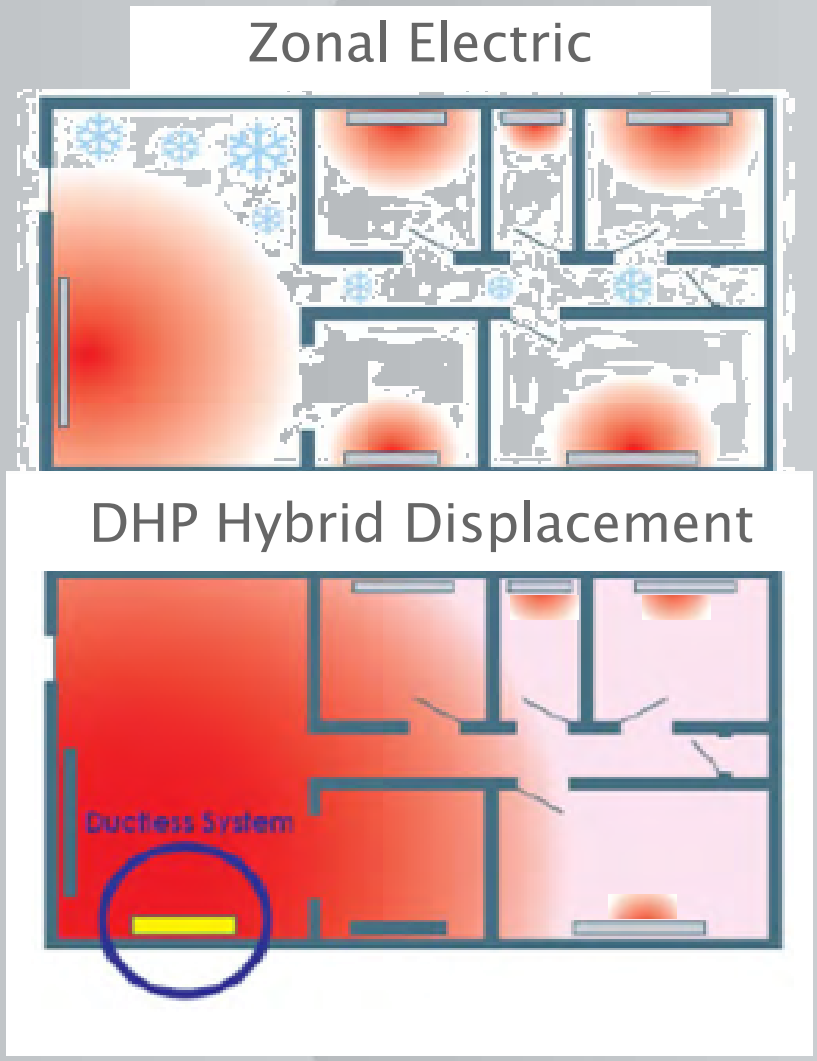
Winkler, J, NREL, 2011

Hybrid DHP/Electric Resistance Systems

- A DHP fan coil located in the main living area in combination with electric resistance zone heaters located in the perimeter rooms.
- The DHP carries the bulk of the home's heating/cooling load while the zone heaters provide supplemental heat.

How DHP Hybrid Displacement Works

- Ideal alternative to electric resistance zonal heated homes
- Reduces heating bills by displacing a large share of zonal electric heat
- DHP installed in the main living area



New Construction Hybrid DHP/ER Study

- **February 2011** – Habitat for Humanity (HFH) seeks help for new housing project from Tacoma Power using DHPs.
- **Fall 2012** - Tacoma Power recruits BPA, SnoPUD, and Cowlitz PUD for new construction hybrid DHP study.
- **Spring 2012** – HFH breaks ground.
- **Spring 2013** – HFH starts construction, first five homes take shape.
- **Late fall 2013** – All co-funder agreements in place. Monitoring begins on first homes, weather station erected onsite.
- **2014/15** – Construction continues, additional 7 homes completed and added to study. Monitoring continues on all homes. One-year data collected on first 7 homes.
- **2015/17** – Neighborhood built out (30 homes). Monitoring continues.

Sponsors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Research Team

Tacoma Power:

Bruce Carter
Rich Arneson
Cathy Carruthers
Jeremey Stewart
Rachel Clark
Molly Ortiz/Ying Tang

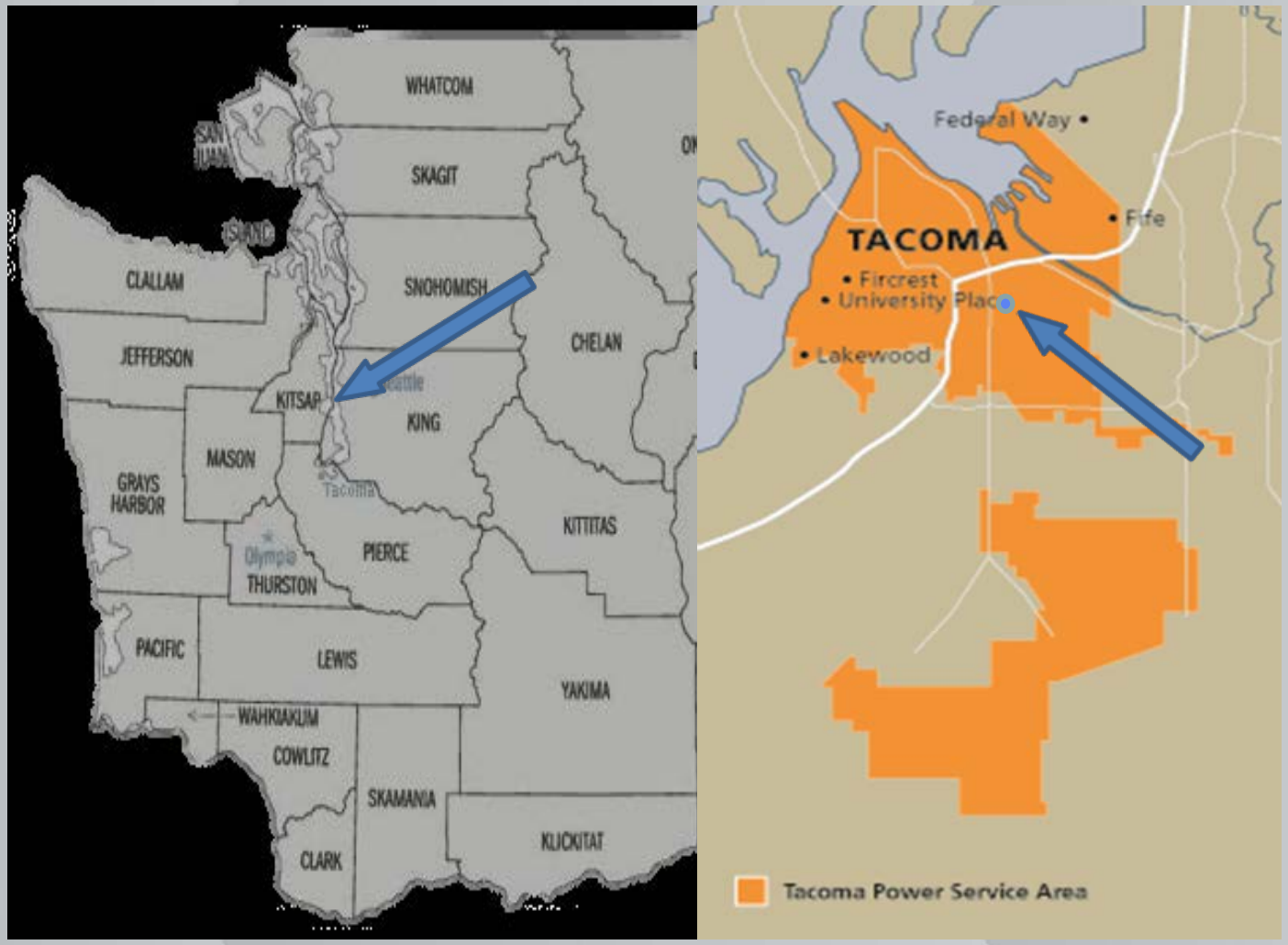
Washington State University Energy:

Mike Lubliner
David Hales
Luke Howard
Ken Eklund
Melinda Spencer

Habitat for Humanity of Tacoma/Pierce County:

Gomer Roseman
Guy Nielsen
Dave Leenhouts

Project Site

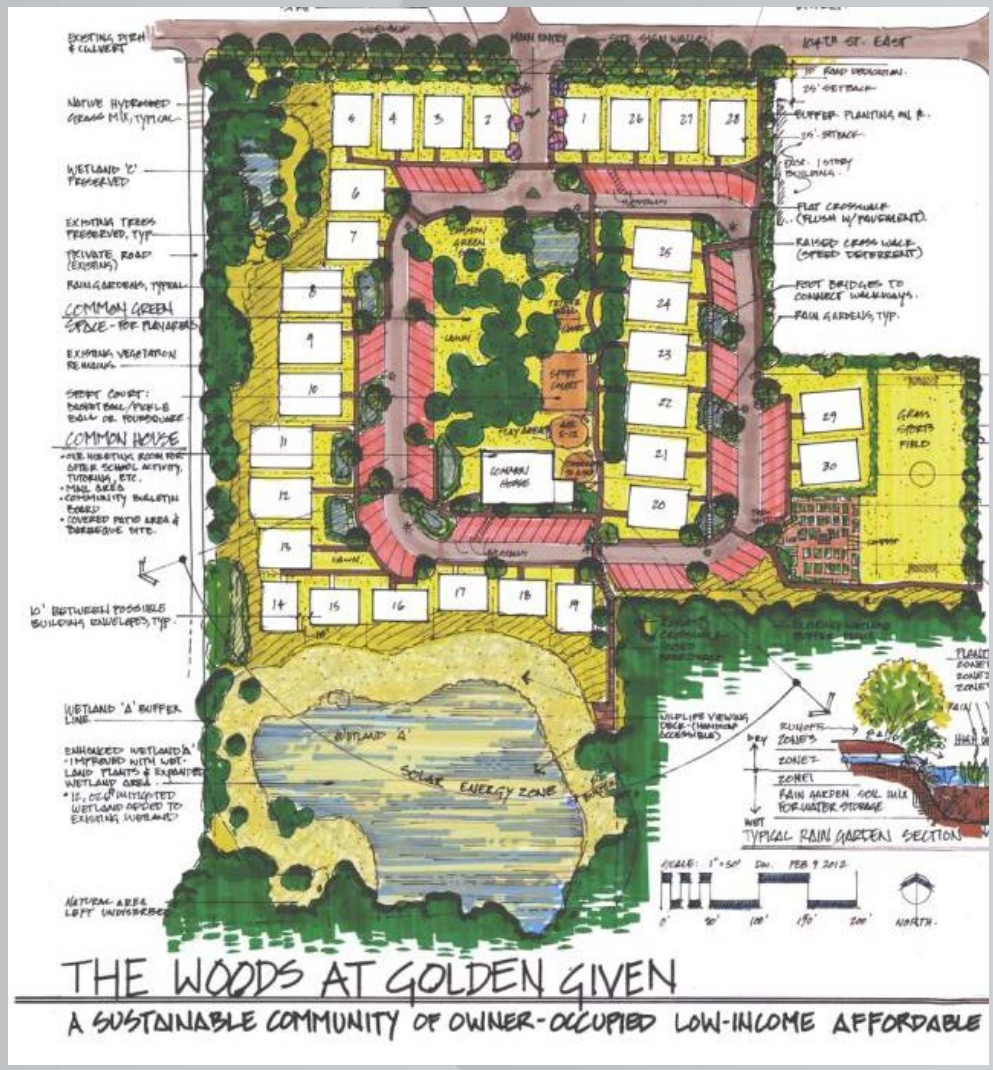


HFH Sustainable Community

- Community of single-family, zonal electric-heated homes
- 30 planned, 12 built to date
- 5 distinct designs

  (950 to 2,200 ft^2)
- Homes comply with NWESH v2

  5% more efficient than 2012 code
- No chimneys for wood stoves/ natural gas

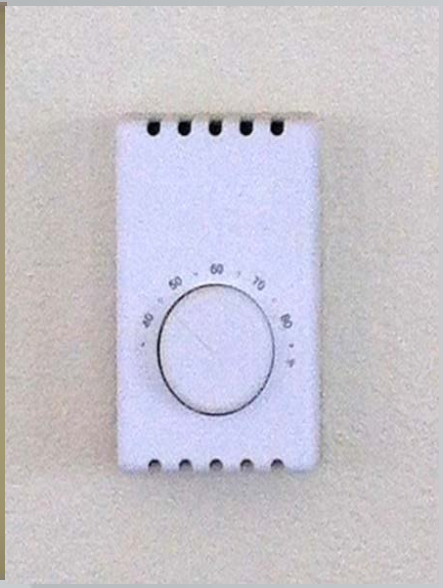


Homes at The Woods

New HFH Homes

Specifications

- Continuous R-15 underslab insulation
- R-21 + R5 exterior walls
- R-49 ceiling
- U-.28 windows
- ENERGY STAR-certified lighting
- Continuous heat recovery ventilation
- Hybrid ductless heat pump-electric resistance heating (DHP-ER)



Homeowner Orientation

Operating and maintaining your heating system

Clean ductless heat pump filters every three months

Let the DHP "heat" the house

)HP thermostat

* Set the ductless heat pump thermostat to maintain a comfortable temperature in the main living area

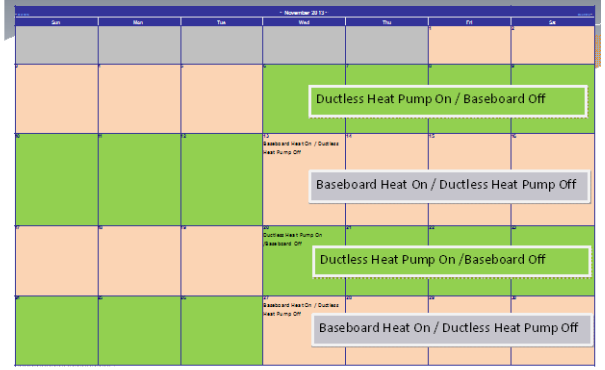
)edroom thermostats

* Set the bedroom thermostat to 62° or where you are comfortable
* Remember, the DHP should help heat the bedrooms as well

Maintaining your heat recovery ventilator

Remove and wash HRV filters monthly

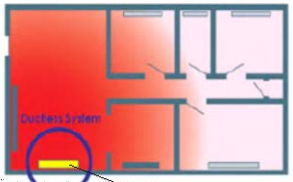
Heating system schedule



Heating systems switch weekly

WEEK 1

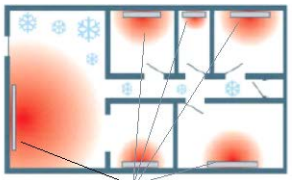
DUCTLESS HP



Baseboard off

WEEK 2

ZONE HEAT



All baseboards on

System electronics

Do not open these panels

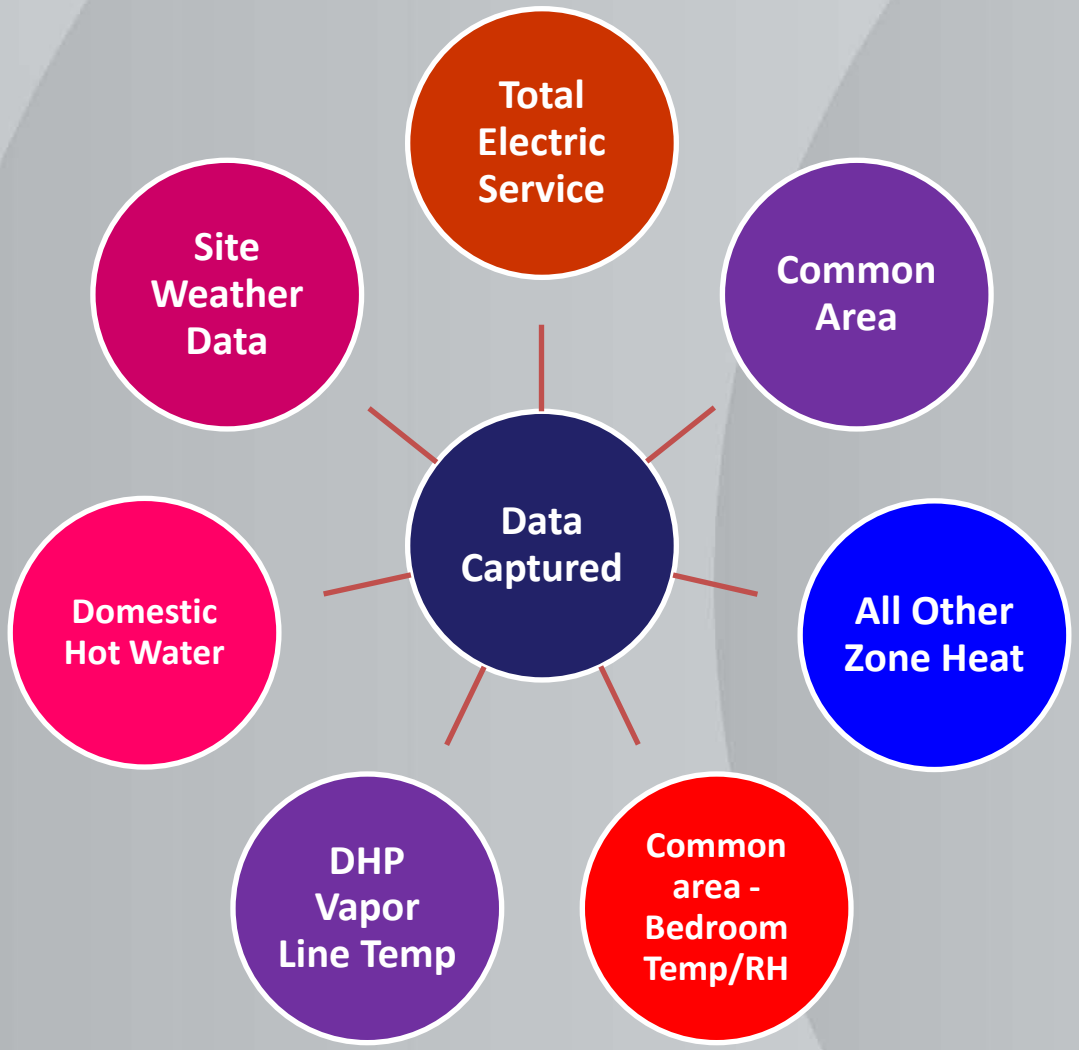
Key Research Questions

1. What are the performance characteristics of a hybrid DHP/ER heating system compared to an all-ER heating system in new construction single-family homes in a marine climate in the Pacific Northwest?
2. What are the average annual electricity savings of the hybrid DHP system over an all-ER system?
3. What are the total and incremental installed costs of this system?
4. What are the average expected life cycle impacts of such a system?
5. What are the occupant perceptions of a hybrid system? Does a hybrid system produce the same comfort levels as an all-ER system?

Study Design of Energy Use

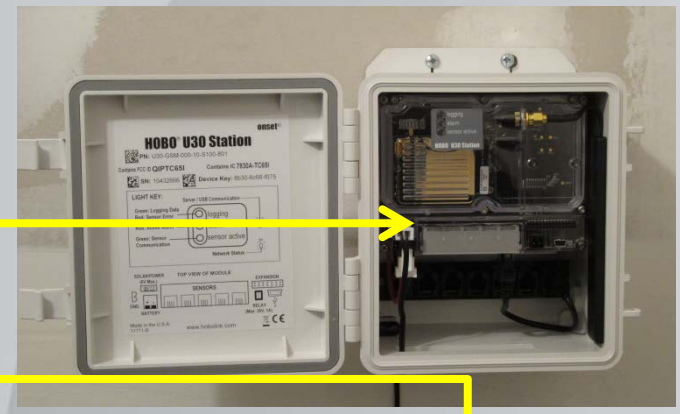
- Compare electrical use of hybrid DHP/ER heat vs. all-ER heat in new construction
- Common area contains both DHP and ER heat switched between the two weekly
  - The switching schedule is staggered between homes
- Each home to act as its own control over a range of temperatures
- Temperature and relative humidity (RH) captured
- Homeowners given choice at end of study of which heating system they would like to keep

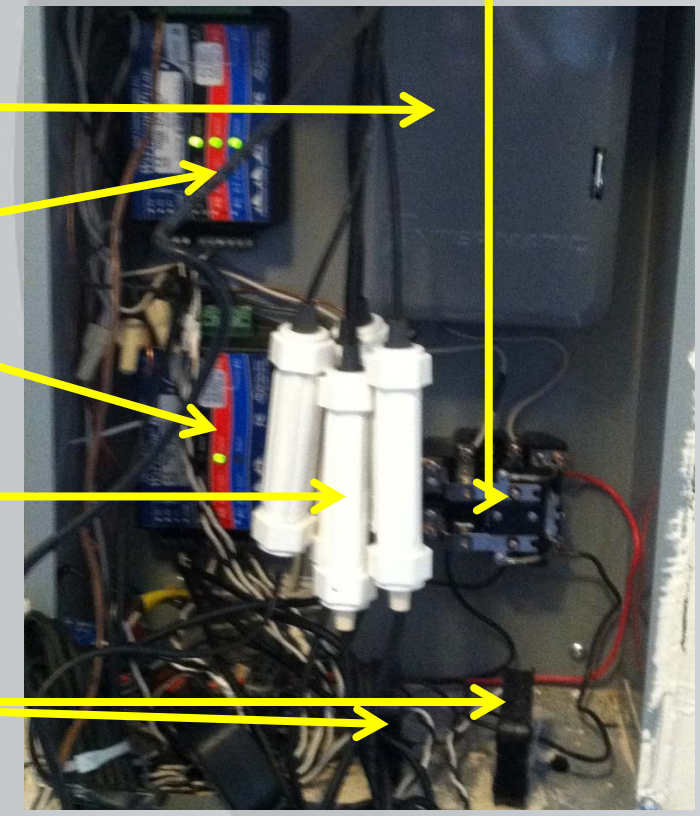
Technical Implementation



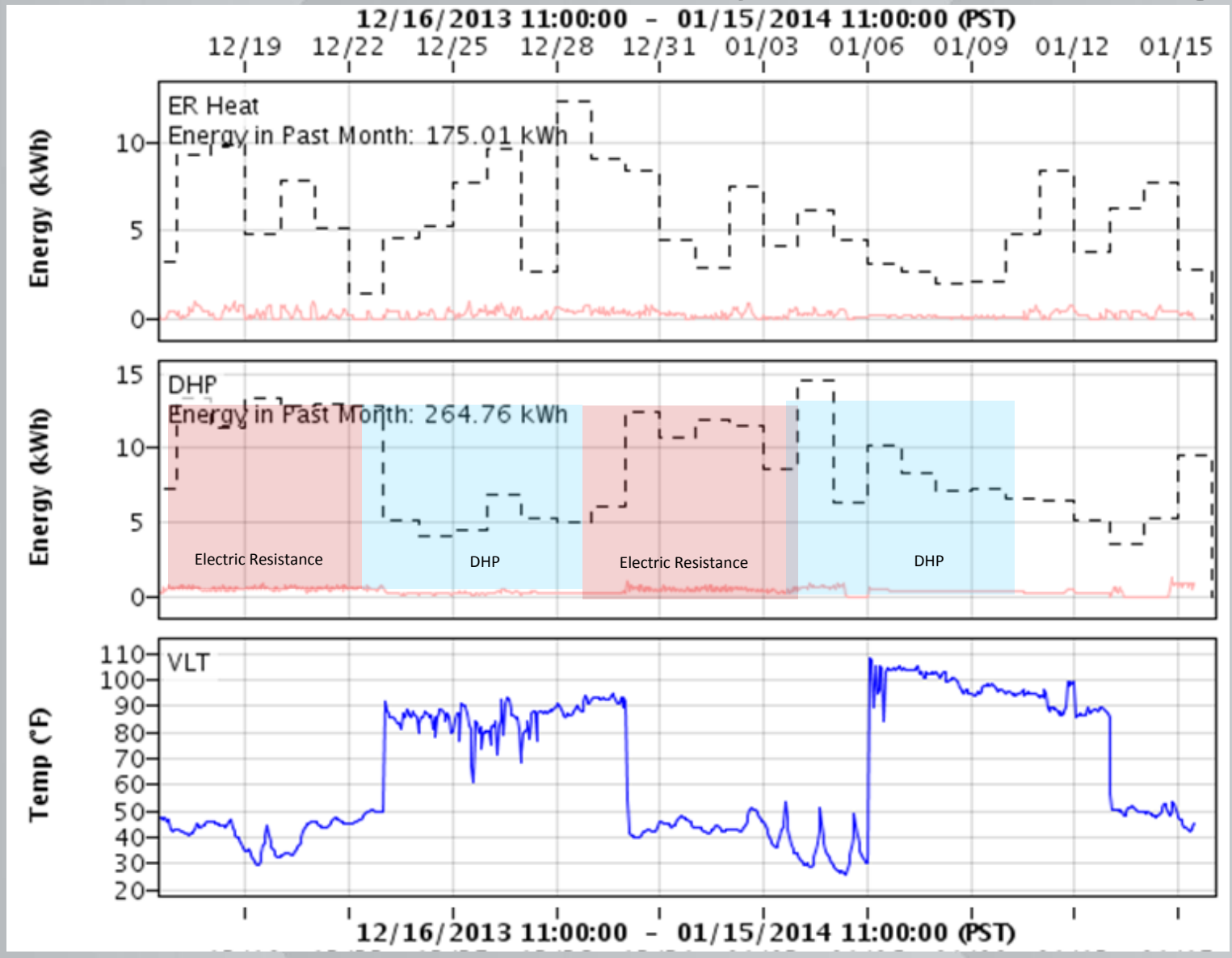
Project Equipment - Installed

- U30-Data logger with cellular communications allows us to monitor data hourly and provides instant error notification
- Relay
- Time Clock
- Watt Nodes used to convert energy consumption pulse data from the current transducers
- Pulse Input Adapter tracks pulses
- Current Transducers (CTs) connected to electrical circuits to measure current





Web Based Hourly Monitoring



Research Question #1

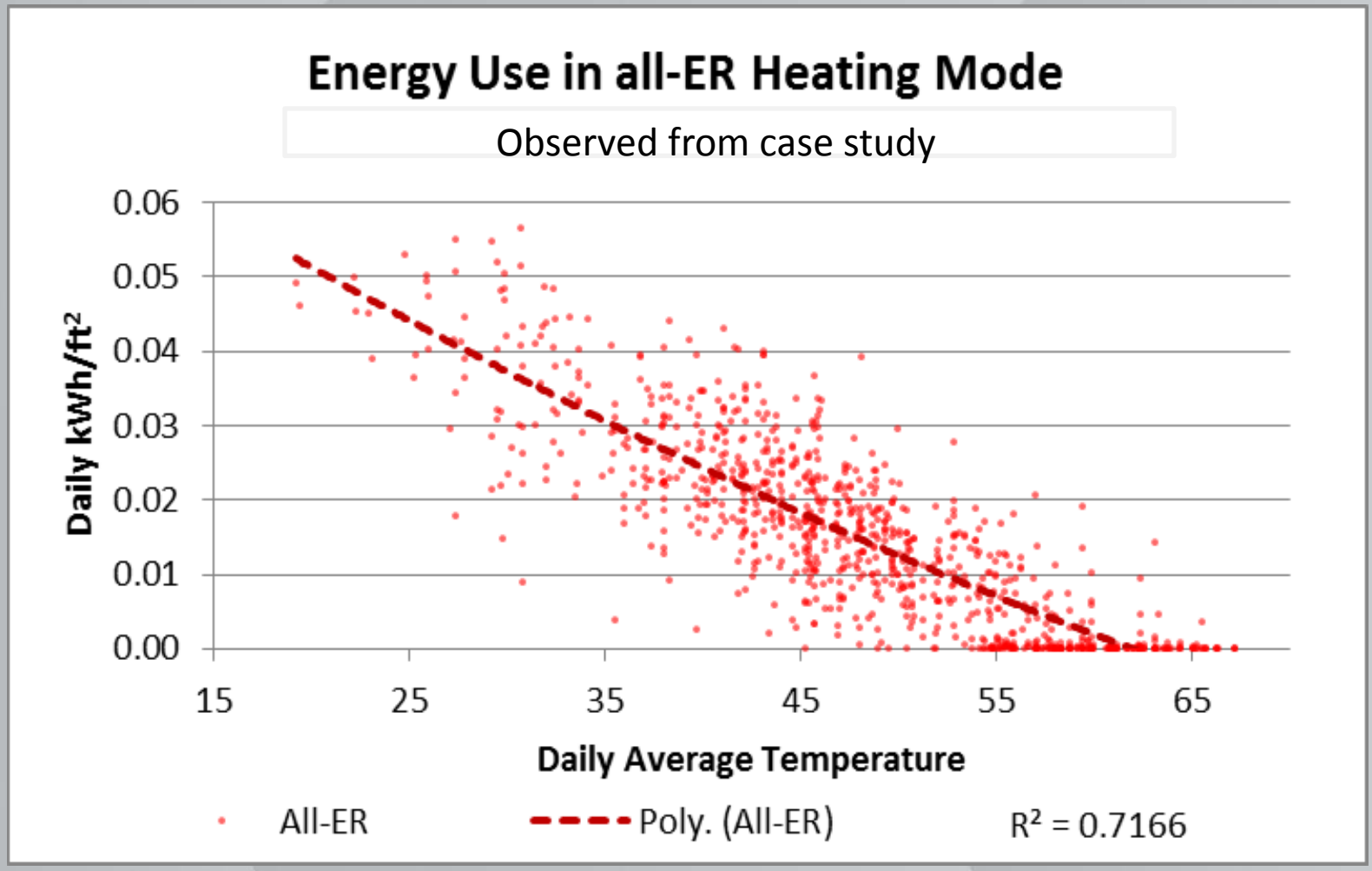
What are the average annual electricity savings of the hybrid DHP system over an all-ER system at The Woods?

- A multivariable regression to control for differences in weather, study periods, and house characteristics estimated savings of 2,640 kWh/year/house for the hybrid DHP-ER heating system for 2014-15 site weather.

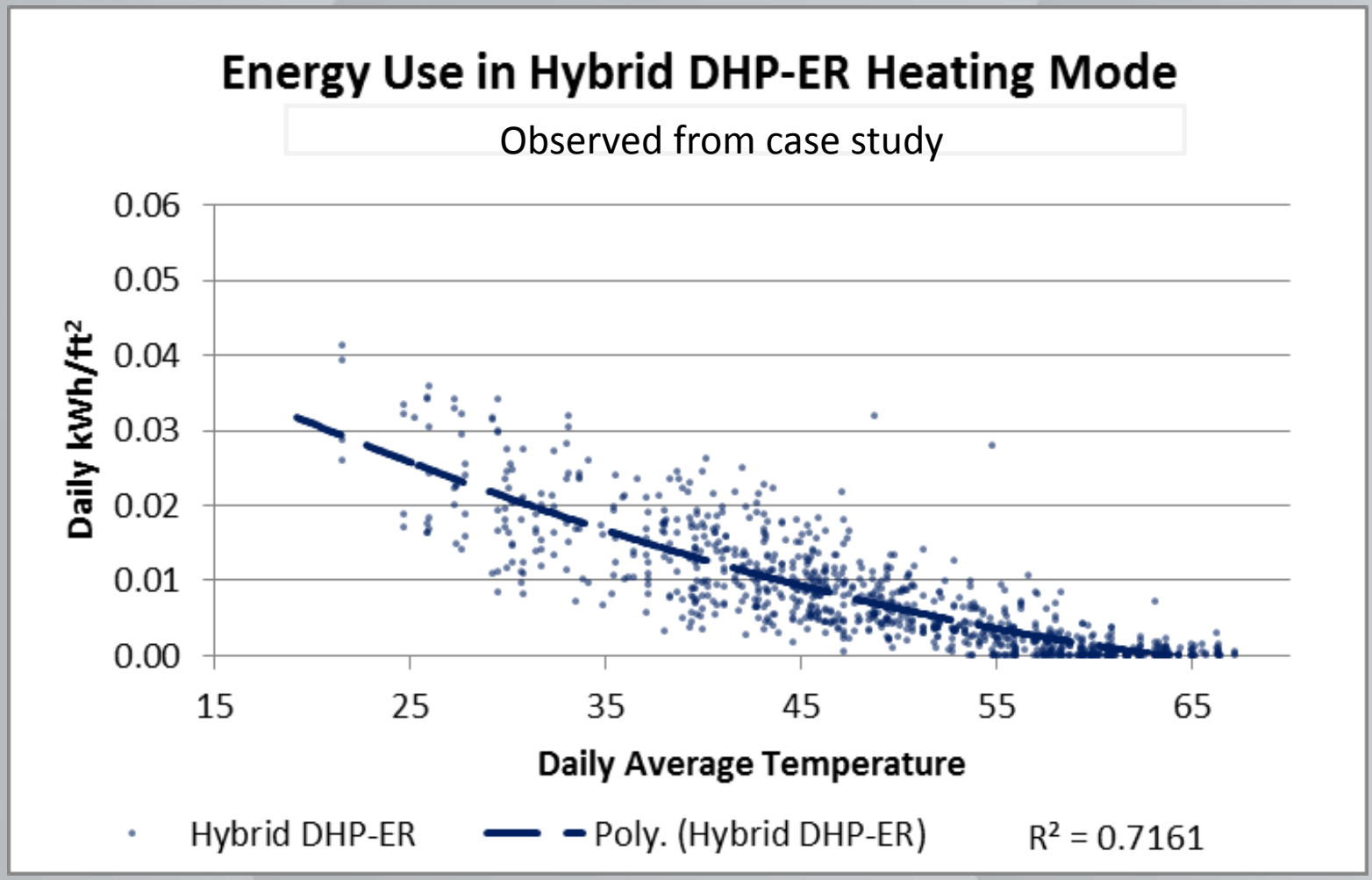
- A variable degree day regression analysis for each house estimated weather normalized savings for Western Washington ranging from 1,787 KWh/year to 3,254 kWh/year with an average of 2,410 kWh/year.

- Using a 2016 weighted average state residential electric rate of $0.0853/kWh, average annual bill savings are **$239** (2806 kWh/year) for a typical 1280 ft2 new home. Site-specific savings at the Woods ranged from a low of 2,019 kWh to just over 4,289 kWh. The savings estimates are based on TPU polynomial regression analysis utilized in the life cycle cost analysis (adjusted for cooling).

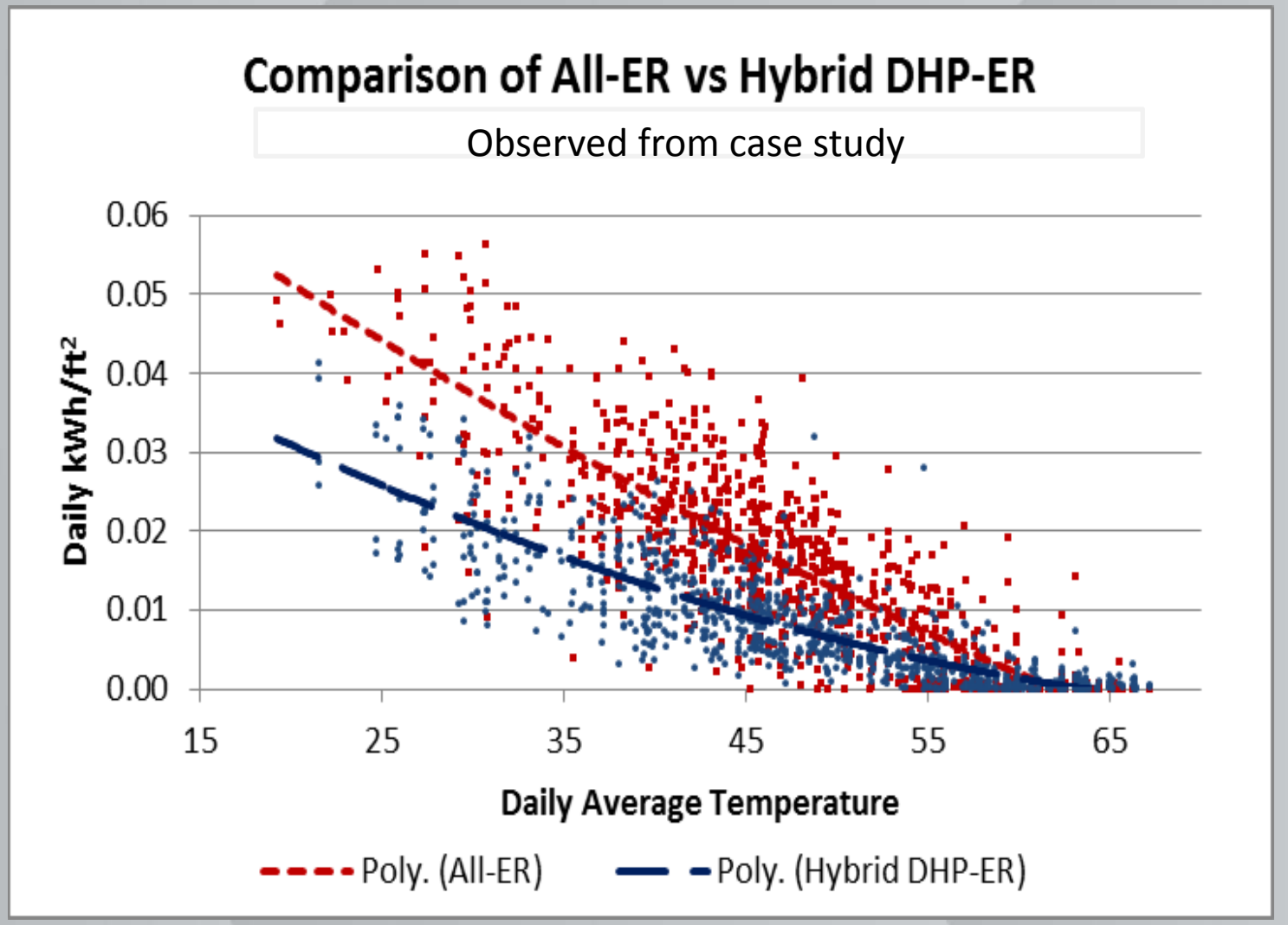
Observations



Observations



Savings Analysis (Heating)



Hybrid DHP System Savings Estimates -TPU

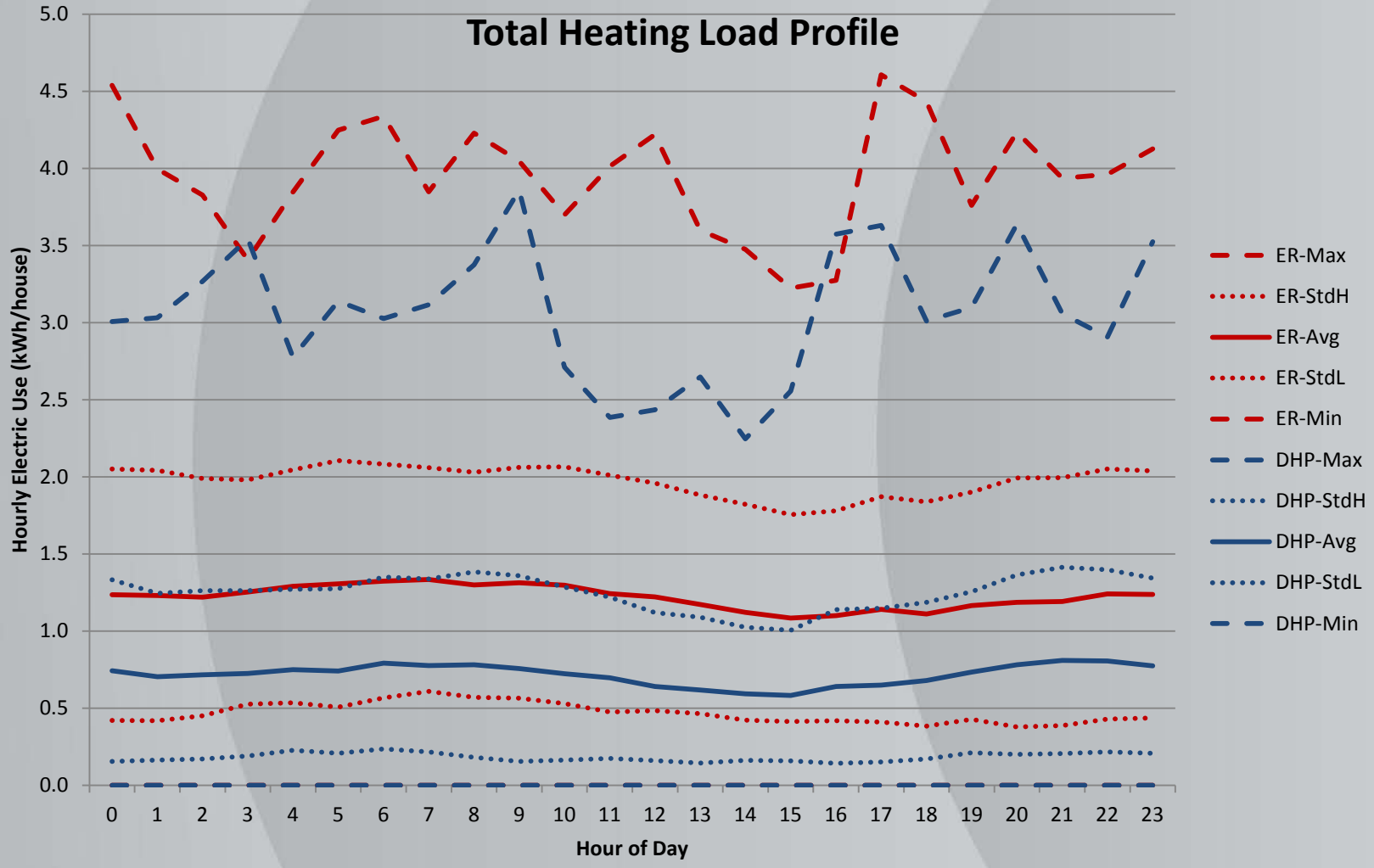
Energy Used (kWh/ft²)	Hybrid DHP-ER	All-ER	Savings
Heating Season	2.47	4.71	2.24
Cooling Season (Jul & Aug)	0.04	-	-0.04
Total	2.52	4.71	2.19

47% savings over all-ER system

1280 ft2 (typical) x 2.19 = 2806 kWh/year

2806 kWh/year x $0.0853/kWh = $239/year

Peak Heating Season – 7 homes



Adjusting for Cooling

Adjusted savings accordingly to account for DHP cooling

No information for cooling in ER mode:

- Common areas placed in DHP mode Jul 11-Sep 19, 2014
- Don't know what equipment would have been bought in absence of DHP

Apply daily average observed in data (0.00067 kWh/ft^2) to Jul & Aug in our "normal" year for DHP energy estimate:

- Assume no cooling in all-ER system

Assumed conservative estimate of DHP savings because:

- Study year was warmer than normal
- No accounting for alternate cooling equipment in ER mode

Summer Period DHP Energy Use
(7/11 – 9/14, 2014)

House	Energy Use (kWh)	Survey Cooling Use	Average OAT (°F)	Maximum OAT (°F)	Cooling Degree Days (base 70°F)
Pine	48	Sometimes	66	95	143
Larch	18	Never			
Fir	115	Often			
Hemlock	76	Often			
Alder	NA	NA			
Oak	30	Sometimes			
Cedar	31	Often			

Research Question #2

What are the total and incremental installed costs of this system?

- The average hybrid DHP-ER heating system cost for a buyer of a new HFH home is $2,746.
- Average cost for an all-ER heating system is $321.
- These costs result in an incremental cost of $2,451 per home.

Research Question #3

What are the expected life-cycle impacts and monthly cash flow?

- On average, these homes have a 2015 present value positive benefit of $3,690 with a hybrid DHP-ER heating system when compared to an all-ER heating system. Assumes 2800 kWh/year savings for a typical 1280 ft2 home
- On average, the monthly cash flow is positive:
  - $8.96-$23.26/month with HFH financing with 30 years, 0% interest loan vs. $8
  - $2.39 - $16.69/month with 15 years, 5% interest loan.

Life Cycle Impacts

- Economic analysis run using Washington State Office of Financial Management (OFM) economic analysis tool
- Hybrid DHP-ER heating system's life-cycle present value benefit = $3,690
- Cash flow positive w/HFH loan (30-year, 0% interest)
- Cash flow positive w/loan at (15-year, 5% interest)

Alternative	Baseline All-ER Zonal System	Alternative Hybrid DHP-ER System	Change
1st Construction Costs	$318	$2,722	2,403
PV of Capital Costs	$503	$6,700	6,198
PV of maintenance Costs	$-	$473	473
PV of Utility Costs	$22,254	$11,893	-10,361
Total Life Cycle Cost (LCC)	$22,757	$19,067	-3,690

Research Question 4a

What are the occupant perceptions of a hybrid system?

Six of the seven household picked the DHP over ER due to:

- Availability of cooling
- Better heating performance
- More furniture placement options
- Safety concerns about the ER heat

One household wants more information: savings, maintenance and replacement costs

Occupant Survey Perceptions

On performance: *"How did [system] perform in heating your common living area to a comfortable temperature?"*

- 6 homeowners gave the DHP a higher rating than ER
- 4 homeowners rated them the same
- Only 1 homeowner rated the ER higher

When asked *"Which system they would choose at end of study?"*

- 10 out of 11 have already decided to keep DHP
- 1 preferred DHP but wants to see energy savings first

Many reasons why DHP is preferred, including:

- Heating performance, cooling function, furniture placement & curtain use, fire hazard & child safety concerns with baseboards

(*) Of the 11 households surveyed, 7 homes were the subject of this report.

Research Question 4b

Does a DHP/hybrid provide the same comfort levels as an all-ER system?

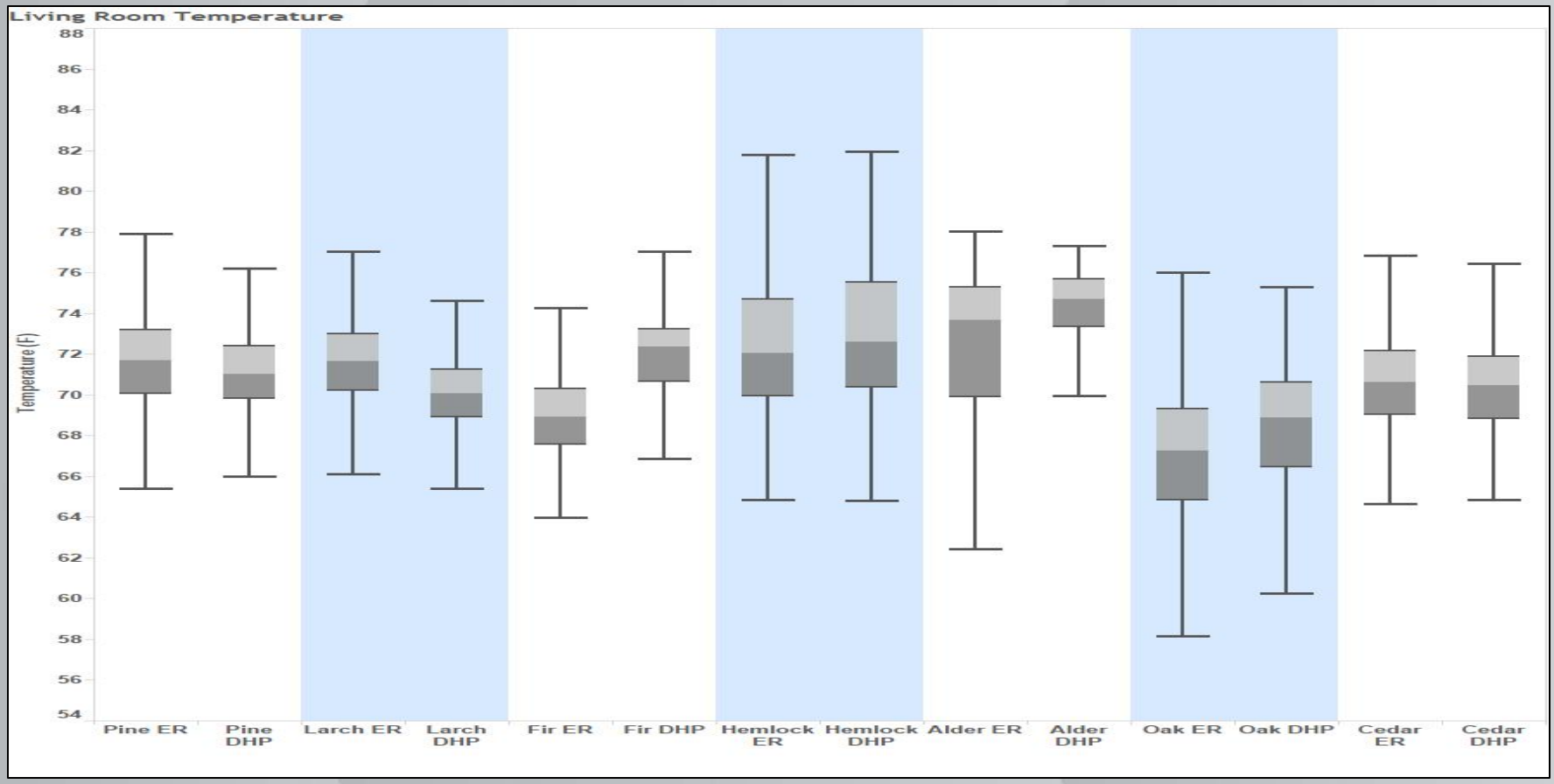
- Indoor temp and RH monitoring maintained comfort conditions with both systems.

- One household said DHP was worse than the ER system. They had the largest drop in average living area indoor temperature in DHP mode, but home was still around 70°F

- Two households behaved differently in DHP mode, lowering the bedroom T-stats and keeping bedroom doors open to allow the DHP to displace a larger portion of the ER heating load. The % energy savings were the highest, suggesting behavior contributed to savings.

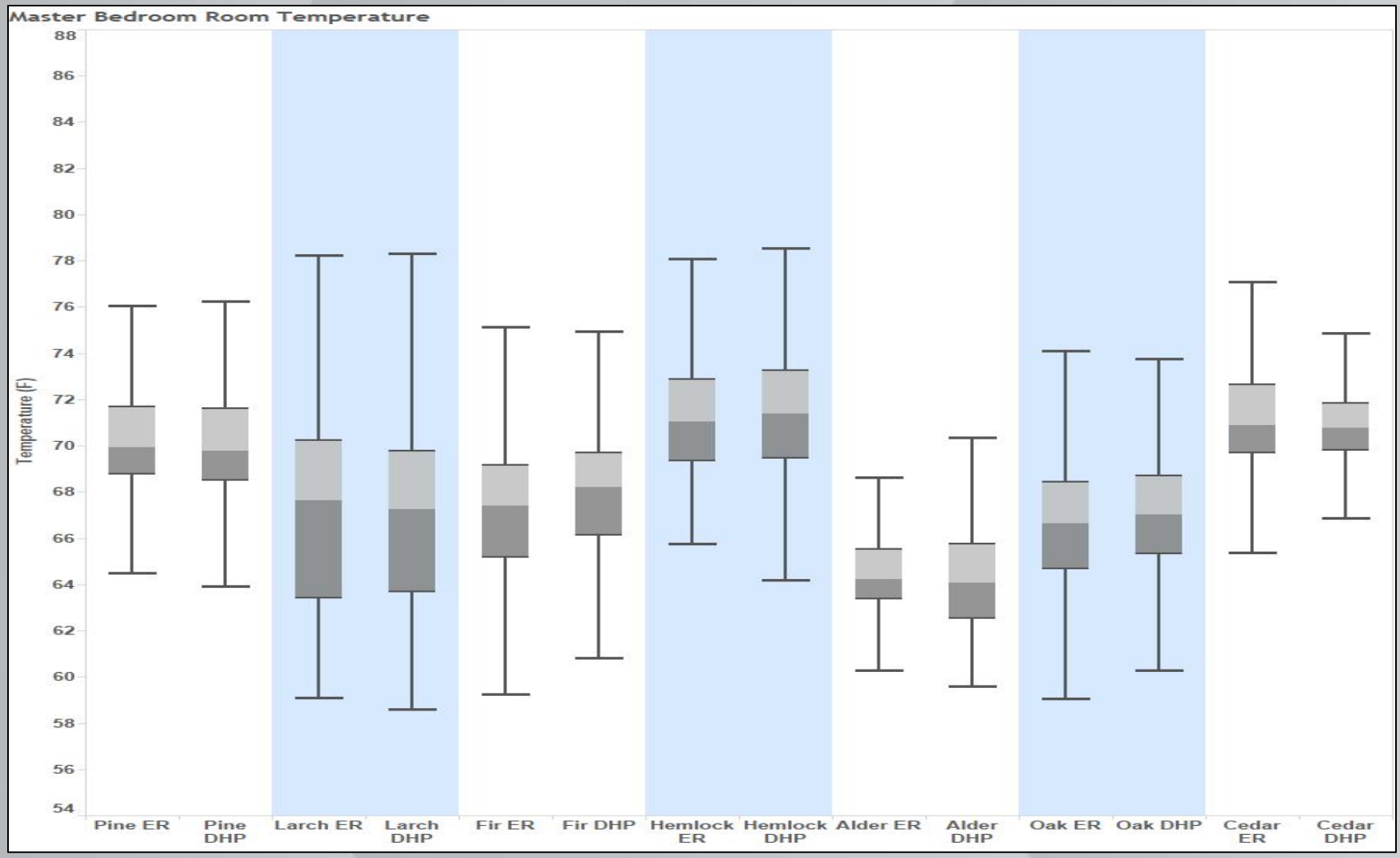
Monitored Temperature Differences

Living Room Temp in ER and DHP Heating Modes



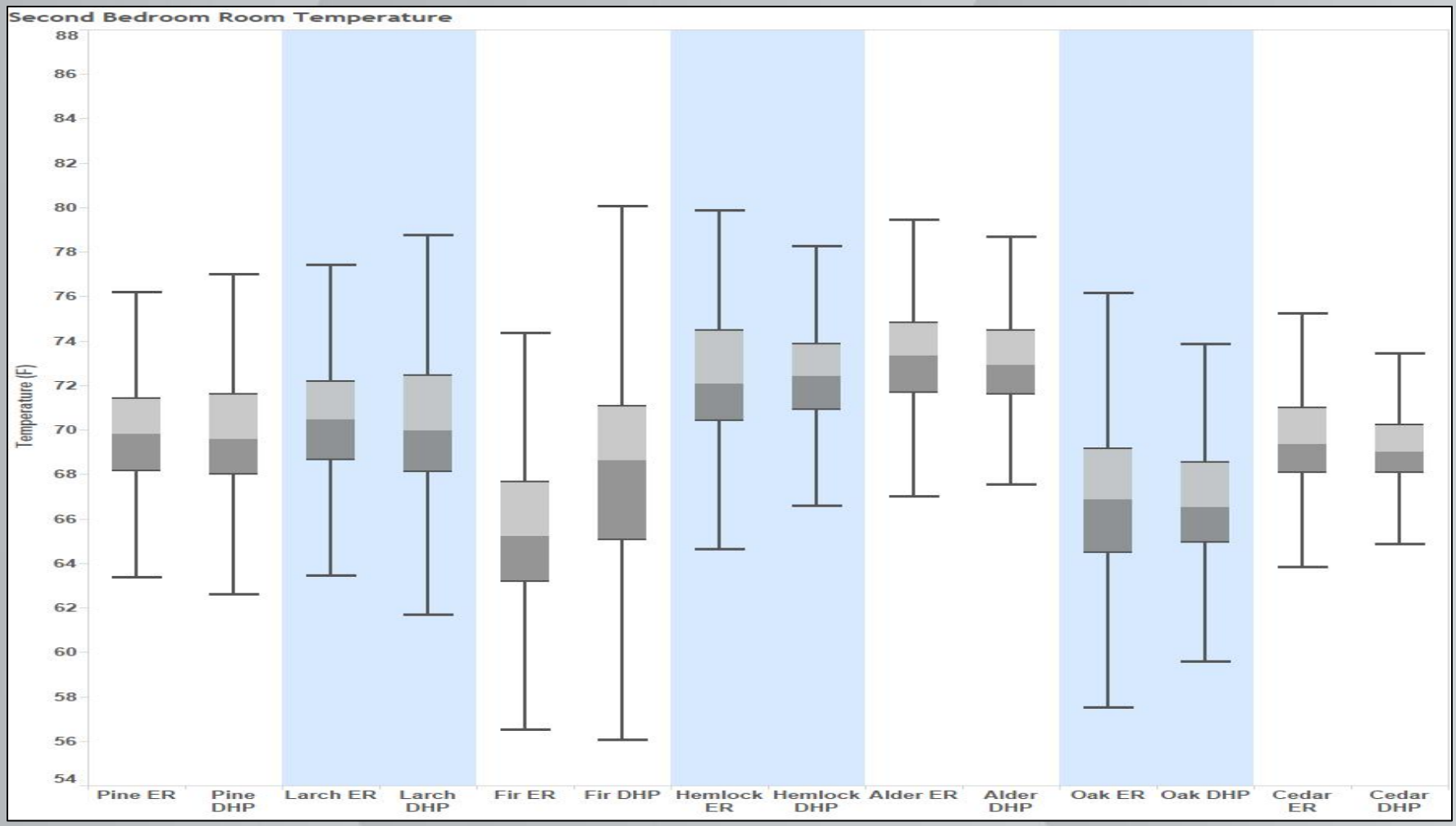
Monitored Temperature Differences

Master Bedroom Temp in ER and DHP Heating Modes



Monitored Temperature Differences

Second Bedroom Temp in ER and DHP Heating Modes



Monitored RH Differences

Living Room RH in ER and DHP Heating Modes

House	Period	Mode	Days	Maximum (%)	+1 Std. Dev. (%)	Average (%)	-1 Std. Dev. (%)	Minimum (%)
Pine	9/27/2013 to 1/22/2015	ER	178	80.1	61.4	**52.2**	43.0	32.2
		DHP	199	81.3	62.0	**53.0**	44.1	27.5
		Difference	-12%	1.2	0.6	**0.8**	1.1	-4.7
Larch	12/13/2013 to 1/22/2015	ER	168	83.9	59.9	**48.2**	36.6	25.3
		DHP	170	88.4	61.8	**50.1**	38.4	18.5
		Difference	-1%	4.5	1.9	**1.9**	1.8	-6.8
Fir	11/26/2013 to 1/22/2015	ER	204	85.2	57.5	**49.2**	41.0	25.9
		DHP	151	75.5	58.6	**48.4**	38.2	20.7
		Difference	26%	-9.7	1.1	**-0.8**	-2.8	-5.1
Hemlock	4/15/2014 to 1/22/2015	ER	111	71.1	58.7	**49.8**	40.9	16.5
		DHP	105	73.0	59.2	**49.3**	39.3	23.8
		Difference	5%	2.0	0.5	**-0.5**	-1.6	7.3
Alder	11/19/2014 to 1/22/2015	ER	29	56.8	43.2	**36.2**	29.1	19.3
		DHP	35	55.0	43.5	**37.8**	32.1	19.5
		Difference	-21%	-1.8	0.3	**1.6**	3.0	0.2
Oak	12/12/2013 to 1/22/2015	ER	170	80.1	63.6	**52.4**	41.2	21.5
		DHP	169	75.1	62.5	**50.1**	37.6	15.0
		Difference	1%	-5.0	-1.1	**-2.3**	-3.6	-6.5
Cedar	3/2/2014 to 1/22/2015	ER	134	68.8	55.7	**47.7**	39.7	22.6
		DHP	126	69.3	57.9	**48.2**	38.6	25.6
		Difference	6%	0.6	2.2	**0.6**	-1.1	3.0

BEOPT vs. Measured

Space Heat Site Energy (kWh/yr.)	Pine	Larch	Fir	Hem	Alder	Cedar	Oak
Case A: 100% ER (heat kWh)	5,111	4,666	3,722	5,484	4,637	4,660	1,964
Measured ER	7,294	8,565	6,520	6,544	NA	7,440	5,131
Case B: 100% DHP (heat kWh)	1,043	1,061	923	1,172	953	982	378
Case A-B (heat kWh) DHP/Hybrid	4,068	3,605	2,799	4,312	3,684	3,678	1,596
Measured Savings	2,218	4,116	3,334	3,201	NA	4,230	2,759
Estimated ER Displacement	70%	67%	86%	86%	81%	76%	77%
Modeled Savings Estimate	2,862	2,418	2,405	3,722	2,998	2,809	1,230

To estimate modeled energy savings, the estimated ER displacement by the DHP (from measured data) was multiplied by the case A-B savings (100% ER-100% DHP). This approach assumes a linear relationship between 100% ER and 100% DHP energy use

BEOPT vs. Measured

- A single zone model cannot model DHP heat in the living area and ER heat in the bedrooms. It can only model 100% DHP.
- Measured energy use is higher than modeled use in all cases.
- In general, modeled energy savings for each house do not match the measured savings very well.
- The average (7 house) modeled savings estimate is 2,636 kWh/year/house, while the average (6 house) measured savings estimate is 3,310 kWh/year/house.

To estimate modeled energy savings, the estimated ER displacement by the DHP (from measured data) was multiplied by the case A-B savings (100% ER-100% DHP). This approach assumes a linear relationship between 100% ER and 100% DHP energy use. Assumes; TMY McChord AFB and Variable Degree Day Regression Analysis.

The displacement calculation assumes 100% displacement in the living room plus any displacement or increase in bedroom ER use in DHP mode. The calculation is basically 100% minus the proportion of total ER mode heating load in the bedroom during DHP mode. Displacement = 1 – Bedroom ER use in DHP mode/total heating use in ER mode.

For More Information

- Case Study: Testing Ductless Heat Pumps in High-Performance Affordable Housing, The Woods at Golden Given – Tacoma, WA

http://energy.gov/sites/prod/files/2015/06/f23/ba_case_study_ductless_heatpumps.pdf

- Contact Mike Lubliner for more information on the WSU/Tacoma Power research report(s).

Contact Information

Bruce Carter
Tacoma Power
bcarter@ci.tacoma.wa.us
253-502-8304

Michael Lubliner
Washington State University Energy Program
lublinerm@energy.wsu.edu
360-956-2082