CO_2 Heat Pump Combined Systems Research Update

Presented by Ken Eklund

ACEEE Hot Water Forum 2017

Portland, Oregon

Success!

- 10 systems in climates ranging from 3,521 to 5,655 HDD provided space and water heat through one to three winters
- High efficiency homes and high capacity heat pump water heaters match very well
- Much was learned regarding
  - Equipment design
  - System design, setup and optimization
  - Monitoring

Overview of Research

- Funded by Bonneville Power Administration under its Technology Innovation Program
- Multi-prong—looking at performance as
  - water heaters
  - demand response tools
  - combination space and water heaters
- Findings assist manufacturer in designing product for US market and combined space and water heating

Basic Technology

Split System

CO_2 Refrigerant

Variable Speed
Inverter Driven

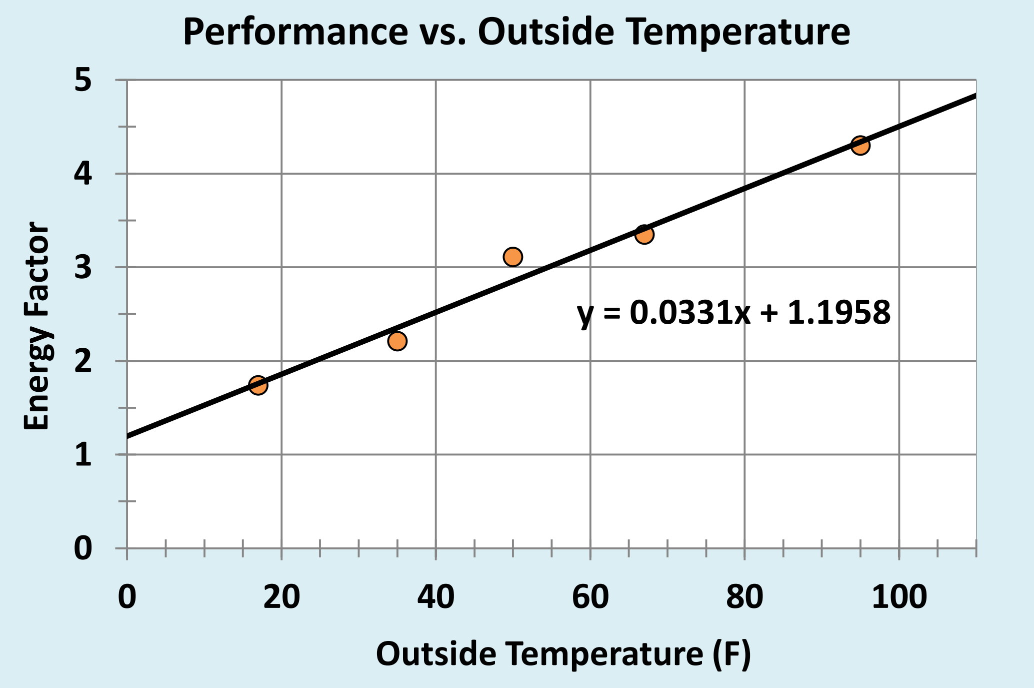
No Electric Element

1.5 kW Input/ 4.5 kW out

From 50 to 150 F in Single Pass

Lab Test Results

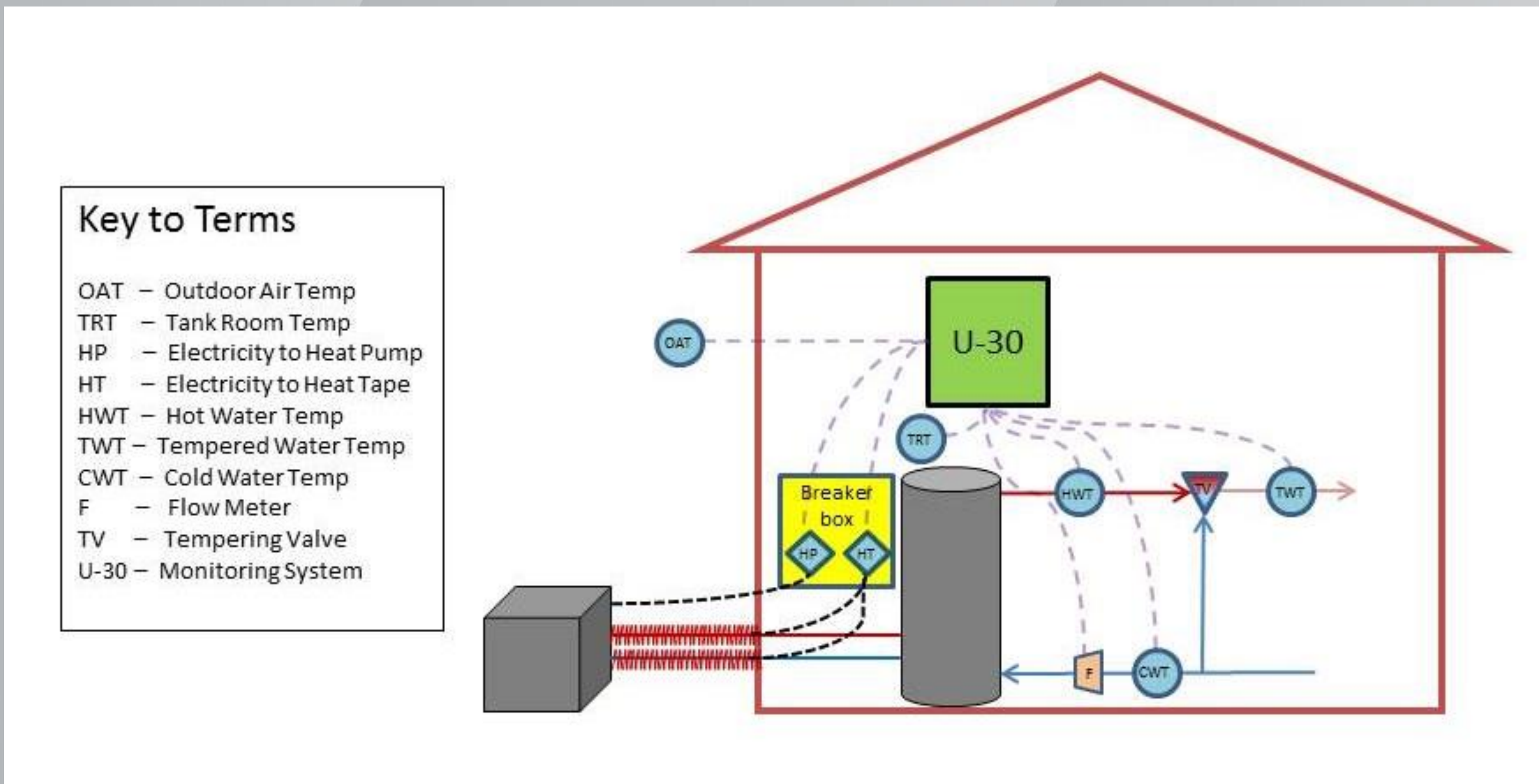
Outside Air Temperature (F)	Energy Factor (EF)	COP	Output Capacity (kW)	Input Power (kW)
17	1.74	2.1	4.0	1.9
35	2.21	2.75	3.6	1.3
50	3.11	3.7	4.0	1.1
67	3.35	4.2	4.1	0.97
95	4.3	5.0	4.6	0.93



- Linear fit of EF to temperature
- Use TMY temperature bins to calculate an annual EF:

Climate	Annual EF
Boise	2.9
Kalispell	2.6
Portland	3.0
Seattle	2.9
Spokane	2.8

Monitoring


Key to Terms
OAT – Outdoor Air Temp
TRT – Tank Room Temp
HP – Electricity to Heat Pump
HT – Electricity to Heat Tape
HWT – Hot Water Temp
TWT – Tempered Water Temp
CWT – Cold Water Temp
F – Flow Meter
TV – Tempering Valve
U-30 – Monitoring System
OAT
U-30
TRT
Breaker box
HP
HT
HWT
TV
TWT
F
CWT

Field Energy Factor

FEF is the combined space and water heating performance

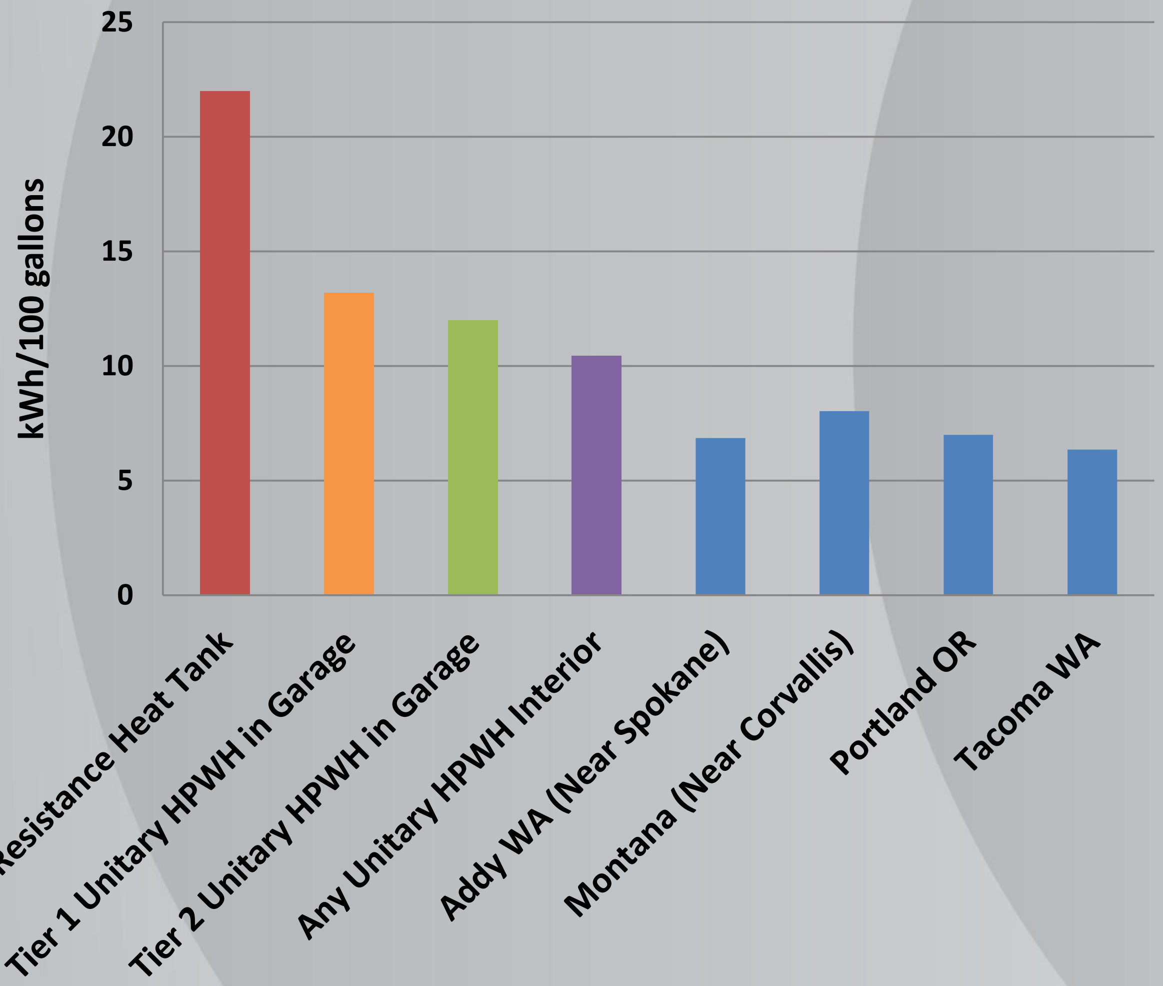
It accounts for all system inefficiencies including:

- Tank loss
- Pipe loss
- Pump energy
- Controls
- Defrost
- Freeze Protection

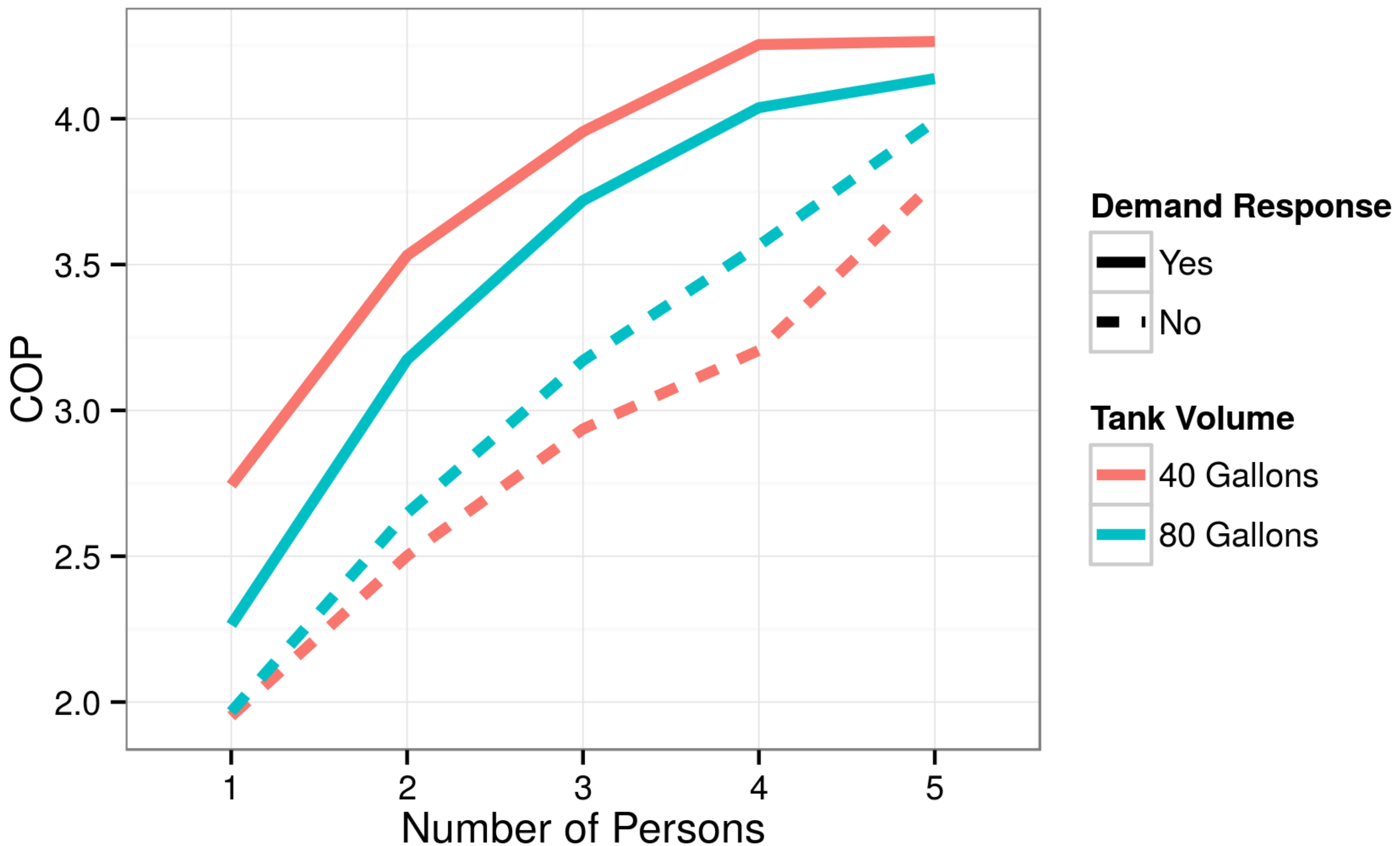
The formula is $FEF = (Q_{DHW} + Q_{SpaceHeat}) / Q_{Energy\ In}$

HPWH Performance

- kWh per 100 gallons water delivered



Impact of DR on System Efficiency



TIP 326

COMBINATION SPACE AND WATER HEATING IN HIGH EFFICIENCY HOMES

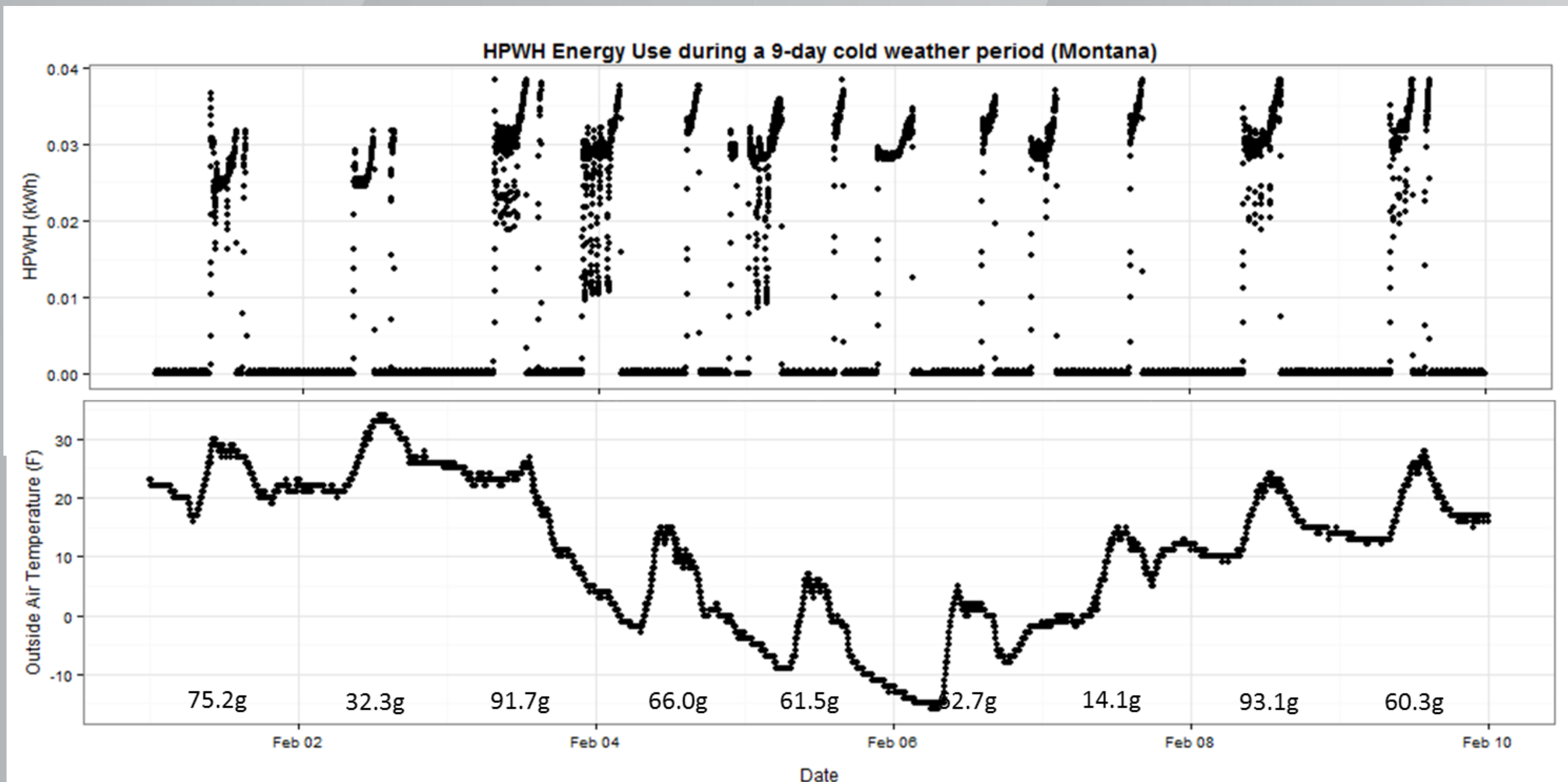
TIP 338

COMBINATION SPACE AND WATER HEATING IN EXISTING HOMES

Successful Background

- Extremely efficient as a dedicated water heater. Average .07 kWh per gallon
- Weekly average FEF is 2.36 including a cold site in Montana that outperforms a regular HPWH in a garage in Sacramento—FEF 1.88
- System serves large loads while operating 25% of time in very cold weather
- Decided to try adding another load

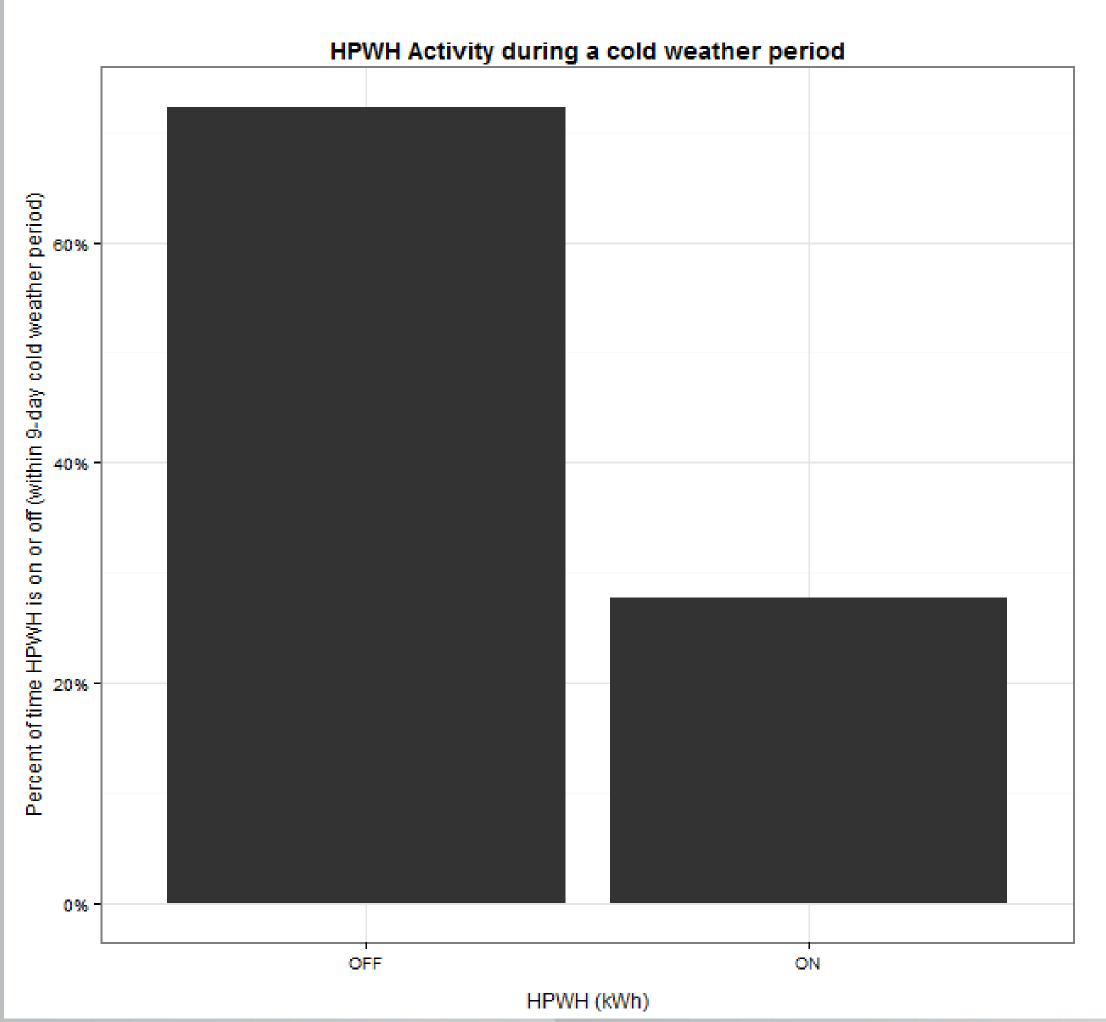
Cold Weather Performance



Combi Concept

- The DHW Performance Field Tests showed the HPWH met water heating loads with minimal operation even in cold weather

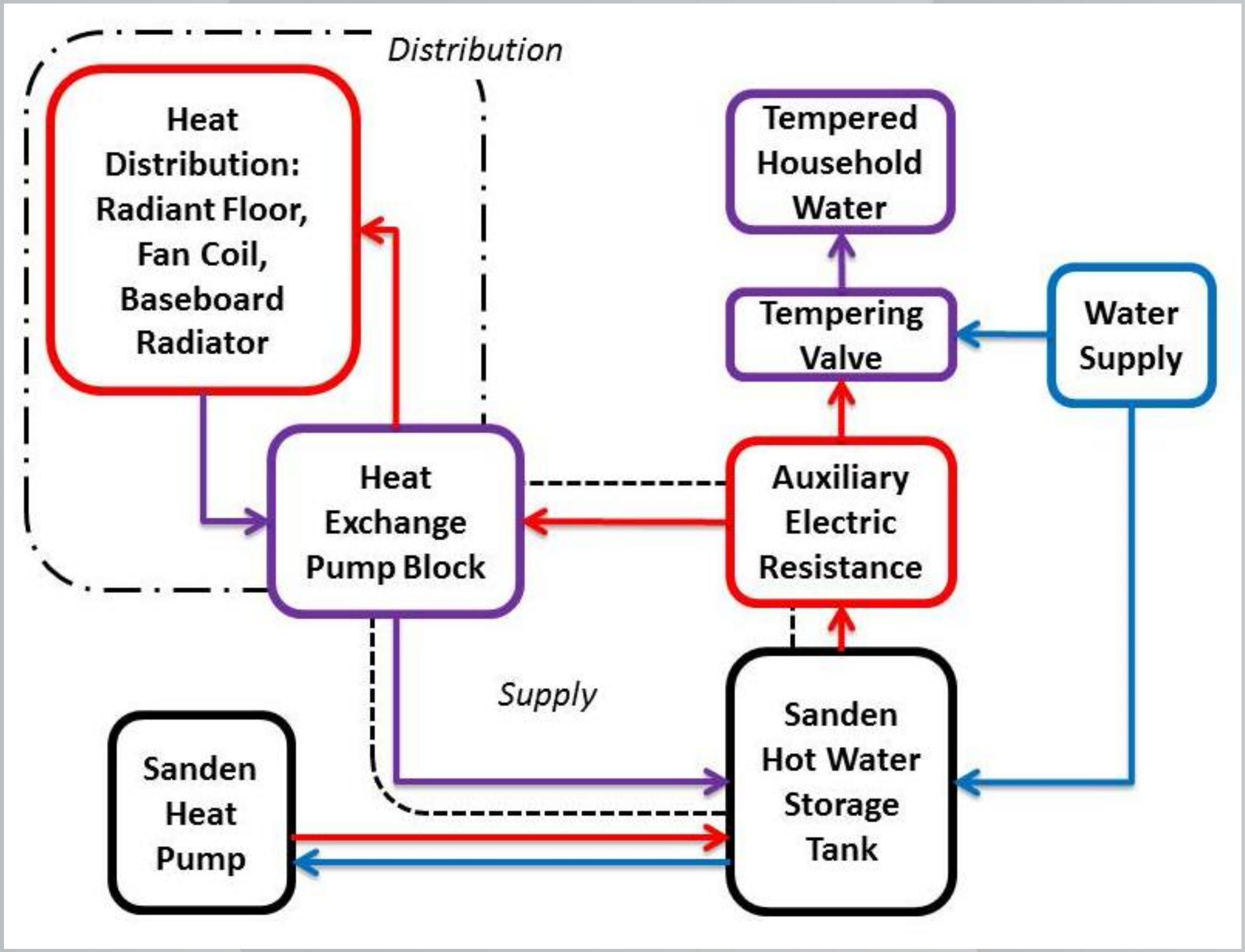
- The system was off 75% of the time



Project Design

- Targeted homes with design loads of 10 to 15 thousand Btu per hour—current WA code house design load is 20 to 30 thousand Btu per hour.
- NEEA provided recruitment, technical assistance to builders, engineering and monitoring through its Next Step Home program
- BPA provided program management, building code support, installation support, lab testing and data analysis and reporting
- 10 original field sites with 7 located in Heating Climate Zone 1 (≥ 6,000 HDD), 1 in Zone 2 (6,001 to 7499 HDD) and 2 in Zone 3 (> 7,500 HDD).

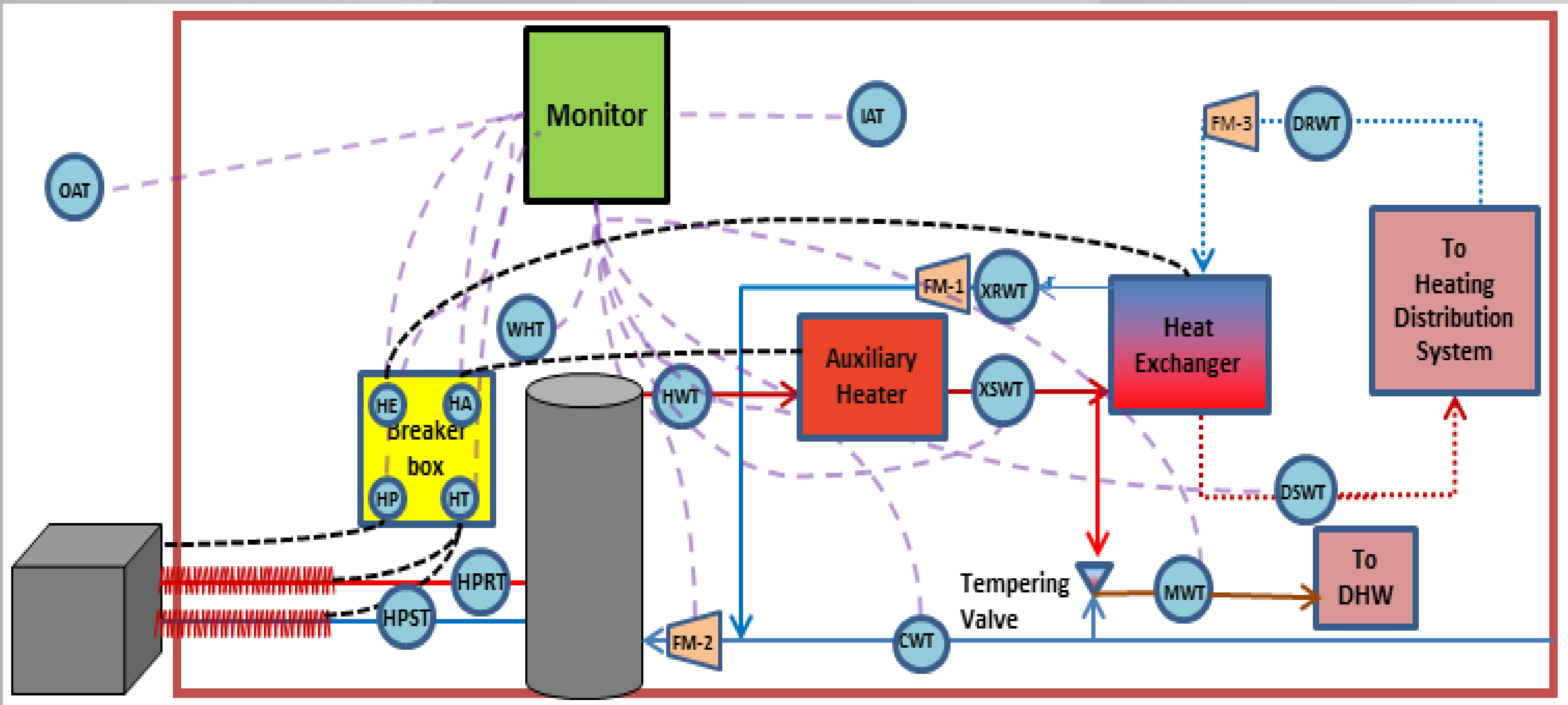
Combi System



Monitoring and Analysis

- Monitoring and analyzing the performance of two loads from the same source is challenging
- In the field study there are more than double the number of sensors in the dedicated water heating research
- A follow-on lab study was designed to capture the interaction of the two loads

Monitoring

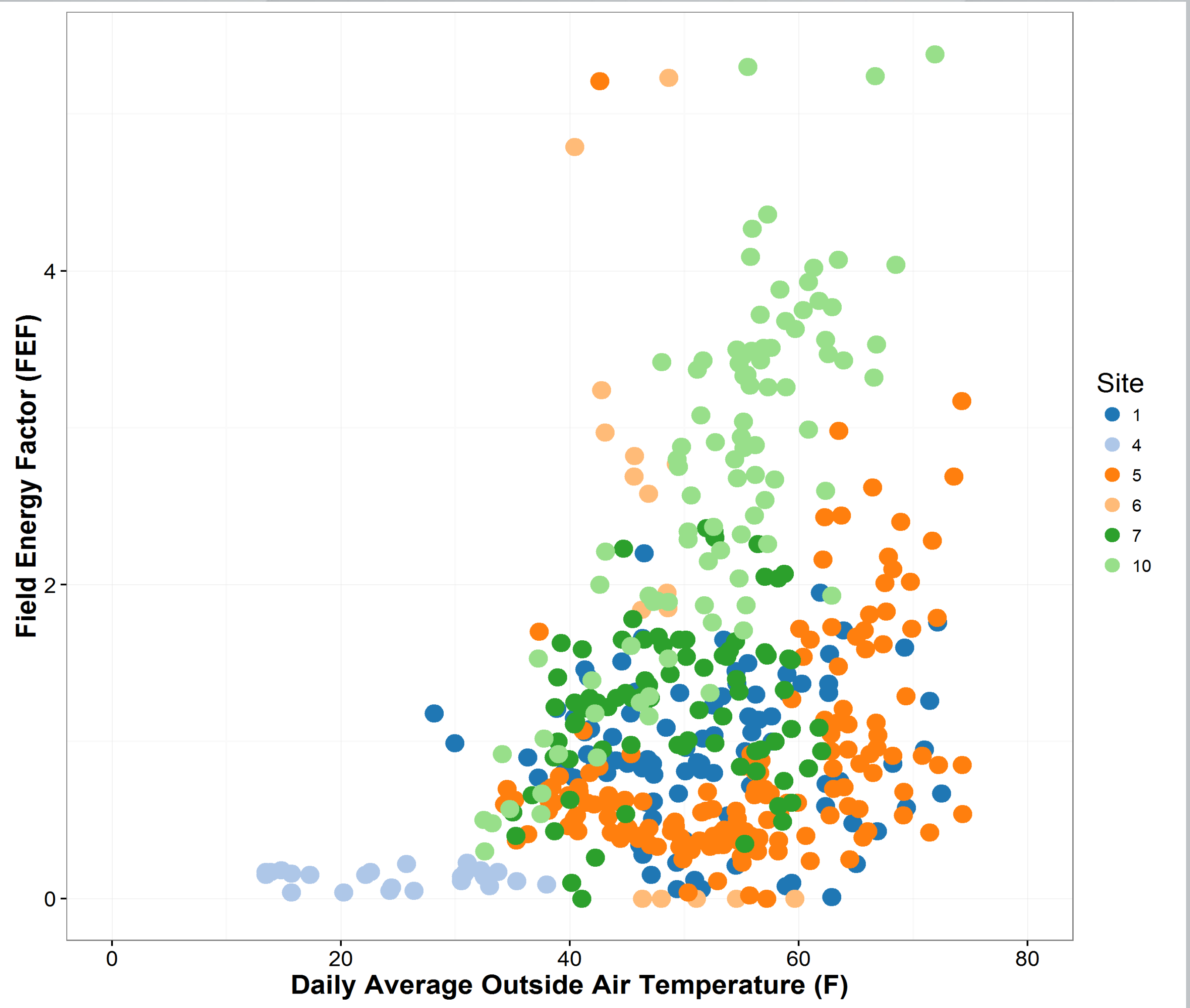


1. Monitor Cold Supply Into System (Flow and T)
2. Monitor DHW to house (Flow and T)
3. Monitor Supply/Return to and from heat exchange (Flow and T)
4. Monitor Distribution Supply/Return (Flow and T)
5. Monitor Air Temperature Inside and Out
6. Monitor Power to compressor, heat tape, pumps and controls

Monitoring Issues

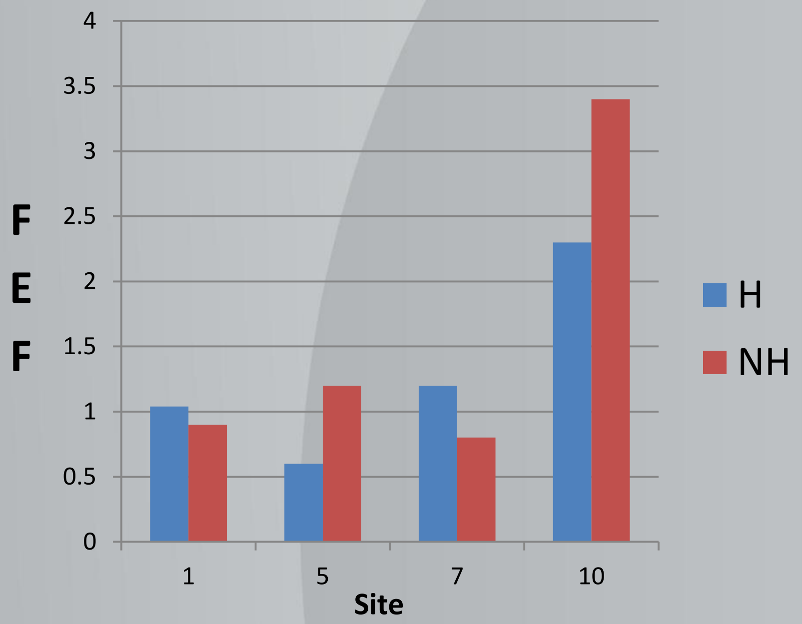
- Murphy works overtime in field research
- Installing monitoring requires many sensor installations and connections and all have to be perfect for collection of complete data
- Internet connections should not be relied on for continuous data collection
- Flow meters must be calibrated to collect accurate data
- Outdoor air temperature sensors are subject to direct and reflected sunlight—very difficult to locate
- Whoops! Plumber moved the sensor. Monitoring is impacted by changes in design, plumbing and wiring

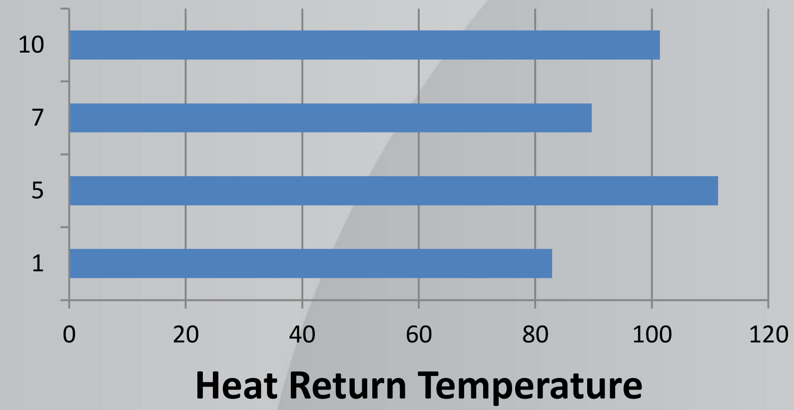
Performance

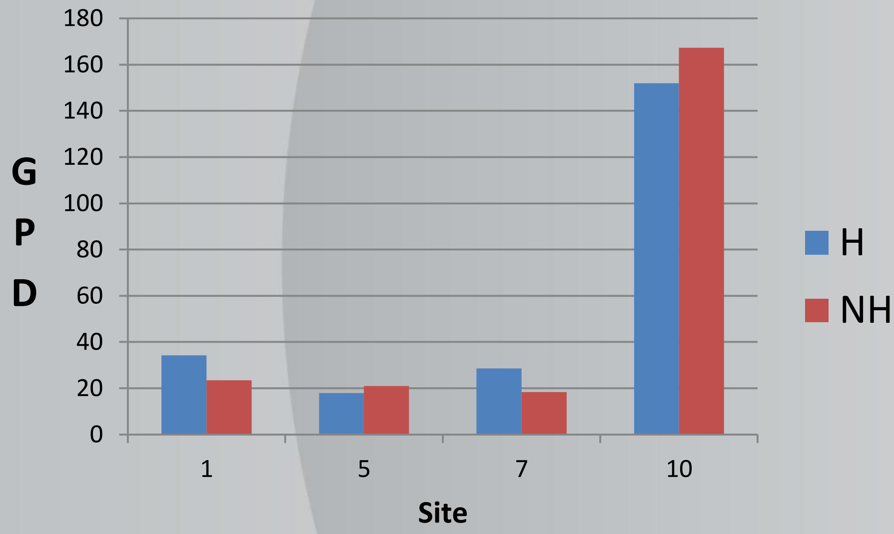


Bellingham, WA
McCall, ID
Olympia, WA
Milwaukee, OR
Seattle (Ballard), WA
Tacoma, WA

Performance Factors

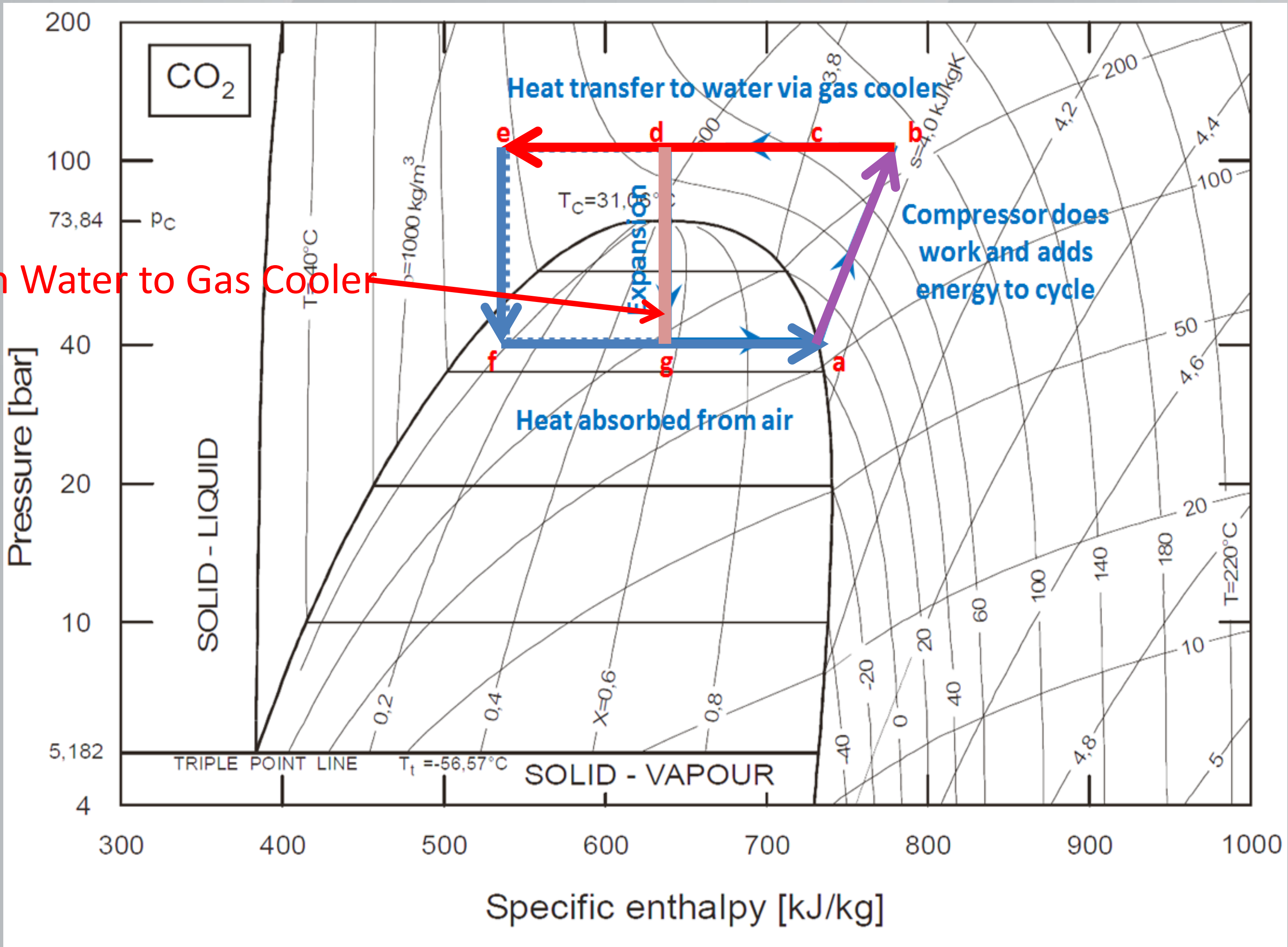






- Lowest performance correlates with highest return water temperature (5)
- Performance of Site 5 doubled in Non Heating due to colder water
- Where DHW use drops, performance during Non Heating drops (1 & 7)
- Largest daily water use correlates with highest FEF due to cold water (10)

How CO_2 Heating Works (& Is Defeated)



Design Issues

- Defrost issues in cold weather when operating as a space heater were addressed by Sanden in new model
- Systems worked best where design load was within heat pump limits—even if load was met by total capacity
- Standard programming for combined heat exchange, control and pump (X Block®) did not operate system properly
- Tank destratification occurred—especially in cold climates and with high temperature heating systems—which reduced efficiency
- Cross flow resulted in reduced operating efficiency

Defrost Failure

- Results from returning water > 90ºF to the outdoor unit
- Designed as a water heater—not as a space or pool heater
- Manufacturer immediately began working to solve the problem. Now has a UL listed version that defrosts up to 140ºF supply temp

Matching Capacity to Load

Sites 4 and 6 were both unoccupied but heated during the same period in winter 2015

At Site 4, design load is 21,061 Btu per hour—at Site 6 it is 6,226

Capacity for both sites was 13 to 15 thousand Btu per hour depending on outdoor air temperature

Note the large difference in FEF

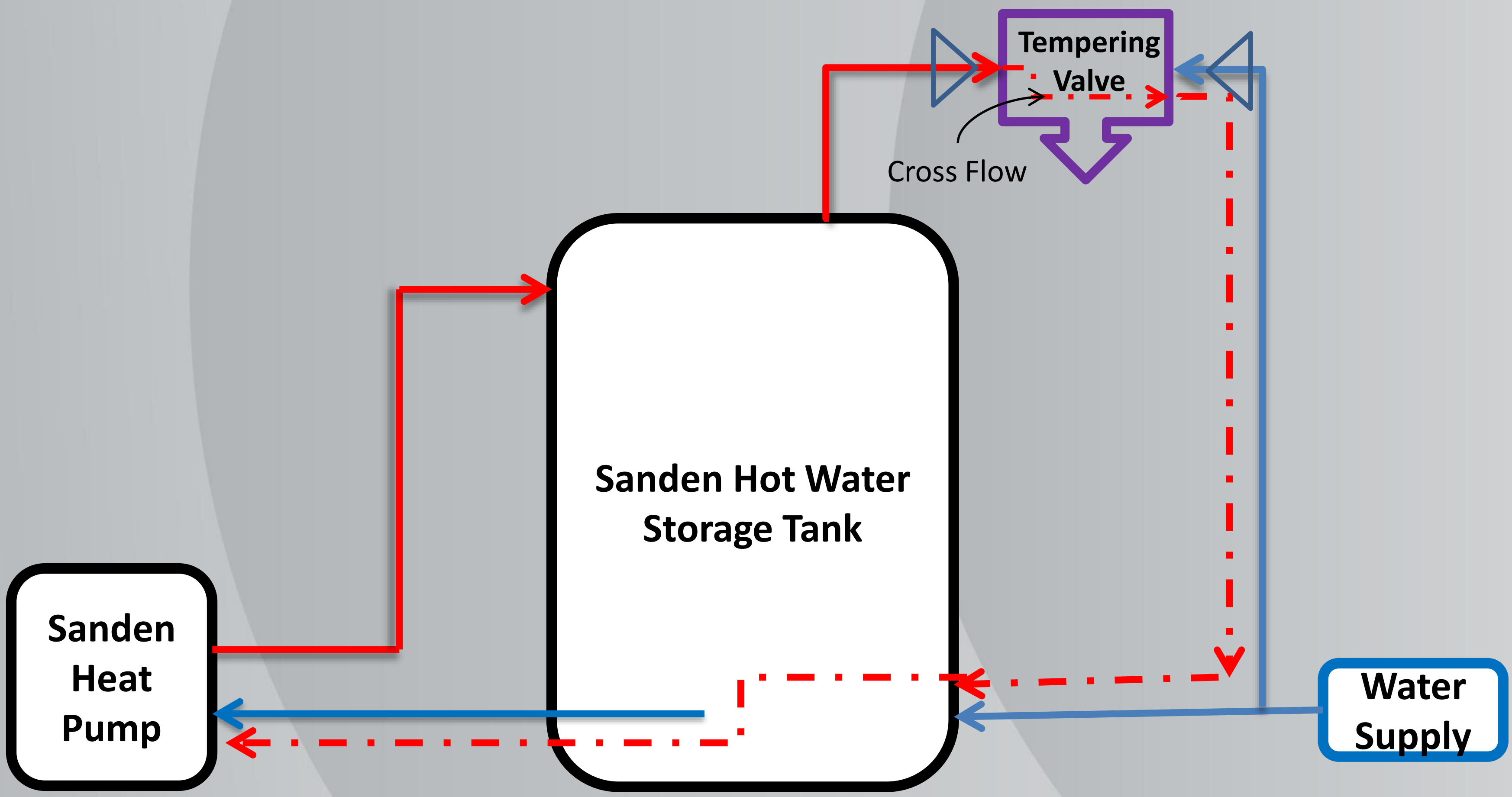
Site	OAT	XRWT (F)	FEF	Days sampled
4	25	80	0.13	24
6	48	106	2.05	16

The very low FEF at Site 4 indicates the system did not function properly

Tank Destratification

- Occurs when the heat demand on the tank results in heat supply flow rates that cycle the storage tank making it all one temperature
- Without temperature difference transcritical operation efficiency plummets
- To maintain tank stratification:
  - Match load to heat pump output
  - Use a larger tank in combined systems—120 gallon is recommended
  - Return water to tank location closest to that temperature
  - Like Site 10 use lots of hot water which pulls cold water into the bottom of the tank—maintaining stratification

Tempering Valve Highway to Reduced Performance



Optimized Efficiencies with Current Design

- To attain summer water heating efficiencies for combi systems like those in field studies of the system used as a dedicated water heater
- To attain combi field efficiencies closer to those predicted in the Ecotope Lab Study of Combined Systems

Climate	Annual Efficiency		
	Water Heating	Space Heating	Combined
Boise	2.9	2.3	2.5
Kalispell	2.6	2.1	2.2
Portland	3.0	2.6	2.7
Seattle	2.9	2.6	2.7
Spokane	2.8	2.2	2.4

TIP 338

SPLIT SYSTEM COMBI DR TEST AT PNNL LAB HOMES
G3 FIELD TEST
CALIFORNIA SITE FIELD TEST
DHP + HOT WATER FIELD TEST
ECO RUNO LAB & FIELD TEST

Eco Runo


Reliability/
Environmental
Laboratory
万家乐
116Kg
严禁侧向码放
严禁摔滚
货物装卸
注意事项
安装前临时放置时注意事项

Next Steps

- Optimize split system combi sites and monitor for another year
- Field Test a Ductless Heat Pump plus DHW
- Field test the Eco Runo
- Present PNNL Lab Home DR and efficiency results at ACEEE Hot Water Forum in Portland, Oregon at the end of this month
- Final report due September 30, 2017

Contact Information

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Washington State University Energy Program

Your regionally, nationally and internationally recognized
energy experts

Unpacked Eco Runo

Back Cover Off Showing Dual Compressors

Eco Runo Specifications

- Designed for space heat only
- 11 kW output (3+ tons)
- COP = 4
- Maximum output temp = 160+

Combined space and water heating concept:

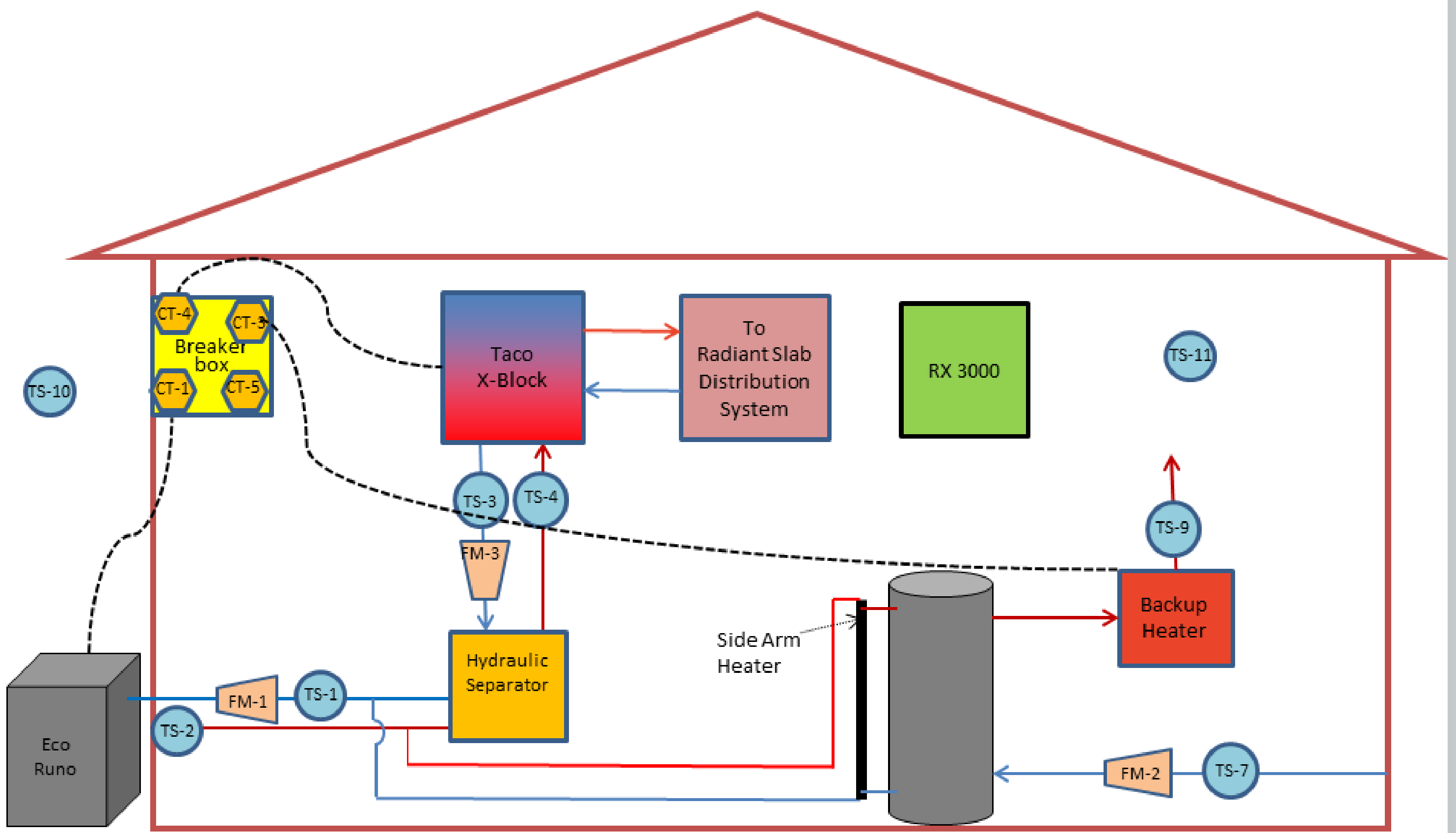
- Flexible heating type—radiant slab, furnace
- Hot water—side arm heater, indirect tank
- Locate in cold climates, larger load houses
- Possible solution for all high temp heating systems

Lab Test

Planned Field Studies

- Radiant slabs in Spokane, WA, McCall, Idaho and Montana
- Electric Resistance Forced air furnace conversions in marine and cold climates
- Mix of indirect tanks and sidearm heaters for hot water

Radiant Slab Eco Runo Monitoring



Set Backs

Lab Test Results Disappointing:

- Could not get output air to 100^{o}F
- Could not get capacity higher than 2 tons
- Could not get efficiency higher than 2.2 COP
- Indirect heater not efficient (1.8 COP at 65^{o} F supply air)

First field install condemned two days prior to installation. Lost a year of baseline data.