



Emerging  
Technologies

# Ecosim Sensitivity Analysis

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# Introduction

Ecotope has conducted the following sensitivity analysis of Ecosim, a standalone energy analysis tool focused on multifamily Commercial Heat Pump Water Heater (CHPWH) systems. Ecosim provides utilities, manufacturers, designers, and regulators with a tool to analyze how CHPWH systems perform against a baseline for various design choices. The following analysis reveals how changes to certain input variables alter the resulting energy input and system coefficient of performance (COP). We analyzed Ecosim’s sensitivity to several variables by selecting and then changing one input at a time while maintaining others at a defined baseline value. The goals are two-fold,

- 1. By modifying variables known at the time of input, such as the source air location or the prototype building, we quantify differences to help define the final Advanced Water Heater Specification (AWHS) modeling runs and understand common scenarios that improve performance and their benefits.

- 2. By modifying variables that are unknown at the time of modeling and may remain unknown until post-occupancy, such as the temperature maintenance (TM) load, we aim to quantify the error in modeled results and prioritize areas for further research.

First, we discuss the baseline model from which we compare results, then the modifications to known variables, and finally, the modifications to unknown variables.

## Baseline Model

Here we are interested in looking at differences across climate zones and heat pump water heater (HPWH) technology. The baseline model is parametrically composed of three multifamily prototypes, five IECC climate zones<sup>ii</sup>, and five HPWHs for 75 different baseline models. The prototypes are weighted, so the results have a maximum of 25 different baseline models. Table 1 describes the baseline model’s climate zones and the associated HPWHs used in the models.

Table 1. Baseline Climate Zones and HPWHs

| Climate Zones                                  | HPWHs                   |
|------------------------------------------------|-------------------------|
| CZ1A Honolulu, Hawaii (very hot, humid)        | Rheem HPHD135HNU_483 MP |
| CZ3A Atlanta, Georgia (warm, humid)            | SanCO2                  |
| CZ4C Seattle, Washington (mixed, marine)       | Mitsubishi QAHV         |
| CZ5A Buffalo, NY (cool, humid)                 | Colmac CxV5 SP          |
| CZ7 International Falls, Minnesota (very cold) | Colmac CxA20 SP         |

The different climate zones are designed to provide a wide selection of climate zones that range from climates always greater than 40F to climates that spend 50% of the year colder than 40F. The selected HPWHs, provide a selection of all the major refrigerants currently available on the market and manufacturers that Ecotope intends to work with through the Product Assessment Data Sheet (PADS) in the short term. Note that the Rheem multipass unit data submittal is an outlier amongst other multipass units; it performs much better than all others in this classification.

Due to the variety of possible sizing guidelines that manufacturers could submit, system sizing remains independent of manufacturer PADS in this analysis. The Ecosizer methodology<sup>iii</sup> can be used to derive appropriate system sizes for each prototype. To simplify runs, we assume that sizing remains constant across climate zones and that HPWH systems are sized for the coldest modeled climate zone. In energy modeling, the total heating capacity has a minor impact on System COP (SysCOP) if the total capacity can meet the load. However, changes in the storage volume can significantly impact performance because surface area changes affect the heat loss to the environment. All the single pass (SP) HPWHs units use the swing tank configuration, while the multipass units (MP) use a return to primary configuration (See Appendix A for AWHs configurations).

Where required modeling variables are absent from PADS, we make professional assumptions. These assumptions include the following:

- The target leaving water temperature (LWT) or supply temperature to the occupants is 120°F.
- Setpoints for SP HPWH models are set to 140°F unless they use R744A, then setpoints are set to 145°F.
- Setpoints for MP HPWH models are fixed at 145°F.
- Setpoints on secondary heaters, series (swing) or parallel, are set to the LWT plus the heater's dead band.

We discuss the baseline prototypes below and explain the baseline values and variable modifications in the following sections.

## Baseline Prototypes

The baseline prototypes follow the standard U.S. Department of Energy low-, mid-, and high-rise apartment buildings. The number of apartment bedrooms implicitly defines the occupancy rates and hot water draws in the Ecosim model<sup>iv</sup>. The model references a set of prototype buildings representative of the state of California's building stock. Ecosim references this representative set, produced by TRC Companies<sup>v</sup>, as part of Ecosim's initiating project funded to supplement California's energy modeling software. Ecosim defines a hot water draw as a flow rate over a period. However, this implicit definition does not align with DOE's prototype definitions. DOE defines prototypes with 1-bedroom apartments only, but with differing occupancy rates. Table 2 compares occupancy rates of building prototypes informed by TRC and DOE, and Table 3 describes the occupancy rates used in Ecosim to define hot water draws. To align with the average

occupancies in the DOE prototypes, we assume that the mid- and high-rise prototypes use the hot water draws defined by the 2-bedroom apartments in Ecosim, and the low-rise prototype uses the hot water draws from 12 1-bedroom and 6 two-bedroom units to derive an average occupancy for the building of 2.02 people/apartment.

**Table 2. Average Occupancy Rates in Prototype Buildings**

| Prototype | Average Occupancy (People/Apt) |     |
|-----------|--------------------------------|-----|
|           | TRC                            | DOE |
| Low-Rise  | 2.18                           | 2   |
| Mid-Rise  | 2.13                           | 2.5 |
| High-Rise | 2.00                           | 2.5 |

**Table 3. Ecosim Occupancy Rates by Apartment Size**

| Apartment Size | Occupancy Rate (People/Apt) |
|----------------|-----------------------------|
| Studio         | 1.37                        |
| 1 Bedroom      | 1.74                        |
| 2 Bedroom      | 2.57                        |
| 3 Bedroom      | 3.11                        |
| 4 Bedroom      | 4.23                        |
| 5 Bedroom      | 3.77                        |

Weighting across low-, mid-, and high-rise buildings represents a unique challenge as the three building prototypes are subject to distinct building code requirements:

residential (low-rise) and commercial (mid- and high-rise). National prototype and climate weights are typically developed for each code, respectively. Therefore, weights for this effort have been developed from a combination of sources. The sources developed weights with a specific focus on new construction.

We use 2019 multifamily building U.S. Census new housing characteristics data to find the fraction of low-rise (42.6%) and mid- and high-rise *units* (57.4%)<sup>vi</sup>. The weighting for mid-rise and high-rise buildings is derived from PNNL commercial new construction weights<sup>vii</sup> and is assumed to be constant across climate zones. We use the total apartment count for each prototype to convert from unit to building weights. This analysis results in weights for the three prototypes for the variants defined by TRC companies<sup>viii</sup> and DOE, which is provided in Table 4. Table 5 describes the differences between TRC and DOE definitions of low-, mid-, and high-rise buildings for each multifamily building schema. This study uses the DOE prototypes as baseline values.

**Table 4. Prototype Building Weighting**

| Prototype | TRC | DOE |
|-----------|-----|-----|
| Low-Rise  | 66% | 64% |
| Mid-Rise  | 27% | 26% |
| High-Rise | 7%  | 10% |

**Table 5. Prototype Buildings by Unit Counts and Sqft**

| Size      | Low-Rise |      |       |      | Mid-Rise |      |       |      | High-Rise |      |       |      |
|-----------|----------|------|-------|------|----------|------|-------|------|-----------|------|-------|------|
|           | TRC      |      | DOE   |      | TRC      |      | DOE   |      | TRC       |      | DOE   |      |
|           | Count    | Sqft | Count | Sqft | Count    | Sqft | Count | Sqft | Count     | Sqft | Count | Sqft |
| Studio    | 6        | 540  | 0     | 0    | 8        | 540  | 0     | 0    | 18        | 540  | 0     | 0    |
| 1 Bedroom | 12       | 720  | 18    | 1200 | 40       | 720  | 31    | 950  | 54        | 780  | 79    | 950  |
| 2 Bedroom | 12       | 1054 | 0     | 0    | 32       | 1080 | 0     | 0    | 45        | 1080 | 0     | 0    |
| 3 Bedroom | 6        | 1410 | 0     | 0    | 8        | 1410 | 0     | 0    | 0         | 0    | 0     | 0    |

The difference in energy usage between TRC-informed prototype buildings and DOE-informed prototype buildings is minimal when comparing Ecosim runs between TRC-informed and DOE-informed apartment counts. The SysCOP in each building size deviates less than 3% between TRC- and DOE-informed prototypes. Out of 198 runs, the largest SysCOP deviation between TRC- and DOE-informed buildings was only 6%. We described the difference in SysCOP for each building size below.

**Table 6. Difference in SysCOP - TRC vs DOE Prototypes**

|                | Low Rise | Mid Rise | High Rise |
|----------------|----------|----------|-----------|
| TRC Prototype  | 2.49     | 2.53     | 2.47      |
| DOE Prototype  | 2.43     | 2.55     | 2.53      |
| Pct Difference | 2.7%     | 0.8%     | 2.6%      |

All runs in this analysis use the DOE-informed building prototypes because of the negligible difference in SysCOP driven by TRC- and DOE-informed building types. Ecotope recommends the DOE-informed

building prototypes for Ecosim runs until an improved data set becomes available.

## Known Variables

Variables to be modeled include tank insulation, the source air location, the prototype buildings, fixture flow rates, and recirculation loop flow rates. The runs described here compose 750 additional runs beyond the baseline runs.

## Tank Insulation

The federal standard requires a minimum tank insulation R-value of 12.5; since the AWHs aims to be a national standard, this value is used for the baseline. This analysis also examines tank insulation at high R-values of 16 and 30. We derive the R-16 data point from code minimum in California Title 24 and R-30 from AO Smith's HPWH optimized storage tank<sup>ix</sup>. When a run has multiple tanks, i.e., primary and swing tanks, all tanks are assumed to have the same level of insulation.

# Fixture Flow Rates

Fixture flow rates are altered to emulate the differences between new and existing buildings. We look at the current federal standards, WaterSense standards released by the EPA, and stricter flow rates defined in California and Washington (CAWA) building codes. The values for showers, bathroom faucets, and kitchen sinks are given in Table 7; the baseline value is aligned with the federal standard.

Table 7. Fixture Flow Rate Standards

| Fixture         | Flow Rates (GPM) |            |      |
|-----------------|------------------|------------|------|
|                 | Federal          | WaterSense | CAWA |
| Shower          | 2.5              | 2          | 1.8  |
| Bathroom Faucet | 2.2              | 1.5        | 1.2  |
| Kitchen Sink    | 2.2              | 2.2        | 1.8  |

# Source Air Locations

We consider three different source air locations for the HPWHs. The baseline assumption is that the source air is the outside air temperature. We modeled HPWHs with source air in below-grade and above-grade garages, as these buffer spaces should significantly change the outdoor air temperature.

For consistency across climate zones and to isolate differences due to HPWH performance, the storage tanks are placed at a constant room temperature, 70°F.

# Unknown Variables

The modeled unknown variables include mains water temperature, TM load, apartment occupancy rates, and the hot

water branches waste model. The number of runs described in this section totals 1650.

# Temperature Maintenance Load

The TM load describes the heat loss rate from the hot water circulation piping and is commonly standardized as a heat loss per apartment unit. Here the baseline value is assumed to be 90 W/Apt, as this corresponds to the median value in Kintner and Larson (2019)<sup>x</sup> and aligns better with new buildings than the widely assumed 100 W/Apt number defaulted to in Ecosizer.

We ran models for six other TM load values ranging from low to high, 50 to 200 W/Apt.

# Return Water Temperature

The standard circulation pump flow rate is calculated to reach a 10°F change across the circulation loop, with an assumed TM loss rate. Practically, this variable is known and could be changed during installation to reach 10°F; it is in this section as it pairs with the TM load and serves to break the one-at-a-time sensitivity analysis rule we established in the introduction.

For each TM load, the baseline flow rate will be calculated to reach a 10°F change across the loop. Because plumbers are unlikely to decrease flow rates below this point, we only analyze the deviation for a flow rate corresponding to a 5°F change across the loop.

# Mains Water Temperature

Ecosim can use multiple models to define the mains water temperature to the HPWH,

a variable that greatly affects SysCOP results because it directly impacts the hot water load and HPWH efficiency.

We assume the mains water temperature follows the sinusoidal equation developed by the National Renewable Energy Laboratory (NREL) in Burch and Christensen (2007)<sup>xi</sup> with the equation described in Hendron et al. (2004)<sup>xii</sup> as our baseline assumption. This model was fit to sites across the United States. Compared to Ecotope's measurement and verification data, this model predicted colder than expected temperatures in cold climates, likely due to large changes in thermal constants and latent heat release due to ground freezing.

As another estimate of the cold-water temperatures, we use the model developed for CBECC-Res in the 2019 Residential Alternative Calculation Method (RACM), which weights the ground temperature and air temperature, an equation shown to work adequately for warmer climates.

Lastly, we use an estimate common among building energy modelers that the mains water temperature matches the ground temperature. Here we add an extra stipulation that the water temperature is the maximum value between freezing and the ground temperature to correct areas with freezing ground temperatures.

## Occupancy Rates

Within Ecosim, modelers can decouple the occupancy (and thus hot water draws) from the other aspects of apartment sizes, such as square footage. We examine how occupancy estimations affect the Ecosim models in DOE prototypes by comparing higher and more expected low occupancy rates. We alter the average occupancy rate by changing the hot water draw selection assigned to different bedroom sizes.

The high occupancy rate assumes, on average, an extra 0.5 people per apartment in each building; since the DOE occupancy estimates are already as high as Ecotope's highest estimate, there is no data to support this level of occupancy in real-world scenarios. For the low occupancy rate, we use the equation defined by Heller et al., 2009<sup>xiii</sup>, based on King County's new construction assessor data, census figures, and occupancy data from recent multifamily developments:

$$\text{Number of Occupants per Unit} = 1 + 0.57 * (\text{bedroom count})$$

For the DOE prototypes, where all the units are 1-bedroom, we can target an average occupancy of 1.57 people per apartment. This number is largely in agreement with Ecotope's recent multifamily projects, where the overall occupancy rate is 1.4 people per apartment. The mixture of apartment sizes used to define the draws and reach this occupancy is shown in Table 8.

**Table 8. Apartment Sizes for Low and High Occupancy Rates**

| Apartment Size             | Low Occupancy |          |           | High Occupancy |          |           |
|----------------------------|---------------|----------|-----------|----------------|----------|-----------|
|                            | Low-Rise      | Mid-Rise | High-Rise | Low-Rise       | Mid-Rise | High-Rise |
| Studio                     | 9             | 14       | 34        | 0              | 0        | 0         |
| 1 Bedroom                  | 9             | 17       | 45        | 6              | 2        | 5         |
| 2 Bedroom                  | 0             | 0        | 0         | 5              | 0        | 0         |
| 3 Bedroom                  | 0             | 0        | 0         | 7              | 29       | 74        |
| Avg Occupancy (People/Apt) | 1.57          | 1.57     | 1.57      | 2.5            | 3        | 3         |

## Draw Patterns

In Ecosim, each apartment unit assigned has a unique draw pattern, up to a limit of 50 unique patterns for studios and 1- and 2-bedroom units. Here we examine if the results are robust against different hot water draw selections or shuffles. For example, a building with ten 1-bedroom units would default to using the 1-bedroom draw patterns numbered from 1 to 10. We then examine whether the results are significantly changed when modeled using draw patterns 11 to 20, modeling five random shuffles of the draw patterns.

Interestingly, because the DOE high-rise prototype contains 79 1-bedroom apartment units, the model has 29 identical hot water draw patterns (1-bedroom #1 through #29 have the same draw pattern as 1-bedroom #51 through #79). This statistically impossible duplication overweighs those particular draw patterns in the overall model.

## Waste Model

Hot water branches, defined as uncirculated branches leaving the loop before entering the apartment, must be modeled separately for how much waste occurs during hot water draws described in the 2019 RACM. A more in-depth analysis might evaluate the waste model and provide an alternative if necessary. This analysis varies the wastewater fractions split between the shower and faucet as described below.

As a default, we model a fraction of 3:1 shower-to-faucet, meaning that of the calculated wastewater, 3 times as much wastewater is attached to shower events than faucet events. We vary this analysis, examining even split (1:1) and a higher split (5:1) shower-to-faucet ratios.

## Draw Profile Types

The draw profiles used in the previous section are associated with market-rate multifamily buildings. These provide excellent minute-by-minute draws for building energy modeling, but whether results can be extrapolated outside this building type remains unclear. For this analysis, we reviewed *hourly* hot water

draws from two buildings monitored by Ecotope: Stream and Elizabeth James. Stream is a market-rate multifamily building used here to determine the effects of converting from minute to average hourly draws. Elizabeth James is a low-income senior housing building with a much flatter normalized draw profile than a market rate building. We compare the buildings' draw profiles to determine their impact on SysCOP.

Additionally, Stream and Elizabeth James data was used to compare simulated SysCOP when using minute data and aggregated hourly data.

## Results

Variables to be modeled include mains water temperature, TM load, apartment occupancy rates, and the hot water branches waste model. The number of runs described in this section totals 1650.

## Tank Insulation

Variation in tank insulation from a baseline value of R16 is 1%, shown in Figure 1. Therefore, for any plausible derate value assigned to the tank insulation, the error accrued in modeling would be about 1%.

Figure 1 shows the results of runs aggregated by HPWH heating cycle, SP/MP, along with the configuration, where RTP is "return to primary." Notably, MP/RTP combination consistently demonstrates the greatest benefit from increased insulation because the MP heating cycle maintains a higher water temperature. Additionally, the MP/RTP setpoint is higher, and the dead band is smaller than other heating cycles/configuration combinations, allowing the tank maintains a 135 to 145 F range. Comparatively, an SP HPWH's water temperature in the lower stratified layers of the tank (near the bottom) can match the mains water temperature.

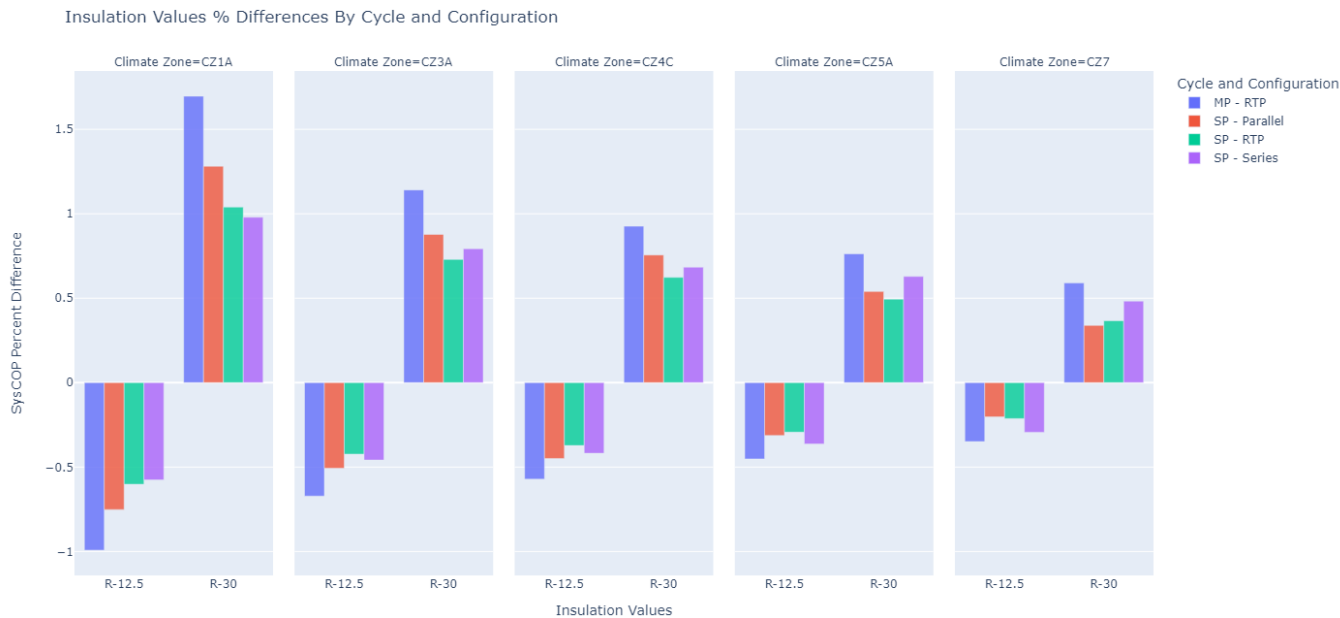


Figure 1. Percent Difference in SysCOP from Difference Insulation Values

## Fixture Flow Rates

The baseline fixture flow rates are set high as the federal standard, as the AWHs aims to standardize HPWH specifications. For most configurations, there is less than a 1% difference caused by decreasing the fixture flow rates to the stricter values defined in the Water Sense and CA and WA plumbing standards across climate zones.

Interestingly, the SP/series configuration does not follow this pattern; see the purple bar in Figure 2.

The *series* configuration shows a notable change in SysCOP across climate zones when decreasing the flow rate standards. Ecosim defines a hot water draw as *a flow rate over a period*. In this analysis, we changed the flow rate only (not the period), leading to less hot water consumption for each hot water draw, which is unlikely to occur in real-world scenarios<sup>xiv</sup>. A decrease in hot water consumption directly affects the efficiency of a *series* configuration because hot water consumption induces the heat pump compressor to provide heat rather than the electric resistance elements in the temperature maintenance swing tank.

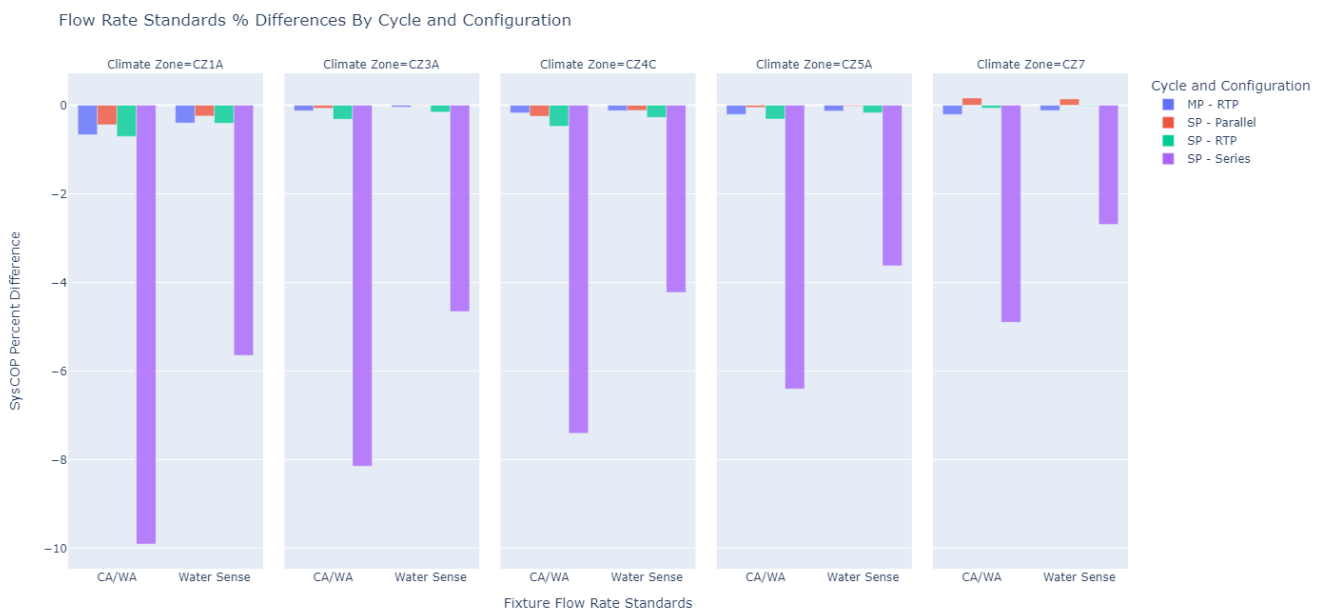


**Figure 2. Percent Difference in SysCOP from Different Flow Rate Standards Compared to the Baseline**

## Source Air Locations

This analysis examined two buffer-space models to represent the source air for the HPWH. 1) an underground garage that does not incorporate internal gains from the rest of the building, and 2) an underground garage that incorporates internal gains from

HVAC equipment energy released into the garage spaces. The first model describes a space that is lightly buffered from the outside, often roughly equal to the outside air temperature. The SysCOP results show no appreciable difference between the garage model and the outside air temperature. The second model

approximates an average temperature between the outdoor dry bulb and conditioned space. Because the air temperature reaching the HP is warmer on

average, this model shows a significant improvement in the SysCOP in warm to very cold climates – from 10 to 30%.

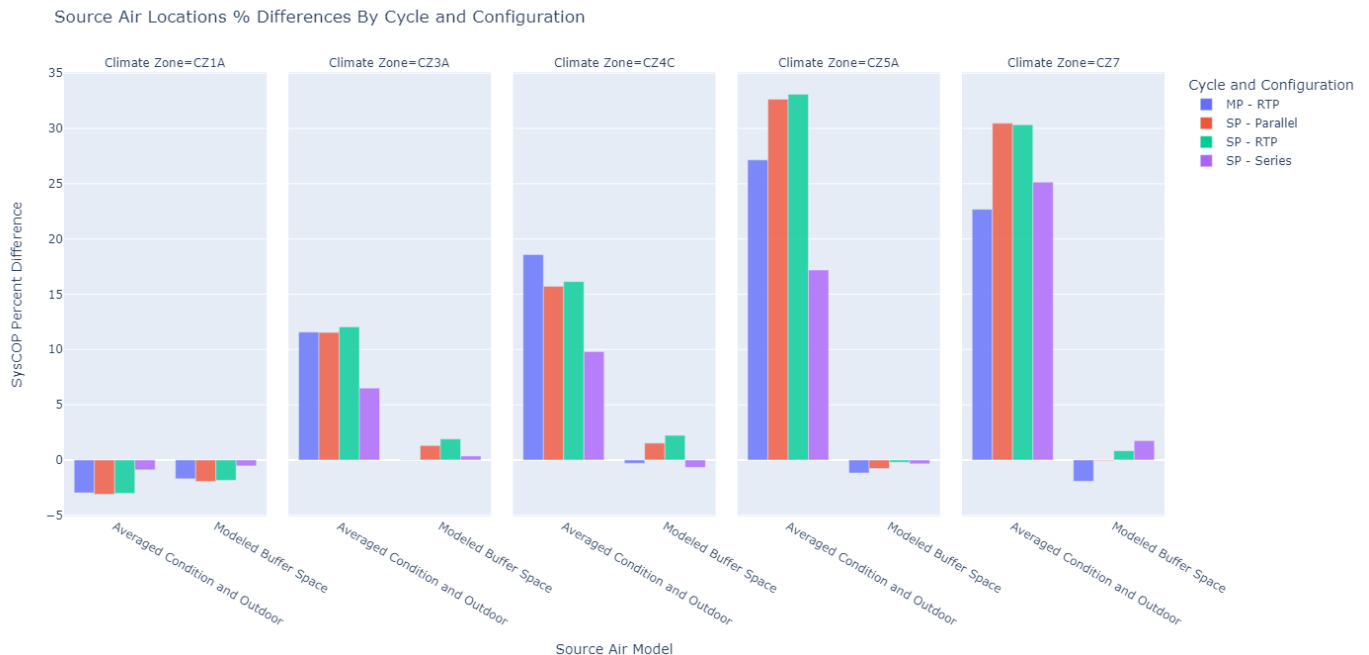


**Figure 3. Percent Difference in SysCOP from Variations in HPWH Source Air Locations**

## Temperature Maintenance Load

For *parallel* and return to primary configurations, variations in temperature maintenance load from the baseline value are less than 5%. However, changes for the *SP/series* configurations result in large changes across the range of plausible temperature maintenance loads, about +/-

20%, depending on the climate zone. For example, even in the Seattle climate zone (CZ4C), decreasing the temperature maintenance load from 90 W/Apt to 50 W/Apt improves the SysCOP by 10%. Unfortunately, modeling temperature maintenance load and predicting SysCOP for a *series* configuration with confidence is notoriously elusive prior to building occupancy.

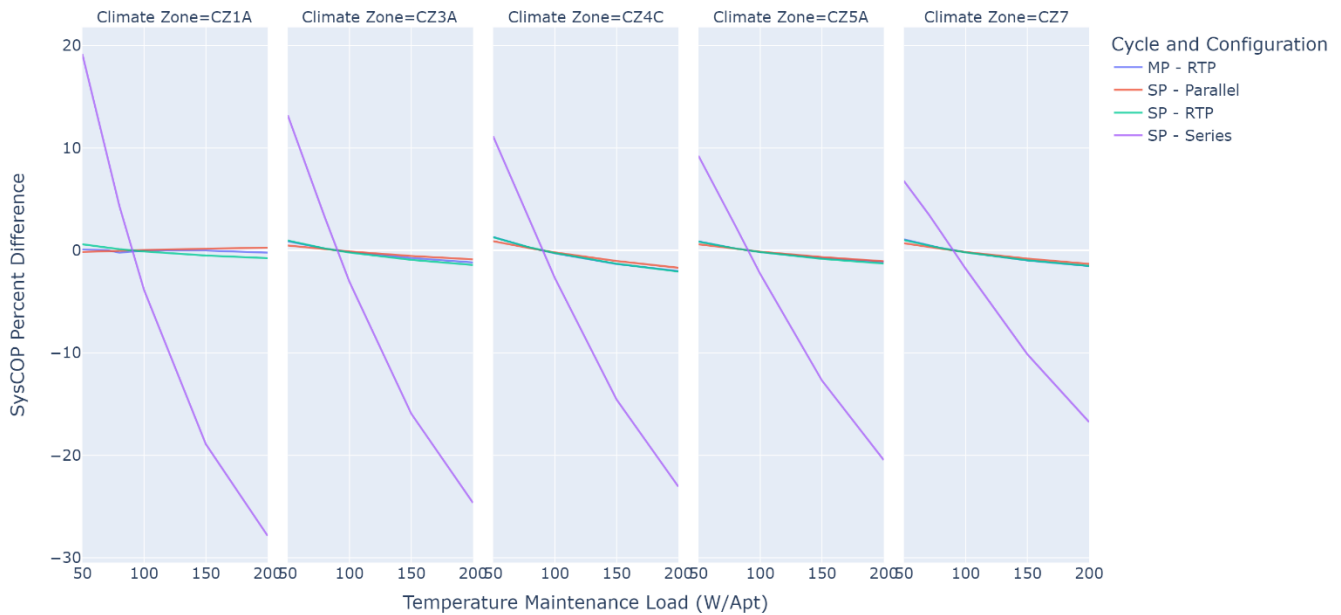


**Figure 4. Percent Difference in SysCOP from Varying Temperature Maintenance Loads Compared to the Baseline of 90 W/Apt**

## Return Water Temperature

Figure 5 describes results from deviations in return water temperature from a baseline value of 110 F. Differences in SysCOP are less than 1% across a 10 F interval, representing all likely return water temperature values from the temperature

maintenance loop and, in turn, all plausible recirculation loop flow rates.

The *series* tank configuration demonstrated an opposite effect from all other configurations; increased return water temperatures to the *series* temperature maintenance tank reduces temperature loss in the tank.



**Figure 5. Percent Difference in SysCOP for Different Return Water Temperatures**

## Mains Water Temperature

In our analysis, temperature differences between mains water models result in errors in the 1% range, except for the *series* configuration. However, significant research

remains to predict mains water temperature variances accurately.

Altering the model from the NREL to the native CBECC model significantly increases SysCOP performance when testing *series* configurations.

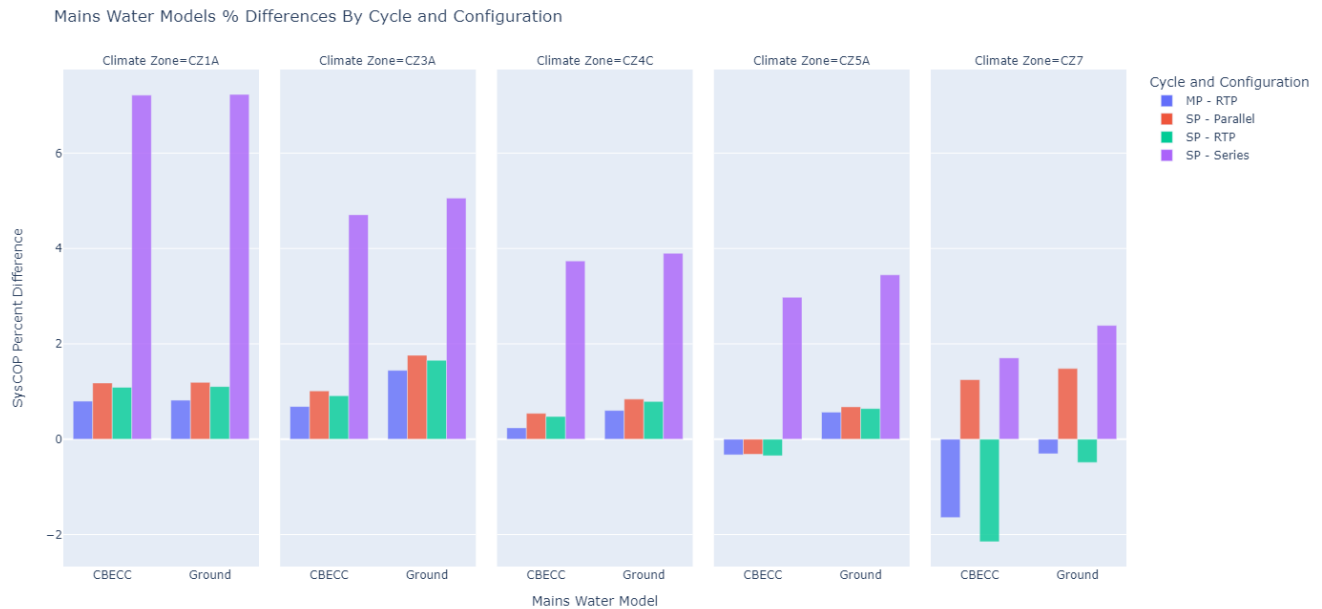


**Figure 6. Percent Difference in SysCOP for different Mains Water Temperatures Models**

## Occupancy Rates

Occupancy rates are never constant and are impossible to model accurately, given the macro social and economic variables that impact multifamily residencies. However, analyzing varying occupancy rates in terms of people per apartment over the building's lifetime can help bound efficiencies.

Figure 7 describes the results of running Ecosim with different occupancy rates compared to the baseline (Tables 2 and 3). Minor variations (less than 1%) occur for most configurations except for the *series* configuration; variations in occupancy affect hot water volume draws while temperature maintenance loads remain constant, resulting in a SysCOPs swing of over 5%.



**Figure 7. Percent Difference in SysCOP for Different Building Occupancy Rates**

## Draw Patterns

Figure 8 describes the random shuffles of draw patterns modeled in this analysis. The

hot water consumption pattern does not significantly impact SysCOP on a minute-by-minute model of hot water consumption, resulting in a variation of less than 0.5%.



**Figure 8. Percent Difference in SysCOP for Different Draw Pattern Shuffles**

## Waste Model

Figure 9 describes how the variations in wastewater impact annual SysCOP as a ratio of their source (faucets or showers). The baseline fraction is 3:1 shower-to-faucet branches from the main to the water outlet, resulting in 3X wastewater from shower events than from faucet events). SysCOP

varied by less than 0.01% in the analysis, meaning that for the annual SysCOP, there is statistically zero impact. However, evaluated at the hourly timescale, variations in SysCOP would likely be much higher, an important consideration when considering load shift characteristics. Again, the *series* configuration has the highest range in SysCOP from this variable, though still less than 0.2%.



**Figure 9. Percent Difference in SysCOP for Different Shower Faucet Waste Ratios**

## Draw Profile Types

Ecosim's baseline hot water draw patterns model minute-by-minute hot water draws averaged to represent a typical market rate multifamily building. Minute-by-minute hot water draw inputs allow the model to deliver results that can incorporate time-of-use energy inputs, accurately predict

electric resistance use, and accurately predict stratified cold-water temperatures at the bottom of storage tanks. For example, a 2 GPM shower for 10 minutes uses 20 gallons of water. However, the same 20 gallons of hot water consumed over an hour result in an effective flow rate of 1/3 GPM for that hour. Additionally, 20 gallons consumed over 10 versus 60 minutes impacts temperature maintenance

efficiency. When 20 gallons from the primary HPWH mixes with temperature maintenance water (or secondary HPWH-heated water in MP cases) at 1/3 GPM for 60 minutes, it results in warmer cold-water temperatures for that hour than the alternative (20 gallons over 10 minutes).

Figure 10 describes the difference between the hourly versus minute-by-minute hot water draws (the baseline) measured in 2 Ecotope buildings – one market rate and the other senior housing. The modeled RTP configurations result in less than 5% change across climate zones, but *series* and *parallel*

configurations can see over 10% change depending on climate zone.

Interestingly, the percent difference in SysCOP change between the market rate and senior housing hourly draw profiles is less than 5% across the board. This result implies that hourly hot water draw profiles are not significant drivers of SysCOP efficiency but that the difference between the market rate and senior rate draws is predominantly due to the change in consumption across many hours, an important factor when considering load shift capabilities.

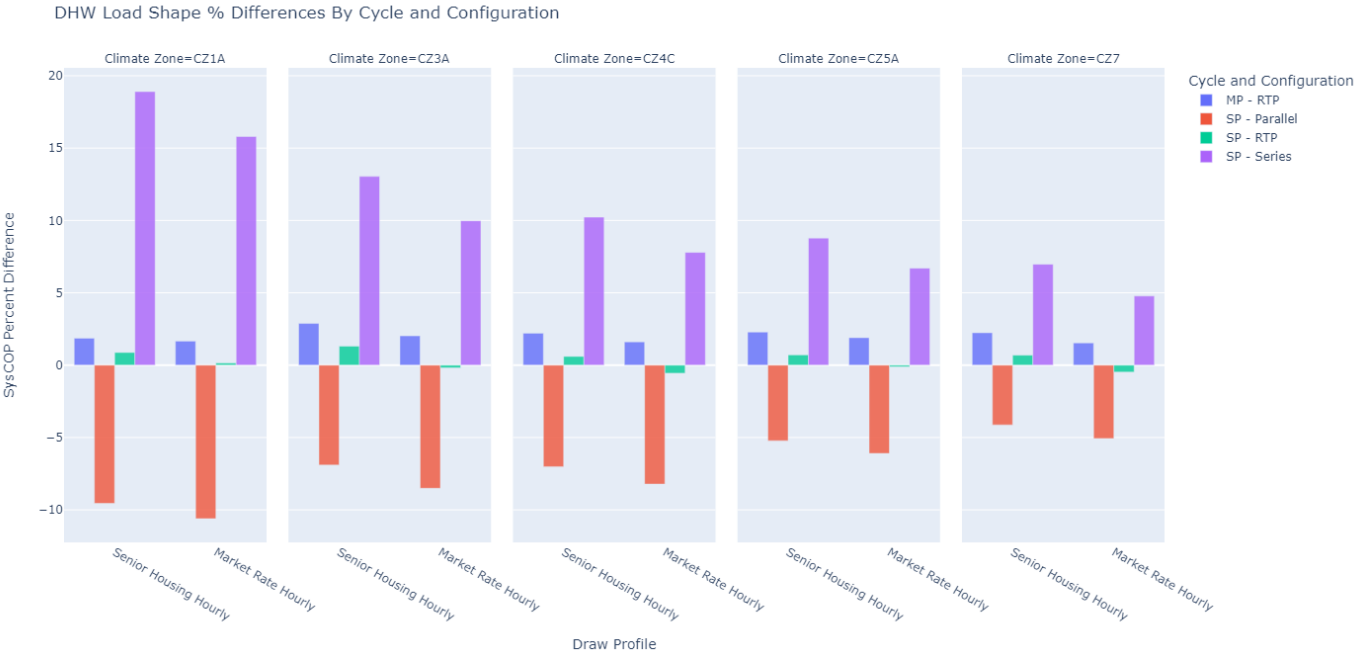


**Figure 10. Percent Difference in SysCOP for Different Shower Faucet Waste Ratios**

# Discussion

Two natural statistical groups appear in this analysis, the *series* configuration, and all other configurations. The *series*

configuration operates relatively differently than the other configurations. In all non-*series* configurations, the temperature maintenance load is always covered by high-efficiency HPWHs. A simple analysis of the results here shows that the SysCOP

standard deviation for the *series* configuration is 0.29 and for all the other configurations is 0.19.

The two most significant contributors to the standard deviations for all the configurations are the mains water temperature and the temperature maintenance load; both deserve further research to constrain values.

Further recommendations to improve annual efficiencies in the QPL would be to model future meteorological years, which will more accurately represent the next 30 years, on average, with warming air temperatures.

# Appendix A – Advanced Water Heating Specification

## CHPWH Configurations

Figures numbers align with the AWHs reference.

**Figure 2. Single-Pass Primary HPWH System without HW Circulation**

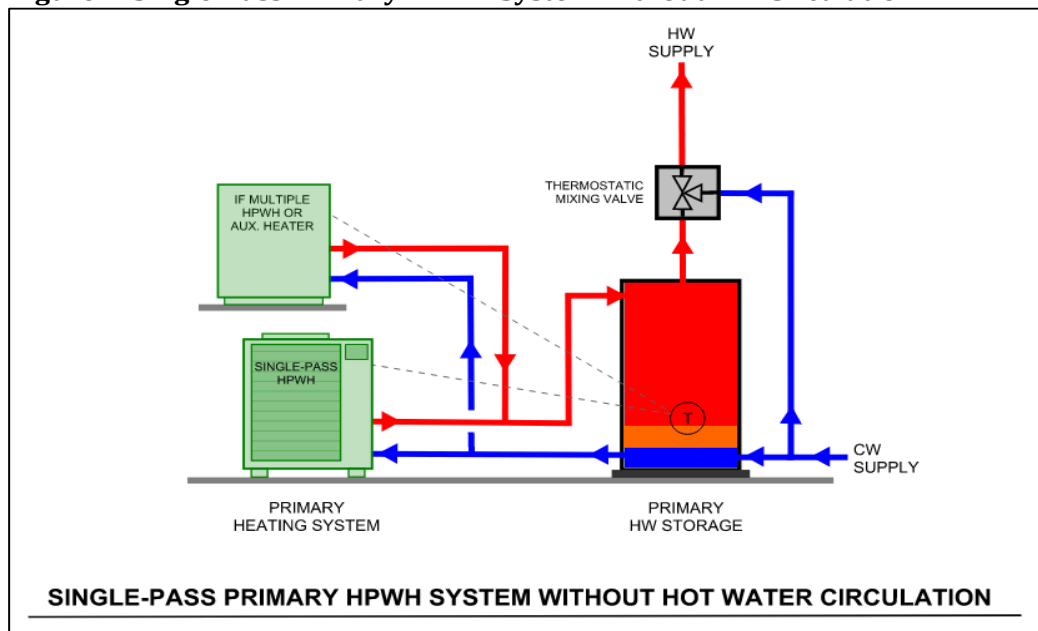


**Figure 3. Single-Pass Primary HPWH with HW Circulation Returned to Primary Storage**

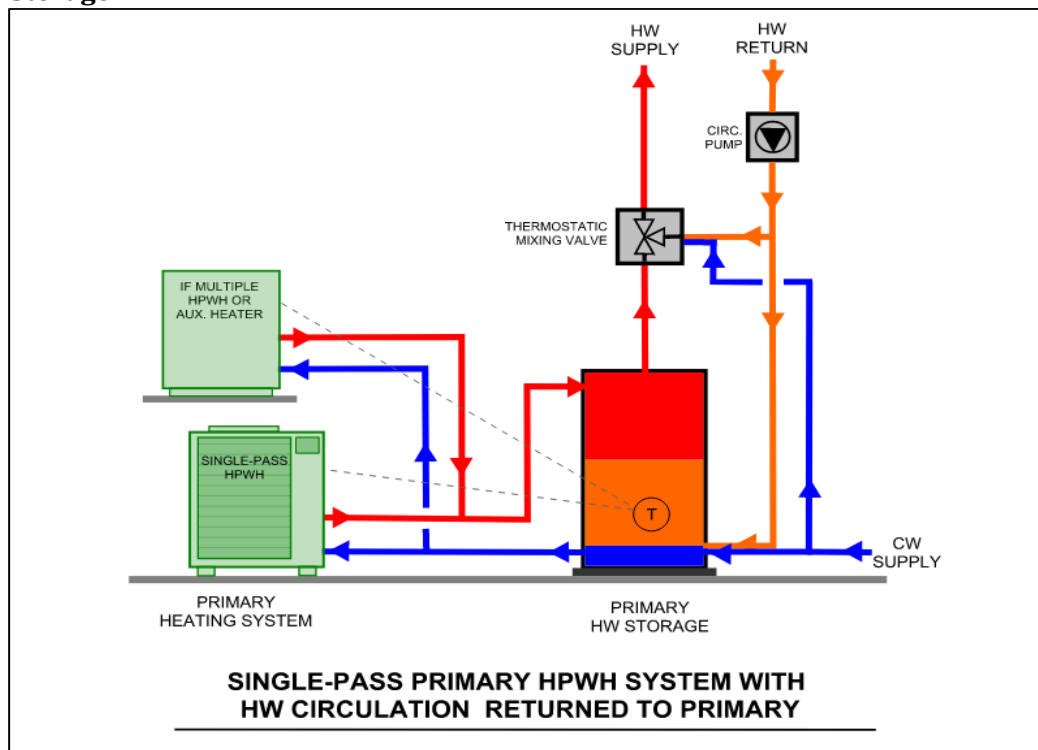


**Figure 4. Single-Pass Primary HPWH with Series Temperature Maintenance Tank System (Swing Tank)**

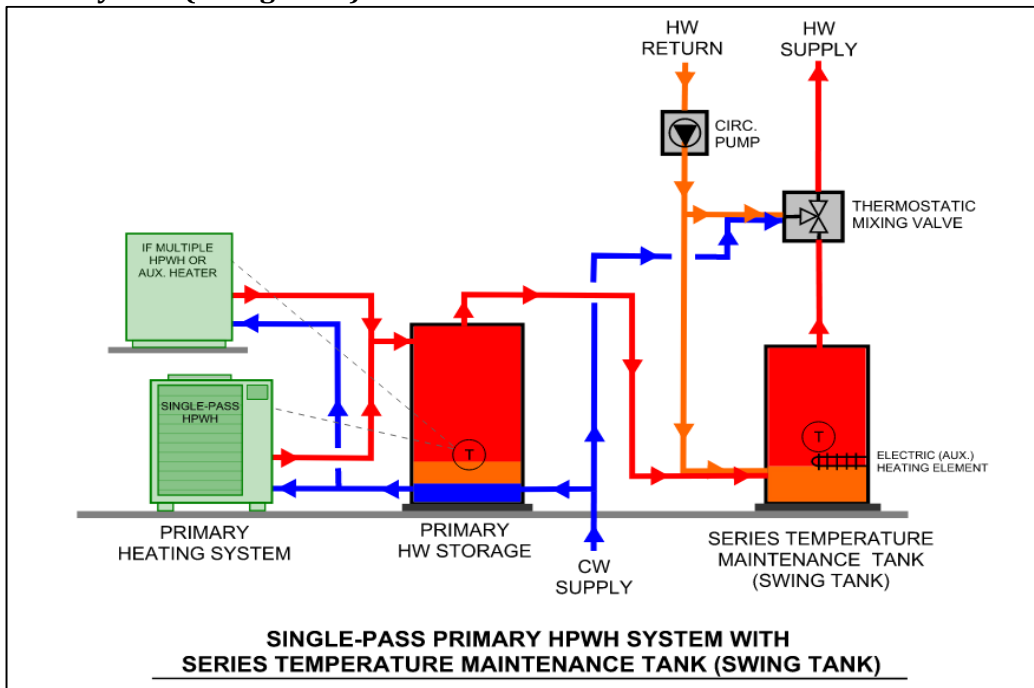


**Figure 5. Single-Pass Primary HPWH with Parallel Temperature Maintenance Tank System**

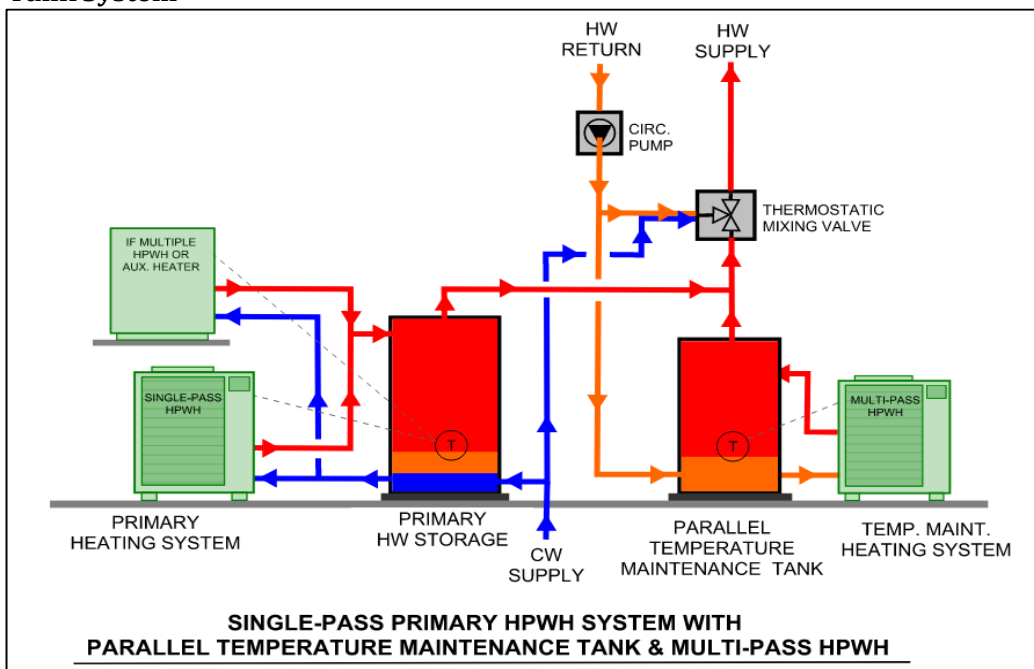


**Figure 6. Multi-Pass Integrated HPWH System without Hot Water Circulation**

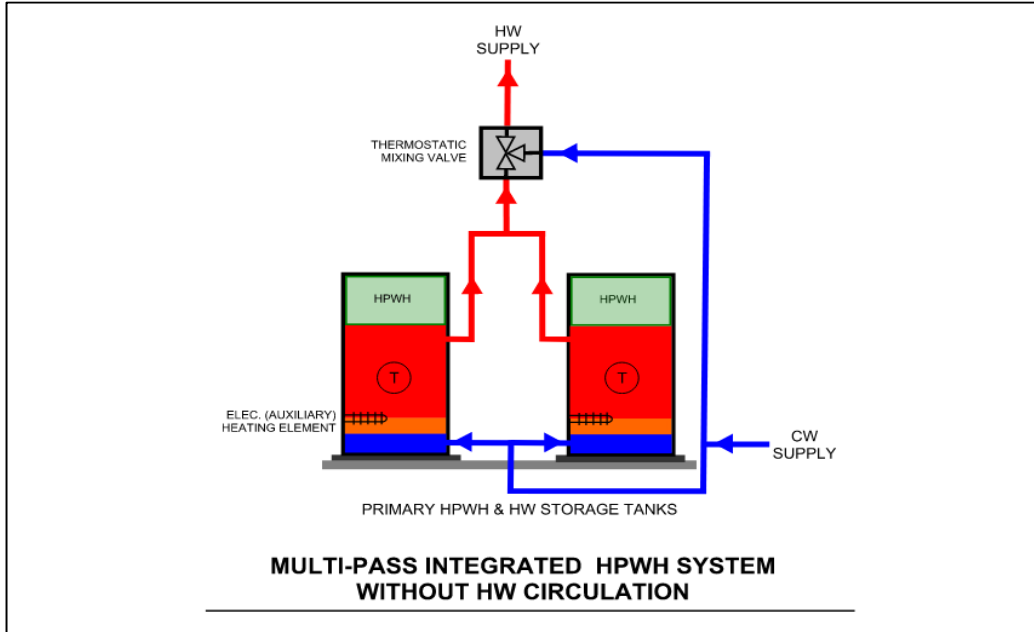


**Figure 7. Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Primary Storage**

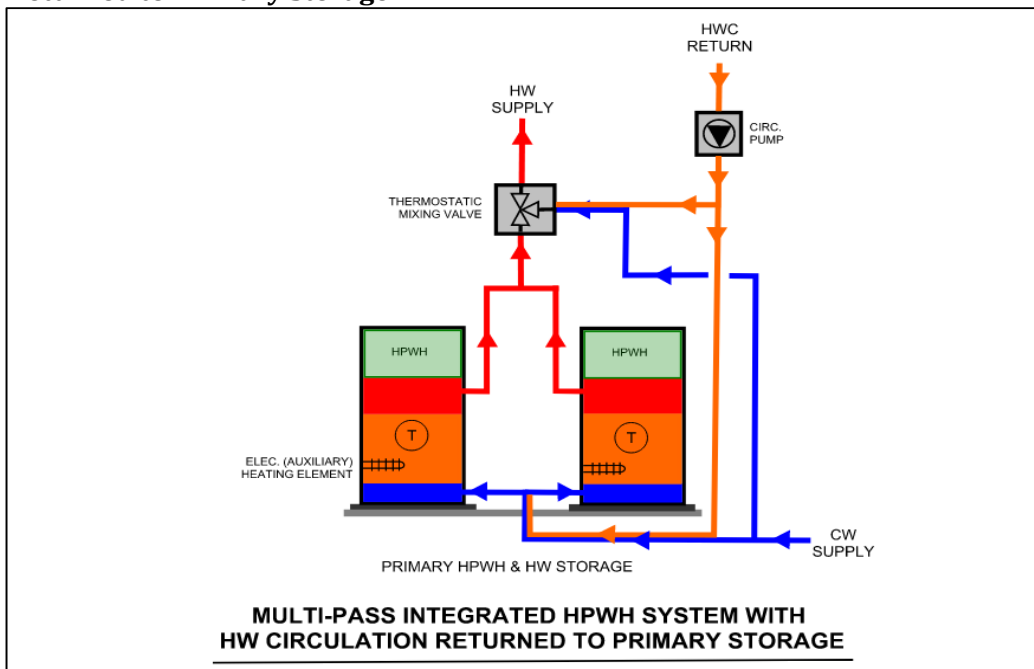
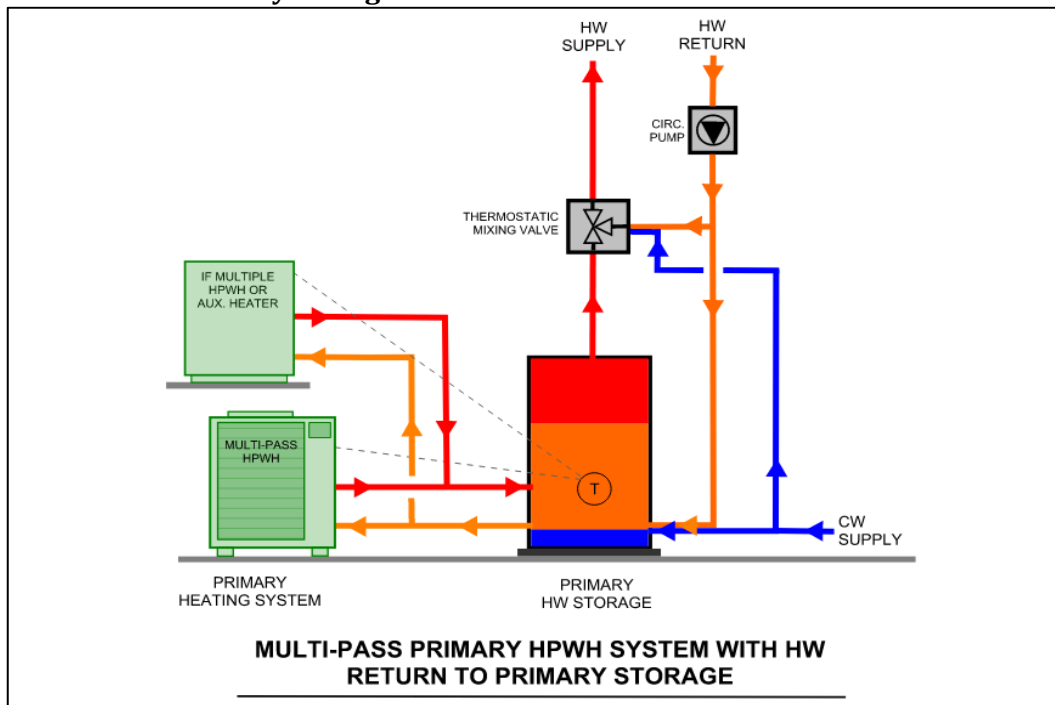


**Figure 8. Multi-Pass Split-System HPWH with Hot Water Circulation System Returned to Primary Storage**



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