Northwest **Power** and **Conservation** Council

July 5, 2017

MEMORANDUM

TO: **Power Committee**

FROM: **Tina Jayaweera, Senior Energy Analyst**

SUBJECT: **CO2 Refrigerant Heat Pumps—A Successful Emerging Technology**

BACKGROUND:

Presenter: Ken Eklund, Washington State University Energy Program

Summary: For the past 6 years, with support from BPA's Technology Innovation Program and NEEA, the WSU Energy Program has researched the applications of CO2 refrigerant hydronic heat pumps including water heating, Demand Response and combined space and water heating. Ken Eklund, the developer and manager of this research will introduce the technology, the research and its findings. Our findings indicate this technology will be the next generation of heat pump technology due to its efficiency, quietness, and environmental friendliness.

Relevance: CO2 heat pumps were not included in the 7th Plan conservation supply curves due to the emerging state of the technology. Continuing advances will likely result in their inclusion in the 8th Plan supply curves.

Workplan: C.1. Prepare for the 8th Plan: Conservation

Background: Mr. Eklund is an experienced research project manager, including managing four Technology Innovation Projects for BPA to conduct lab and field testing of CO_2 refrigerant heat pump water heaters (HPWHs). (One of these projects concluded in fall 2015.) He also recently completed managing a three-year ventilation effectiveness study in tight homes for the Northwest Energy Efficiency Alliance (NEEA). Previously, Mr. Eklund managed the Idaho Exhaust Air Heat Pump Study for Bonneville Power Administration (BPA), and the State Technology Advancement Collaborative (STAC) Heat Pump and Air Conditioner Performance Enhancement Research Project in partnership with BPA and the Energy Trust of Oregon, and subcontractors Ecotope, Stellar Processes, and state energy offices.

Mr. Eklund is currently the Building Science and Standards Team Leader for the WSU Energy Program. He has been with the WSU Energy Program for eight years, and prior to that he was with the Idaho Energy Office for 21 years. His education includes a B.A. in history from Stanford University and a J.D. from the University of Idaho.

More Info: WSU Energy Program website: http://www.energy.wsu.edu/Home.aspx

CO_2 Heat Pump Systems Research Overview

Presented by Ken Eklund

Power Committee NWPCC, July 11 2017

Vancouver, Washington

Overview of Research

- Funded by Bonneville Power Administration under its Technology Innovation Program and supported by NEEA
- 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

Four Projects on Advanced HPWH

- TIP 292—Performance as a Water Heater
- TIP 302—Demand/Response Potential of Split and Unitary Systems
- TIP 326—Combination Space and Water Heating in High Efficiency Homes
- TIP 338— Combination Space and Water Heating in Existing Homes—Three System Types

Features of CO2 Heat Pumps

- Function
  - Air Source
  - Heat Water
- Environmental Benefit
  - Quiet—the neighbors do not know it is operating
  - Carbon Dioxide Refrigerant

    (Standard Refrigerants have Global Warming Potential of 1,400 to 2,000. CO_2's is 1)

Basic Technology

CO_2 Refrigerant

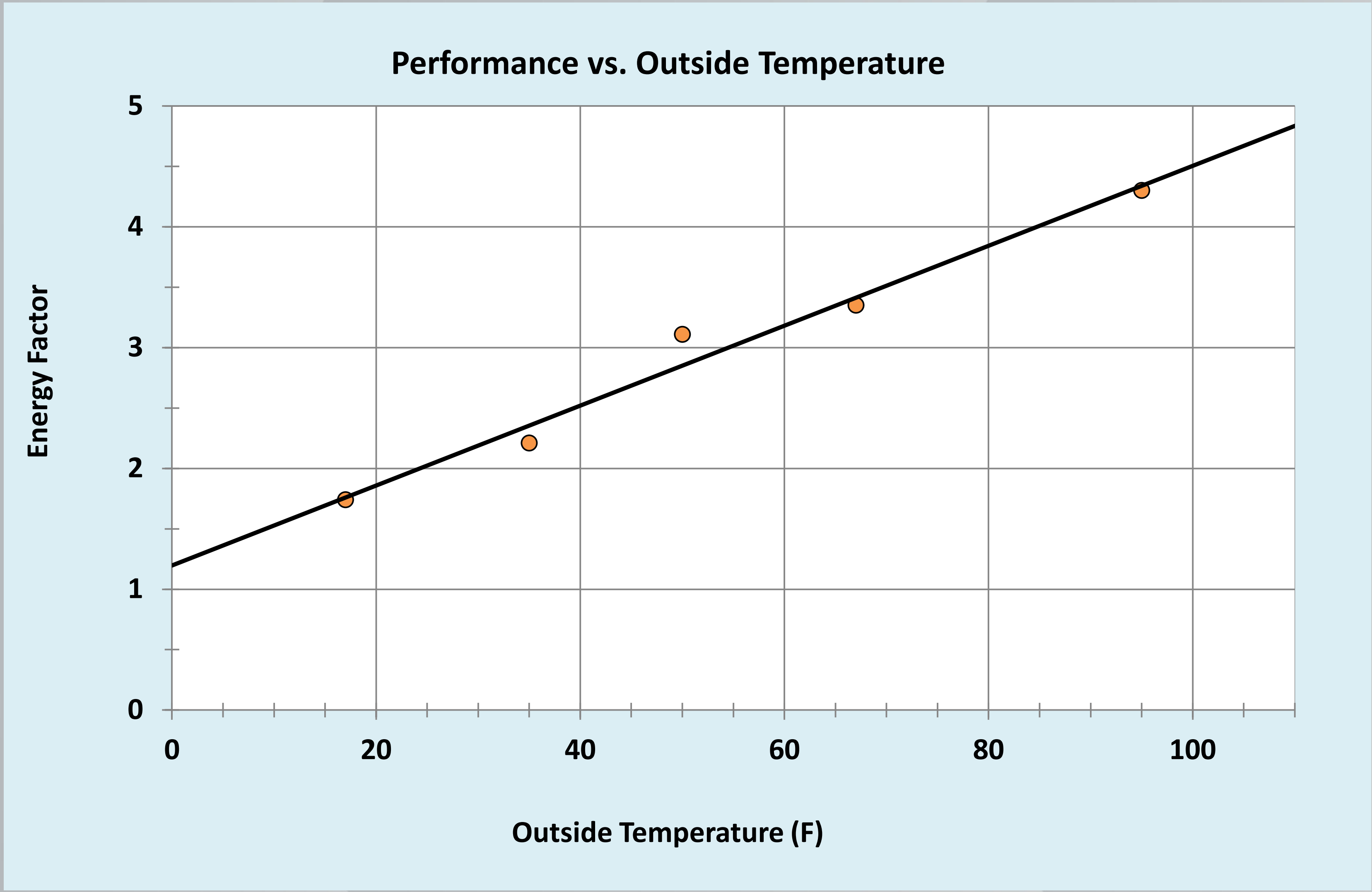
Variable Speed
Inverter Driven

No Electric Element

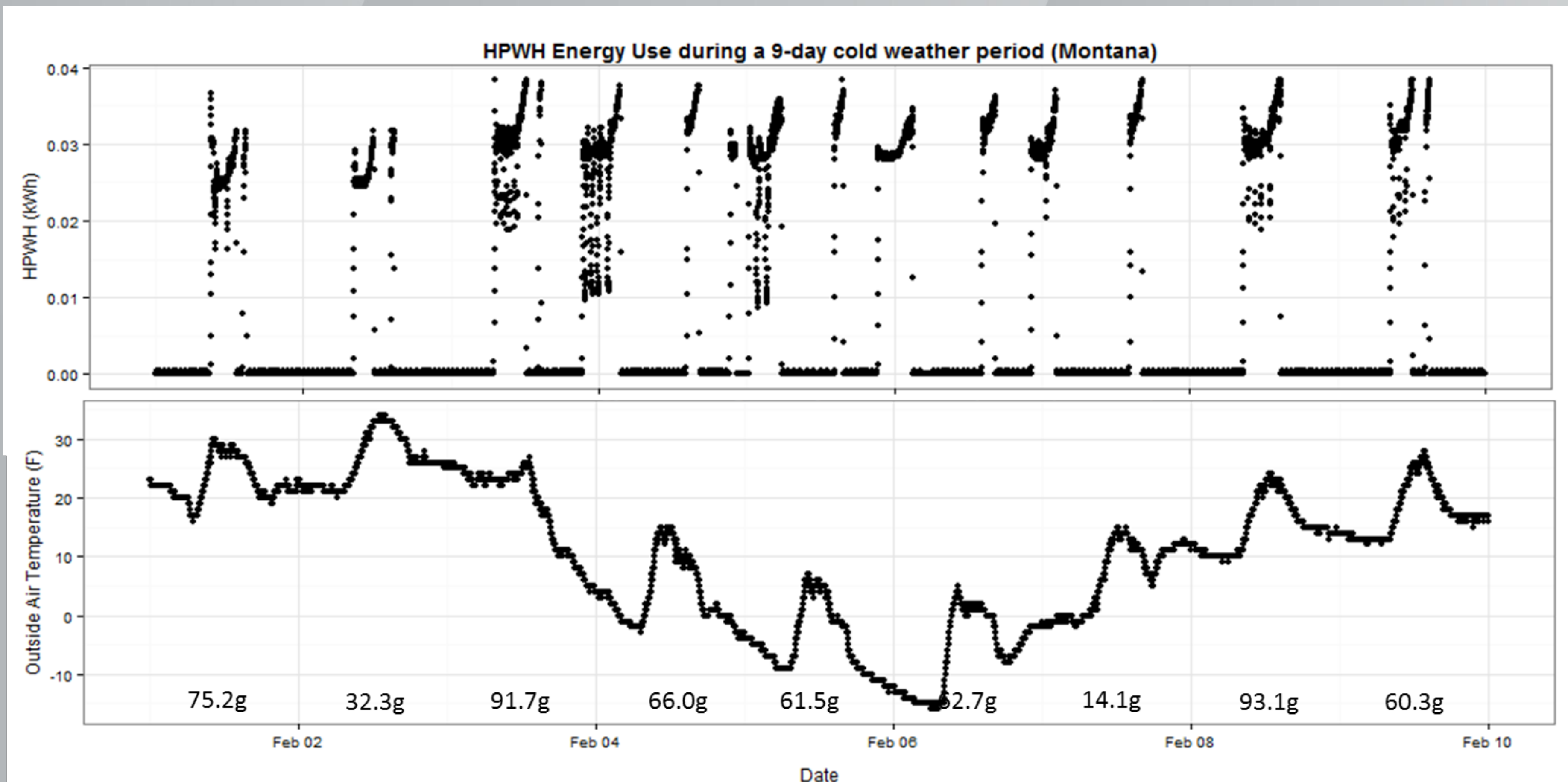
1.5 kW Input/ 4.5 kW out

From 50 to 150 F in Single Pass

Lab Test Results

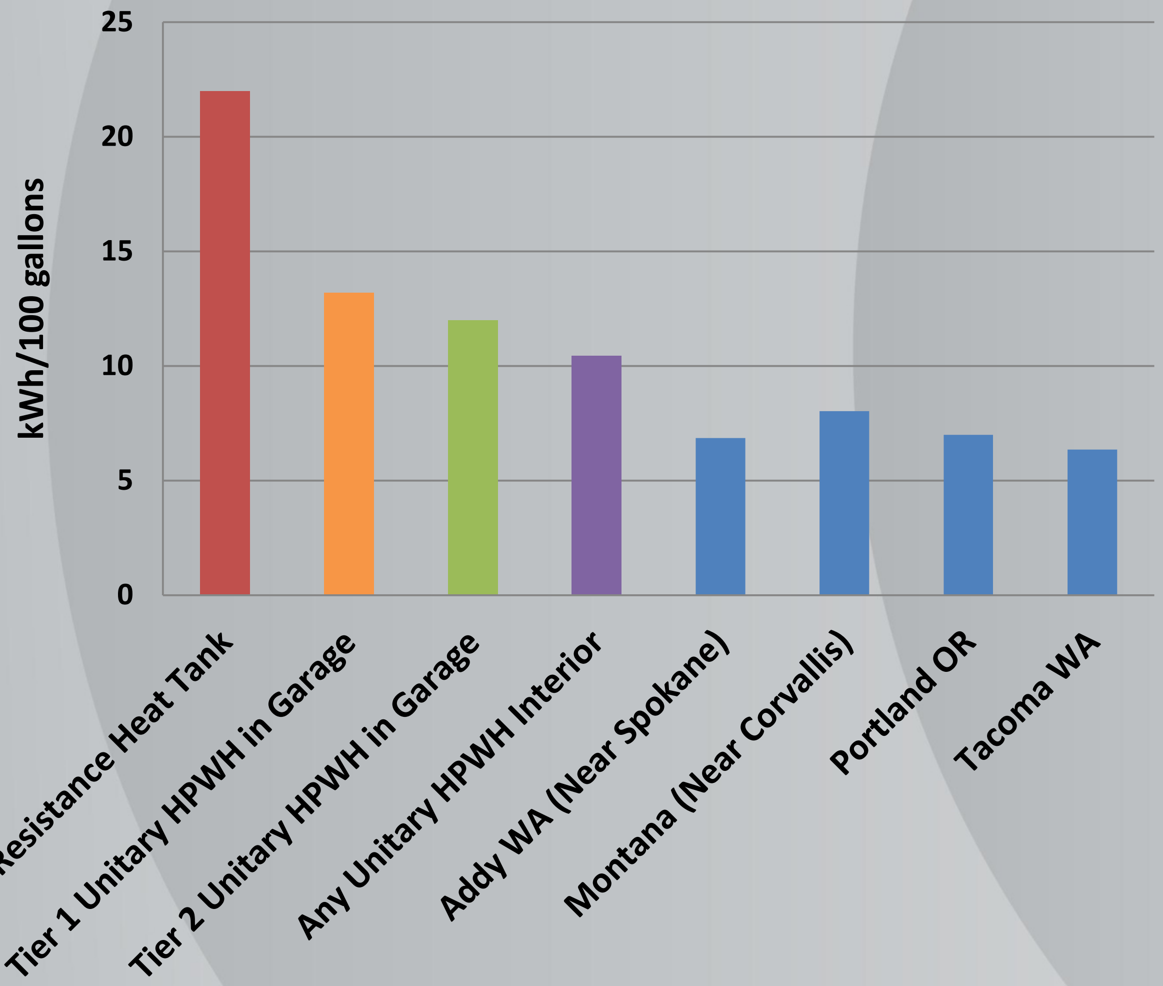


Cold Weather Performance



HPWH Field Performance

- kWh invested per 100 gallons water delivered



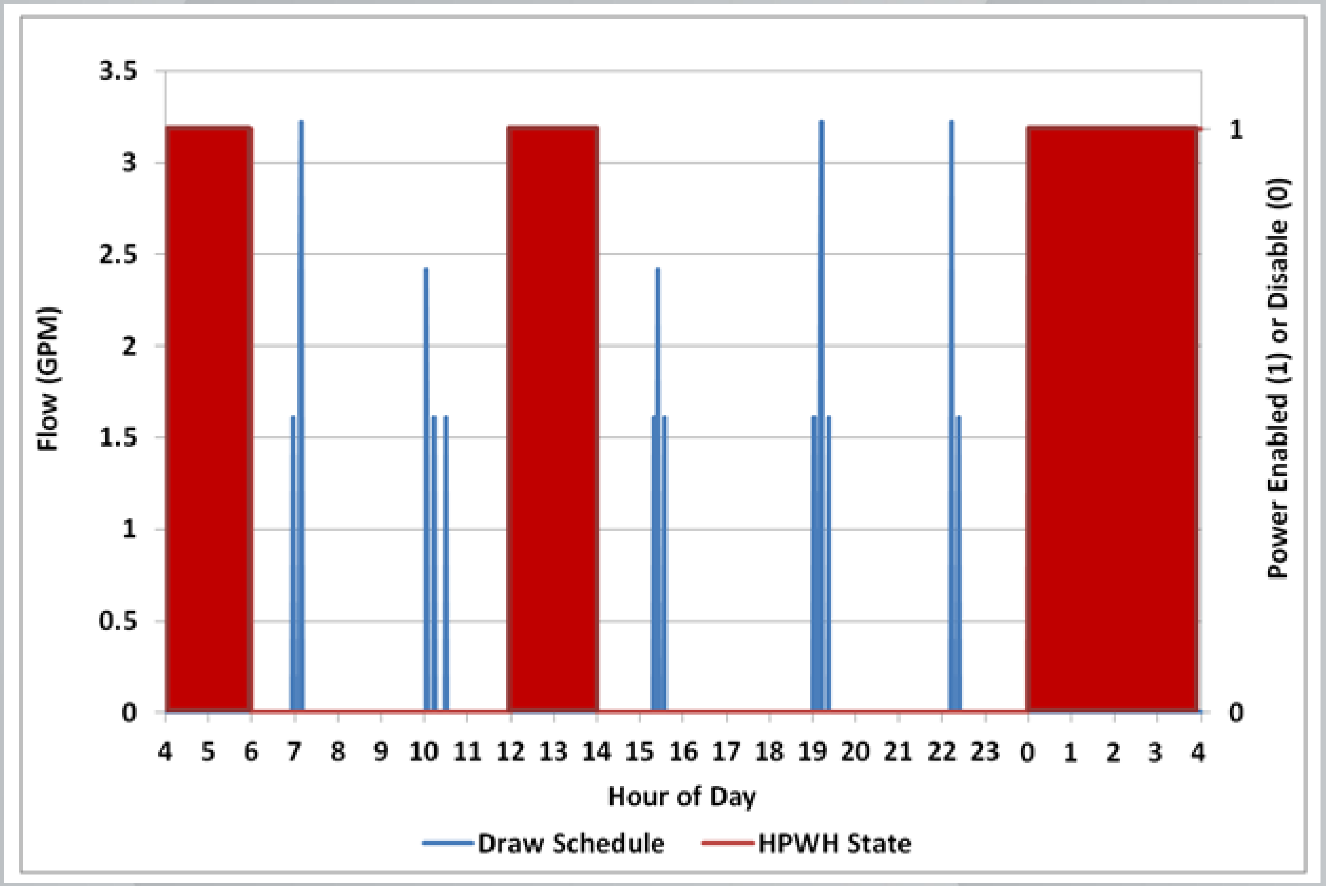
Power Consumption Consideration

- Every heat pump water heater sold in this country gets its heat from the space it is placed in
- The CO_2 split system is placed outdoors and gets all its heat from outdoor air
- If this advantage is credited, the average power consumption of the CO_2 system with at least a 45 gallon per day load (3 average persons) is .05 kWh per gallon—and it is much quieter than heat pump water heaters indoors

Future of CO_2 Water Heating

- Current technology works well for:
  - Large families or big water users
  - Multi-family apartments
  - Swimming pools
  - Restaurants and commercial/institutional kitchens
- Smaller CO_2 heat pumps for hot water loads less than 15 gallon per person per day

Demand Response Operation



Blue lines are hot water draws

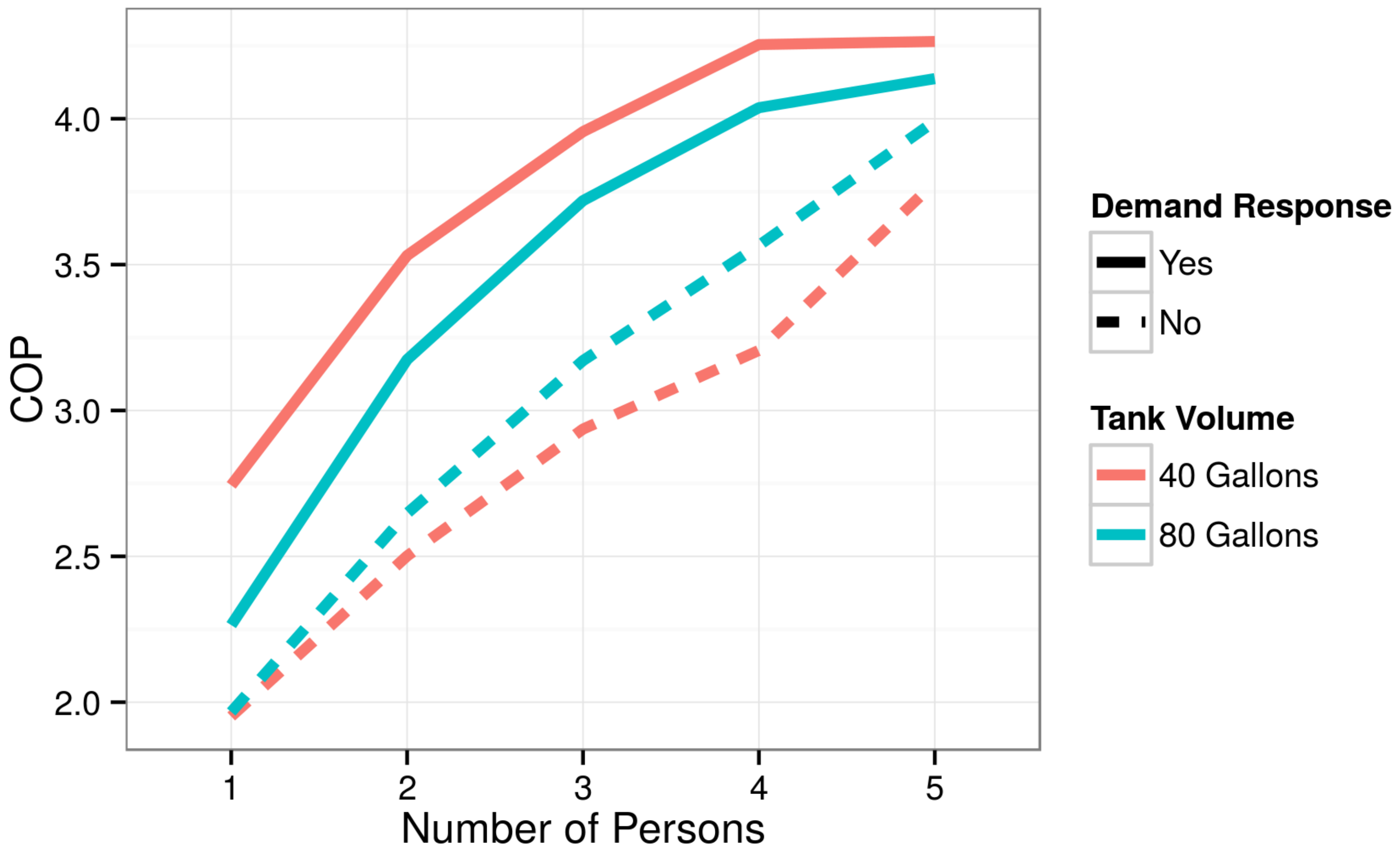
Red blocks are off-peak times when heat pump is allowed to operate

The CO_2 heat pump has a programmable time block feature

Demand Response Questions

- What does the DR pattern accomplish?
- Most of the heat pump function is pushed to times of colder outside air—
  - This requires the heat pump to use more energy
  - Doesn’t this hurt the water user?
  - Would the utility have to pay ongoing DR fees to the water user?

Impact of DR on System Efficiency



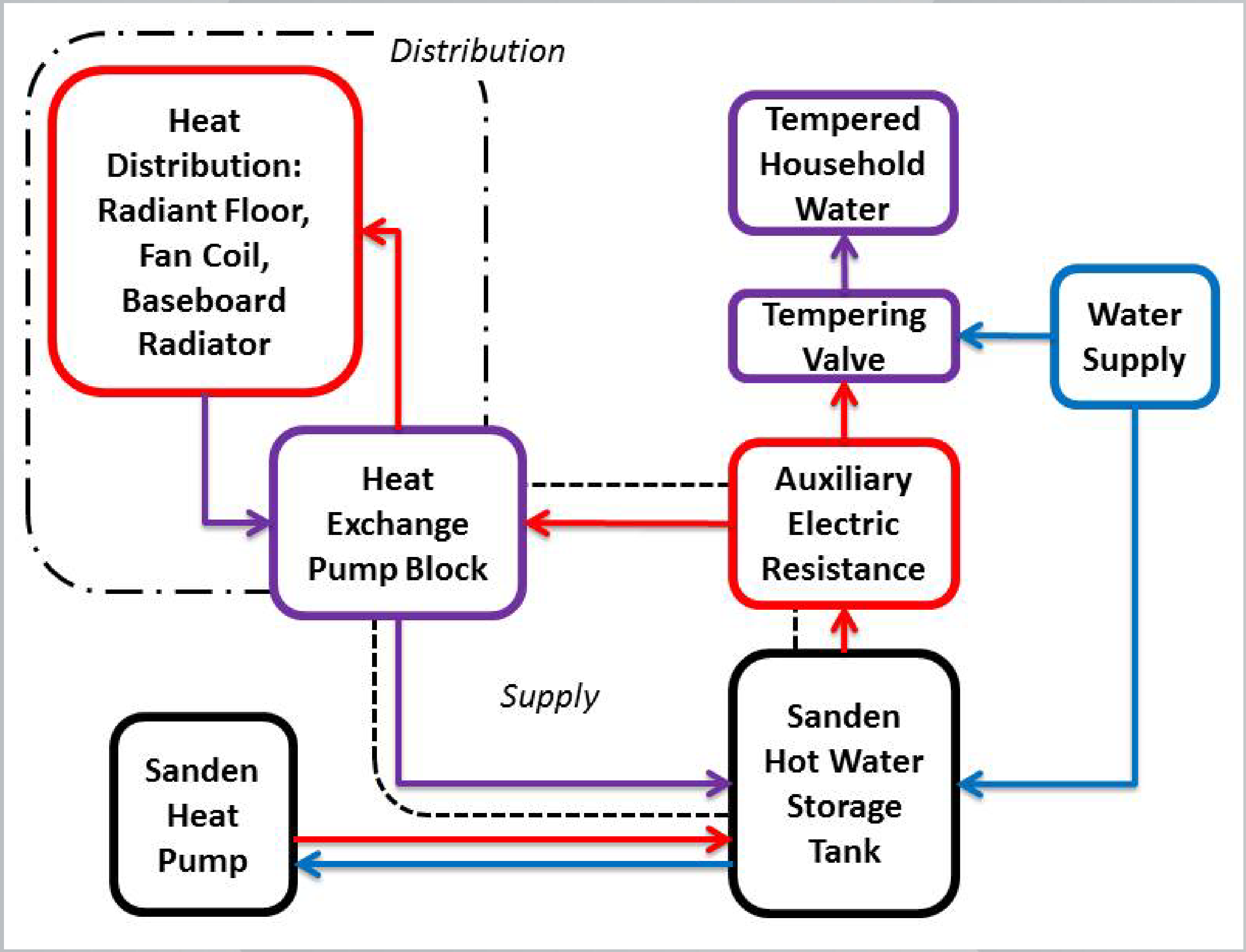
Combined Space & Water Heat Success!

- 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 CO_2 hydronic heat pumps match very well
- Much was learned regarding
  - Equipment design
  - System design, setup and optimization
  - Monitoring

Successful Background

- Extremely efficient as a dedicated water heater.
- Weekly average Field Energy Factor 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

Combi System



Optimized Efficiencies

- 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

Combined Design Issues Solved

- The defrost system failed to operate when warm water was returned to the tank from the space heater

  Solution: design a system that can defrost in this situation. This feature is now in the UL listed product.
- Systems in the coldest climate (McCall, Idaho) had difficulty because the heat load exceeded the heat pump limits—even if load was met by total capacity

  Solution: provide a larger capacity CO_2 heat pump. This equipment has been lab tested and is being field tested with very positive results
- Low hot water use reduces system efficiency by reducing cold water flow into the system

  Solution: operate the system in DR mode to increase efficiency and increase hot water use—fill your hot tub!

Eco Runo

Commercial/Industrial Applications

- Dairy and food processing where simultaneous heating and cooling take place
- Grocery store high efficiency cooling
- Large scale ground source heat pumps
- Mid to large scale multi-family water heating
- Coca Cola vending machines worldwide

Contact Information

- **Ken Eklund**, Building Science & Standards Lead
  Washington State University Energy Program
  eklundk@energy.wsu.edu
  Project Principle Investigator and Manager

Washington State University Energy Program

Your regionally, nationally and internationally recognized
energy experts