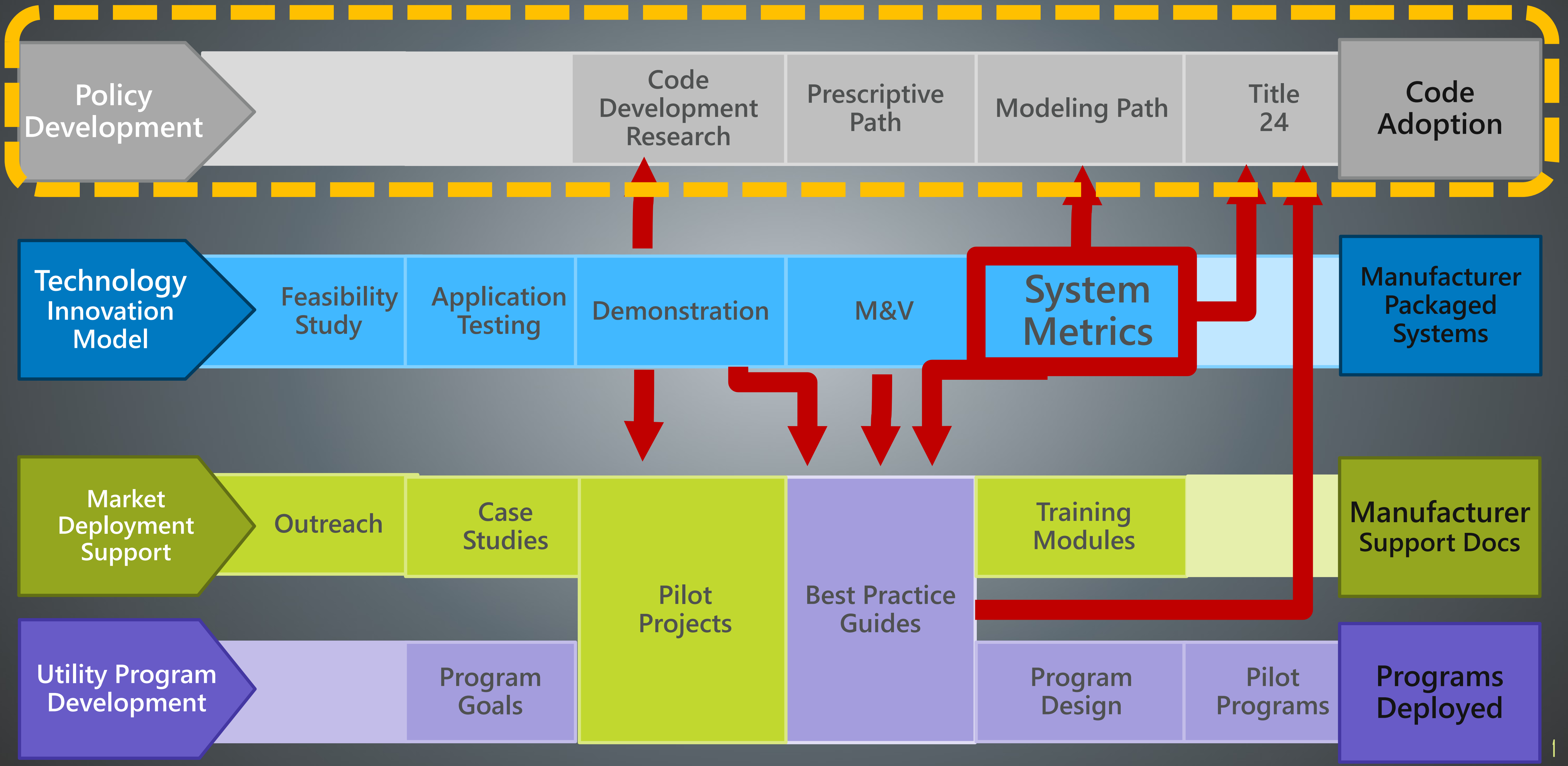
Parallel Development Paths



PG&E Test Lab Updates

Heat Pump Hot Water System Testing in Multi-Family Buildings

Central Water Heating Work Group Meeting
June 2nd, 2020
Amin Delagah
ATS Performance Testing and Analysis Unit

Together, Building a Better California

Applied Technology Services

Committed to delivering practical solutions to challenging problems

Overview

- Lab overview
- Background on current HP system testing
- Tests completed
- Current status
- Schedule of upcoming work
- Vision for future lab testing
- Questions for the working group

Supporting California’s Codes and Standards

Program Objective:

The Statewide Codes & Standards Utility Program supports the Energy Commission in the development and substantiation of new building codes and appliance standards.

The Program also supports the advancement of building energy modeling simulation tools.

- This is accomplished through activities such as laboratory testing to collect data to support robust models as well as technical analysis to inform software adjustments.

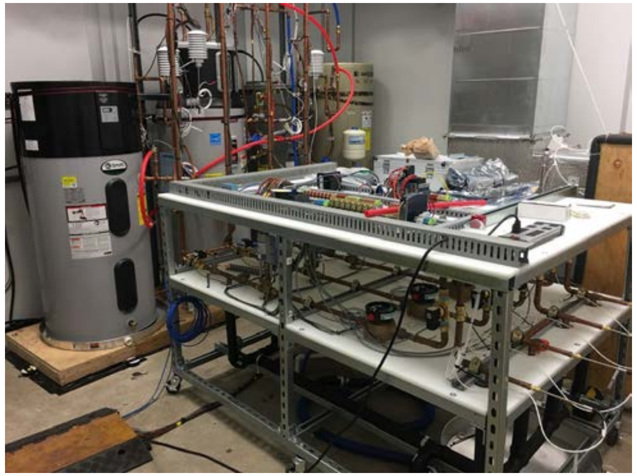
C&S Testing in the Advanced Technology Performance Lab

Hydronic Circulators

Commercial HVAC

Applied Technology Services

6 Test Chambers in ATPL, 1 large enclosed room in MET building



Heat Pump Water Heater

Boilers

Commercial Dryers

ATPL Upgrade – Centralized Resources for Water and Air Tempering

6 Cartridge Boiler

160°F
Hot Water

Mix Streams To Desired Test Condition

Heat Exchangers

41°F
Chilled
Water

20 T Water Chiller

2 Glycol Chillers - 40 Tons Total

0°F - 32°F
Glycol

Needle Valves

12 lb Steam

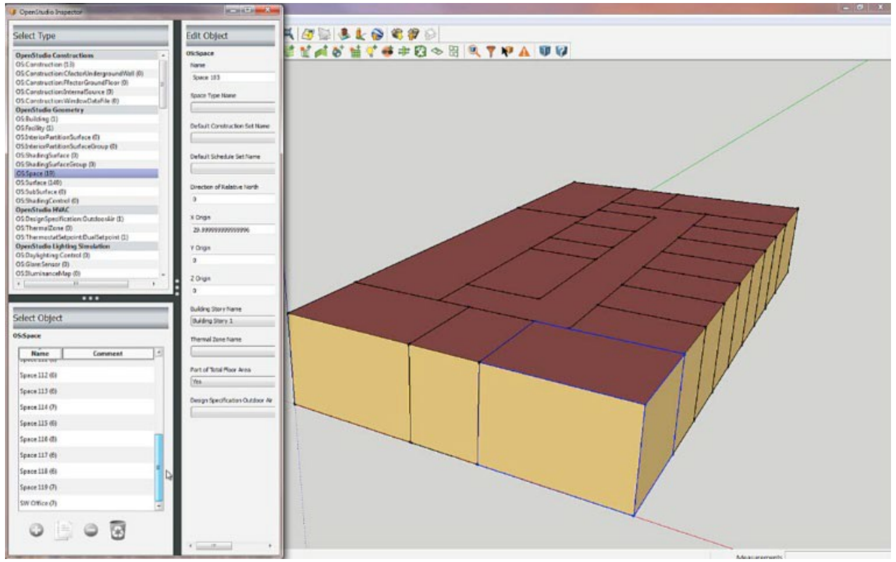
Steam Boiler

City Water

Softened
City Water

HP System Performance Testing in Multi-Family Buildings

Extensive Lab Testing, Why?



- Identify high-performance HP based hot water designs
- Update building energy simulation software applications
- Support advancement of the CBECC compliance software central multifamily water heating features
    - Initially developed for gas boilers and doesn't have an electric heat pump option
    - Software ignores significant issues that are critical for HPWHs (e.g. impact of the pumped distribution loop on inlet water temperature)
- Without reliable design criteria and performance data, it is not possible to accurately model multifamily HPWH systems to develop prescriptive and system modelling based energy efficient building regulations

Scope

Total of 9 HPs and 9 storage tanks in roughly 24 configurations will be tested

Storage volume ranges from 80 gal to 1200 gal

Heat pump heating capacity ranges from 1.2 kW (4,200 Btu/h) to 60 kW (204,000 Btu/h)

Four distribution system types

- No recirculation
- Continuous recirculation
- Aquastat (temp. control)
- Demand controller (temp. + water demand)

HP + Tank Integrated

Split HP + Tank

Steady State Testing of Commercial HPs

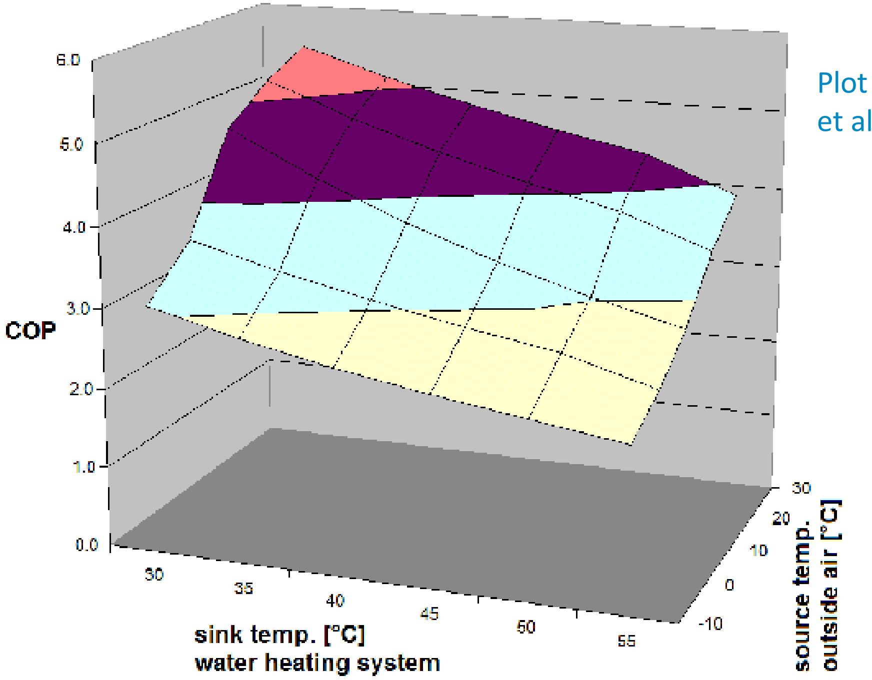
HP Performance Map Testing:

- COP
- Input power
- Output heating capacity

For a full range of expected air and water conditions for medium to large HPs

4 setpoints for each condition:

- Minimum HP operating ambient air temp or as low as 5°F and up to 95°F
- Water temperatures of 45°F to 115°F
- Relative humidity of 30% to 72%



Plot Credit: Dott et al. 2012

Total System Performance Testing

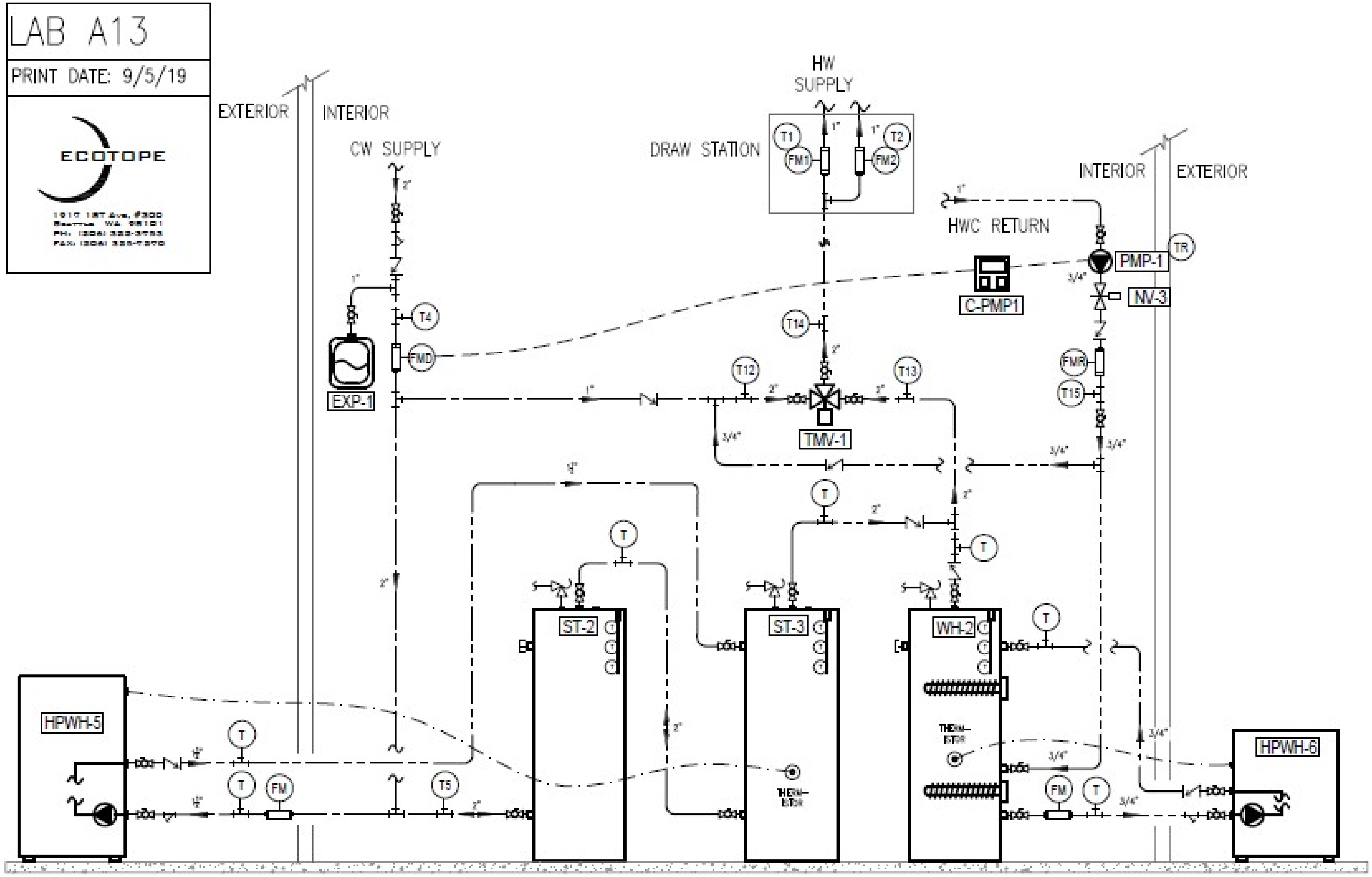
Application testing involves 24-h water use tests using three profiles

Test impact of various configurations

- Performance of HP
- Volume and configuration of tanks
- Size and type of distribution system
- Recirculation pump controls
- Mixing valve types

Four apartment prototypes (4, 8, 36, 88 units)

HP and tank sizes will be matched to apartment prototypes

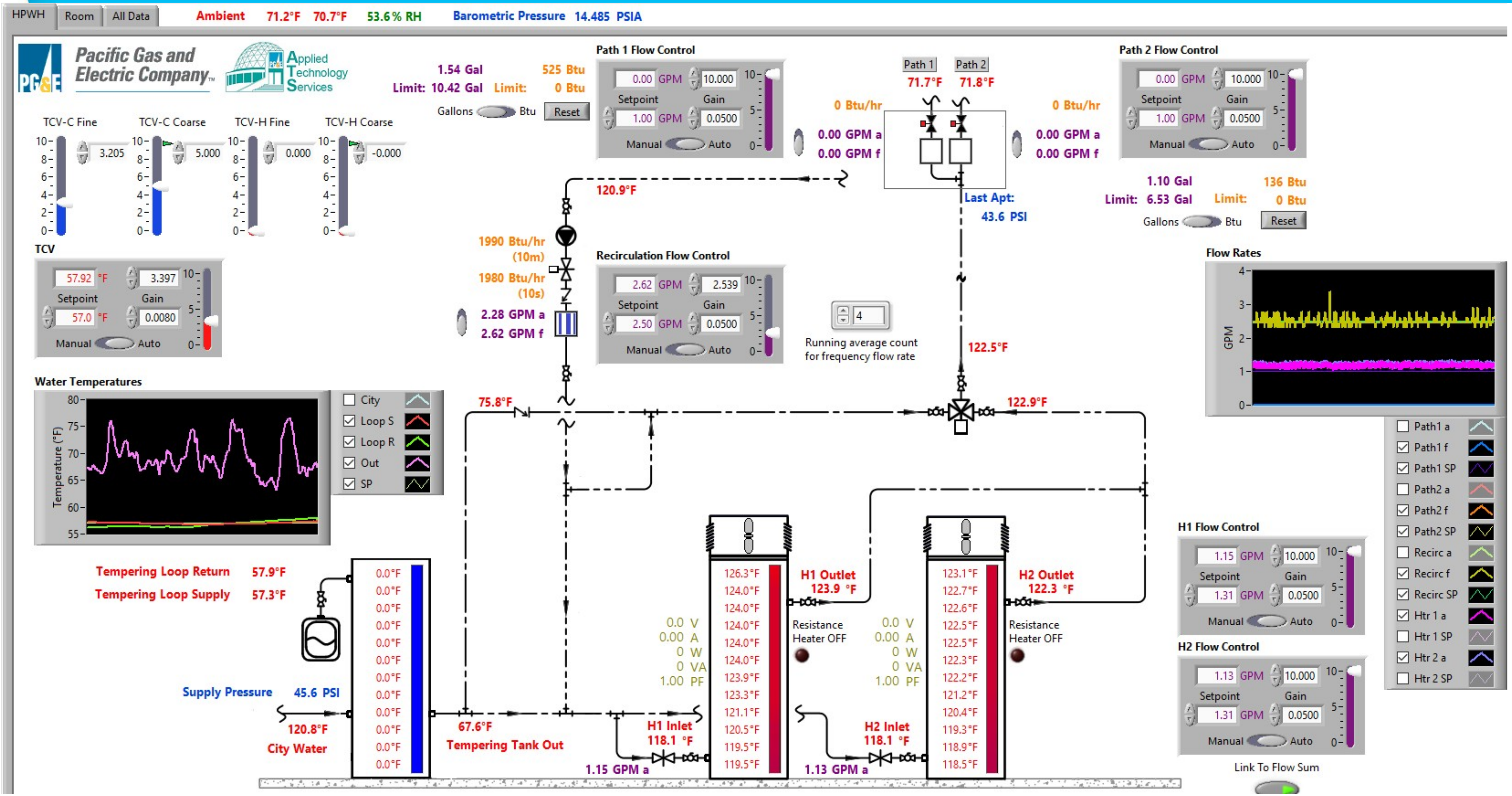


Testing of Smallest HPs Completed

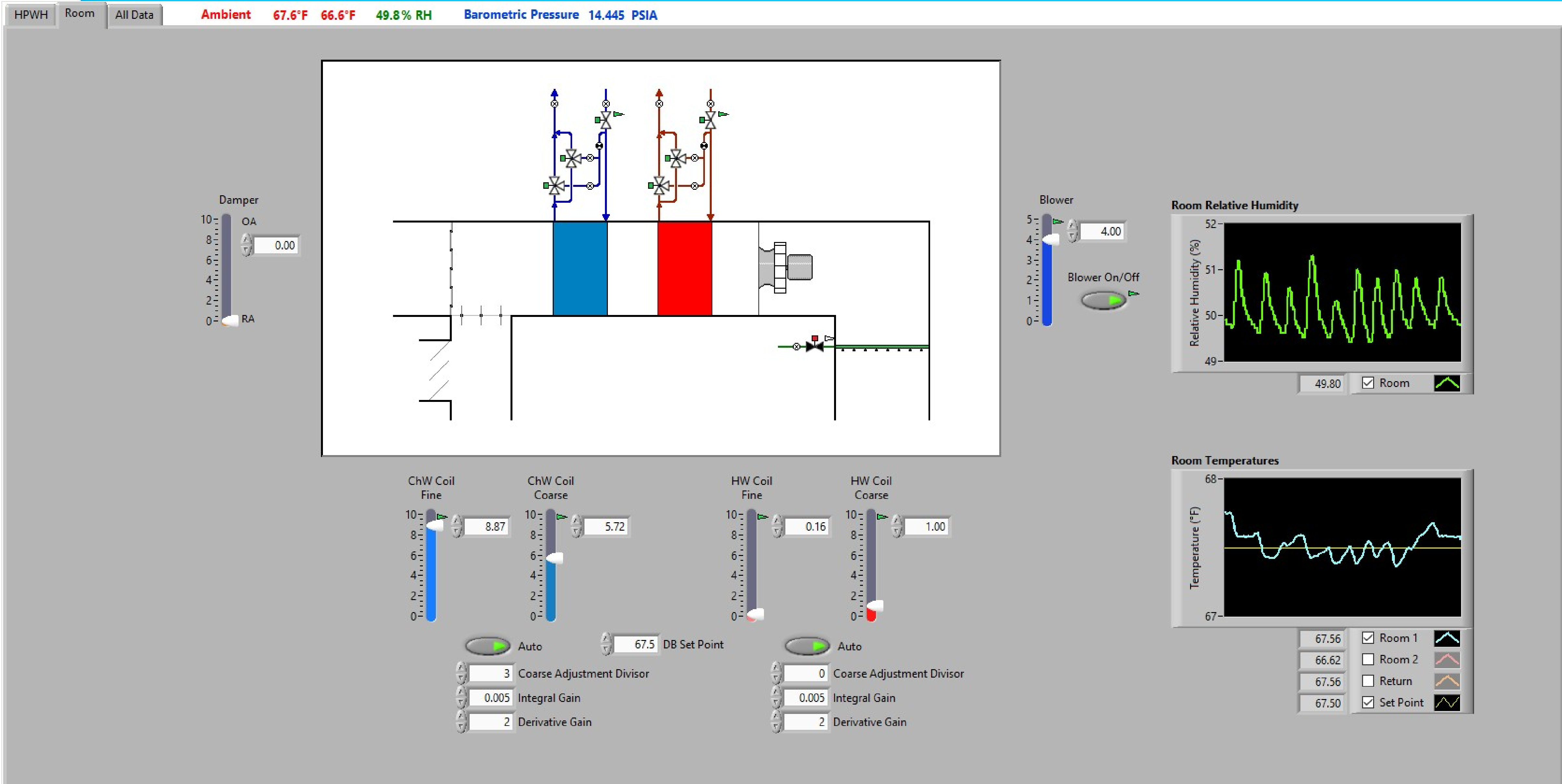
Mimics hot water systems in 4-8 unit apartment buildings

- Distribution pump controls
- Currently testing 80 gallon integrated HPWHs
- Distribution loop
- Draw stations (Apartments)

Lab View Control and Testing Interface (HP Test Screen)



Lab View Control and Testing Interface (Space Conditioning Screen)



Integrated 80 Gal. HP Based HWS Tests Completed

Test Matrix (4 configurations, 17 24-hour tests)

No recirculation

- Single HP
- Parallel HP

Single and Parallel configurations with recirculation pump

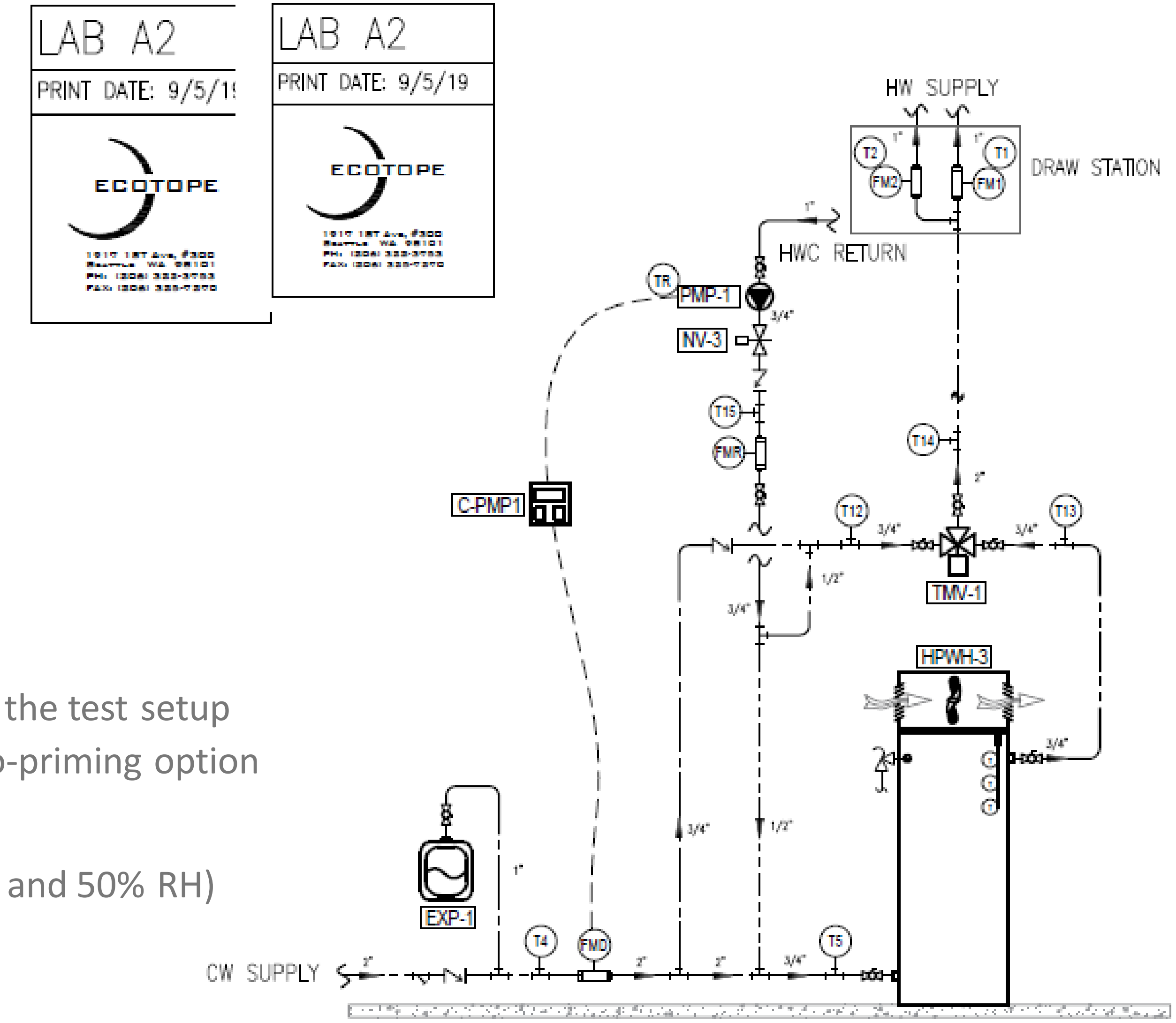
- Continuous Recirculation, Demand control, Aquastat
- 125°F, 140°F tank setpoints
- 100 Watts and 200 Watts per apartment loop heat loss testing
- 4 Unit medium water flow profile testing
- 8 Unit low and medium water flow profile testing

Additional tests

- Additional testing to commission system and continuously improve the test setup
- Additional demand control tests to understand (20 min to 1hr) auto-priming option

Validation tests to compare to prior testing from Ecotope

- Heater COP testing over the range of tank temperatures (67.5°F DB and 50% RH)
- Heater UEF test (95°F DB and 40% RH)



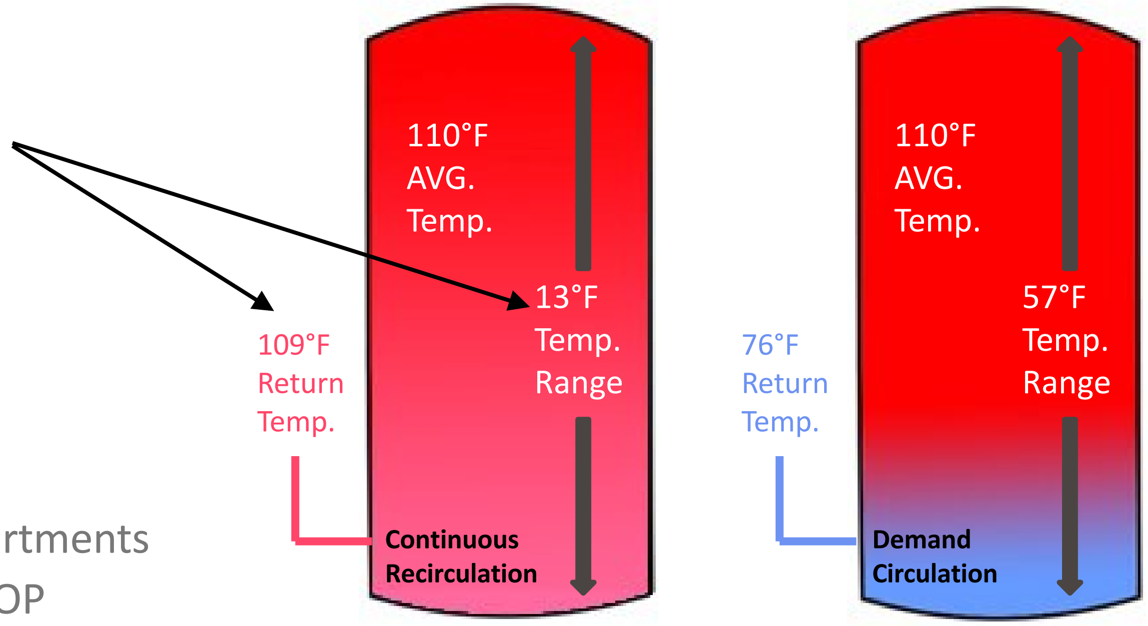
Preliminary Findings of Small Integrated HPs

Continuous recirculation

- Major loop heat loss due to 24 h pump operation
- Poor tank stratification due to high recir. return temp.
- Can’t maintain 125°F setpoint temperature
- Poor system COP of 1.4

Demand circulation

- Good tank stratification equates to high COP of 2.5
- Digital mixing valve has poor response time
- Maintains solid hot water delivery performance to apartments
- 59% decrease in energy use, 81% increase in system COP



	Heater Outlet Temp.	Mixing Valve Hot Inlet Temp.	Mixing Valve Outlet Temp.	Apartment Delivery Temp.	Pump Run Time	Loop Heat Loss	Energy Use	System COP
Continuous Recirculation	114°F	114°F	113°F	109°F	24 h	154 Watts/Apt 29.6 kWh/d	17.5 kWh/d	1.4
Demand Circulation	123°F	120°F	117°F	111°F	0.4 h	50 Watts/Apt 9.6 kWh/d	11.0 kWh/d (59%↓)	2.5 (81%↑)

Preliminary Findings

- The loss of tank stratification with a pump operating continuously is causing a reduction in heater recovery rate and this is further compounded by the significant loop heat loss rates
- Integrated heater(s) can’t keep up in HP mode with continuous flow recirculation with 4 or 8 unit Medium Flow Profiles
- Causes the system test to either go out of spec as it can’t hold thermostat temperature or if there is a significant reduction in tank temperature, it kicks on electric resistance heating
- If applied to real-world apartment building, the facility would need:
  - Two HPWHs for 4 unit apt. building
  - Three HPWHs for 8 unit apt. building
- Parallel tank configuration with continuous recirculation is not viable for these small apartments from a system performance, installation and operating cost standpoint
- Pump control scenarios show potential, but further refinements are necessary

Current Status of Lab

- Recommenced on HP project in late May in the laboratory to improve test setup and recommissioning the lab
- Finished up testing of integrated 80-gal units with two supplemental tests with modified loop heat loss rates
- We will soon start decommissioning the integrated HP heaters and transition to build and commission the residential HP split system
- Testing to begin thereafter and continue for 6 weeks covering 5 configurations and a total of 23 tests.

Schedule of Upcoming Work

- Reduced activity in the lab due to pandemic to mitigate health risks (50% staff hours onsite)
- This will reduce the speed in which we build and commission the lab and change test setups
- Added remote desktop to enable testing offsite and remote coordination with techs onsite
- Will update schedule periodically depending on the pace we can achieve through summer

	Test Type	Q1 2020	Q2 2020	Q3 2020	Q4 2020	Q1 2021
Integrated HPWH #1 (1 Ton or less)	24-h Profile Testing	Complete				
Split Heat Pump #1 (1 Ton or less)	24-h Profile Testing					
Split Heat Pump #1 (>1-5 Tons)	Performance Mapping					
Split Heat Pump #1 (>5-30 Tons)	Performance Mapping					
Split Heat Pump #1 (>5-30 Tons)	24-h Profile Testing					
Split Heat Pump #2 (>5-30 Ton)	Performance Mapping					
Split Heat Pump #2 (>5-30 Tons)	24-h Profile Testing					
3 Split HP Models (>1-30 Tons)	Low-Temp Performance Mapping					
Integrated HPWH #2 (1 Ton or less)	24-h Profile Testing					

Energy/Cost Comparison in a Large Apartment Building

Gas-fired water heaters have roughly 90% of the market share

Without stringent efficiency regulations, HPs are a tough sell to building owners and developers

Goals:

- Operations at cost neutral or better versus existing heaters
- Achieve large site and source energy savings

Heater Type	Gas-Fired Heater (80-95% TE)	Electric-Heat Pump (COP 4.5)
Efficiency Characterization	Average	Very Efficient
Heat to Water (Btu/d)	1,000,000	1,000,000
System Efficiency	**60%**	**3.0**
Site Energy (Btu/d)	**1,666,666**	**333,333**
Source-Site Energy Ratio	1.05	3.14
Source Energy (Btu/d)	1,750,000	1,046,667
California Utility Cost ($/d)	**$18.20**	**$20.50**

Utility cost based on $1.09/Therm and $0.21/kWh

Mixed Bag with Market and Regulatory Outlook

Challenges

- Continuation of utility cost trend of increased electrical rates and flat gas rates
- ASHRAE Guideline 12-2020 Legionella mandates if adopted would reduce system efficiency of centralized systems with recirculation

Opportunities

- New 2022 CEC Time Dependent Valuation calculations will favor electric HPs over natural gas water heaters for the first time

Illustration Credit: UC Davis Western Cooling Efficiency Center

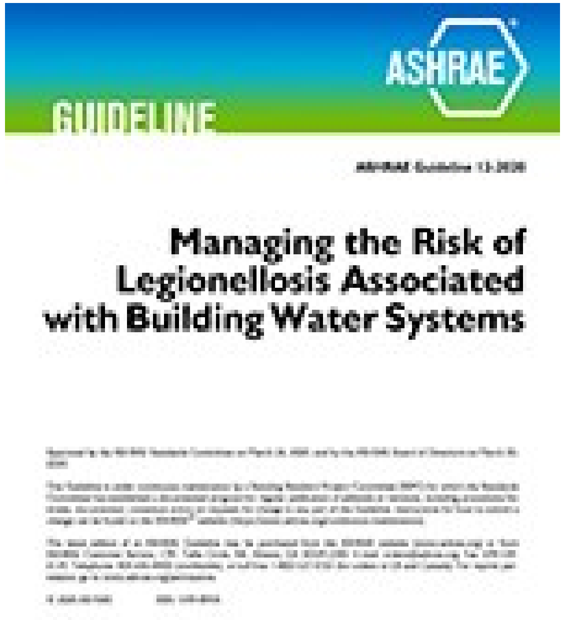
What is the Prediction or Vision for the Lab in the Future?

Upcoming Project

- Upcoming Riser distribution system testing to mimic midrise 36 unit prototype apartment building

Vision for Future Projects

- Continued testing of centralized HP systems with advanced refrigerants
- Load shifting in centralized systems
- Application of ASHRAE Legionella prescriptive guidelines and impact on system COP
  - Higher temperature supply and return
  - Mixing valves upstream in distribution loop and downstream after branch line connections



GUIDELINE

ASHRAE

Managing the Risk of Legionellosis Associated with Building Water Systems

What is the Prediction or Vision for the Lab in the Future?

Vision for Future Projects

- Combi mode testing (Utilize space cooling byproduct for summer/shoulder season space cooling

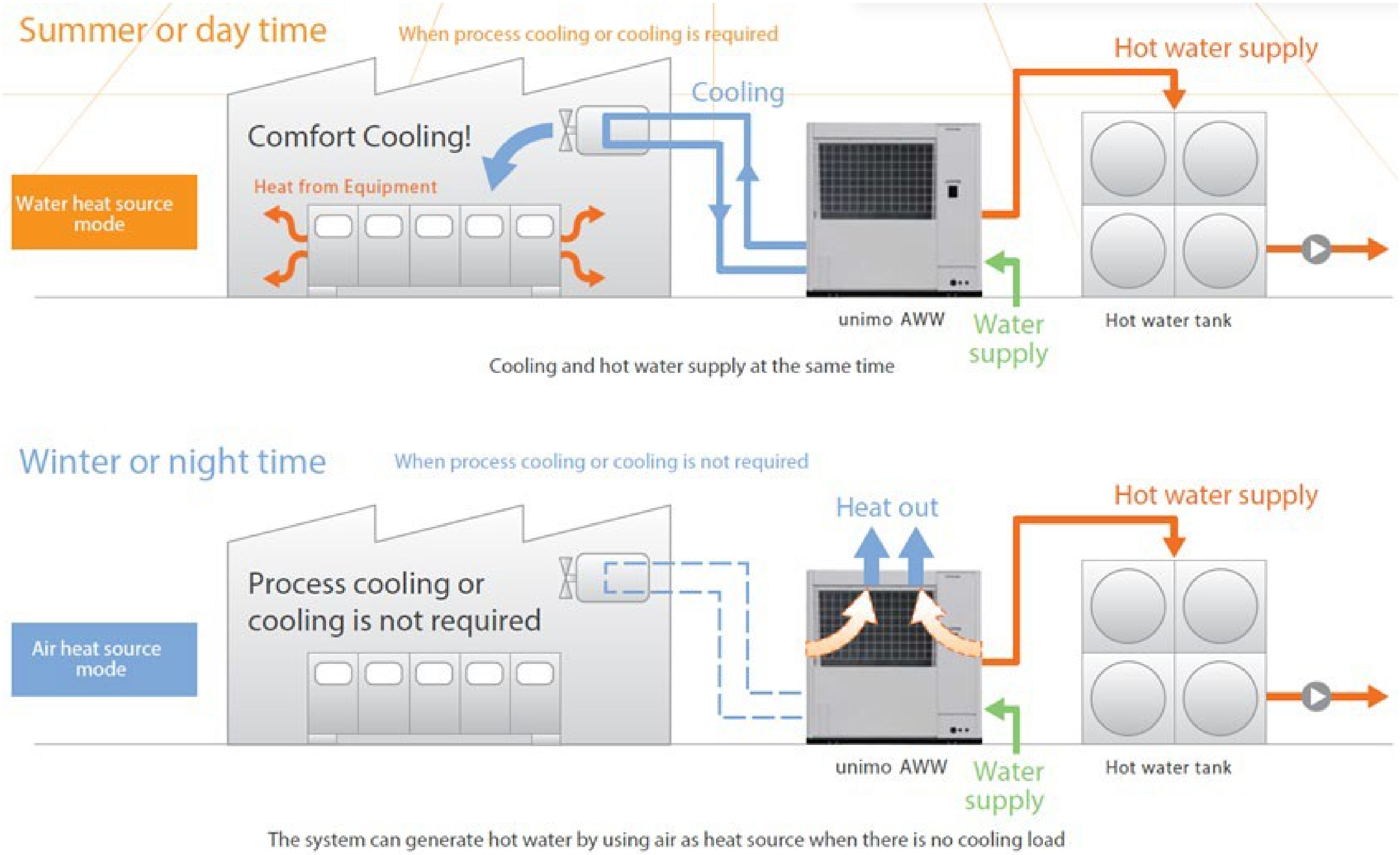


Illustration Credit: Mayekawa

What is the Prediction or Vision for the Lab in the Future?

Vision for highest performance systems

- Clustered centralized systems with optimized plumbing/layout and no recirculation
  - For example, a water heater would be placed centrally in a vented closet in a 2 unit x 2 story configuration with a shared wall and mirrored bathrooms and kitchens on the common wall
  - This minimizes size and length of distribution piping to allow for adequate hot water delivery performance while maximizing the performance of the HP

Illustration Credit:
https://www.themayfairalgiers.com/

What is the Prediction or Vision for the Lab in the Future?

Vision for highest performance systems

- Individual fully integrated space conditioning and water heating systems for low energy buildings
  - 1 HVAC appliance versus 3 appliances
  - Comprehensive HVAC project

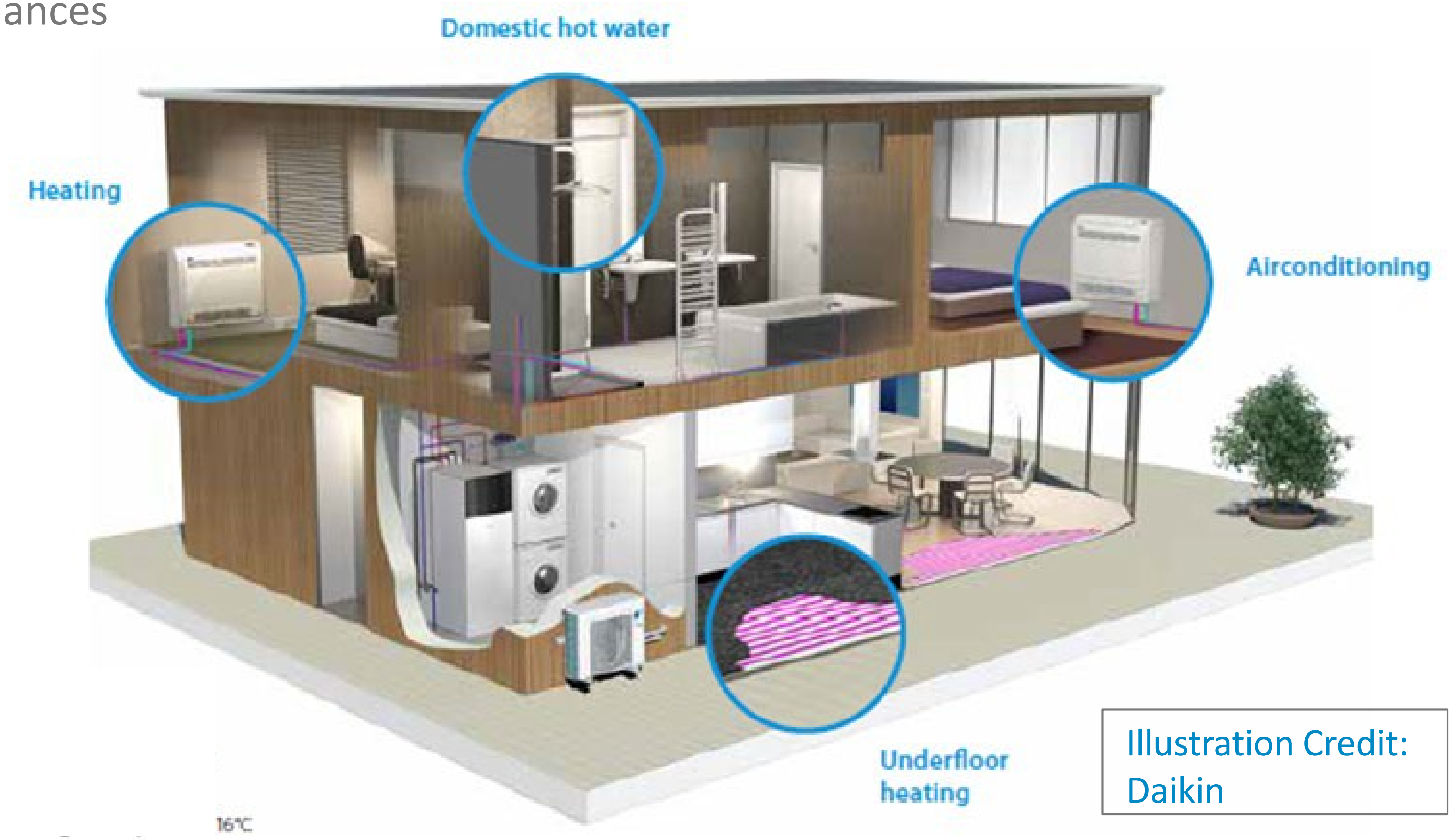


Illustration Credit: Daikin

Questions for Work Group

What technical information do others have and what have others learned?

Is there other dedicated hot water system testing labs to potentially collaborate with?

- Aware that NREL is building a lab for smaller HP systems

What is needed from others to make this vision happen?

Other ideas for next steps

Thank you!

Follow the project progress at:
https://title24stakeholders.com/support-for-energy-modeling-advancements/

CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

This program is funded by California utility customers and administered by Pacific Gas and Electric Company (PG&E), San Diego Gas & Electric Company (SDG&E®), Southern California Edison Company (SCE), Los Angeles Department of Water and Power (LADWP), and Sacramento Municipal Utility District (SMUD) under the auspices of the California Public Utilities Commission.

PG&E

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CA Code Development Update

Central HPWH Status in Title 24

Danny Tam
June 2, 2020
California Energy Commission

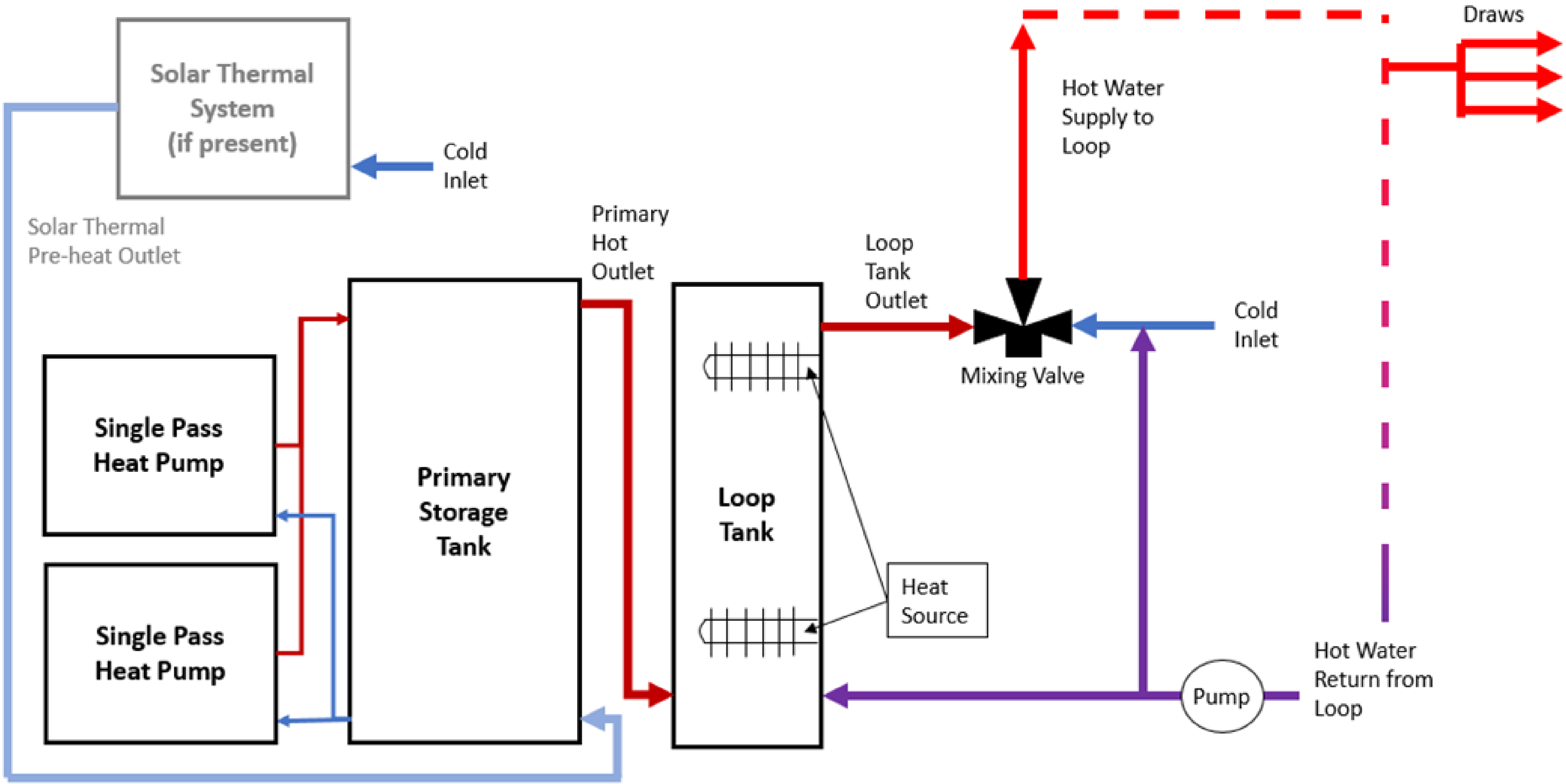
CHPWH Implementation Timeline

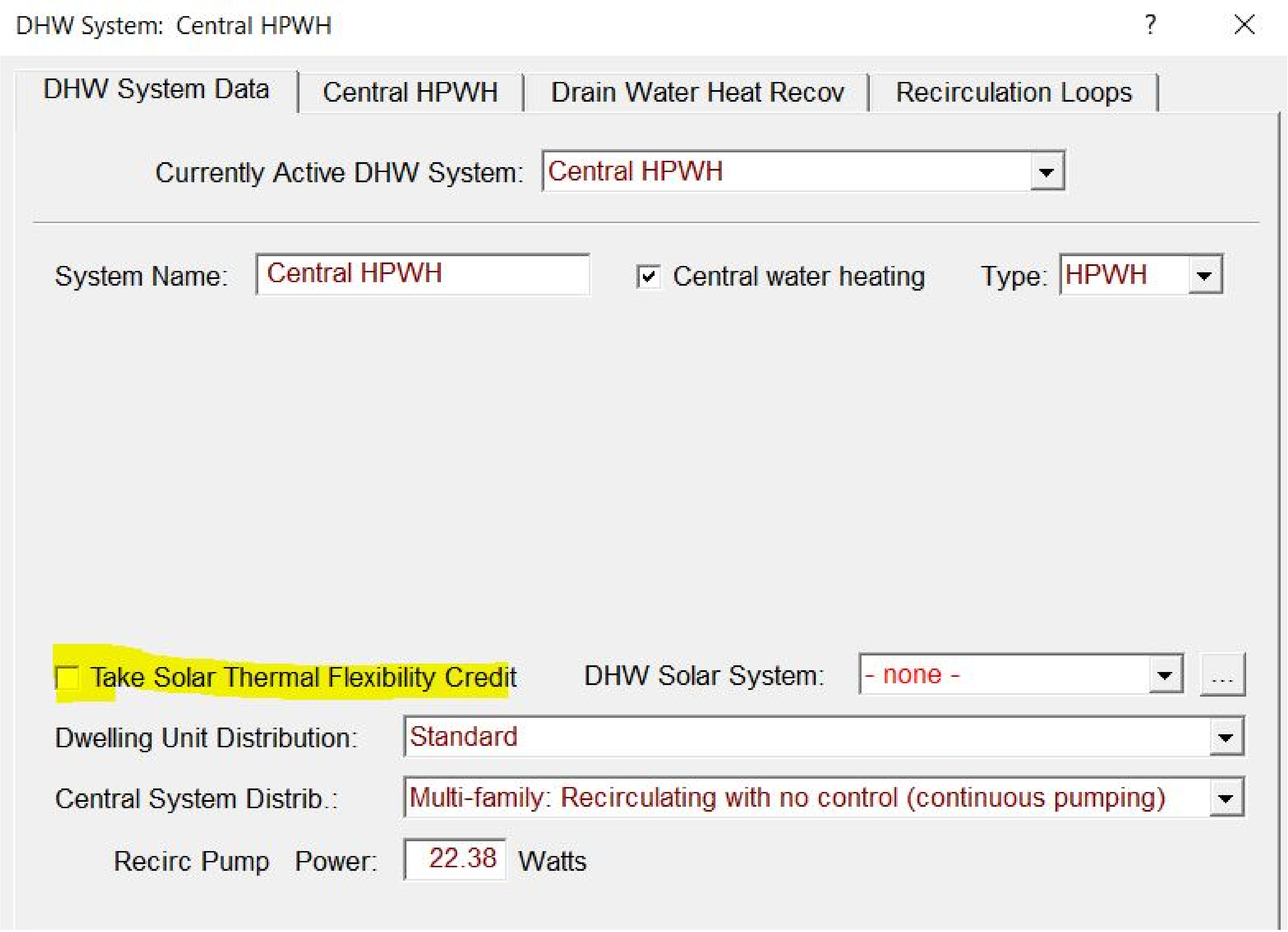
- Phase I
  - – Executive Director approved prescriptive option
  - – "Physics-based" model for ganged split system HPWH
- Phase II
  - – Manufacturer self-reported process to capture performance data
  - – Self-reported declaration and datasheet on CEC website
- Phase III
  - – PG&E Lab test

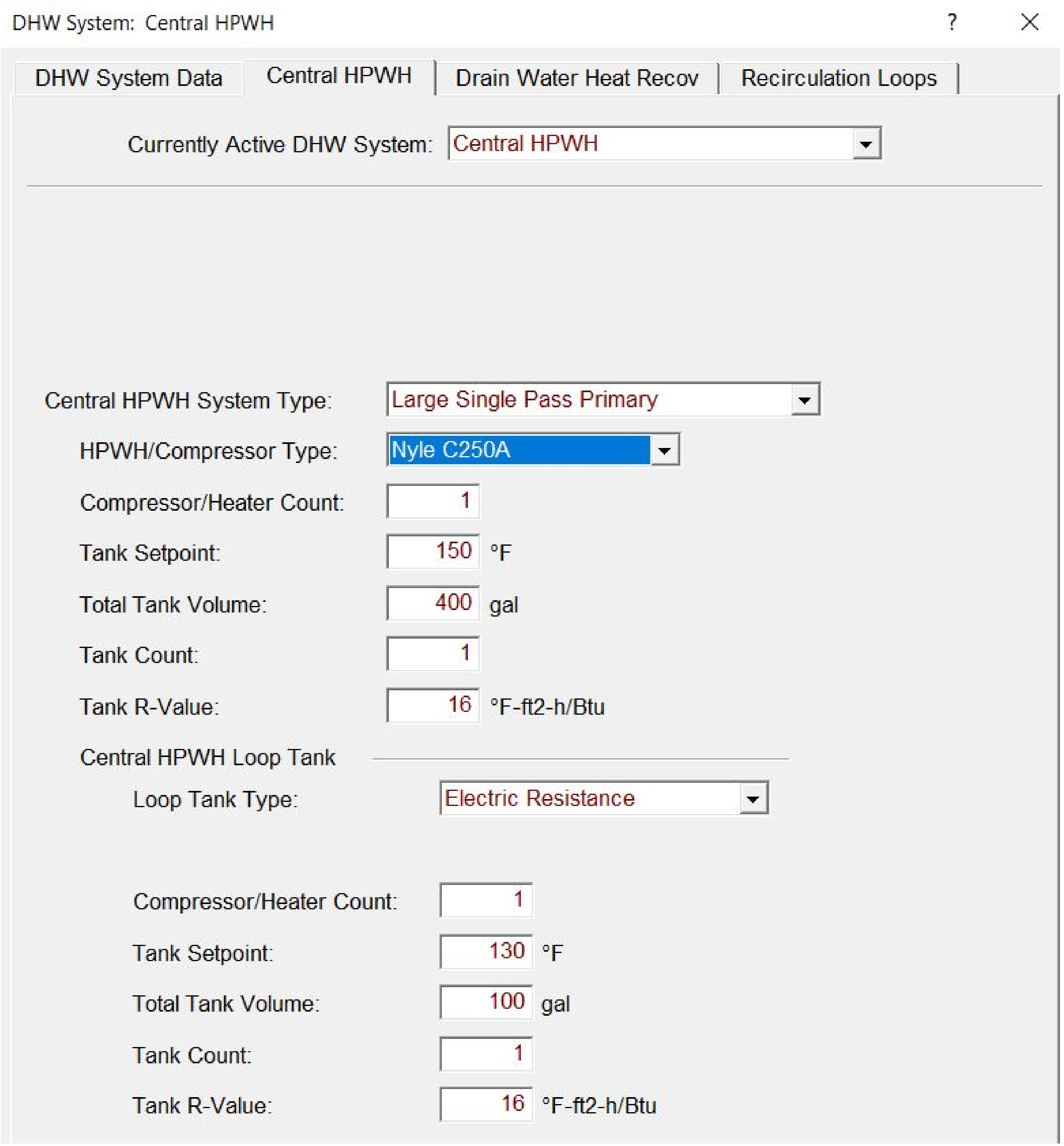
Prescriptive Option for Central HPWH

- Limited to split-system HPWH in series
- Primary heating load separated from temperature maintenance load.
- Sizing requirement based on number of bedroom and dwelling units for:
  - Number of compressors
  - Primary tank volume
  - Loop tank volume
- Allow PV tradeoff in place of solar thermal requirement

System Schematic




DHW System: Central HPWH
DHW System Data
Central HPWH
Drain Water Heat Recov
Recirculation Loops
Currently Active DHW System:
Central HPWH
System Name:
Central HPWH
Central water heating
Type:
HPWH
Take Solar Thermal Flexibility Credit
DHW Solar System:
- none -
Dwelling Unit Distribution:
Standard
Central System Distrib.:
Multi-family: Recirculating with no control (continuous pumping)
Recirc Pump Power:
22.38
Watts


DHW System: Central HPWH
DHW System Data
Central HPWH
Drain Water Heat Recov
Recirculation Loops
Currently Active DHW System: Central HPWH
Central HPWH System Type: Large Single Pass Primary
HPWH/Compressor Type: Nyle C250A
Compressor/Heater Count: 1
Tank Setpoint: 150 °F
Total Tank Volume: 400 gal
Tank Count: 1
Tank R-Value: 16 °F-ft2-h/Btu
Central HPWH Loop Tank
Loop Tank Type: Electric Resistance
Compressor/Heater Count: 1
Tank Setpoint: 130 °F
Total Tank Volume: 100 gal
Tank Count: 1
Tank R-Value: 16 °F-ft2-h/Btu

Central Heat Pump Water Heater Performance Map

If the Central Heat Pump Water Heater compliance option is claimed on the performance certificate of compliance, the performance map must be certified to the California Energy Commission. Manufacturers are required to submit performance certification information electronically using the following declaration statement:

- Declaration - Word
- Datasheet - Excel

CONTACT

Submit forms and questions to:
CertifiedtoCEC@energy.ca.gov

Danny Tam
916-654-8435

CATEGORIES

Topic
Efficiency

Division
Efficiency

Program
Building Energy Efficiency Standards - Title 24

Max Operating Temperture T_{in}	110
Min Operating Temperture T_{in}	40
Max T_{air} for Heat Pump Operation	95
Min T_{air} for Heat Pump Operation	45

Tair @ 95	Tout (F)	Input Power (kW) Tin (F)				Output Capacity (kW) Tin (F)			
		40	63	87	110	40	63	87	110
	125								
	137.5								
	150								

Tair @ 78	Tout (F)	Input Power (kW) Tin (F)				Output Capacity (kW) Tin (F)			
		40	63	87	110	40	63	87	110
	125								
	137.5								
	150								

Tair @ 62	Tout (F)	Input Power (kW) Tin (F)				Output Capacity (kW) Tin (F)			

Questions?

System Metrics

- **Outcomes**
  - Manufacturers require clearly defined regulatory path
  - Utilities require persistent and reliable performance
  - Designers need reliable design guidelines to reduce risk and cost

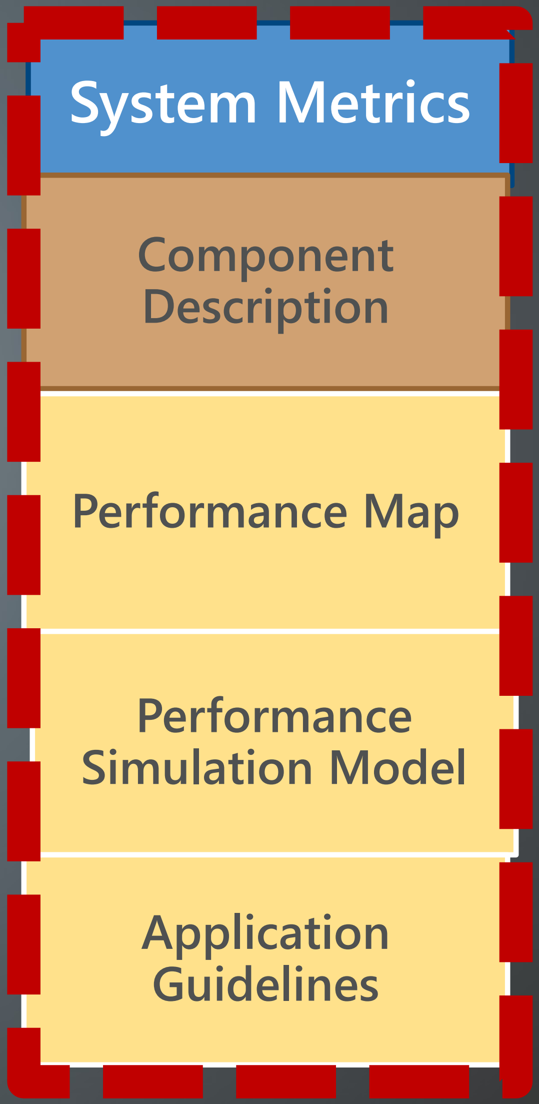
Code Comparisons

- **California Code**
  - Designed to speed adoption of CHPWH in marketplace by allowing multiple manufacturers to self-certify
  - Requires reliably vetted tested design configurations
- **Washington Code**
  - Credits any project with "HPWHs".
  - No control over application, design, system metrics
  - Incentivizes poor performance

System COP

- Full System Performance metrics are needed for EE programs and planning) – not the compressor widget in isolation
- Measures the impact of fans, pumps, defrost cycles, pipiing configuration, integration of back-up heating and temperature maintenance systems

- Two methods to determine System COP:
  1. Performance Map and physics-based model e.g. CA modeling software
  2. Direct measurement in the field



Test Method/Procedure

- **National testing protocol ?**
  - Requires fully functional domestic water heating systems – not compressor only
  - Tested under full range of operating conditions
- **Current DOE test for AWHPs**
  - Not useful because uses a single test point with 80.6F air temp, 70F entering water, and 120F leaving water.

Technology Innovation Model

- Feasibility Study
- Application Testing
- Demonstration
- Measurement and Verification