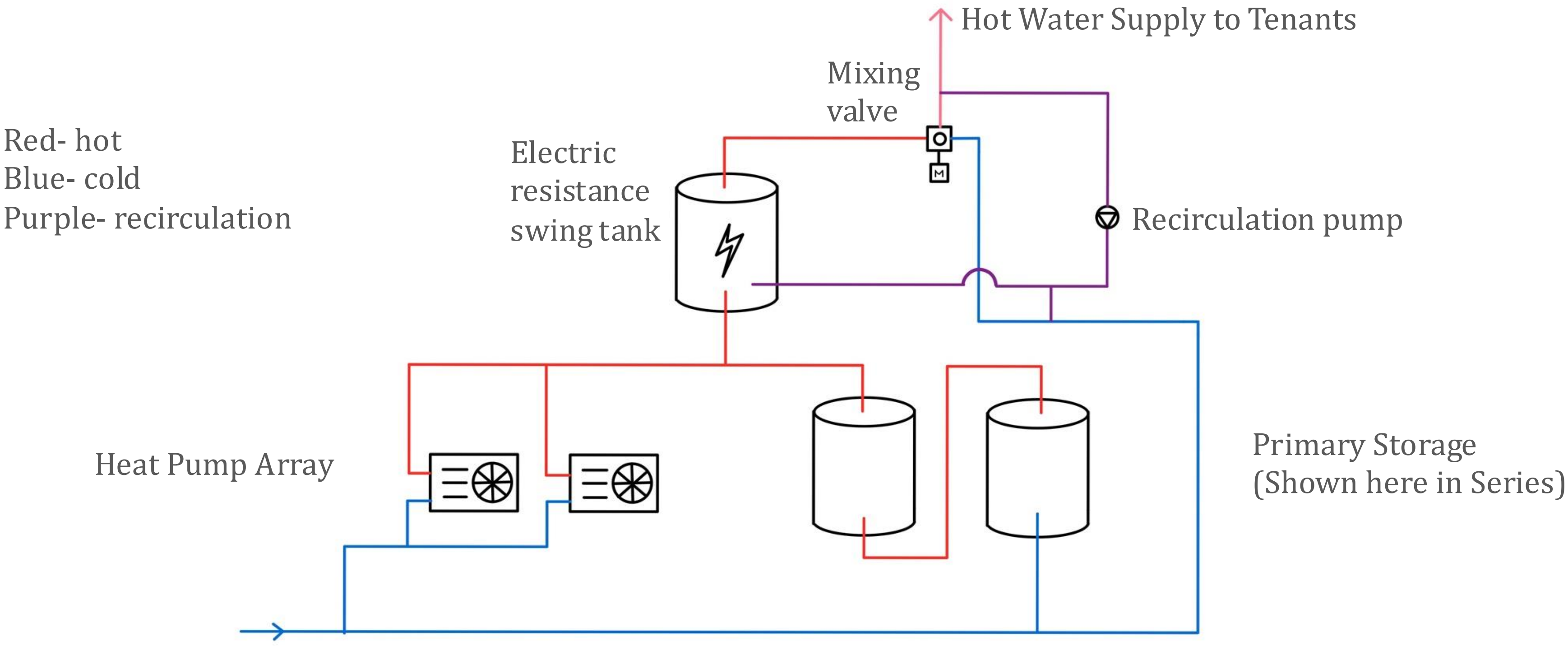
Roadmap to Scaling: Best Practices from CO2 Heat Pump Water Heater System Pilots

Air Source Central Heat Pump Water Heating (CHPWH) System Diagram



BUILDINGENERGY BOSTON

Roadmap to Scaling: Best Practices from CO2 Heat Pump Water Heater System Pilots

Charlie Simek, New Ecology

Neil Donnelly, New Ecology

Curated by Kurt Roth

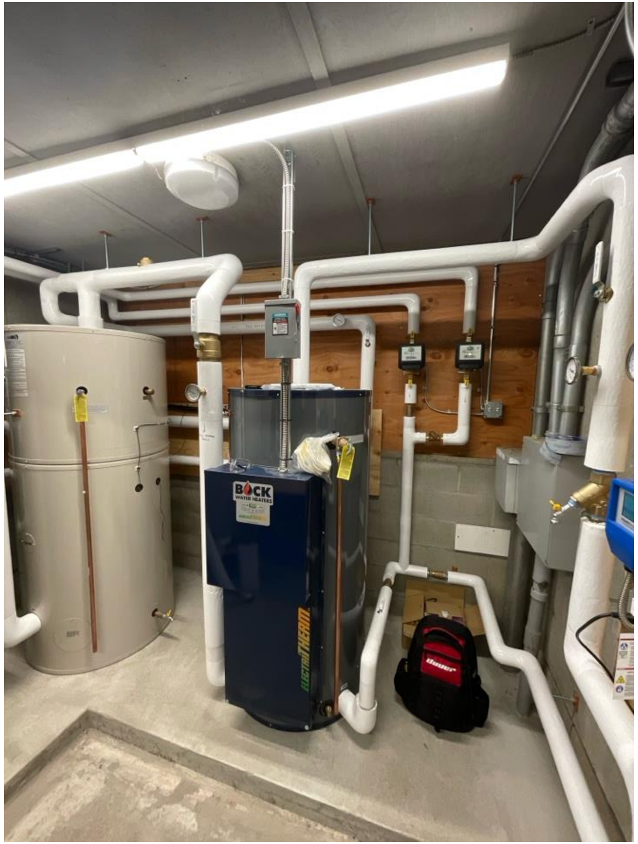
Northeast Sustainable Energy Association (NESEA) | March 20, 2025

Decarbonization Process

- Load Reduction & IAQ
- Equipment Optimization
- Electrification
- Serve with Renewables

DHW Decarbonization Priorities

- Provide the service
  - Keep it simple
    - Accessibility, through low costs & support



Goals

- Recognize the common pitfalls of implementing a novel system in new markets.
- Integrate measurement and verification with commissioning to increase the likelihood of pilot success.
- Define best practices to effectively implement a new mechanical system.
- Explain how project planning can affect pilot outcomes.

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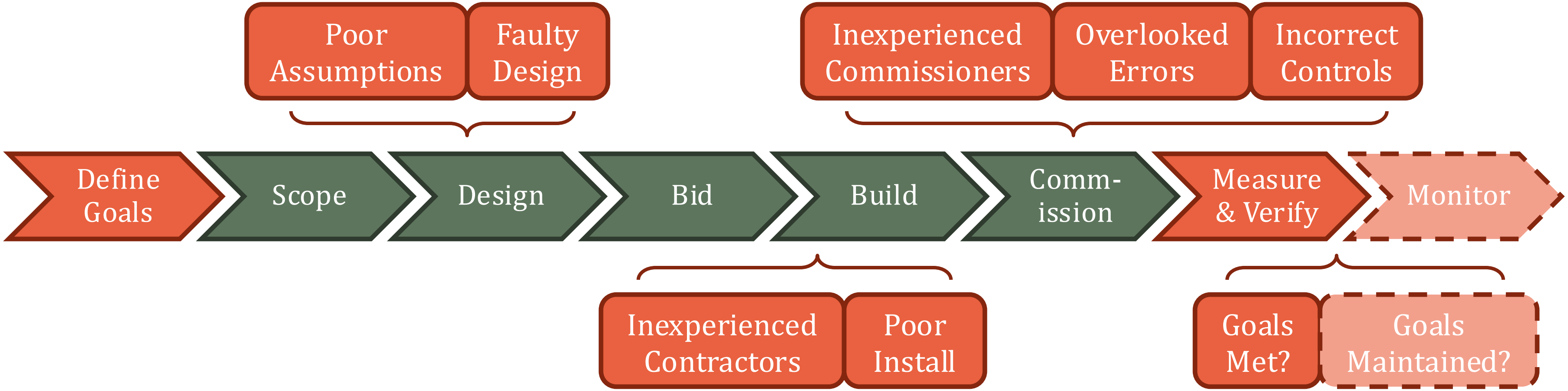
Project Roadmap

Project Roadmap: Failure Points



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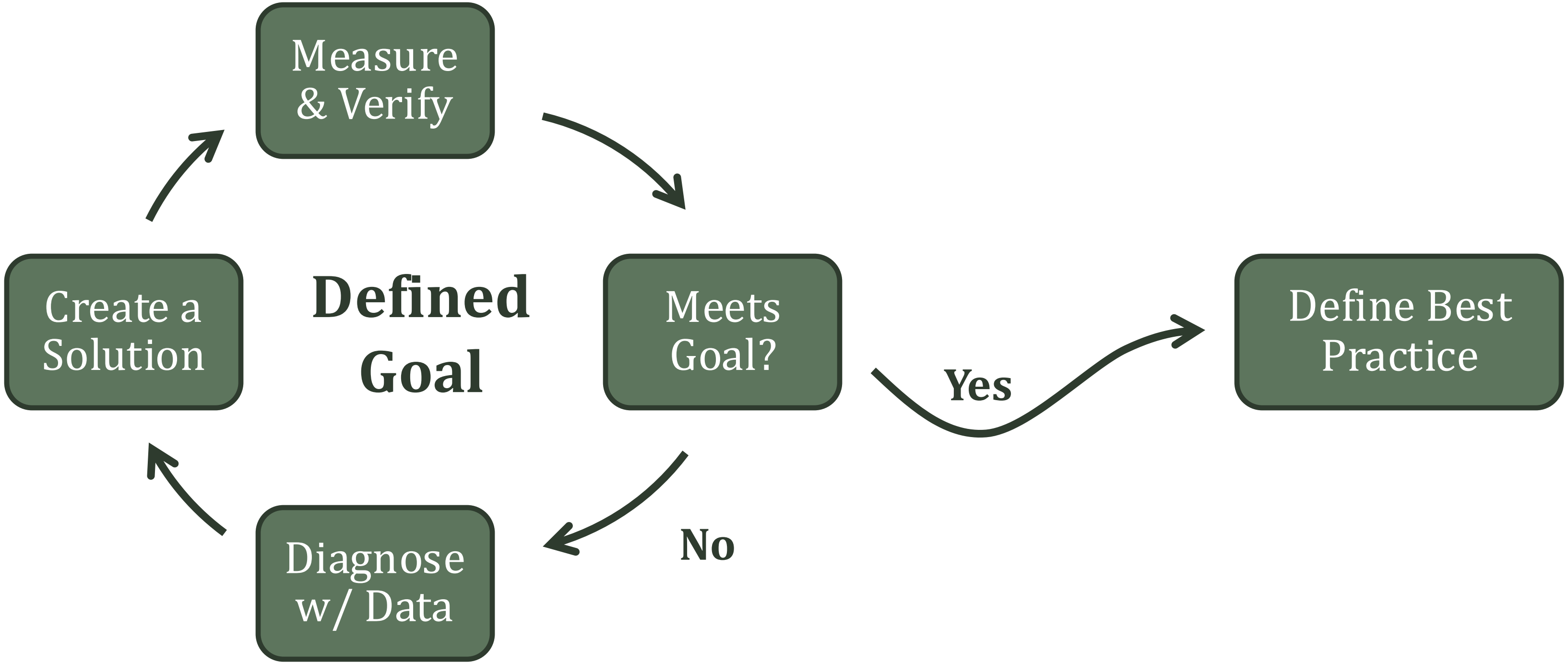
Iterative Monitoring to Define Best Practices



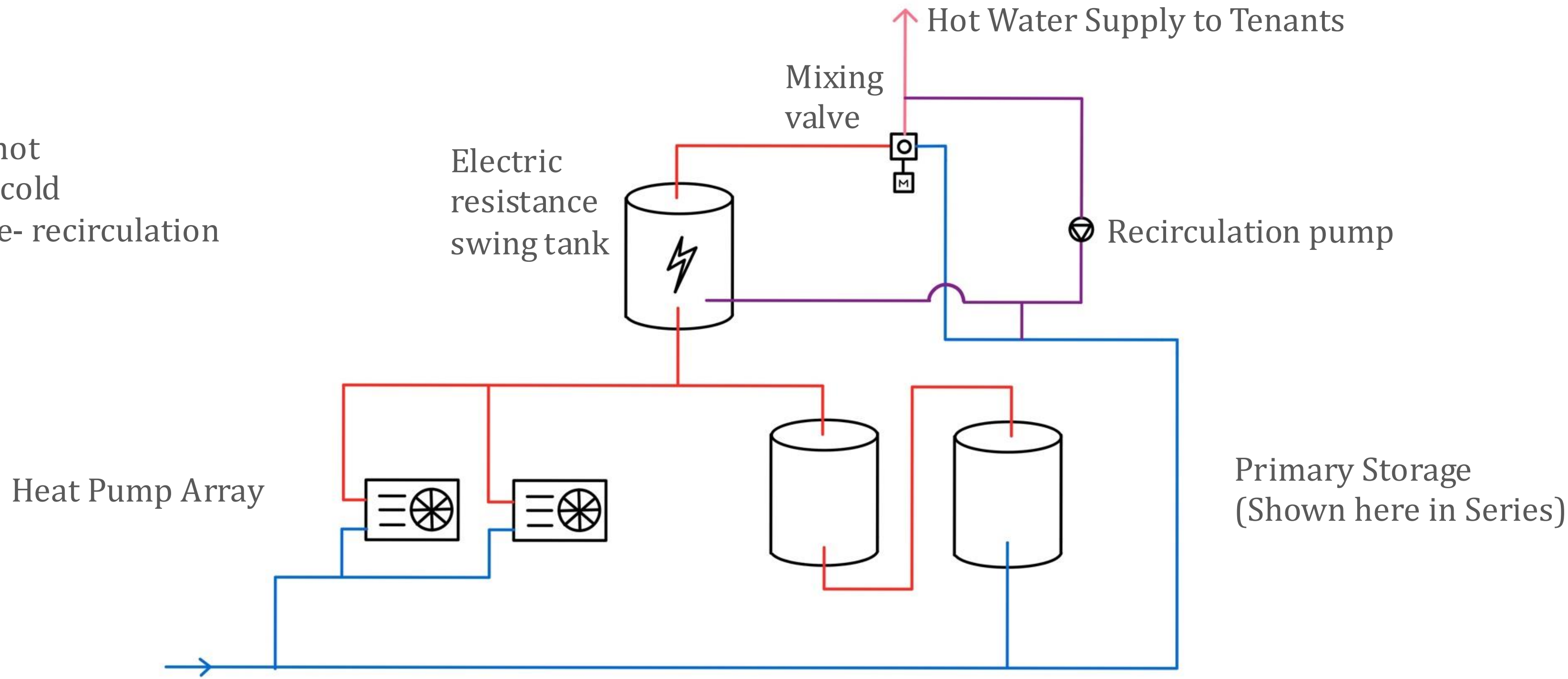
Project Goals

- 132-unit affordable elderly building
- Existing central electric resistance hot water at end of life
- Replace existing with a more efficient system
  - *Save money*
  - *Reduce emissions*
- Tenants don't recognize any change

Define Goals → Scope → Design → Bid → Build → Commission → Measure & Verify → Monitor

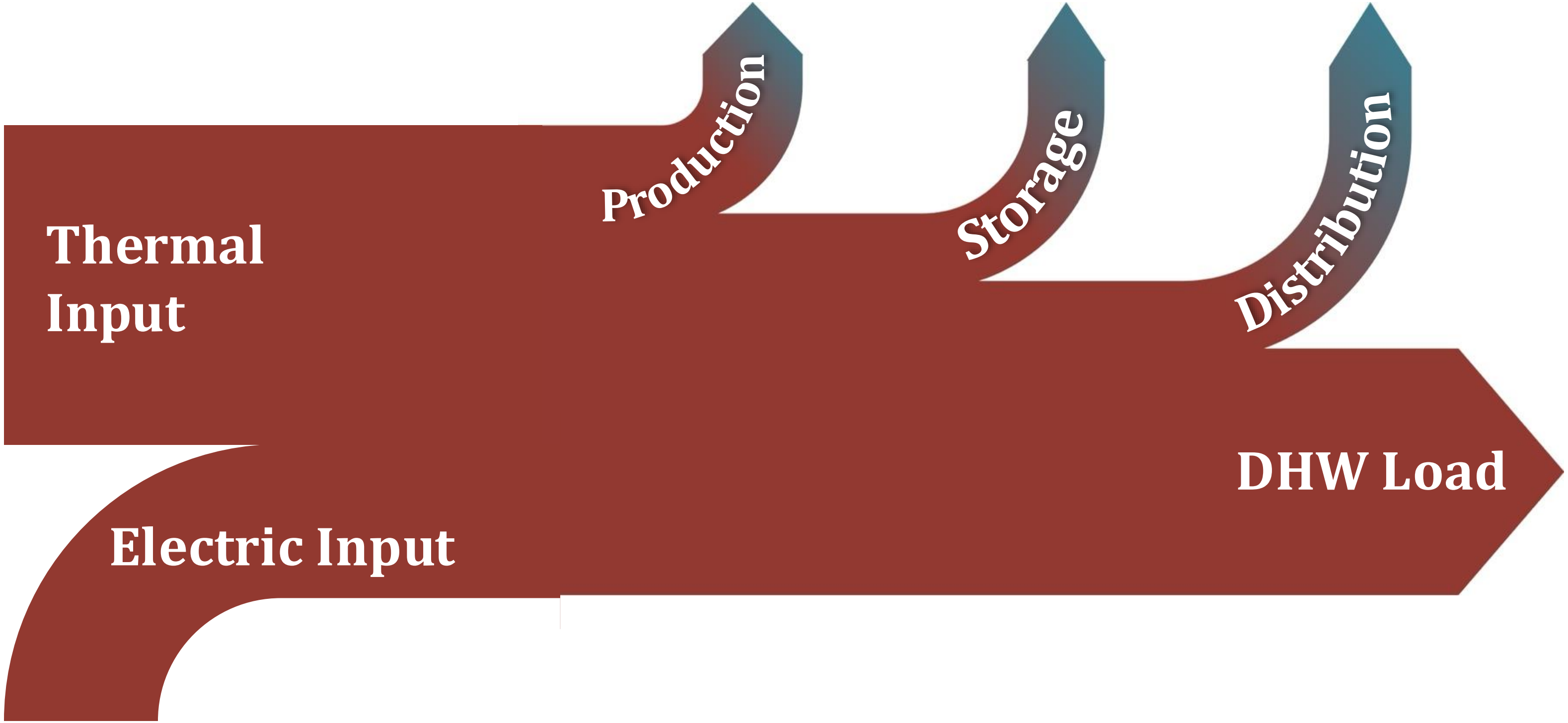
Scope – Central Heat Pump Hot Water System (CHPHW)

Red- hot
Blue- cold
Purple- recirculation

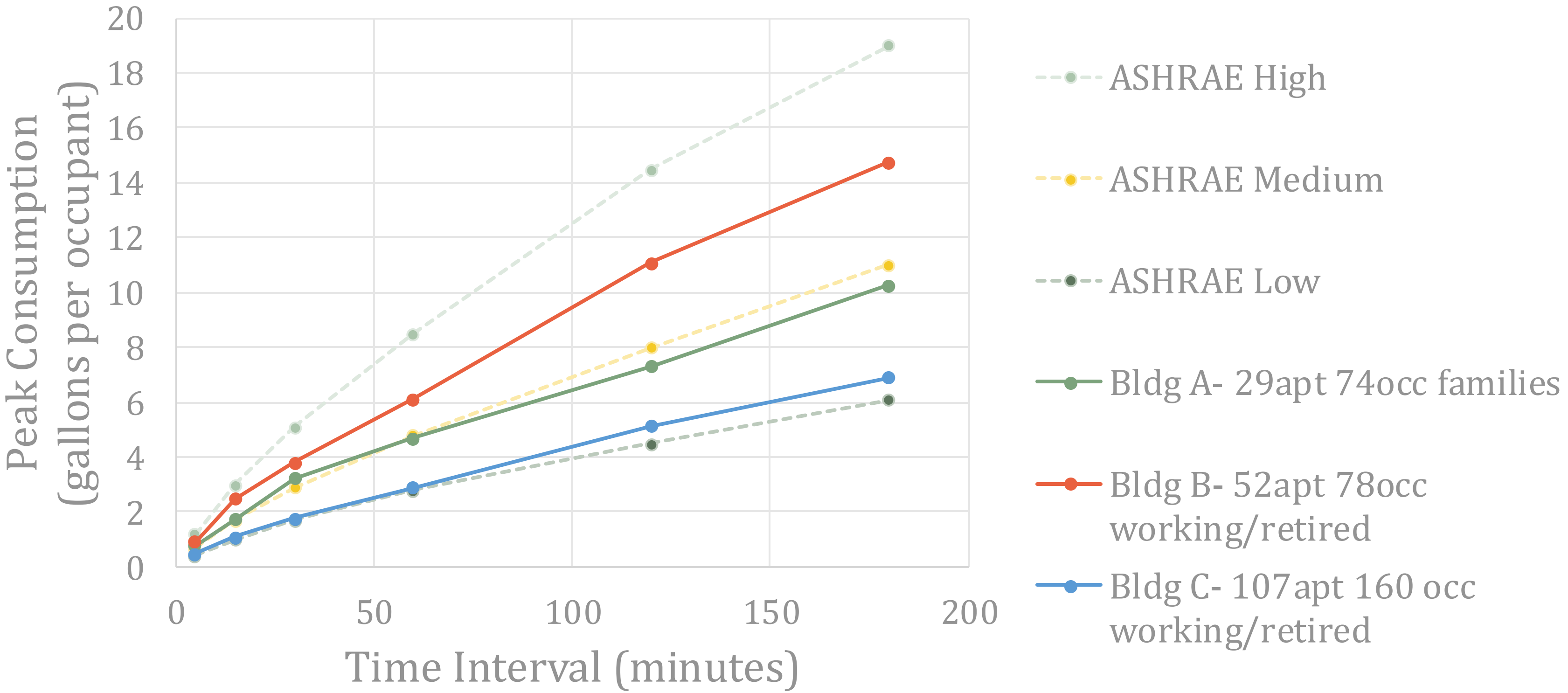


Define Goals | Scope | Design | Bid | Build | Commission | Measure & Verify | Monitor

Hot Water Energy Flow Diagram- Heat Pump

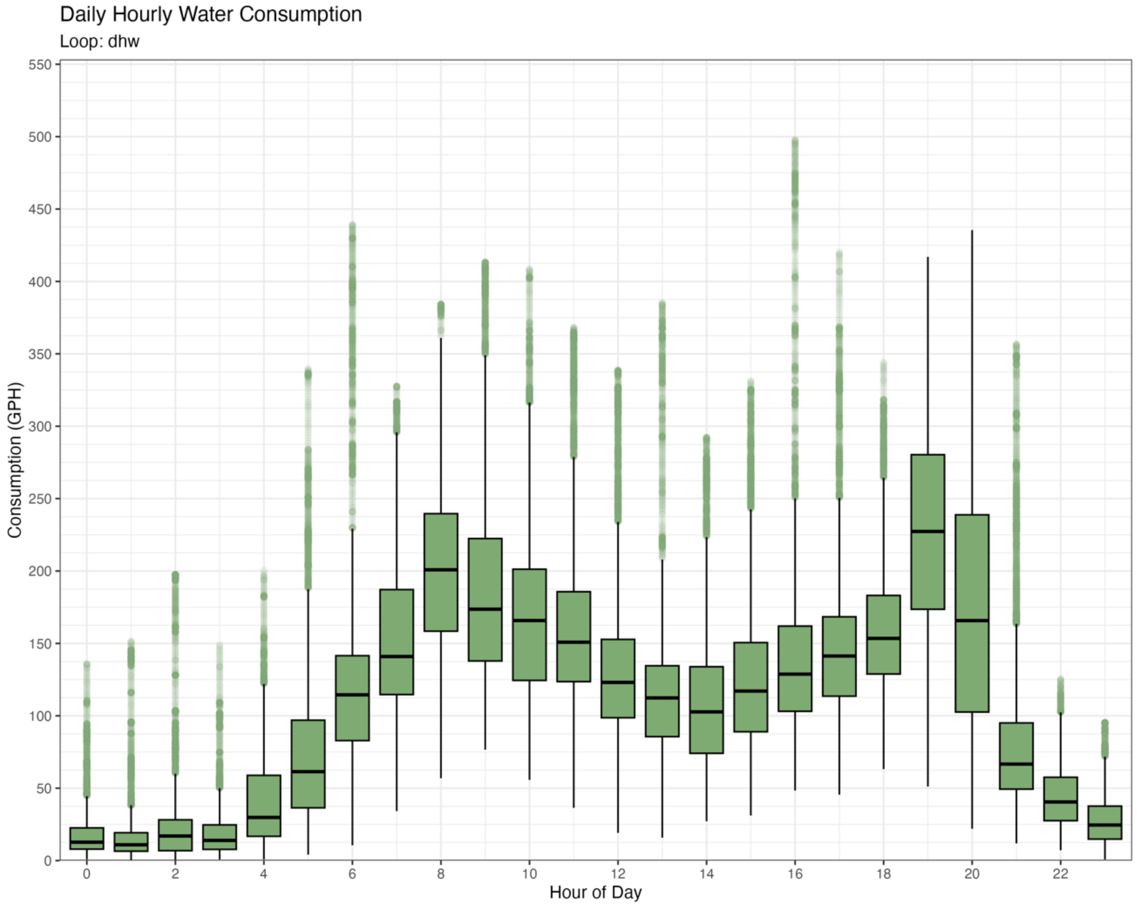


Design – ASHRAE Standards vs. Measured Peak DHW Usage

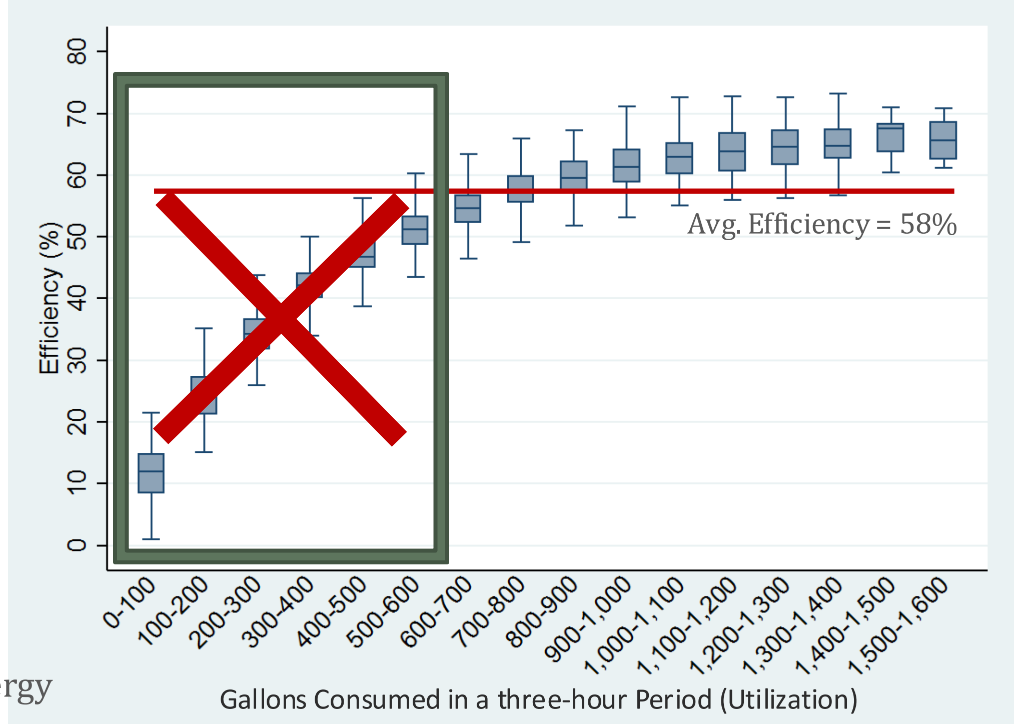


Define Goals | Scope | Design | Bid | Build | Commission | Measure & Verify | Monitor

Design – Understand Demand → Size the System



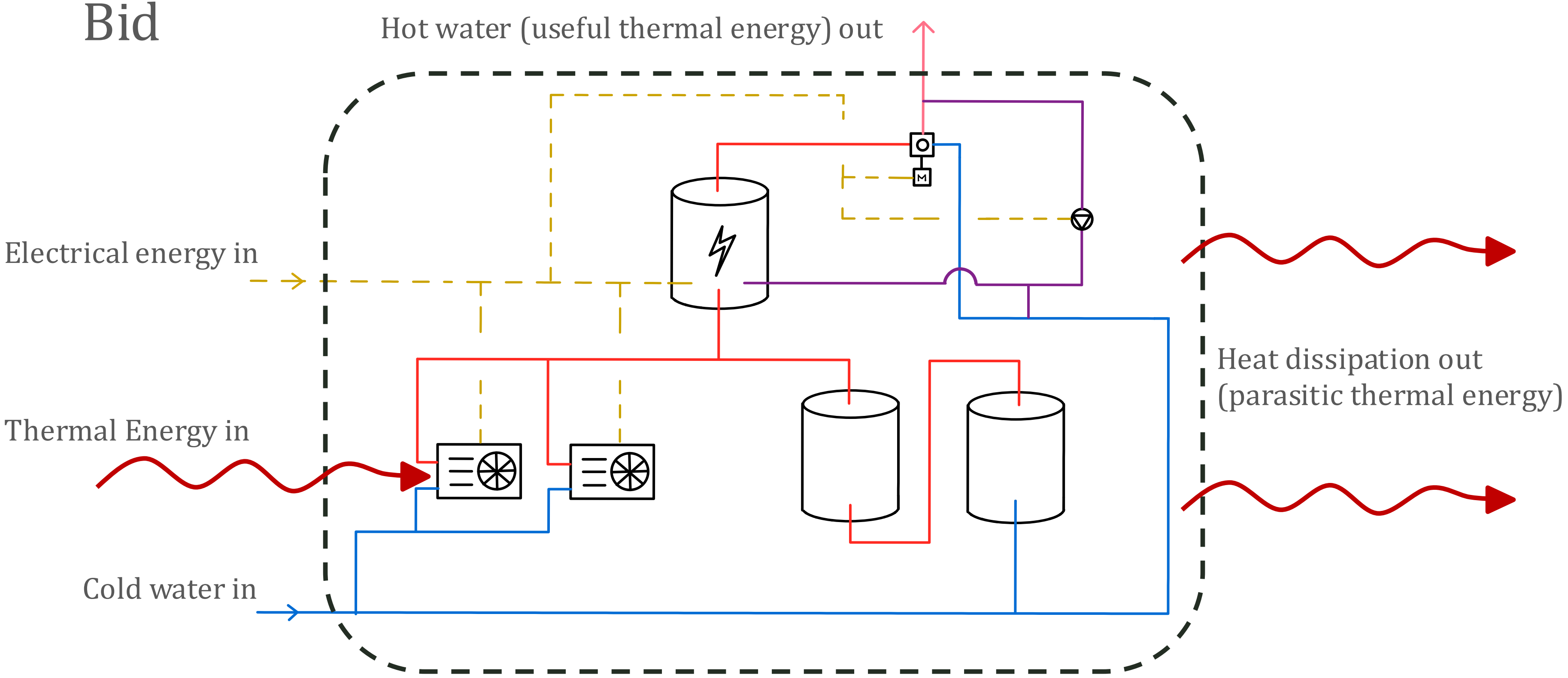
Total System Efficiency vs. Utilization (Central Gas System)



Efficiency=
DHW Load / Input Energy

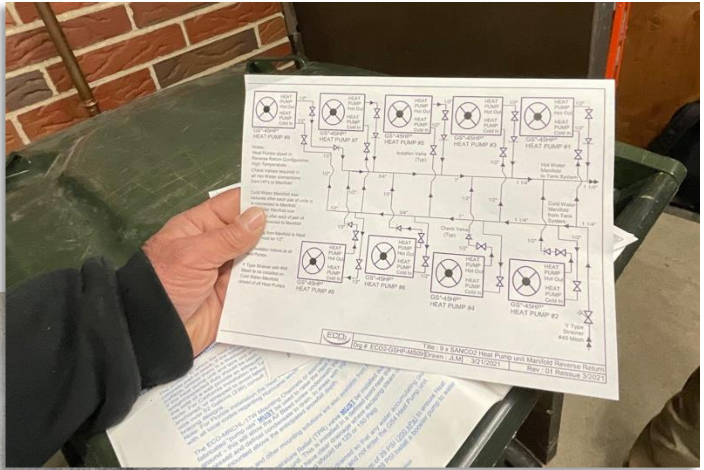
Define Goals | Scope | Design | Bid | Build | Commission | Measure & Verify | Monitor

Bid


Hot water (useful thermal energy) out
Electrical energy in
Thermal Energy in
Cold water in
Heat dissipation out
(parasitic thermal energy)

Build

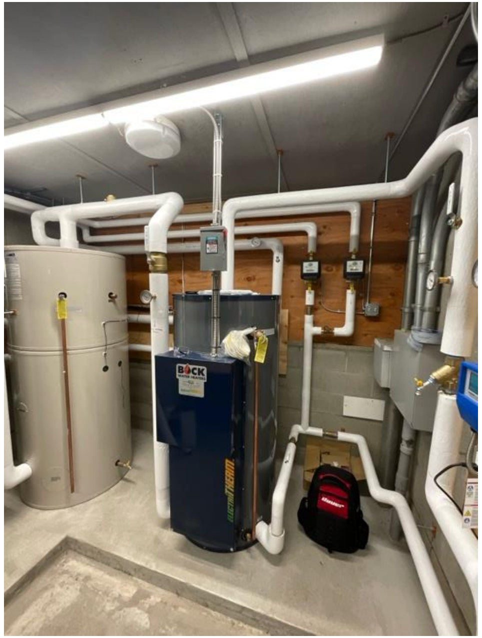
- Clear communication of system design
- Frequent visits to work through installation problems or confusion
- All stakeholders should be aware of progress



Define Goals → Scope → Design → Bid → **Build** → Commission → Measure & Verify → Monitor

Commissioning

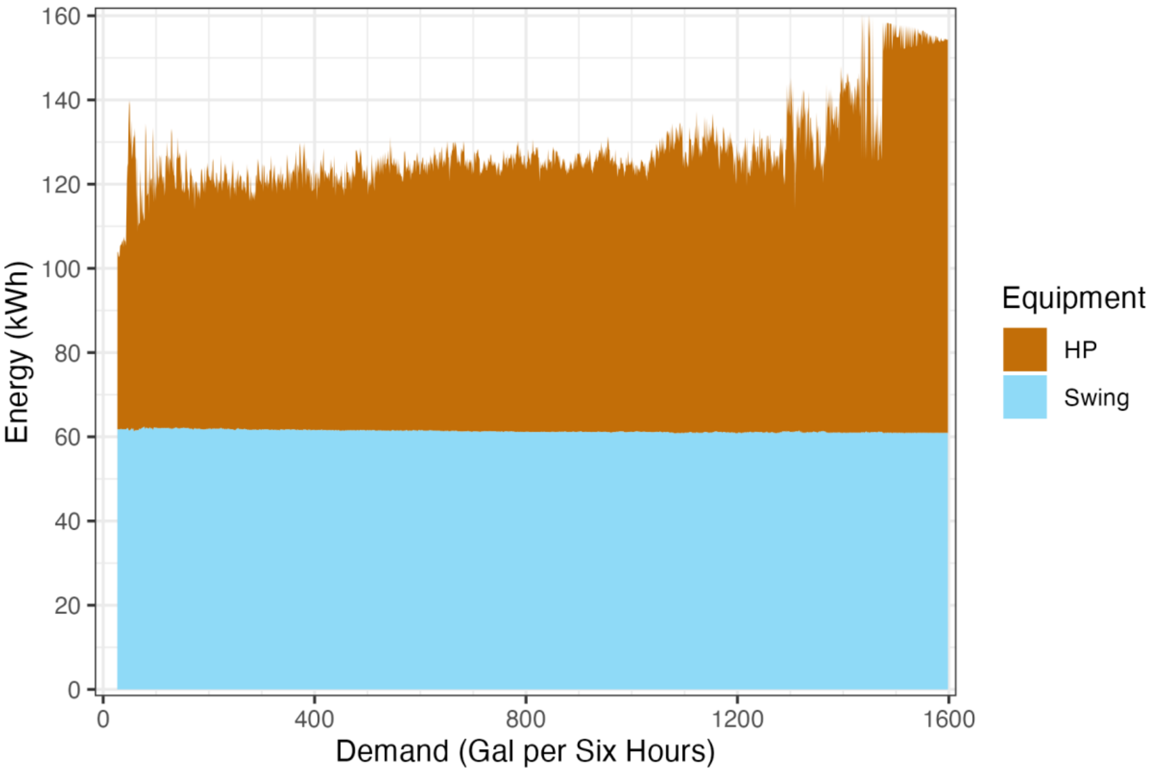
- **Piping**
- **Controls**
  - *Communication and physical wiring*
  - *Sensor location*
  - *Setpoints*
    - Staging
    - Swing tank
    - Mixing valve
    - Recirc pumps
- **Overall operation**



Define Goals | Scope | Design | Bid | Build | **Commission** | Measure & Verify | Monitor

Commissioning

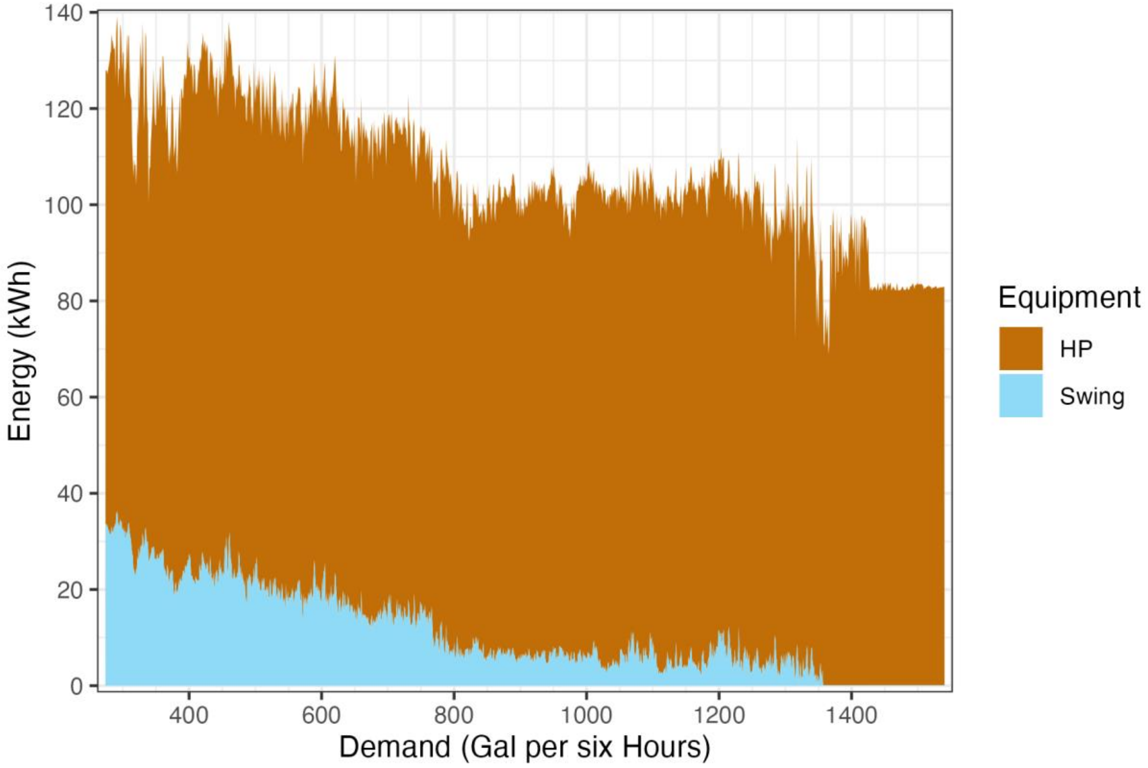
- **Cold water complaint post commissioning**
- **Incorrect diagnosis → Incorrect solutions**
  - *Re-piping of heat pump header to tanks*
  - *Contractor jacked up swing tank setpoint*



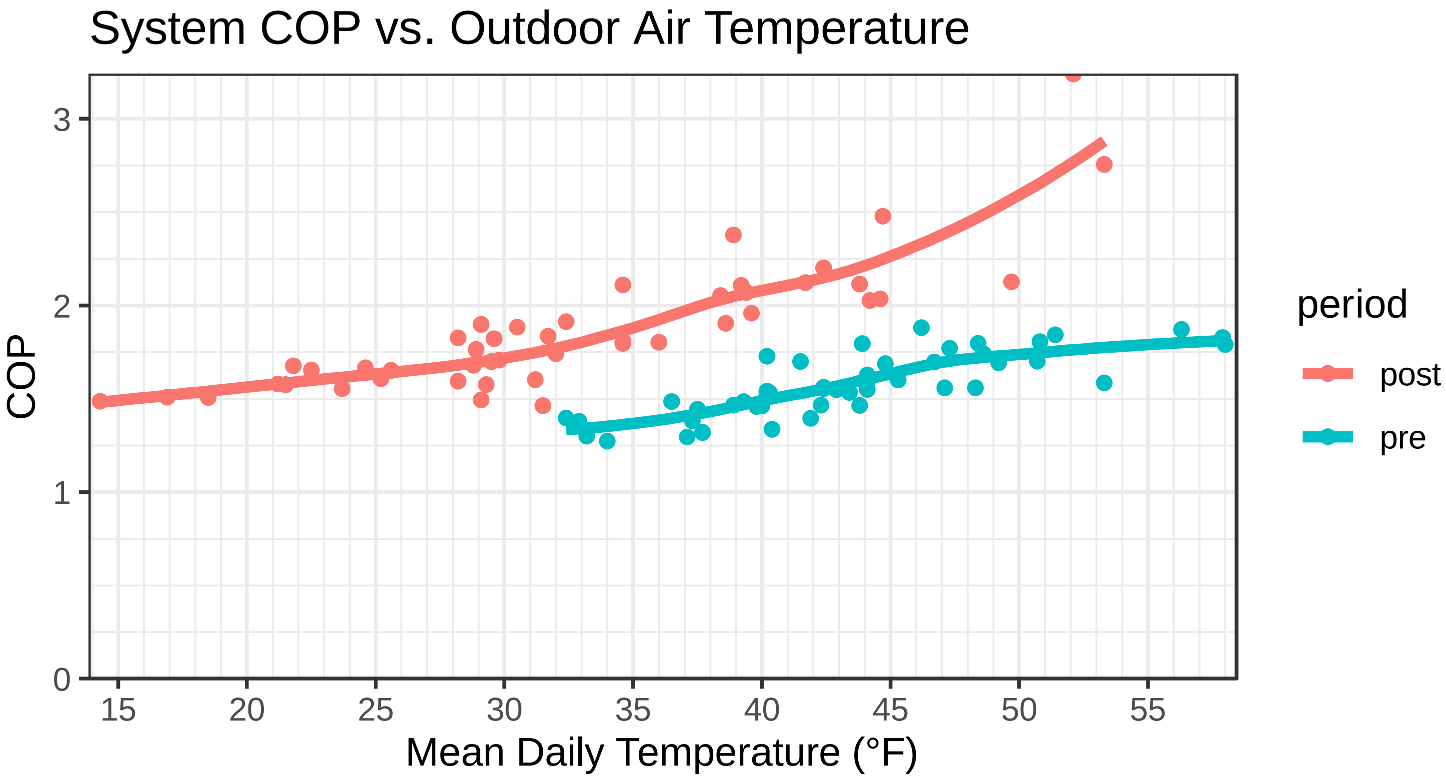
Define Goals → Scope → Design → Bid → Build → **Commission** → Measure & Verify → Monitor

Commissioning

- Lowering swing tank setpoint
- Lowering recirc pump speeds and mixing valve setpoint
  - *Maintained adequate loop temperatures*



Measurement & Verification



Ongoing Monitoring & Alerting

- **Maintain system efficiency**
  - *Small changes to operation can result in large efficiency losses*

- **Alert during failures**
  - *Know when something goes wrong so something can be done*

Freeze Protection & Emergency

It will happen to YOU!

Define Goals | Scope | Design | Bid | Build | Commission | Measure & Verify | **Monitor**

Freeze Protection & Emergency

- Alerts
- Emergency Power
  - *Redundancy*
- Piping Strategies

Define Goals | Scope | Design | Bid | Build | Commission | Measure & Verify | **Monitor**

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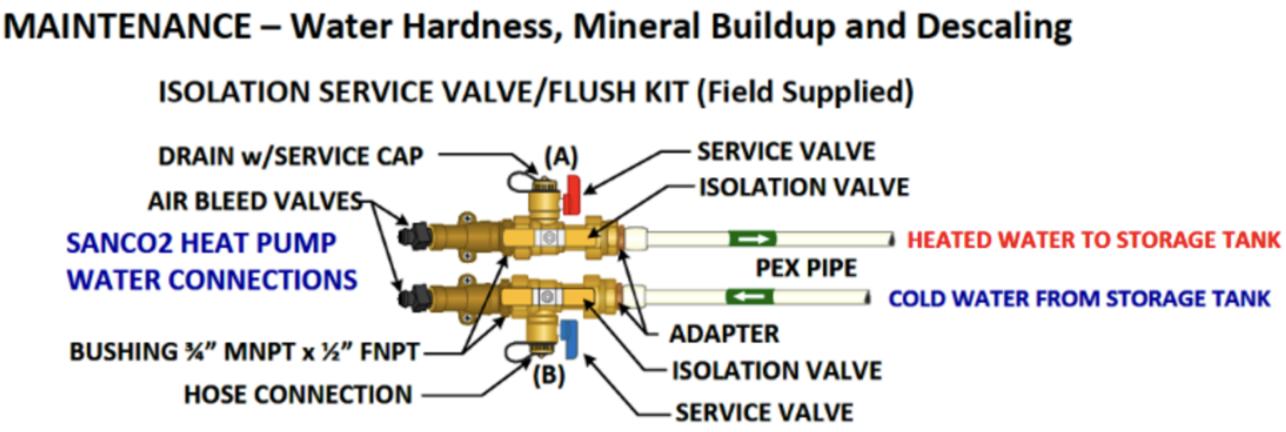
Reinventing the Wheel

- Piping Layouts
- Control Logic
- Heat Trace- UPS
- Alarms & alerts

Advanced Water
Heating Specification

New Stuff



- Supply full descaling kit
- Auxiliary room heat
- Service outlets for descaling and monitoring
- Heat Trace UPS, self-regulating, externally activated, separate breakers
- Control wiring as homeruns without splices
- Piped for ease of monitoring

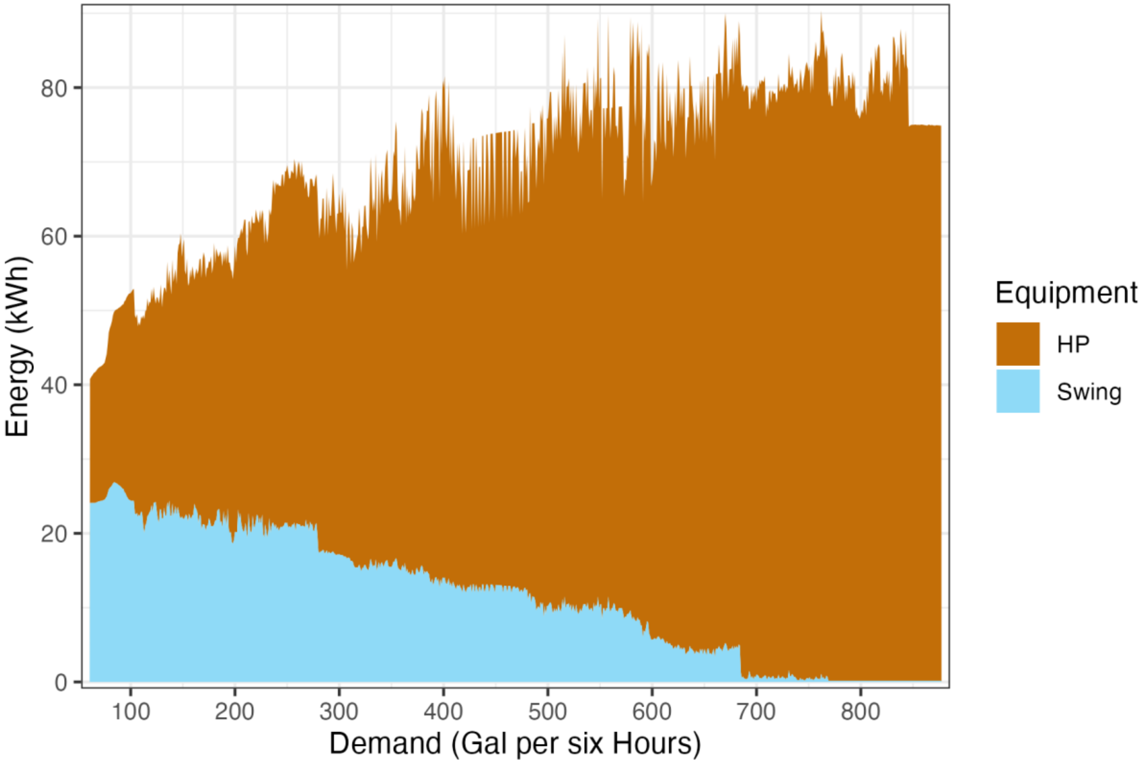
100 Unit Building Description

Multi Sanco HPWHs with Storage

- *100 one bedroom units, ~103 occupants*
- *12 Sanco heat pump water heaters*
- *1000 gallons of storage (Primary Setpoint of 145°F)*
- *120 gallon swing tank with 13.5 kW elements*

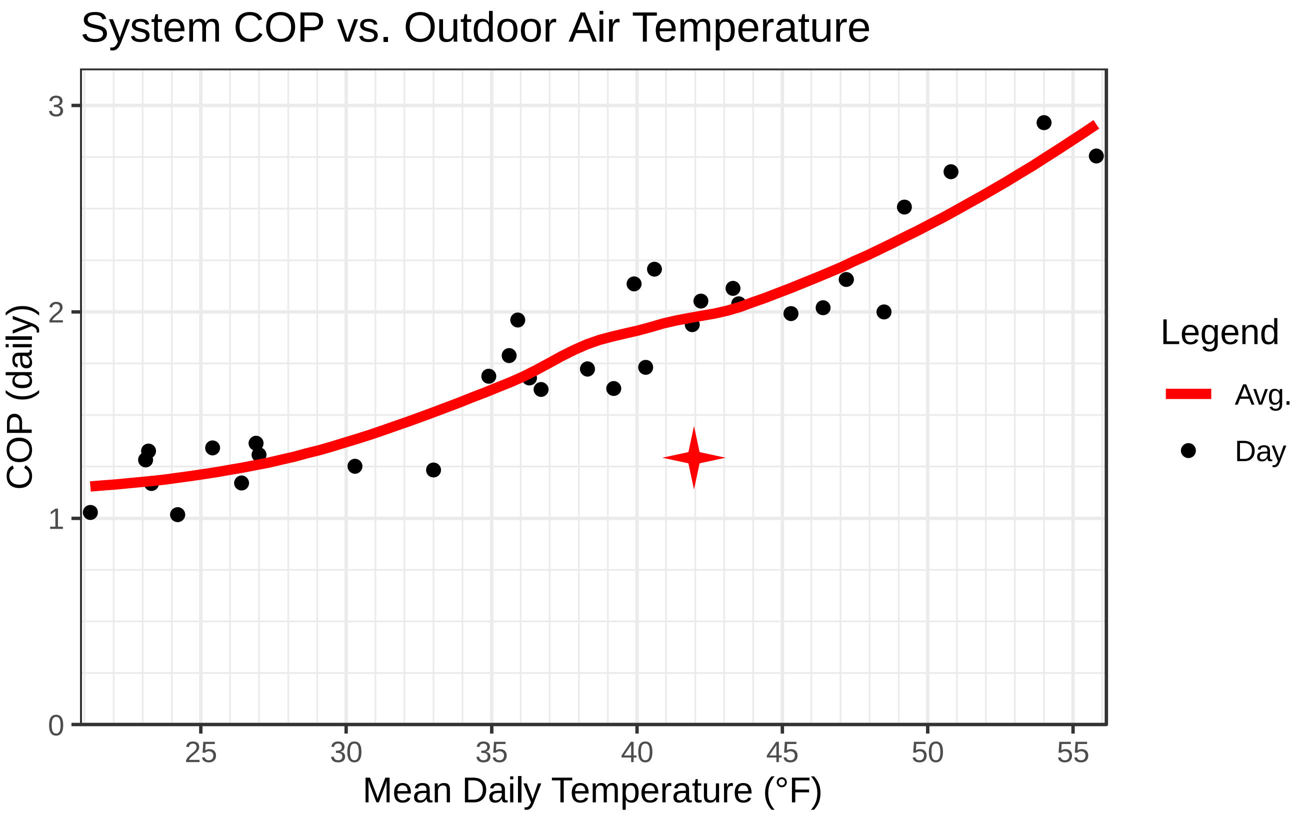
What was different:

- Piping details
- New HP Control
- New Central Control



What Happened Next:

- **HP Networking**
- **Swing Tank Burnout**
- **Recirc**
- **Controls**
- **Setpoints**

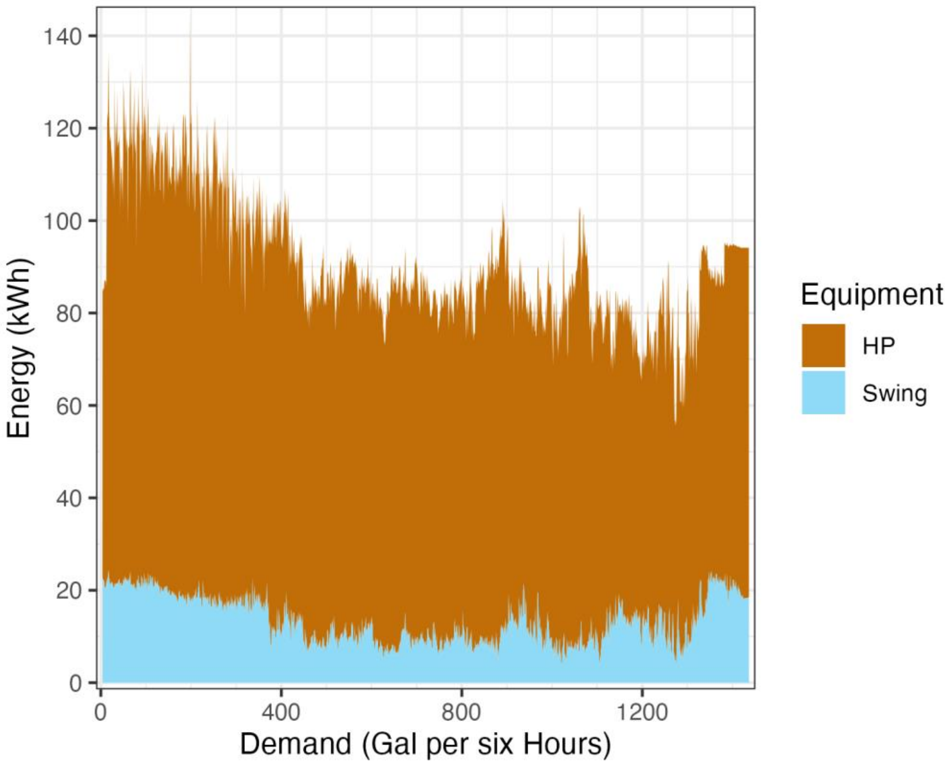


New Aspects (to us)

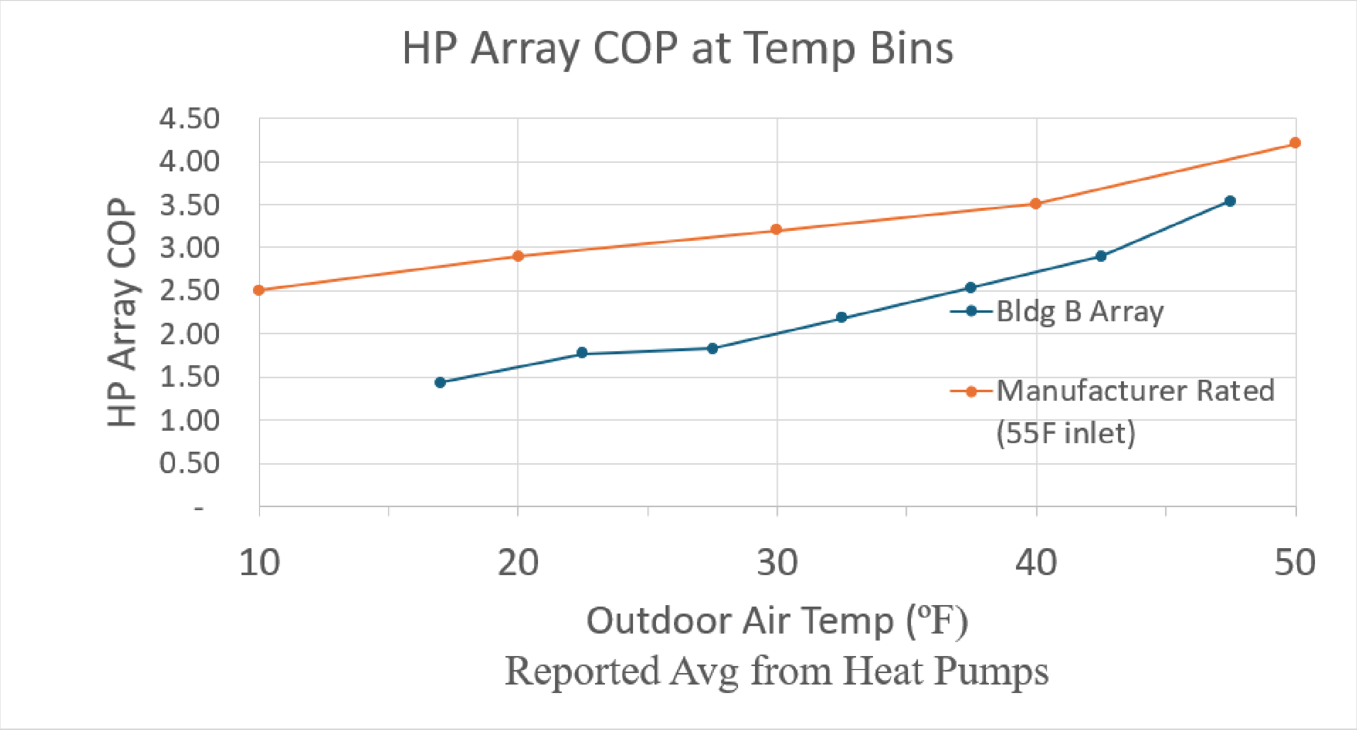
Known: setpoints, repiping, controls

New:

- HP Staging & Cycling
- Freeze Protection & Emergency Failures
- Recirc & Primary Setpoint Games

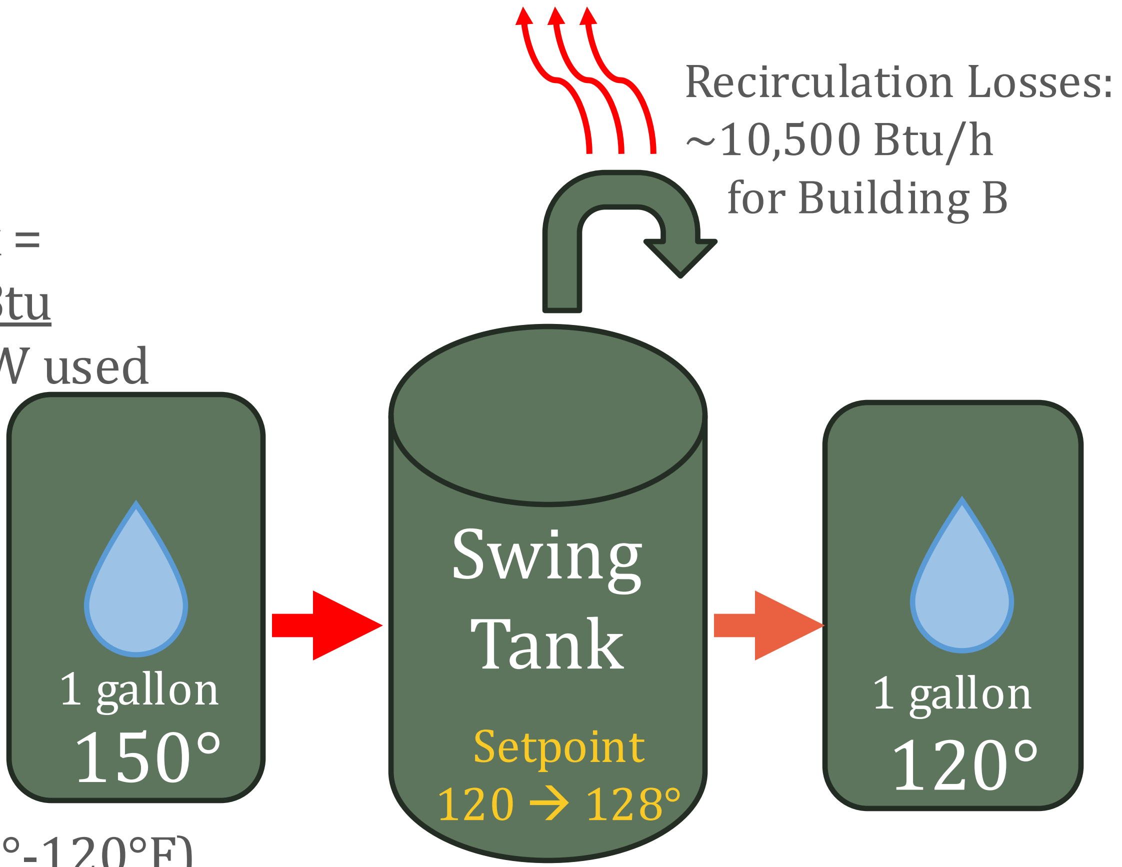


HP Staging & Cycling



Swing Tank

BTUs accumulated in Swing Tank =
8.33 x Gallons x (150°-120°F) = <u>Btu</u>
250 'extra' Btus per gallon of DHW used

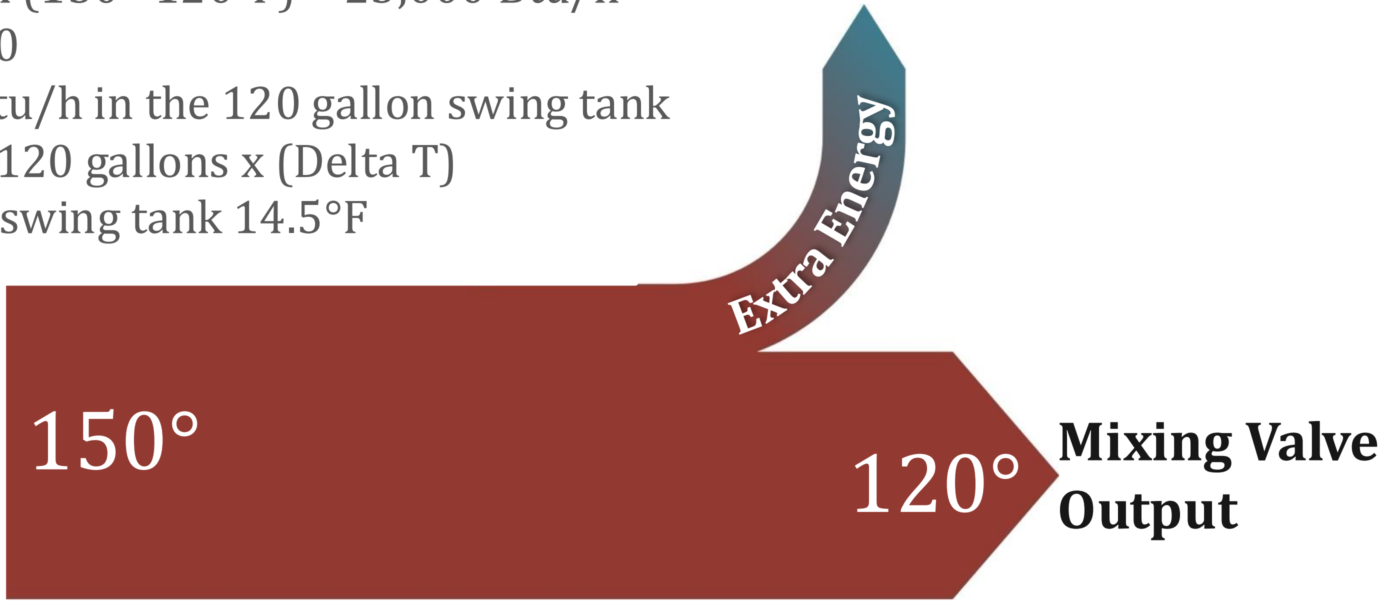


10,500 Btu/h =
8.33 x <u>Gallons</u> x (150°-120°F)
→ 42 gallons of DHW use per hour to offset recirc losses

BTUs accumulated in Swing Tank =
8.33 x Gallons x (150°-120°F) =
250 'extra' Btus per gallon of DHW used

Swing Tank

100 gallons of DHW per hour…
8.33 x 100 gallons/hr x (150°-120°F) = 25,000 Btu/h
Minus the recirc 10,500
Accumulates 14,500 Btu/h in the 120 gallon swing tank
14,500 Btu/h = 8.33 x 120 gallons x (Delta T)
Raising the 120 gallon swing tank 14.5°F

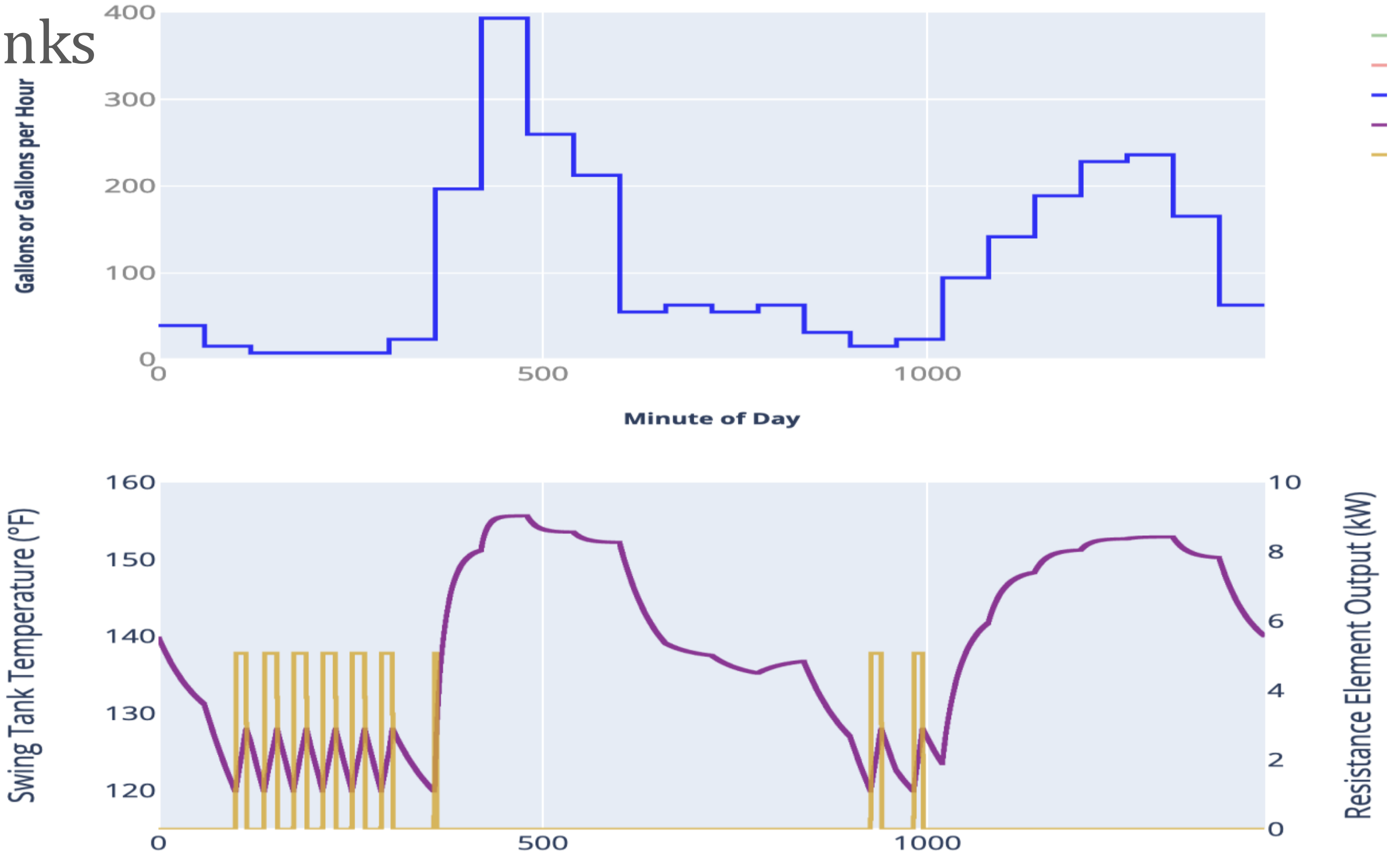


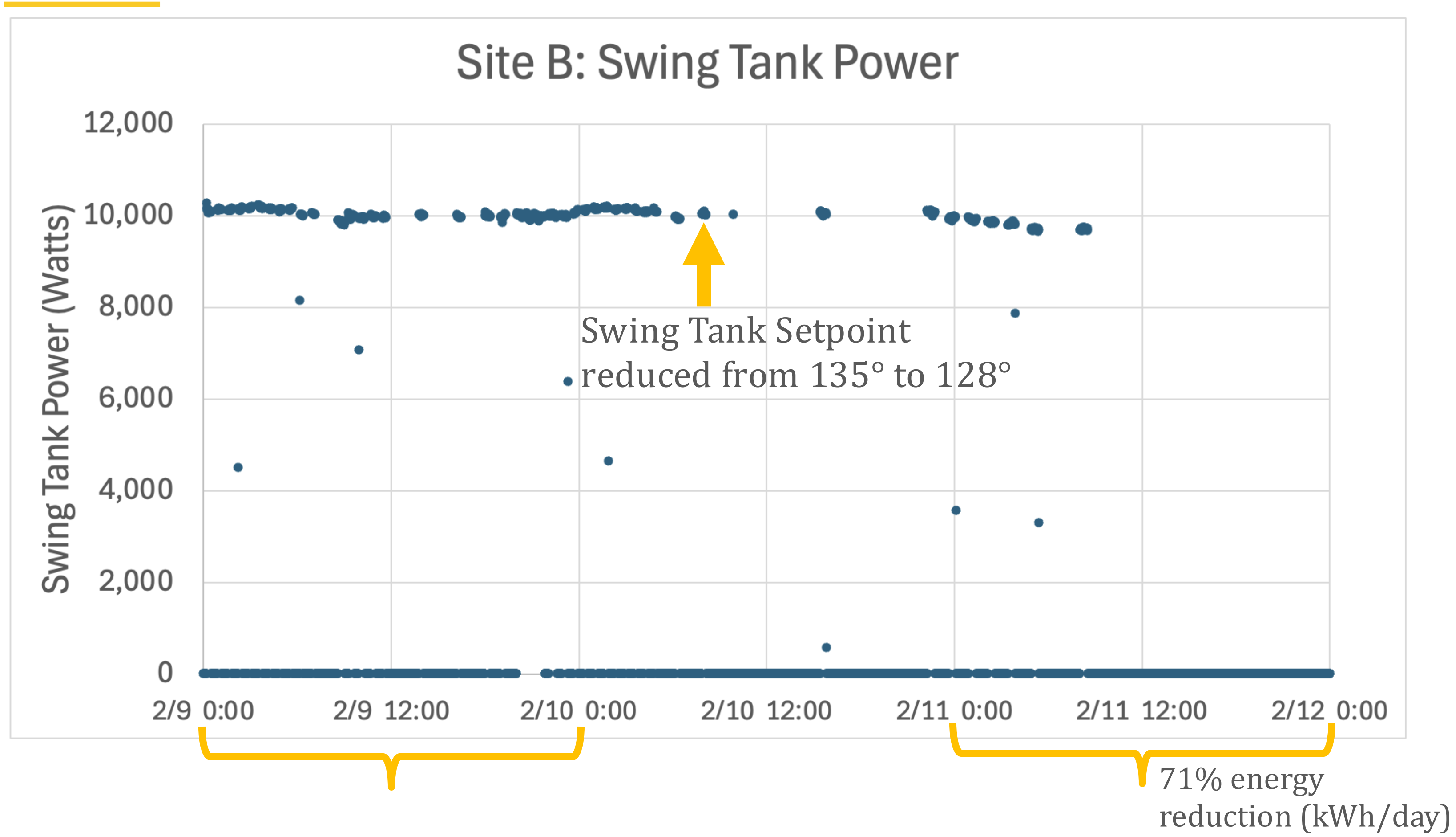
Swing Tanks

Gallons of DHW Usage

Swing Tank Temperature (°F)

Swing Tank Electric Resistance (kW)





Site B: Swing Tank Power
Swing Tank Power (Watts)
12,000
10,000
8,000
6,000
4,000
2,000
0
2/9 0:00
2/9 12:00
2/10 0:00
2/10 12:00
2/11 0:00
2/11 12:00
2/12 0:00
Swing Tank Setpoint
reduced from 135° to 128°
71% energy
reduction (kWh/day)

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Keys to Success (System):

- Minimize recirculation flow to maintain a return of 110°F
- Decisions on backup power use, if available
- Detailed piping diagram: pipe sizes, max lengths, components, sensors, locations
- Pipe the system to allow for easy monitoring of the DHW load, recirculation load and heat pump array flow
- Heat Trace
    - Powered from its own breaker, separate from the heat pump panel
    - should not be wired through or controlled by the heat pumps.
    - Activated by external control with its own outdoor air temperature sensor to turn on power to the heattrace when the outdoor air temperature drops below an adjustable setpoint
    - Heat trace to be self-regulating in its heat output
    - Heat Trace and control on a UPS to provide 24 hours of backup operation during a power outage.
- Provide service outlets for descaling procedure and dedicated monitoring outlets

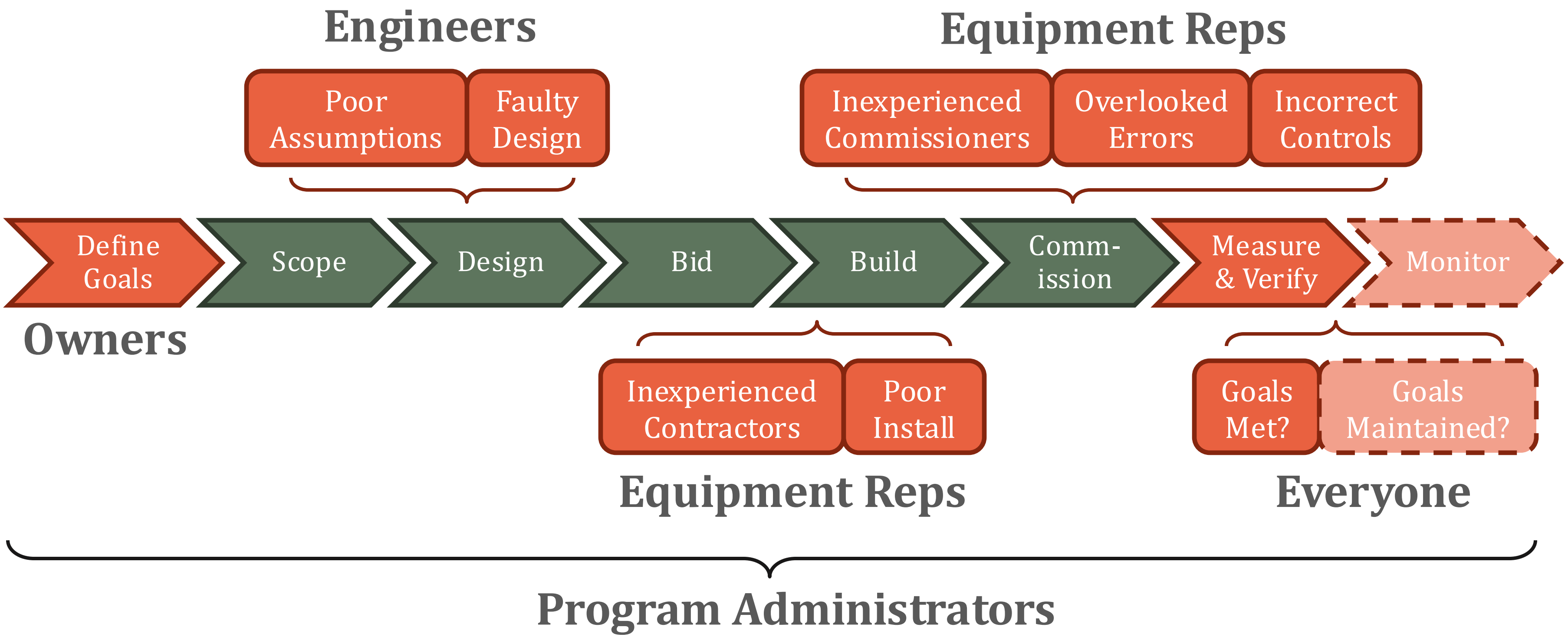
Keys to Success (System) continued:

- Alarms for failure (appliance or power): warning light external to the mech room, alerts sent to key personnel, with alerts demonstrated
- Connect larger systems to the internet for remote review
- Spare parts: especially pumps and freeze protect valves
- Supply full descaling kit required for the system. Demonstrate procedure for staff, and video this demonstration for future staff.
- Post all maintenance procedures and frequency on a printed poster, with QR code to descaling video demonstration.
- Provide auxiliary heat to the DHW room if it was previously heated with system losses
- Setpoints
  - Set swing tank setpoint to 128°F (assuming 8° deadband, so maintaining 120° min)
  - Set recirculation balancing valve to minimize flow through the swing tank while maintaining mixing valve setpoint during periods of no demand
- Electronic mixing valve set for 120-125* with backup power or 24 hour UPS
- Control wiring to be homeruns without splices

Keys to Success (Process):

- System Operational Assessment of the Existing System
    - Sequence of operation, Seeing the system as a whole
- Monitor Existing Loads to inform sizing, and define assumptions
- Design for Monitoring,
- Include ‘levers’ for optimization built in
- Continuous monitoring. Using it, not just having it, making it available
- Minimize complexity for the future- if it can go wrong, it will
- Build in education and training for contractors & site staff early on
- Design for failure & fixability
- Talking about maintenance early in the process

What’s Next for You



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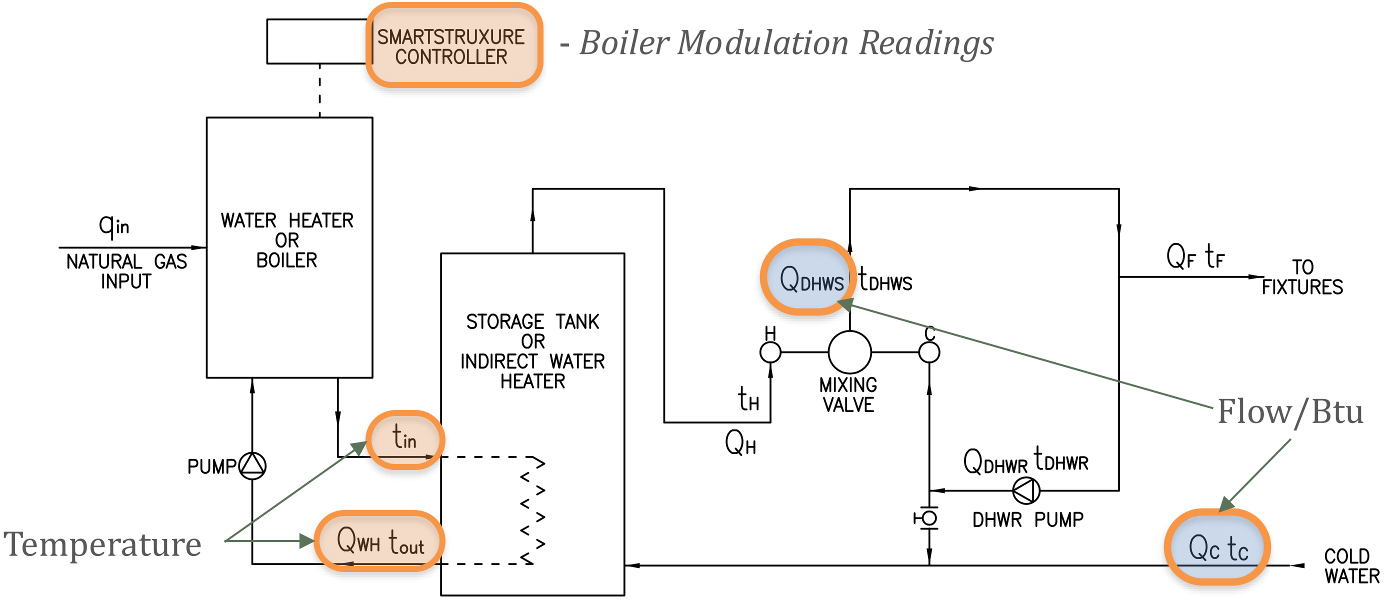
Resources:

- Ecosizer (Ecotope): https://ecosizer.ecotope.com/sizer/
  - *System sizing, Hot Water Simulation, Open Source Documentation*
- Advanced Water Heating Specification (Northwest Energy Efficiency Alliance) - : https://neea.org/our-work/advanced-water-heating-specification
  - *Qualified products list, system efficiency data, System Diagrams, Keys to success*

A.1 - System Schematic, Temperature, and Flow/Btu Sensor Locations

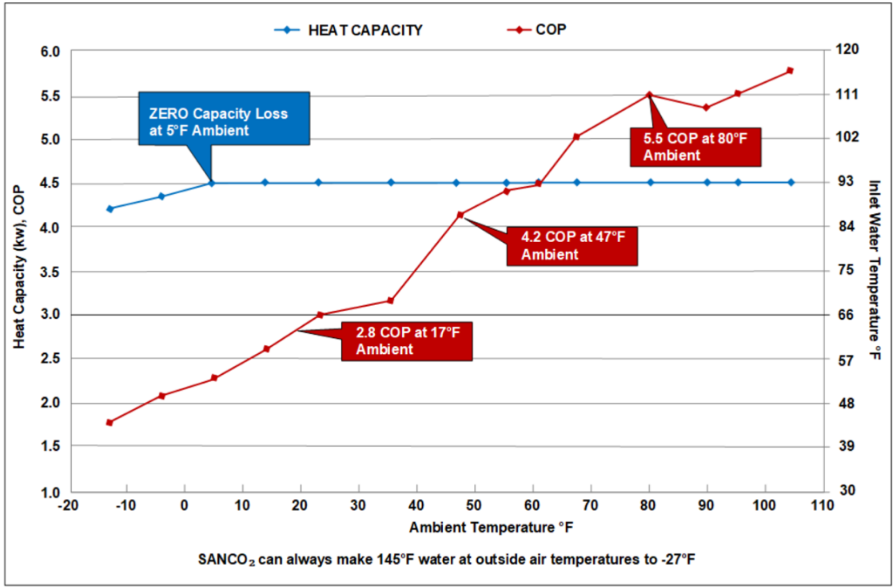


A.2 - Data Accuracy & Error Checking

- Ultrasonic flow meter accuracy:
  - *±1 gpm for the range of flow rates encountered*
- Temperature Sensor accuracy: ±1% temp reading
- Temperature sensor transient response
- Consumption below or above expected values
- Checking measured energy and water consumption against utility meters

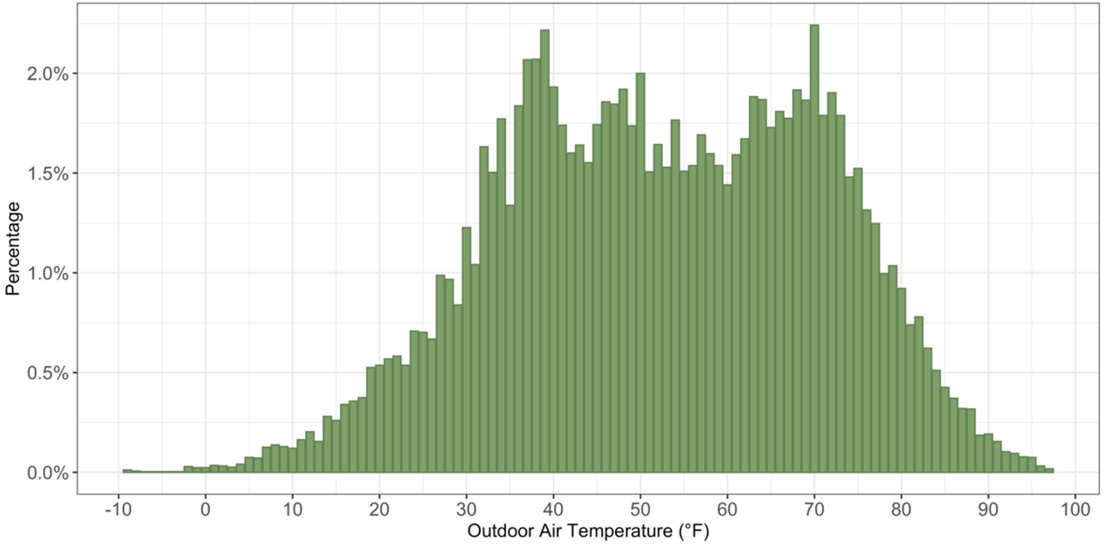
A.3 - Outdoor Air Temperatures and Heat Pump Capacity

- As outdoor air temperatures decrease ASHPs that are extracting heat from the ambient air must work harder to output the same amount of heat
- At a certain threshold the heat pump's capacity will begin to decrease as well
- Heat pumps using CO_2 as their refrigerant can operate down to colder temperatures than other refrigerants without losing capacity
- CO_2 has the added benefit of only having a global warming potential (GWP) of 1.0 compared to other refrigerants with GWPs in the 1000s



https://www.eco2waterheater.com/_files/ugd/e88920_b4075b5329fe46edb29044ae9b7116bf.pdf

A.4 - Outdoor Air Temperature Histogram (Boston)



- Supplement the capacity of the hot water system with electric resistance or boilers to meet the load when heat pumps lose capacity

A.5 - First Cost Implications

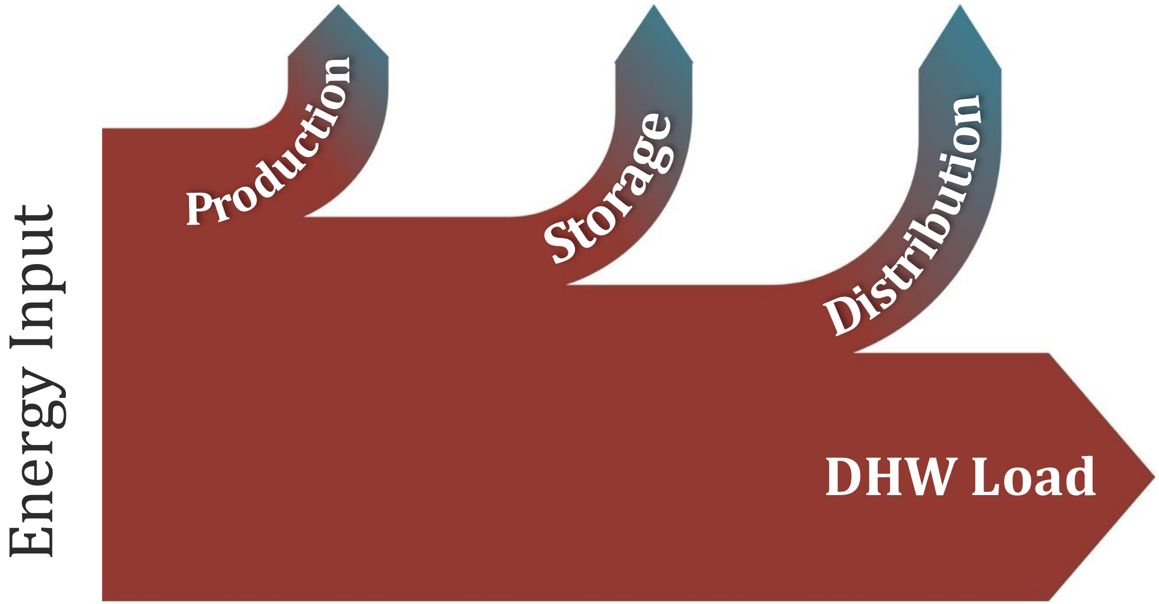
	Peak Minutes								
Guideline	**5**	**15**	**30**	**60**	**120**	**180**	**Max Daily**	**System**	**Cost**
Low	0.4	1.0	1.7	2.8	4.5	6.1	20	6s+300	$119,000
Medium	0.7	1.7	2.9	4.8	8.0	11.0	49	13s+300	$198,000
High	1.2	3.0	5.1	8.5	14.5	19.0	90	24s+500	$346,000
Measured	.71	1.58	2.95	4.30	6.69	9.37	35.4	10s+300	$164,000

Gallons per person at 120°F

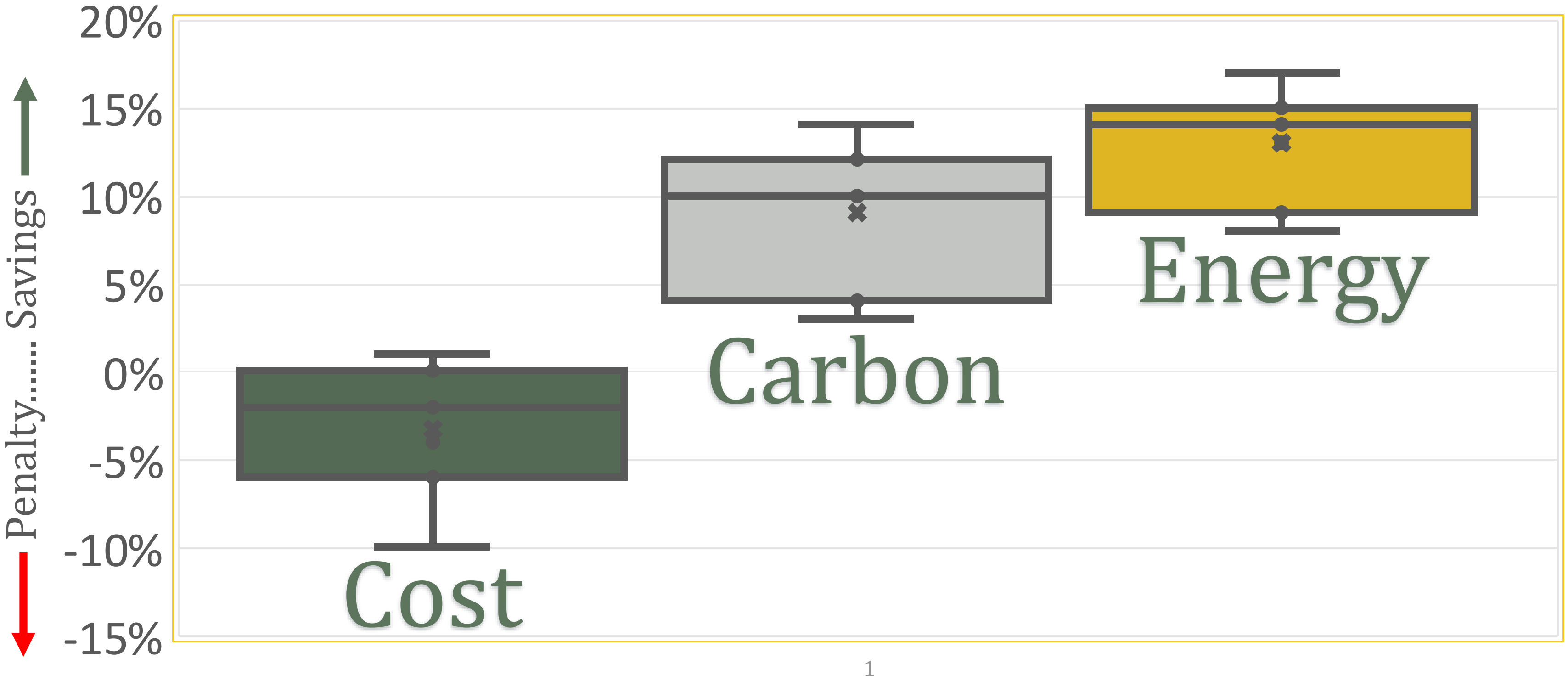
A.6 - Recirculation Loads

	Bldg 1	**Bldg 2**	**Bldg 3**	**Bldg 4**
Recirc gpm	2.5	5.8	18.7	7.2
DHWS	117.5	134.6	132.1	127.1
DHWR	115.1	126.7	125.5	117.1
Btu/h Recirc	3,100	22,870	61,391	35,750
# apts	29	52	107	92
Watts/apt	**31**	**129**	**168**	**113**
Btu/h/apt	107	440	574	387

A.7 - Hot Water Energy Flow Diagram- Gas Fired



A.8 - ASHPWH Estimated Savings (relative to whole building annual use)



A.9 - SysCOP

Advanced Water Heating Specification Appendix H
https://neea.org/our-work/advanced-water-heating-specification

$$\boldsymbol{SysCOP} = \frac{\boldsymbol{Heating_{Primary}} + \boldsymbol{Heating_{Temp.\ Maintenance}}}{\boldsymbol{Power\ Input}}$$

Where…

$$\boldsymbol{Heating_{Primary}} = m_{cold\ water} * c_p * (T_{loop\_supply} - T_{cold\ water}),$$

$$m_{cold\ water} = \text{mass flowrate of cold water entering system},$$

$$c_p = \text{specific heat of water},$$

$$\boldsymbol{Heating_{Temp.\ Maintenance}} = m_{recirc} * c_p * (T_{loop\_supply} - T_{loop\_return}),$$

$$m_{recirc} = \text{mass flowrate of recirculation loop},$$

AND

$$\boldsymbol{Power\ Input} = \boldsymbol{HPWH_{Power}} + \boldsymbol{ER\_Heat_{Power}} + \boldsymbol{Fan_{Power}} + \boldsymbol{AuxHeat_{Power}} + \boldsymbol{HeatTrace_{Power}}$$

$$HPWH_{Power} = \text{Electrical power used by HPWHs}$$

$$ER\_Heat_{Power} = \text{Electrical power used by electric resistance water heating equipment}$$

$$Fan_{Power} = \text{Electrical power used by auxilary fans when HPWHs are installed indoors}$$

$$AuxHeat_{Power} = \text{Electrical power used by space heating equipment which provide heat to HPWHs}$$

$$HeatTrace_{Power} = \text{Electrical power used by heat trace freeze protection systems}$$

A.10 - Sizing for the Majority of Runtime