Multifamily Domestic Hot Water Greenhouse Gas and Costs

Project Number ET24SWG0005

GAS EMERGING TECHOLOGIES (GET) PROGRAM
January 2025

Prepared by ICF for submission to Southern California Gas Company

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Acknowledgments

ICF is responsible for this project. This project, ET24SWG0005, was developed as part of the Statewide Gas Emerging Technologies (GET) Program under the auspices of SoCalGas as the Statewide Lead Program Administrator. Lincus, Inc conducted this technology evaluation with overall guidance and management from ICF Project Manager, Steven Apodaca and Technical Lead Steven Long. For more information on this project, contact Steven.Long@icf.com.

Disclaimer

Abbreviations and Acronyms

Acronym	Definition
ACC	Avoided cost calculator
CET	Cost effective tool
COP	Coefficient of performance
CPUC	California Public Utilities Commission
DHW	Domestic hot water
EHPWH	Electric heat pump water heater
EUL	Expected useful life
GAHP	Gas absorption heat pump
GET	Gas Emerging Technologies
GHG	Greenhouse gas
HPWH	Heat pump water heater
IOU	Investor-owned Utility
MF	Multifamily
ODP	Ozone depletion potential
PG&E	Pacific Gas & Electric
RACC	Refrigerant avoided cost calculator
ROI	Return on investment
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
TOU	Time-of-use
TRC	Total resource cost
TSB	Total system benefit

Executive Summary

This study aims to evaluate the performance of various domestic hot water (DHW) systems in multifamily buildings in California, focusing on energy consumption, operating costs, and greenhouse gas (GHG) emissions. The systems under consideration include a baseline 84% efficient boiler, a 97% efficient condensing boiler, an electric heat pump water heater (EHPWH), and two configurations of gas absorption heat pumps (GAHPs).

Project goal: The primary goal of this study is to provide a comprehensive comparison of these DHW systems to inform decision-making for energy efficiency upgrades in multifamily buildings. By assessing energy consumption, utility costs, capital costs, return on investments, GHG emissions, and total system benefits, this study will help identify the most cost-effective and environmentally friendly options.

Technology description: The study analyzes the following DHW systems:

- Baseline: 84% efficient gas-fired boiler
- Measure Case 1: 97% efficient condensing gas-fired boiler
- Measure Case 2: Electric heat pump water heater
- Measure Case 3: Gas absorption heat pump with preheating of make-up water and reheating of recirculation water
- Measure Case 4: Gas absorption heat pump with preheating of make-up water

Project recommendations: GAHP systems offer a strong balance of energy efficiency and economic viability, especially in certain climate zones. These systems reduce emissions and provide competitive operational costs compared to EHPWHs.

As renewable energy increases on the grid, monitoring its impact on the performance and cost-effectiveness of EHPWHs is essential for future assessments.

Improvement in modeling of DHW systems is necessary, especially surrounding recirculation, due to EnergyPlus' current capabilities and functions.

Further research on the long-term performance and maintenance costs of GAHP systems is needed to better understand their reliability and overall suitability for multifamily buildings.

Policymakers should consider implementing incentives to offset the higher upfront costs of energy-efficient DHW systems like GAHPs, helping to drive their adoption and support toward sustainable building practices.

Introduction

Based on results from a previous modeling study on Dual Fuel Single-Family Heating (ET23SWG0005) where the cost to run an EHPWH was 68% to 144% more than a gas furnace, the GET team believes that installation of GAHP water heaters will save utility costs when compared with condensing gas-fired boilers and EHPWHs. Additionally, based upon another GET study (ET23SWG0012), which investigates the sizing of heat pump water heaters (HPWH), the GET team believes that EHPWHs may have much larger upfront capital costs in a multifamily retrofit due to the large amount of recommended storage tank volume. In many multifamily (MF) buildings, there is not enough space in existing mechanical rooms or boiler enclosures for the additional storage tanks, meaning an expensive roof installation is the only option.

This project is a modeling study of DHW systems in MF buildings using models based upon approved DEER prototypes. MF models used in this study will be the best available prototypes: either DEER models themselves, or DEER models modified to include DHW primary and recirculation loops. This project will model the therm, kW, and kWh use of the following technologies:

- Baseline: 84% efficient gas-fired boiler
- Measure Case 1: 97% efficient condensing gas-fired boiler
- Measure Case 2: Electric heat pump water heater
- Measure Case 3: GAHP with preheating of make-up water and reheating of recirculation water
- Measure Case 4: GAHP with preheating of make-up water

The objectives of this project are to compare the following metrics across condensing gas-fired boilers, GAHPs, and EHPWHs technologies for two (2) different MF rate tariffs and all 16 California climate zones:

1. Utility costs
2. Capital costs
3. Return on investment (ROI)
4. Greenhouse gas (GHG) impacts
5. Total system benefit (TSB)

Background

The results from GET Study ET23SWG005: Dual-Fuel Single-Family Modeling indicated that running an EHPWH to heat a single-family home would cost anywhere from 68% to 144% more than a gas furnace depending upon the climate zone where the home is located. In dollars, this is between $53/year and $391/year more than a gas furnace. It stands to reason that the operating costs of an EHPWH may be significantly more than for a condensing boiler or a GAHP. Higher DHW operating costs in a MF property are likely to be passed onto renters. Operating cost is always an important factor in an energy efficiency upgrade, but it is especially important in MF homes. Before COVID, over half of renters in California were cost burdened (on average shelter costs exceeded 30% of household income). Renters may not be able to support additional DHW operating costs, which come in the form of increased rent.

Additionally, initial findings from GET Study ET23SWG0012: GAHP Sizing, Screening, and Design indicate that the recommended water tank storage sizing for EHPWHs would, in many cases, necessitate installation of the water heating components on a roof thereby increasing an already high upfront capital cost.

The GET Program is running several field studies for GAHPs in DHW systems, which will evaluate the GHG impacts of the GAHPs compared to theoretical EHPWHs. However, these studies are not going to compare capital costs or utility costs, and they are limited to those sites where the GAHPs are installed.

This study will provide broader results that can be used to characterize GAHP advantages over condensing boilers and EHPWHs in California MF buildings so contractors can speak to their advantages when offering this measure through incentive programs.

Assessment Objectives

The objectives of this study are as follows:

1. Compare metrics for the following DHW systems that operate with:
    a. A condensing boiler replacing a code baseline 84% efficient boiler (a condensing boiler system)
    b. An EHPWH replacing a code baseline 84% efficient boiler (a fuel substitution EHPWH system)
    c. A GAHP paired with an 84% efficient boiler to preheat the make-up water and reheat the recirculation water (a GAHP system: Permutation #1)
    d. A GAHP paired with an 84% efficient boiler to preheat the make-up water (a GAHP System: Permutation #2)

2. Metrics to be compared are below:
    a. Operating costs for 2024 (gas and electric)
    b. Operating costs for 2025–2035 (gas and electric)
    c. GHG emissions
    d. Capital costs and simple payback
    e. TSB and TRC (relative to a DHW system operating with an 84% code baseline efficient boiler)

These study objectives were completed using the following project tasks:

1. Utility Rate Tariffs and Emissions Analysis
2. DHW Models, Emissions, and Fuel Costs Analysis
3. TSB and Simple Payback Analysis

Utility Rate Tariffs and Emissions Analysis

Estimating operating costs and GHG emissions are dependent on a comprehension of available rate tariffs and the investor-owned utility (IOU) balancing the region. An analysis was performed on the available rate tariffs offered for MF buildings by California IOUs and expected GHG emission factors for the purpose of calculation and comparison of energy costs and emissions in each climate zone.

Climate Zone – Utility Mapping

The climate zone is the most significant variable in this analysis as, in most cases, it determines the territory's controlling IOU and, thus, the available rate tariffs and balancing area region. The balancing area region dictates both the California Independent System Operator (CAISO) market participation, and the emission factors applied in the 2024 Avoided Cost Calculator (ACC). Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E) both belong in the SP-15 balancing area region, while Pacific Gas & Electric (PG&E) belongs in NP-15. There are five climate zones that have more than one IOU per fuel source (CZ10, CZ13, CZ14, CZ15, CZ16), and two of these have different market participation (CZ13, CZ16). CPUC *Resolution E-5009* determined the representative utility for each climate zone (California Public Utilities Commission, 2019, pp. A-7). The same list of representative utilities is recognized by the California Energy Commission (Energy+Environmental Economics, 2020). The resolution draws on DEER2020 building weights representing the prevalence of each utility by building type and climate zone that were earlier derived from Residential Appliance Saturation Survey data. A summary of the representative IOUs per climate zone is included in Table 1.

Table 1: Predominant IOU to Use for Statewide Savings Analysis

CA Climate Zone	Electric[1]	Gas1	IOU Balancing Area Region[2]
CZ01	PG&E	PG&E	NP-15
CZ02	PG&E	PG&E	NP-15
CZ03	PG&E	PG&E	NP-15
CZ04	PG&E	PG&E	NP-15
CZ05	PG&E	PG&E	NP-15
CZ06	SCE	SCG	SP-15
CZ07	SDG&E	SDG&E	SP-15
CZ08	SCE	SCG	SP-15
CZ09	SCE	SCG	SP-15
CZ10	SCE	SCG	SP-15
CZ11	PG&E	PG&E	NP-15
CZ12	PG&E	PG&E	NP-15
CZ13	PG&E	PG&E	NP-15
CZ14	SCE	SCG	SP-15
CZ15	SCE	SCG	SP-15
CZ16	SCE	SCG	SP-15

For the analysis, only the predominant IOU in each climate zone is used. This results in one electric tariff per climate zone and service type.

Electric Rate Tariffs and Cost Analysis

Representative electric rate tariffs were chosen for this analysis from each IOU, both for tiered and time-of-use (TOU) plans. Prior to choosing, all residential electric rate tariffs were compiled and evaluated. Rate tariffs and related documents published by PG&E, SCE, and SDG&E, as well as those from the U.S. Utility Rate Database (National Renewable Energy Laboratory), are listed in Table 2 along with their key features.

[1] (California Public Utilities Commission, 2019)
[2] (Energy+Environmental Economics, 2022)

Table 2: Available Electric Rate Tariffs and Key Features

IOU	Tariff Option	Type	Qualifier	Multifamily Eligibility	Details
PG&E	E-1	Tiered		Yes	Residential Services
	EM	Tiered		Yes	Master-Metered Multifamily Service
	ES	Tiered		Yes	Multifamily Service
	ESR	Tiered		No	Residential RV Park and Residential Marina Service
	ET	Tiered		No	Mobile home Park Service
	EM-TOU	TOU		Yes	Residential Time-of-Use Service; multifamily/RV
	E-TOU-C	Tiered/TOU		Yes	Residential Time-of-Use Service
	E-TOU-D	TOU		Yes	Residential Time-of-Use Peak Pricing 5-8pm non-holiday weekdays
	EV	TOU	EV	Yes	Residential Time-of-Use Service for Plug-In Electric Vehicle Customers; EV separately metered
	EV2	TOU	EV	Yes	Residential Time-of-Use Service for Plug-In Electric Vehicle Customers; home and EV metered together
	E-ELEC	TOU	EV, Electric Home	No	Residential Time-of-Use (Electric Home) Service for Customers with Qualifying Electric Technologies
SCE	D	Tiered		Yes	Domestic Service
	D-CARE	Tiered	CARE program	Yes	California Alternate Rates for Energy Domestic Service
	DE	Tiered	SCE Employees	Yes	Domestic Service to Utility Employees
	D-FERA	Tiered	FERA Household	Yes	Family Electric Rate Assistance
	DM	Tiered		Yes	Multifamily Accommodation – Residential Hotel – Qualifying RV Park
	DMS-1	Tiered		Yes	Domestic Service Multifamily Accommodation – Sub metered

IOU	Tariff Option	Type	Qualifier	Multifamily Eligibility	Details
	DMS-2	Tiered		Yes	Domestic Service Mobile home Park Multifamily Accommodation – Sub metered
	DMS-3	Tiered		No	Domestic Service Qualifying RV Park Accommodation – Sub metered
	D-SDP	–	Direct load control device	No	Domestic Summer Discount Plan
	ESC-OO	–	No smart meter	Yes	Edison SmartConnect Opt-out
	MB-E	–	Medical baseline allocation	Yes	Medical Baseline – Exemption
	SEP	–	Direct load control device	Yes	Smart Energy Program
	TOU-D-4-9PM	TOU		Yes	Time-of-Use Domestic (peak, off-peak, super off-peak)
	TOU-D-5-8PM	TOU		Yes	Time-of-Use Domestic (peak, off-peak, super off-peak)
	TOU-D-PRIME	TOU	EV or Battery or HPWH or HP HVAC	No	Time-of-Use Domestic (peak, off-peak, super off-peak)
SDG&E	DR	Tiered		Yes	Domestic Service
	TOU-DR	TOU		Yes	Residential – Time of Use Service
	DR-SES	TOU	Solar energy system	No	Domestic Time-of-Use for Households with a Solar Energy System
	E-CARE	–	CARE program	Yes	California Alternate Rates for Energy Program
	DM	Tiered		Yes	Multi-Family Service
	DT-RV	Tiered		No	Sub metered Service – Recreational Vehicle Parks and Residential Marinas
	EV-TOU	TOU	EV	No	Domestic Time-of-Use for Electric Vehicle Charging

IOU	Tariff Option	Type	Qualifier	Multifamily Eligibility	Details
	EV-TOU-2	TOU	EV	No	Domestic Time-of-Use for Households with Electric Vehicles
	EV-TOU-5	TOU	EV	No	Cost-Based Domestic Time-of-Use for Households with Electric Vehicles
	DE	-	SDGE Employees	Yes	Domestic Service to Utility Employees
	FERA	-	FERA Household	Yes	Family Electric Rate Assistance Program
	E-SMOP	-	No smart meter	Yes	Electric Residential Smart Meter Opt-Out Program
	TOU-DR1	Tiered/TOU		Yes	Residential Time-of-Use
	TOU-DR2	TOU		Yes	Residential Time-of-Use
	DAC-GT	-	DAC-GT Program	Yes	Disadvantaged Communities Green Tariff (DAC-GT)
	CSGT	-	CSGT Program	No	Community Solar Green Tariff
	TOU-ELEC	TOU	EV or Battery or HPWH or HP HVAC	No	Domestic Time-of-Use for Households with Electric Vehicles, Energy Storage, or Heat Pumps

Representative Electric Rate Tariffs

Not all residential tariffs apply to multifamily residences. The initial step to narrow the pool of potential representatives was to determine multifamily eligibility for each tariff. In most cases, tariffs clearly outlined the eligible building types; however, some did not. For these cases, an engineering judgment was made regarding their suitability for use in a multifamily setting based on the available language.

Secondly, tariffs with unique qualifiers such as EV, solar, IOU employment, and other special programs were excluded from the analysis, as they do not represent the most widely applicable scenarios. The remaining tariffs were researched using the U.S. Utility Rate Database (National Renewable Energy Laboratory) to validate each tariff's approval status and effective/end dates. Tariffs with end dates typically do not allow new customers to switch to or start service under these tariffs, making them poor candidates for representation.

Lastly, prevailing rate tariffs were examined with greater scrutiny, and those deemed the most widely applicable were chosen from each IOU. One Tiered and one TOU tariff was chosen from each IOU and are shown in Table 3.

Table 3: Representative Electric Rate Tariffs by IOU

IOU	Type of Service	Electric Rate Tariff
PG&E	Tiered	ES – Multifamily Service
	TOU	TOU – C – Residential Time-of-use
SCE	Tiered	D: Domestic Service
	TOU	TOU – D – 4-9PM
SDG&E	Tiered	DS - Domestic Service
	TOU	TOU – DR – Residential – Time of Use Service

Cost Calculation Methods Based on Rate Tariffs

All active rate tariffs were observed to have fixed charges applied either on a monthly or daily basis. This analysis considers all charges found in the tariffs to provide an accurate comparison between plans. Within each tariff, there are correlations between climate zone, season, and baseline allowance. Large disparities among baseline allowances across climate zones were observed, particularly in the summer season baselines. In contrast, differences in winter season baseline allowances were comparatively unremarkable.

The use of the full rate tariff, including fixed charges and daily baseline allowances, is only rational for a whole building analysis. Cost analysis on specific systems must either use a whole building energy analysis with the full tariff or use the system energy and the marginal cost of energy.

Table 4: Rate Calculation Types and Relevance

Rate calculation type	Relevance
Full rate tariff	Whole-building energy models
Representative marginal hourly cost ($/kWh)	Direct Comparison of Sub-systems

The simplified rate calculation values differential changes in energy usage at the marginal cost to the customer for incremental changes in energy usage ($/kWh) as a function of month and seasonal/TOU period, if applicable.[3] This calculation starts with a reference whole building hourly load profile. The exact rate tariff is first applied to the reference model. For tiered rates, the achieved tier is identified for each monthly and seasonal/TOU period based on usage. The energy charge ($/kWh) for the achieved tier is taken as the marginal cost. Typically, the rate increases with each successive usage tier, giving a marginal rate that is often higher than the average rate, which is simply the energy charges divided by the usage within the given period.

The whole building EnergyPlus model setups are designed to output the electric and gas consumption of the entire facility as well as the modeled DHW system energy and gas consumption. An Excel workbook was created to provide detailed rate tariff information in a tabulated format. This workbook can be found in the appendices under "ET24SWG0005 (MS02b) Fuel Tariff Write-up (2024-08-27).xlsx." Each representative tariff is detailed in its own tab, which includes rate information and tables for calculating monthly and marginal costs. Users only need to enter the whole building and system hourly data into the 'Data Entry' tab and select the climate zone, type of service (Tiered/TOU), and start year on the 'Dashboard' tab. The dashboard provides an overview of monthly energy consumption, costs, and emissions. The individual tariff tabs will give a detailed breakdown of the costs in each tier or the hourly costs for TOU tariffs.

Sample data was created using the default DEER multifamily EnergyPlus model, which includes an AC/Gas Furnace and natural gas water heater. There are 24 dwellings in this model which were run for each climate zone. The results were divided by the number of units in the facility (24) because the rate tariffs used are for sub-metered households. For testing the workbook, only the CZ01 results were used. However, the workbook was also tested with different climate zones using the same profile. After inputting the data and selecting the climate zone and type of service, the workbook will display which tariff is being used for the calculation on the dashboard. Table 5 shows the results of the tool for climate zone 1 with tiered service (PG&E ES – Multifamily Service).

[3] Note that some rate tariffs define tiers accrual and reset on a daily time scale. For the current work, this is also simplified using equivalent tier thresholds at a monthly time scale.

Table 5: AC/Gas Furnace Model Cost per kWh Analysis with PG&E Schedule ES – Multifamily Service

Month	kWh Usage	Monthly Baseline	Highest Tier this Month	Total	Marginal $/kWh
January	268.31	251.1	Tier 2	$117.17	$0.48617
February	244.70	226.8	Tier 2	$106.98	$0.48617
March	266.37	251.1	Tier 2	$116.23	$0.48617
April	258.09	243	Tier 2	$112.64	$0.48617
May	266.71	251.1	Tier 2	$116.40	$0.48617
June	265.57	213	Tier 2	$119.21	$0.48617
July	268.91	220.1	Tier 2	$120.50	$0.48617
August	273.54	220.1	Tier 2	$122.75	$0.48617
September	260.23	213	Tier 2	$116.61	$0.48617
October	268.20	251.1	Tier 2	$117.12	$0.48617
November	261.11	243	Tier 2	$114.10	$0.48617
December	271.23	251.1	Tier 2	$118.59	$0.48617

Note the dashboard may display different results for the total cost due to the addition of credits or other charges that are distributed evenly each month.

Gas Rate Tariffs and Cost Analysis

Similarly, the natural gas tariffs offered for residential customers by the three IOUs were evaluated. Table 6 contains the complete list of available tariffs, their qualifiers, and multifamily eligibility.

Table 6: Available Gas Rate Tariffs and Key Features

IOU	Tariff Option	Type	Qualifier	Multifamily Eligibility	Details
PG&E	G-1	Tiered		Yes	Residential Service
	GM	Tiered		Yes	Master-Metered Multifamily Service
	GS	Tiered		Yes	Multifamily Service
	G1-NGV	-	NGV/HRA	No	Residential Natural Gas Service for Compression on Customers' Premises
	GL-1	Tiered	CARE Program	Yes	Residential CARE Program Service
	GML	Tiered	CARE Program	Yes	Master-Metered Multifamily CARE Program Service
	GSL	Tiered	CARE Program	Yes	Multifamily CARE Program Service
	GTL	Tiered	CARE Program	No	Mobile home Park CARE Program Service
	GL1-NGV	-	CARE Program	No	Residential CARE Program Natural Gas Service for Compression on Customers' Premises
SoCalGas	GS	Tiered		Yes	Multifamily Service
	GM	Tiered		Yes	Master-Metered Multifamily Service
	G-NGVR	-	NGV/HRA	No	Natural Gas Service for Home Refueling of Motor Vehicles
	G-CARE	-	CARE Program	Yes	California Alternate Rate for Energy (CARE) Program
	GO-AC	Tiered	Gas AC	Yes	Optional Rate - Air Conditioning
SDG&E	GS	Tiered		Yes	Multifamily Service
	GM	Tiered		Yes	Master-Metered Multifamily Service
	G-CARE	-	CARE Program	Yes	California Alternate Rate for Energy (CARE) Program
	G-NGVR	-	NGV/HRA	No	Natural Gas Service for Home Refueling of Motor Vehicles
	G-SMOP	-	Analog Meter	Yes	Residential Gas Smart Meter Opt-Out Program

The same sources and methods used for choosing the representative electric tariffs were also applied to choose the gas tariffs. There are far fewer options for natural gas rates. Special qualifiers and programs were avoided, resulting in only one or two options per IOU. Multiple tariffs were selected for each IOU where possible.

Table 7: Representative Gas Rate Tariff by IOU

IOU	Default Electric Rate Tariff
PG&E	G-1: Residential Service
	GS: Multifamily Service
SoCalGas	GS: Multifamily Service
	GM: Master-Metered Multifamily Service
SDG&E	GS: Multifamily Service
	GM: Master-Metered Multifamily Service

The inclusion of master-metered tariffs was looked at more carefully as there are no master-metered electric tariffs being used in the analysis. After reviewing each tariff, it was found that there are no rate differences between sub-metered and master-metered gas tariffs for both SoCalGas and SDG&E.

Using the same sample model used previously, the results for one gas tariff in CZ01 were calculated and are presented in Table 8.

Table 8: AC/Gas Furnace Model Cost per Therm Analysis with PG&E Schedule G-1

Month	Therms Usage	Monthly Baseline (Therms)	Highest Tier this Month	Total	Marginal $/Therms
January	38.73	79.98	Baseline	$87.84	$2.162
February	39.90	62.16	Baseline	$89.98	$2.162
March	34.52	68.82	Baseline	$78.74	$2.162
April	36.69	21.6	Excess	$89.98	$2.606
May	32.71	22.32	Excess	$79.44	$2.606
June	30.81	21.6	Excess	$74.67	$2.606
July	31.80	22.32	Excess	$77.06	$2.606
August	31.88	22.32	Excess	$77.26	$2.606
September	30.92	21.6	Excess	$74.95	$2.606
October	32.79	22.32	Excess	$79.63	$2.606
November	35.66	66.6	Baseline	$81.08	$2.162
December	41.01	79.98	Baseline	$92.77	$2.162

GHG Emissions Factors

Building energy models output site energy usage (electric kWh and gas therms). To evaluate and optimize source fuel usage or greenhouse gas emissions, source fuel and GHG factors from the 2024 CPUC California ACC Electric and Gas models were used. The 2024 ACC models provide hourly emissions per unit of electric consumption for the years 2023-2054. It should be noted that ACC factors are typical values considering typical weather and grid load patterns over several years. These factors are designed to evaluate marginal operating source energy and emissions, rather than averages, since the key application for these factors is for evaluating the benefits of incremental changes from efficiency and demand response measures. Because of its relevance to regulated incentive programs and its derivation from typical data rather than a single year of historical data, the 2024 ACC was selected as the most representative source of both source fuel and emissions factors.

Unlike calculating the costs, the emissions calculations are not sensitive to using whole building results rather than system results. The analysis workbook includes calculations for monthly electric and gas GHG emissions. By selecting a climate zone on the dashboard, the appropriate table of emissions factors (NP-15/SP-15) will be used. The start year selected will determine the column of data used from the table. For natural gas consumption emissions, the calculations are far simpler, with the 2024 ACC gas model referencing a single value of 0.00531 Tonnes-CO_2/Therm.

The same sample model was again used to produce results for GHG emissions. The system does not consider any electric inputs for the water heating. Table 9 contains the sample results.

Table 9: AC/Gas Furnace Model, Gas Water Heaters Emissions Analysis

Month	System kWh Usage	System Therms Usage	Facility kWh Usage	Facility Therms Usage	System GHG Emissions (kg CO2/yr)	Facility GHG Emissions (kg CO2/yr)
January	-	30.37	268.31	38.73	161.17	330.38
February	-	27.47	244.70	39.90	145.80	309.40
March	-	30.30	266.37	34.52	160.81	272.35
April	-	29.34	258.09	36.69	155.71	272.19
May	-	30.29	266.71	32.71	160.77	253.63
June	-	29.15	265.57	30.81	154.71	263.84
July	-	30.09	268.91	31.80	159.67	275.73
August	-	30.15	273.54	31.88	160.01	299.91
September	-	29.21	260.23	30.92	155.00	281.61
October	-	30.25	268.20	32.79	160.53	294.75
November	-	29.40	261.11	35.66	156.05	304.38
December	-	30.35	271.23	41.01	161.06	338.36

Operation Costs and Emissions Tool Usage

The excel tool developed in this task is used in the remaining project tasks, including evaluating operational costs and emissions based on modeled energy consumption and calculating simple payback. The data input to this tool is the hourly electric and gas consumption received from the EnergyPlus output files. Additional inputs are the climate zone and service type (tiered, time-of-use).

DHW Models, Emissions, and Fuel Costs Analysis

Project Description and Objectives

This section analyzes several DHW systems used in multifamily buildings, utilizing models based on approved DEER EnergyPlus prototypes. Multifamily models used in this study will be the best available prototypes: either DEER models themselves, or DEER models modified to include DHW primary and recirculation loops. This project models the therm, kW and kWh used for all measure cases.

The following metrics will be compared across condensing gas-fired boilers, GAHPs, and EHPWH technologies for at least two different rate tariffs from each eligible Investor-Owned Utility and all 16 California climate zones:

1. Energy savings
2. Utility fuel costs
3. Greenhouse gas emissions

Modeling Approach

The energy savings of DHW modeling in a multifamily property were calculated as the difference between the base case and measure case energy consumption derived from building energy use simulations. The energy models were based on DEER residential prototype buildings for each climate zone (CZ01-CZ16). The model was modified to include the proposed architecture for the recirculation loop. Inputs were left to DEER prototype defaults unless otherwise noted below.

The base and measure case energy use models were changed to reflect the appropriate base and measure case configuration as described in the following section. The make-up water temperature for DHW application varies across climate zones and is calculated based on outdoor dry bulb temperature. When using “Correlation” method in EnergyPlus to estimate make-up city water temperature based on outdoor air temperature, two input parameters “Average Annual Outdoor Air Temperature” and “Maximum Difference in

Monthly Average Outdoor Air Temperatures” need to be given to EnergyPlus. Table 10 presents these two parameters in each climate zone in California.

Table 10: Weather Statistics for California's Climate Zones

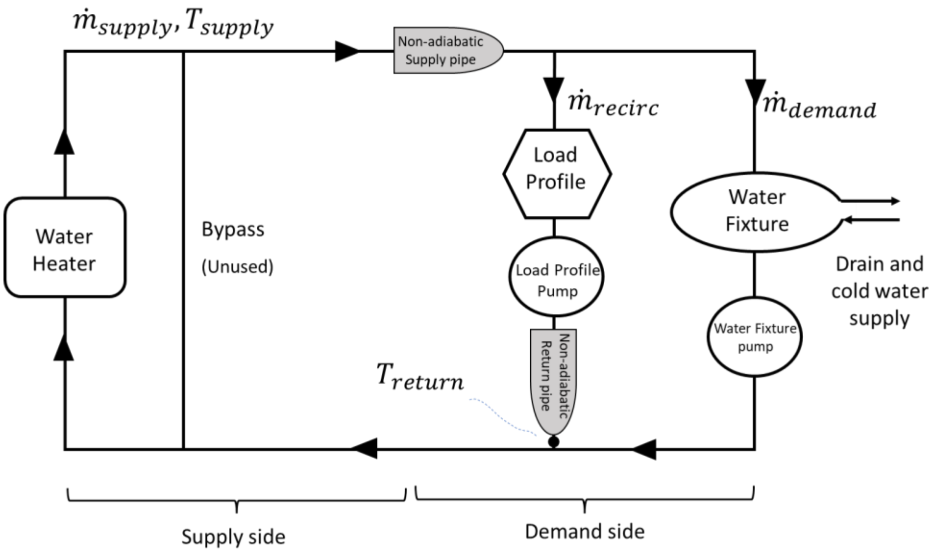
Climate Zone	Average Annual Outdoor Air Temperature (°F)	Maximum Difference in Monthly Average Outdoor Air Temperatures (°F)
CZ01	51.40	12.40
CZ02	57.54	18.97
CZ03	57.83	13.64
CZ04	60.18	19.08
CZ05	57.83	13.78
CZ06	63.30	12.83
CZ07	64.07	16.02
CZ08	64.18	16.90
CZ09	65.06	16.72
CZ10	65.49	29.75
CZ11	64.09	39.25
CZ12	62.34	31.71
CZ13	65.93	39.11
CZ14	69.06	43.61
CZ15	75.56	37.71
CZ16	58.62	43.61

DHW Recirculation Loop Proof-of-Concept

Figure 1 presents the schematic configuration used to model a domestic hot water (DHW) recirculation loop in EnergyPlus. This diagram illustrates the recirculation architecture for DHW as implemented in the EnergyPlus model.

Note that the GAHP model was only recently added to EnergyPlus and is only available as of EnergyPlus v23.1. The latest version, EnergyPlus v24.1, was used for this model. Since DEER residential prototypes are only available up to EnergyPlus v9.5, the DEER models were first updated from v 9.5 to v 24.1 using the IDFVersionUpdator.

Figure 1: DHW EnergyPlus Architecture



The water fixture branch (far right) contains objects that use DHW such as baths, sinks, showers, and appliances. Note that to solve flow and pressure in the water fixture branch, EnergyPlus requires a pump at the location labeled "Water Fixture Pump". Make-up water is supplied to the water fixture in the diagram above. The cold-water supply is located in the far-right branch after the water fixture and water fixture pump delivers the required make-up water to the storage tank.

The recirculation branch, denoted by m_{recirc}, models the recirculation flow rate and pipe thermal losses. By placing the recirculation pump within this branch, the recirculation loop return flow rate is decoupled from the dwelling unit demand flow rate. In EnergyPlus, flow rates are not controlled directly via pumps but by inserting objects that demand flow from the pumps. A bare pipe cannot request flow; therefore, this branch includes a "LoadProfile" object that requests a flow rate based on an hourly lookup schedule, which is available in the IDF fields of the LoadProfile object. Please note that the DEER residential prototype includes the recirculation branch only with non-adiabatic pipes.

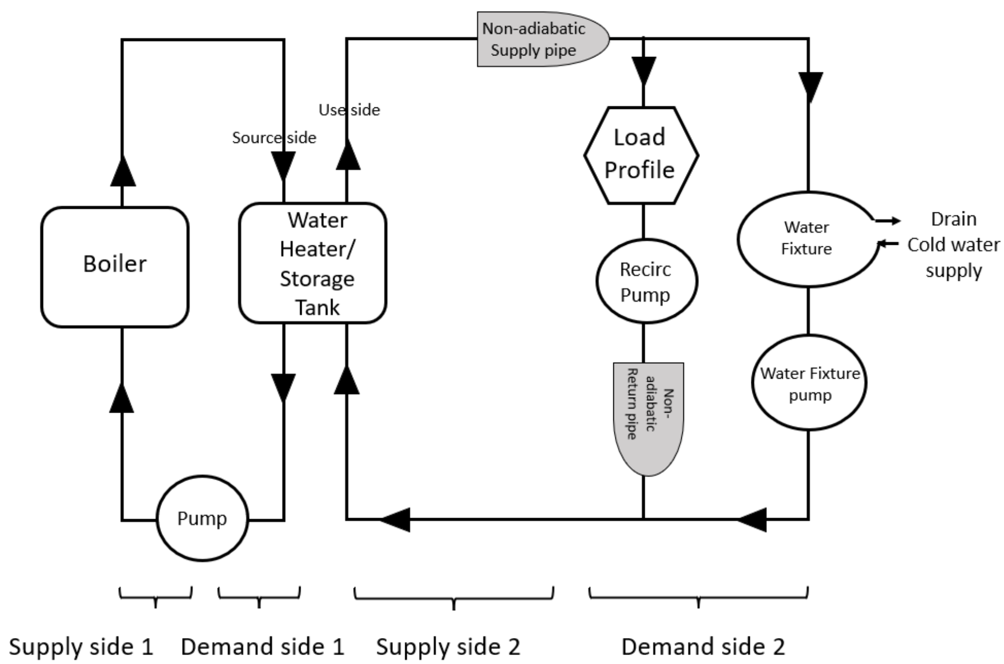
Table 11: Model Summary Info

Model setup property	Model selected option
Platform	EnergyPlus
Model Type	MFm DEER EnergyPlus Prototypes
Energy Modeling Engine	EnergyPlus version 9.5 for Boiler and HPWH models and EnergyPlus version 24.1 for GAHP included models
Prototype Source	DEER EnergyPlus Prototypes

Base Case: Boiler with 84% Thermal Efficiency

Figure 2 illustrates the EnergyPlus-translated architecture for the base case. In this design, the storage tank (water heater with zero capacity) is indirectly heated by the boiler. The loop on the right encompasses both the domestic hot water demand branch and a recirculation branch. The demand branch features a water fixture and pump that facilitate flow for end uses, while the recirculation branch consists of non-adiabatic supply and demand pipes that account for losses in the piping. The recirculation loop also includes a load profile object to simulate a scheduled demand, ensuring a consistent hot water flow. Additionally, recirculated and make-up water mix before entering the storage tank, which is indirectly heated by the boiler, while the output from the storage tank supplies the end uses. It is important to note that the temperature setpoint for the outlet of the water heater/storage tank on the use side is 135°F, and the boiler capacity is automatically sized by EnergyPlus.

Figure 2: Boiler EnergyPlus Architecture



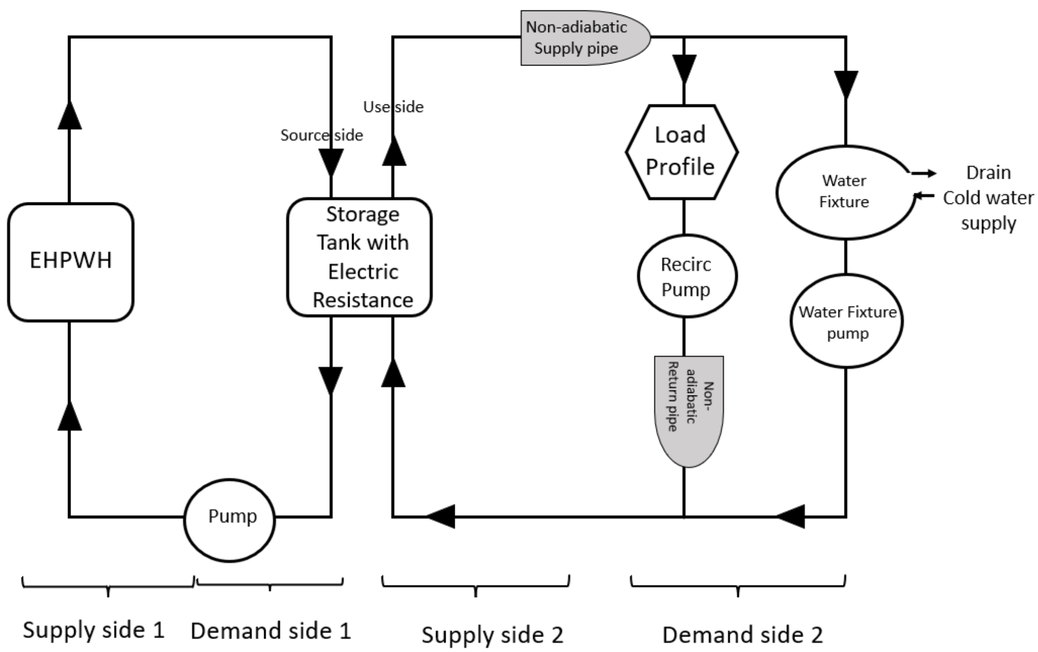
Measure Case 1: Condensing Boiler with 97% Thermal Efficiency

The architecture of the measure case is the same as the base case (Figure 2). The differences between the base and measure cases are the thermal efficiency changed from 84% to 97% and the boiler efficiency curve changed from non-condensing to the condensing efficiency curve. Similar to the base case, the temperature setpoint for the outlet of the water heater/storage tank on the use side is 135°F, and the boiler capacity is automatically sized by EnergyPlus.

Measure Case 2: Electric Heat Pump Water Heater

Figure 3 demonstrates the simplified EnergyPlus architecture for this measure. The storage tank, which includes an electric resistance element, is indirectly heated by a heat pump water heater (HPWH). The electric resistance is for backup purposes and will run if the temperature in the storage tank drops. Mixed recirculated and make-up water flows into the tank, where the HPWH heats the water. Additionally, the storage tank includes an electric resistance to compensate for any temperature drops below a specified threshold. The threshold is specified as the tank setpoint temperature (135°F) – deadband (3.6°F).

Figure 3: EHPWH EnergyPlus Architecture



The inputs for this model are obtained from the Ecosizer tool, which is used to determine the appropriate tank volume and heating capacity for the EHPWH. The curve fit from Ecosizer is then hardcoded into EnergyPlus for simulation purposes. Figure 4 displays the inputs from our model into the Ecosizer tool, while Figure 5 shows the Ecosizer curve fit that serves as input for the EnergyPlus model. It is noted that the setup and assumptions used with the Ecosizer tool are applied only for EHPWH. Detailed inputs and calculations for the Ecosizer tool can be found in the file titled “DHW Flow Rate and Ecosizer Inputs.xlsx” in Appendices. Please note that the temperature setpoint for the outlet of the water heater/storage tank on the use side is 135°F, and the EHPWH capacity and tank volume are hard coded from the curve fit results of the Ecosizer tool.

Figure 4: Ecosizer Tool Inputs

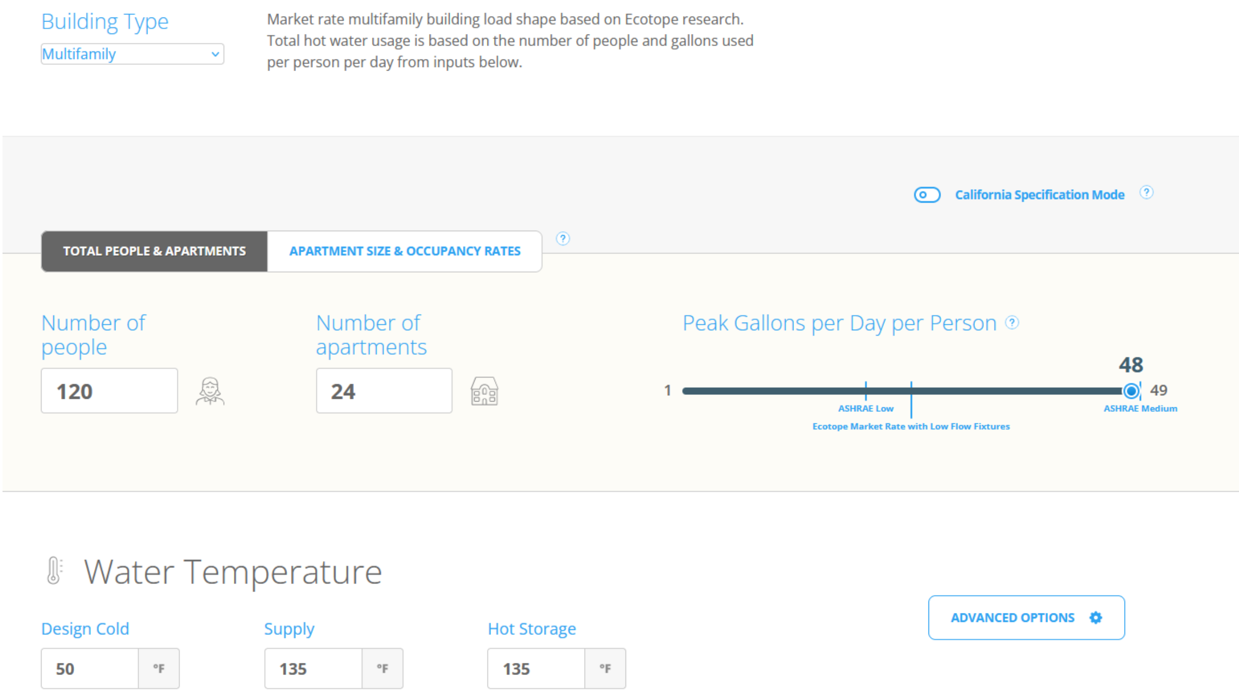
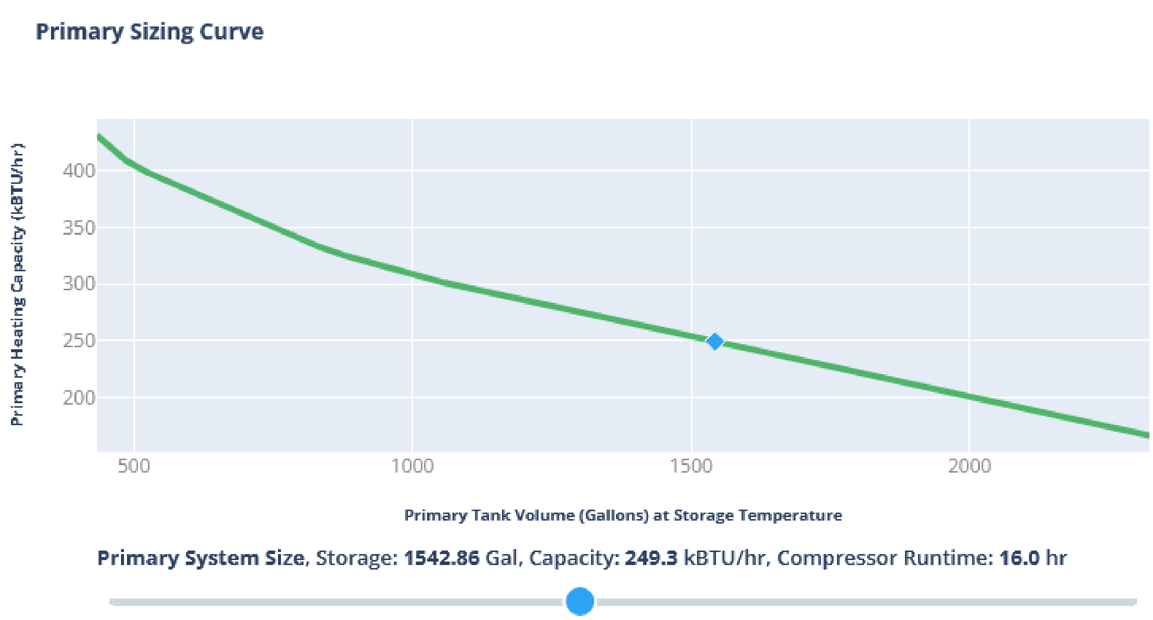


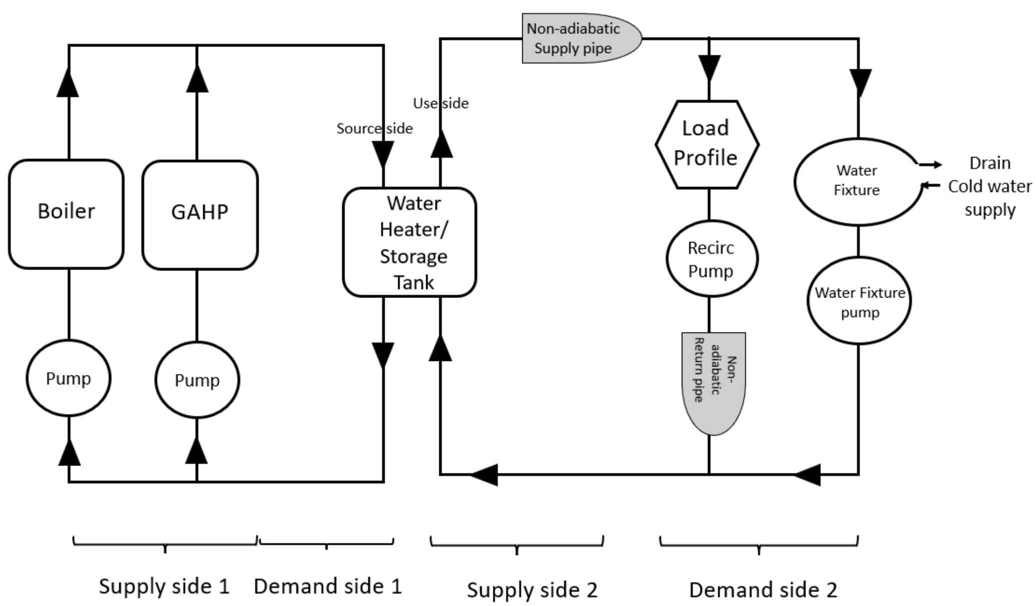
Figure 5: Ecosizer Tool Outputs



Measure Case 3: GAHP Acting as Preheat and Reheating Recirculation Water (GAHP-v1)

The simplified EnergyPlus architecture for this measure is illustrated in Figure 6. In this design, recirculation water mixes with make-up water before flowing into the storage tank. The gas absorption heat pump and boiler operate in parallel to heat the storage tank, after which hot water is delivered to the fixtures. The load distribution scheme for the two heating sources is set to "Optimal" in EnergyPlus, ensuring that each piece of equipment operates at its optimal part-load ratio. The outlet temperature setpoint for the water heater/storage tank on the usage side is 135ºF. For this case, the GAHP with a capacity of 123 kBTU is used, along with the boiler and tank capacities that were already auto sized in the base case.

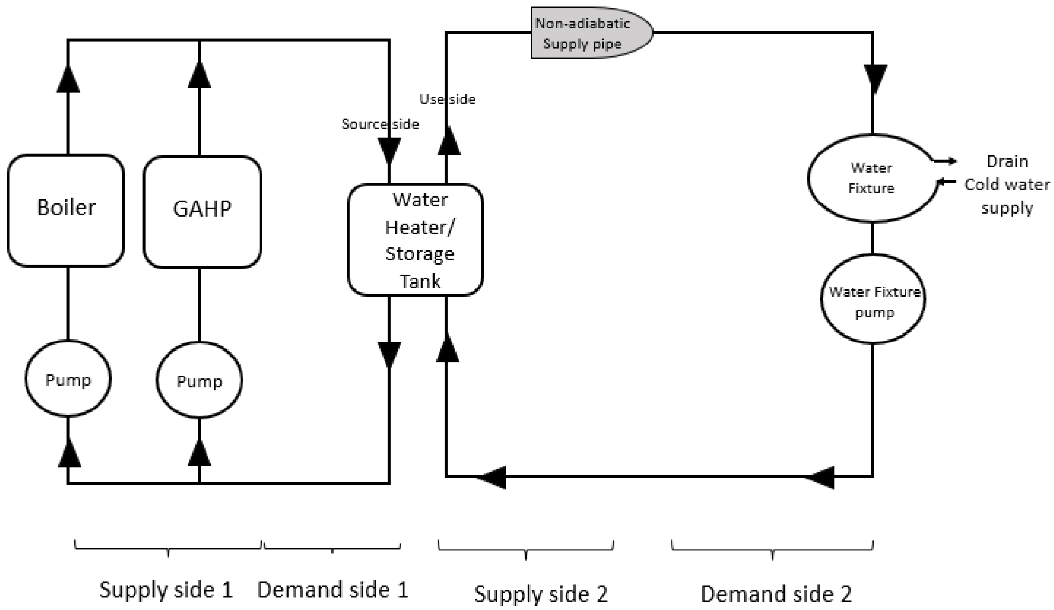
Figure 6: GAHP EnergyPlus Architecture



Measure Case 4: GAHP Acting as Preheat (GAHP-v2)

For this measure, the same architecture shown in Figure 6 is used but modified by removing the recirculation branch from the right loop. Instead, the calculated recirculation energy use is added to the boiler energy consumption in the left loop. This makes the boiler responsible for heating the recirculated water to the appropriate temperature rather than the more efficient GAHP.

Figure 7: GAHP EnergyPlus Architecture



Model Energy, Cost, & Emissions Results and Discussion

Figure 7 illustrates the annual energy consumption for various cases: the base case (Boiler with 84% thermal efficiency), measure case 1 (Condensing Boiler with 97% thermal efficiency), measure case 2 (EHPWH), measure case 3 (GAHP-v1), and measure case 4 (GAHP-v2).

The base case exhibits the highest site energy consumption, which varies across different climate zones due to differences in city water temperatures influenced by local weather conditions. The EHPWH demonstrates the lowest site energy consumption, attributable to its high coefficient of performance (COP) of 3.2, making it the most efficient case on a site energy basis. GAHP-v2 shows slightly higher energy consumption than GAHP-v1, as GAHP-v1 benefits from higher temperature water entering the non-stratified storage tank (a mix of recirculation and make-up water), whereas GAHP-v2 relies only on make-up water.

Figure 8: Modeled Annual Energy Consumption of DHW Systems

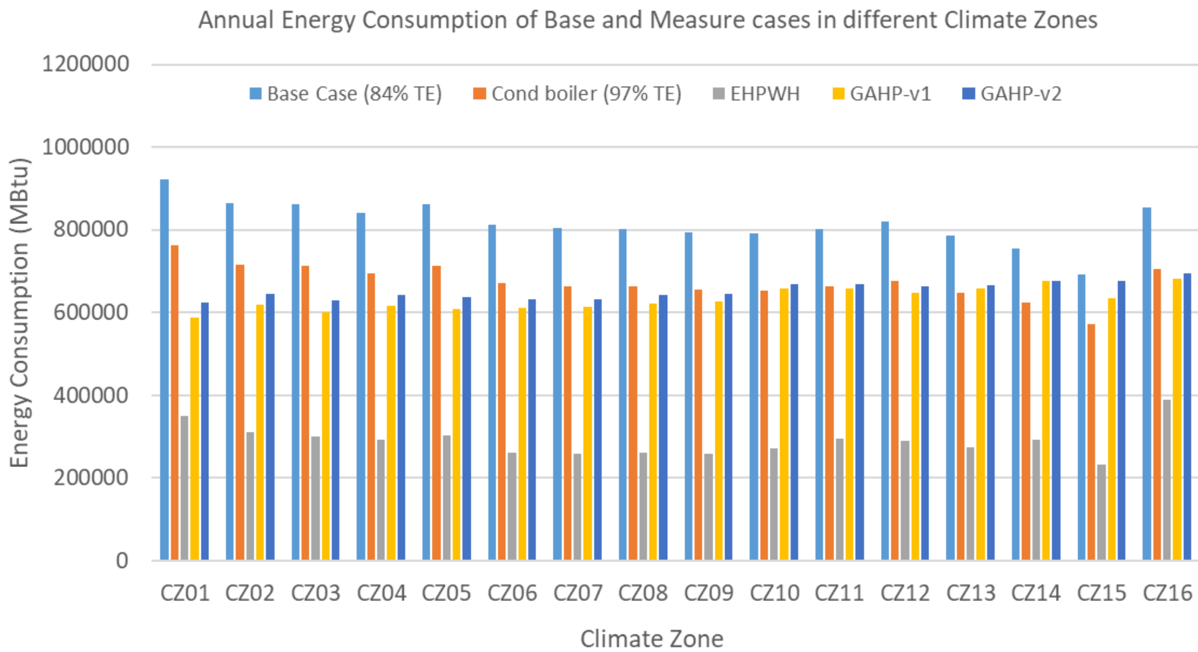


Figure 8 illustrates the savings percentage of the measured case compared to the 84% thermal efficiency baseline. The EHPWH demonstrates the highest site energy savings due to the 3.2 COP when compared to the 84% thermal efficiency of the baseline. Conversely, the condensing boiler with 97% thermal efficiency shows the lowest site energy savings and GAHP-v1 shows slightly higher savings compared to GAHP-v2 for the reasons mentioned in the above paragraph.

Figure 9: Modeled Site Energy Savings Percentage by System Type

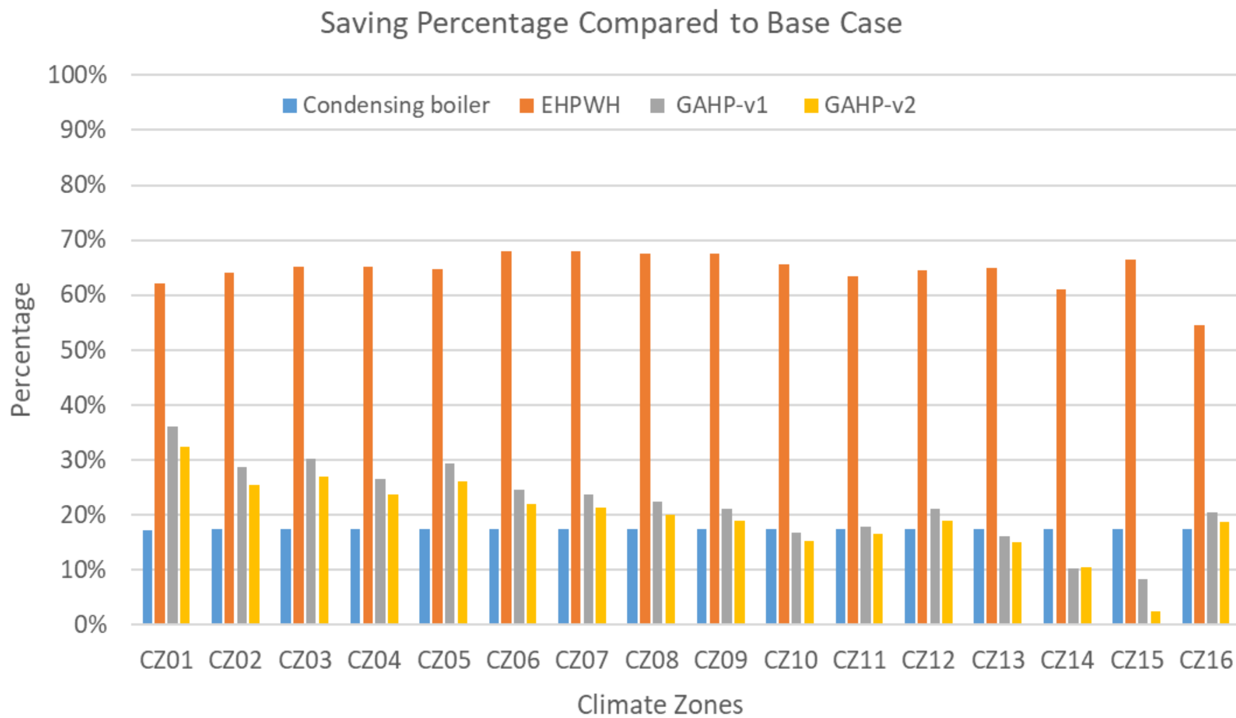
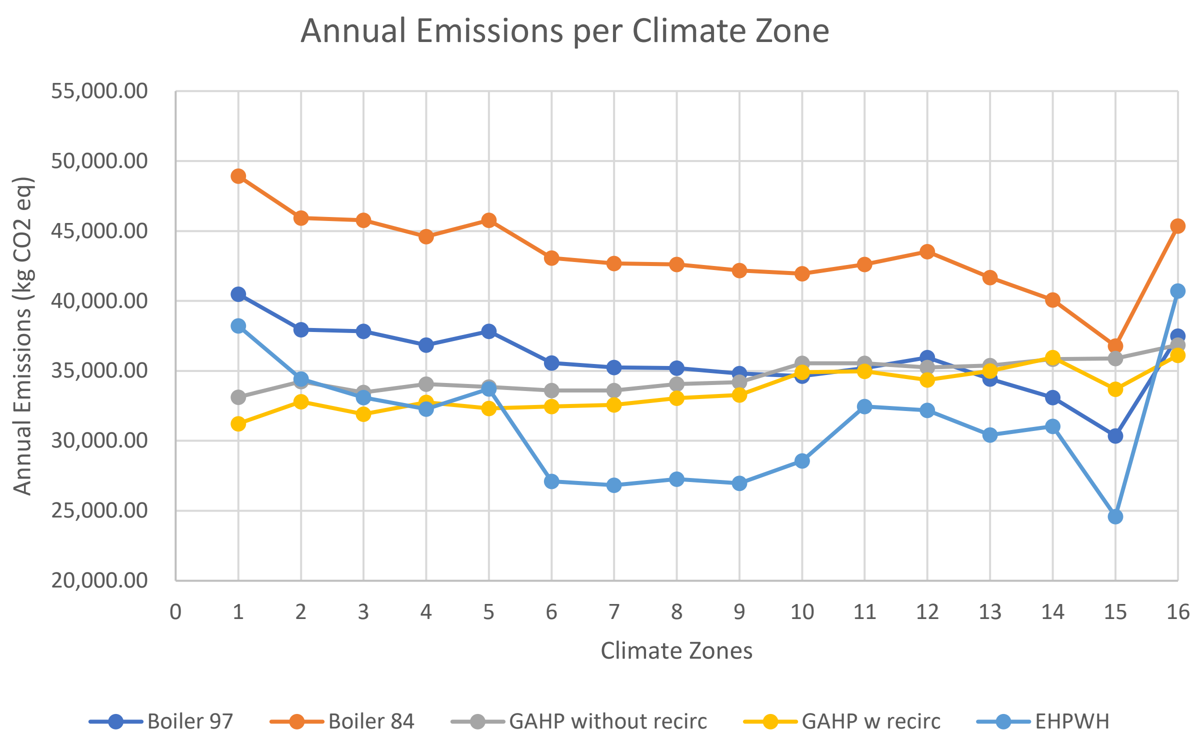


Figure 10 shows utility (source) emissions for each case for all sixteen climate zones of California in 2025. Emissions were calculated for all cases using the calculator created in the previous section of this project. The calculator utilizes the 2024 Avoided Cost Calculator (ACC) electric and gas models to determine the emission factors for the years 2025 to 2034. The highest emission is attributed to the base case and the least emission is attributed to the EHPWH or the GAHP-v2 depending on the climate zone. The GAHP-v2 specifically has lower emissions in climate zones 1, 2, 3, and 16.

Figure 10: Projected 2025 Annual Emissions per Climate Zone



Annual emissions would not be expected to change over time for the gas systems in this study, while the EHPWH is expected to reduce its annual emissions every year due to greener grid operations. Figure 10 shows the expected annual emissions per year for the EHPWH. The emissions are calculated to decrease by 17% by 2030 and 18% by 2034.

Figure 11: EHPWH Annual Emissions per Year

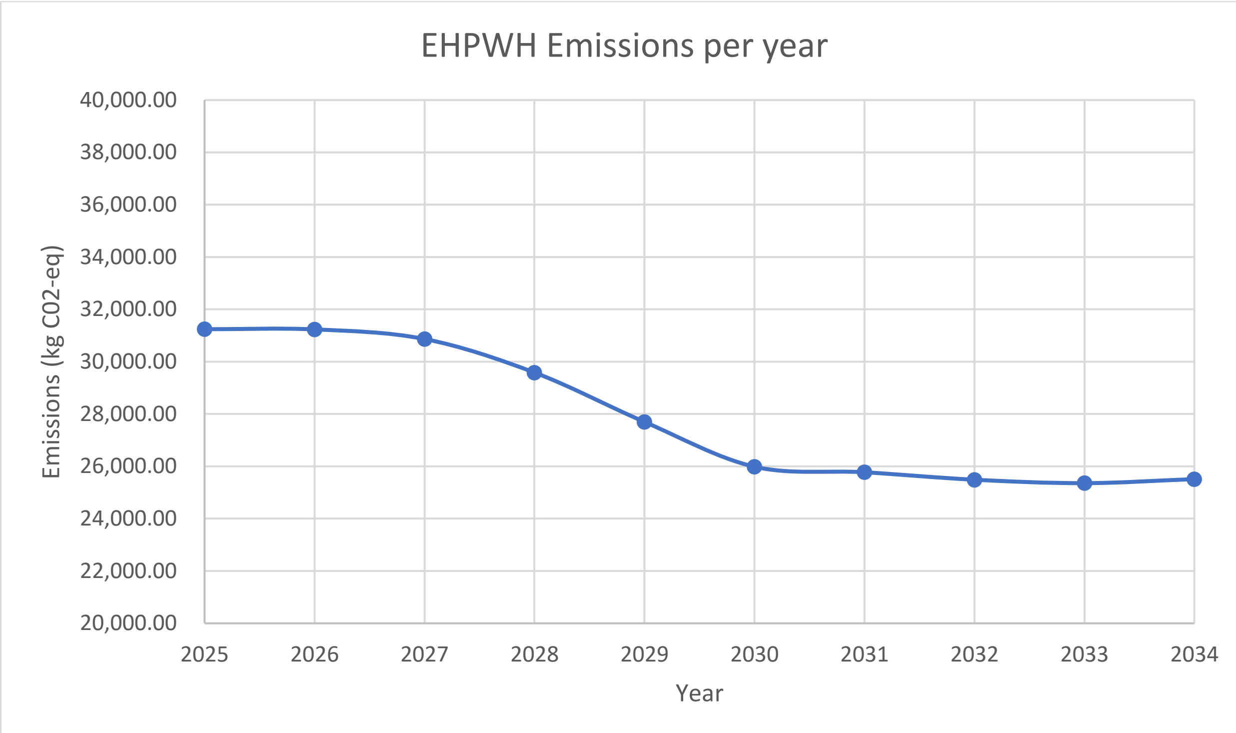
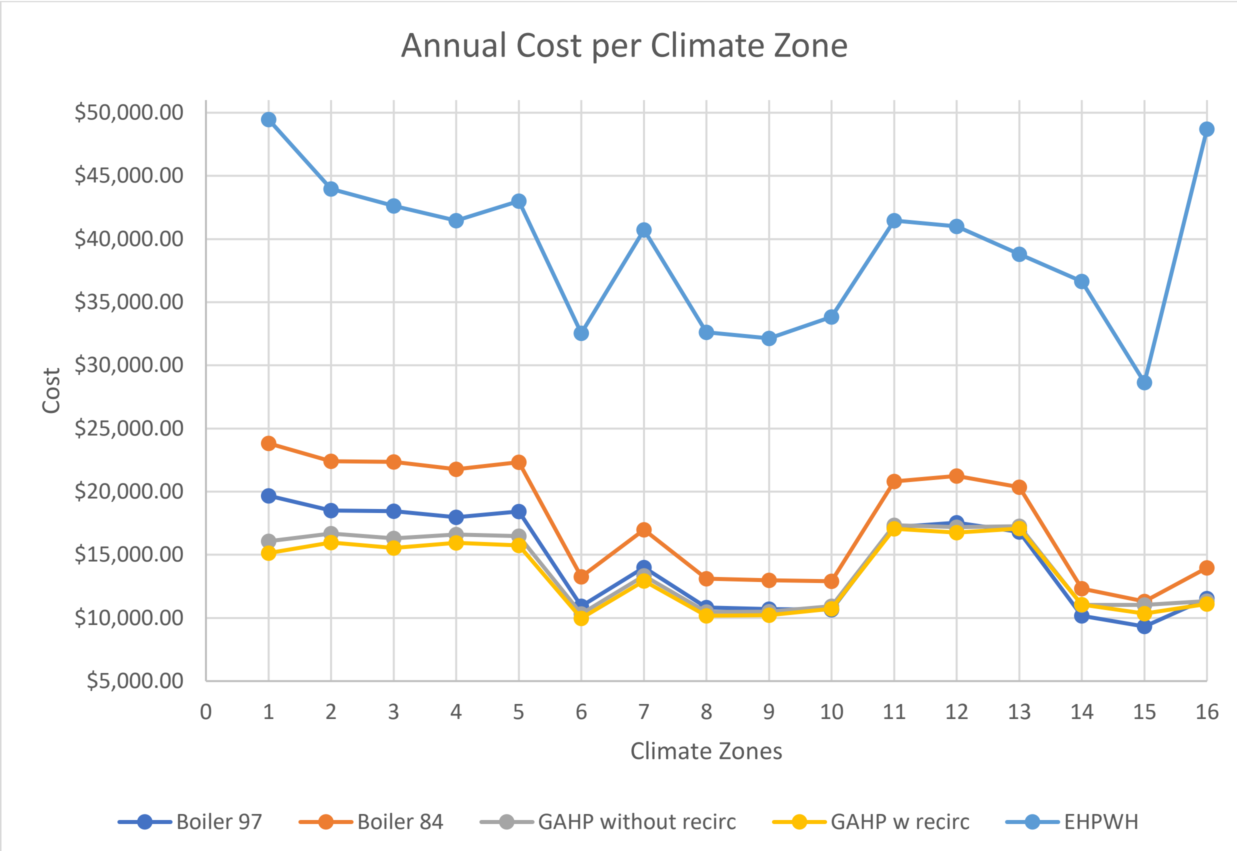


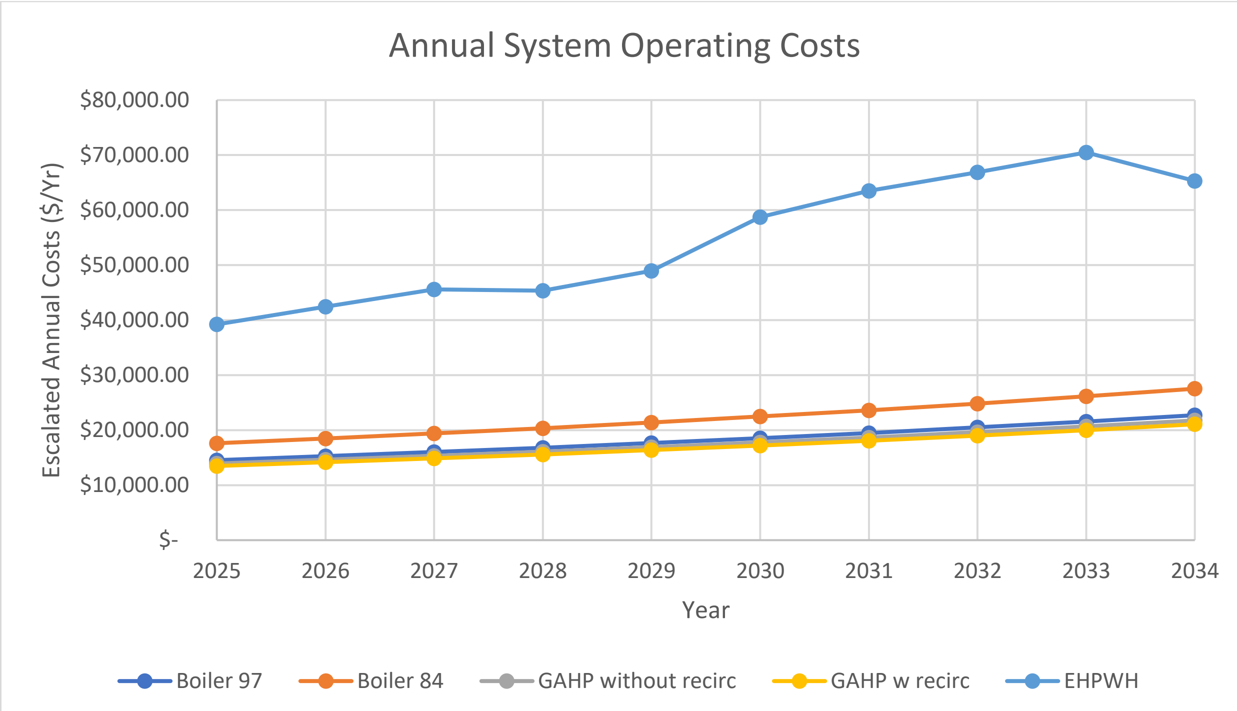
Figure 11 shows the annual utility cost per system based on modeled energy consumption. To calculate the costs, the energy consumption and demand results from the models were input into the tool created in the previous section. Costs are determined for each climate zone based on the representative IOU's tariffs. The cost of electricity in California is significantly higher compared to gas, which contributes to the EHPWH operating costs being larger than any of the gas counterparts.

Figure 12: Annual Cost per Climate Zone



According to the 2024 ACC data, the difference between electric and gas costs are expected to grow. Using the ACC electric model's Total Annual $/MWh data and the ACC gas model's avoided cost values, escalation factors for each year from 2025 to 2034 were determined using the percent change in the cost data relative to the 2025 costs. It is unknown whether the relationship between the changes in total avoided costs are reflected in customer rates. Although rate changes do not happen every year, it is assumed for this analysis that the rate changes follow the escalation factors found in the ACC data. Figure 12 shows the results of the expected annual operating costs.

Figure 13: Annual System Operating Costs (Escalated using ACC 2024)



In summary, Table 12 presents the average site and source energy consumption (in MBtu) across all sixteen climate zones for the base case, condensing boiler, EHPWH, GAHP-v1, and GAHP-v2, along with the percentage savings compared to the base case. It is important to note that conversion factors of 2.8 for electricity and 1.05 for natural gas for the site-to-source energy conversion were used, based on information from ENERGY STAR[4]. Based on Table 12, the average site and source energy savings for natural gas equipment remain consistent, while the savings for EHPWH have decreased from 64% in site energy to only 5% in source energy. This significant reduction is attributed to the higher site-to-source energy conversion factor for electricity compared to natural gas.

[4] https://portfoliomanager.energystar.gov/pdf/reference/Source Energy.pdf

Table 12: Average Site and Source Energy Use of Different Cases and Percentage Saving Across California's Sixteen Climate Zones

Case	Non-condensing Boiler	Condensing Boiler	EHPWH	GAHP-v1	GAHP-v2
Average Site Energy Consumption across sixteen climate zones (Mbtu)	1.31E+07	1.08E+07	4.64E+06	1.01E+07	1.04E+07
Average Site Energy Consumption across sixteen climate zones (Mbtu)	1.37E+07	1.13E+07	1.30E+07	1.06E+07	1.1E+07
Average percentage site energy savings	----	17	64	23	20
Average percentage Source energy savings	----	17	5	23	20

Based on the modeling results, it can be concluded that all measure cases have outperformed the baseline in terms of energy consumption and GHG emissions, though not necessarily in terms of fuel costs. The results of the cost analysis indicate that the contrast between electric and gas-fueled systems will only grow, making gas-fueled systems much more economically viable over time. It is evident from the energy consumption and cost figures that while the EHPWH consumes the least site energy among the options, its operational cost is at least three times higher than that of equipment running on gas.

In terms of emissions, the GAHP systems do compete with the EHPWH in certain climate zones, particularly, climate zones 1, 2, 3, 4, 5, and 16. However, there are several climate zones where the EHPWH produces significantly lower emissions. It is important to understand that electric systems will only improve in the case of lower emissions and operating costs as the grid introduces more renewable and clean energy sources.

The operational costs calculated in this task will be a component in determining the TSB and simple payback in the next task. The same modeled energy results and calculated costs are used.

TSB and Simple Payback Analysis

The total system benefit (TSB) measures the dollar value of energy efficiency measures, summing their energy savings and refrigerant benefits into one metric. The simple payback calculation determines the amount of time it takes to start receiving a return on investment from an implementation. In the case of energy efficiency measures, this is in the form of operational cost savings from reduced energy consumption.

Previously the operational costs and energy consumption were calculated for 5 water heating systems in a multifamily building modeled in EnergyPlus.

The objectives of this task are to compare the following metrics across condensing gas-fired boilers, GAHPs, and EHPWH technologies using the results from EnergyPlus and the operational cost analysis done previously.

1. Total System Benefit
2. Simple Payback

The metrics are calculated for each system in all 16 California climate zones.

Total System Benefit (TSB)

TSB Calculation

The TSB is calculated using the CEDARS Cost Effectiveness Tool (CET) (California Public Utilities Commission, 2024). The TSB is calculated in the tool using the following equation:

Equation 1. Total System Benefit

$$TotalSystemBenefit = (ElecBenGross + GasBenGross + NumUnits * RefrigBens) - (ElecSupplyCostGross + GasSupplyCostGross + NumUnits * UnitRefrigCosts)$$

The EHPWH is the only measure system that has a non-zero value for “UnitRefrigCosts” due to it being the only system that uses refrigerants with environmental impacts. The GAHP utilizes a refrigerant with zero ozone depletion potential (ODP) and the refrigerant components of the TSB can be neglected. The Refrigerant Avoided Cost Calculator (RACC) 3.0 was used to calculate the refrigerant benefits/costs to use in the CET input file. The results of the EHPWH determined a unit refrigeration cost of $28.72 and referenced in “ET24SWG0005 (MS04c) - RACC-FSC_v3.1_EHPWH (2024-11-20).xlsx” in Appendices.

Measure Costs

The unit measure cost for each system is also required to calculate the TSB in the CET tool. Costs are derived from different sources based on data availability. All cost calculations were performed in "ET24SWG0005 (MS04b) TSB and Simple Payback Analysis (2024-11-20).xlsx" in Appendices. Costs for storage are not considered in this analysis. It was observed that, due to the auto-sizing function of both capacity and storage by EnergyPlus, system capacities were sized smaller than what may be expected while storage was extremely large for all systems. Storage in the base case was sized larger than all the measure case systems. Considering this, it is assumed all measure cases will utilize the existing storage available.

The costs for the 97% efficient condensing boiler are derived from 2024 RS Means listed material and labor charges for condensing boilers ranging from 71 – 365 kBtu/h capacities. The average total cost is $51.94/kBtuh.

The cost for the EHPWH was taken from the "Large Heat Pump Water Heater, Commercial and Multifamily, Fuel Substitution" measure package (SWWH028) cost analysis. Costs in the analysis are from actual projects and include material, labor, and some infrastructure costs (except panel upgrade). These categories can be broken down further into:

- Material
  - Equipment
  - Sensors and controllers
- Labor
  - Equipment labor
  - Sensors and controller labor
  - Commissioning and startup labor
- Infrastructure
  - Electrical circuits
  - Panel and main service modification

It should be noted that permitting is neglected in this analysis as no cost information was collected in the original measure package costs. The total measure cost for EHPWH is calculated to be $184.35/kBtuh.

GAHP costs for both versions are assumed to be the same. Material costs are based on previous systems that have been paid for per emails from Steven Long (Long, 2024). Due to many of the available cost data including items such as freight or air-handling units bundled in, data was limited to two (2) 80 kBtu/h units with an average cost of $12,250 and an assumed freight cost of $200. Removing the freight, the total material cost for each GAHP case is $150.63/kBTUh.

Labor costs for the GAHP were calculated based on (2) proposals for Robur systems at 123.5 kBtu/h capacity. Due to the other system costs in this analysis not including items such as permitting and maintenance, these were excluded from the labor costs for the GAHP as well. The labor cost is calculated to be $170.30/kBtuh. The total measure cost for the GAHP is calculated to be $320.92/kBtuh. Costs for the GAHP systems are much higher than other systems, which can be expected for an emerging technology very early into entering the market. It is expected the costs for labor will go down as adoption increases. All system costs are summarized below in Table 13.

Table 13: System Costs

System	Material Cost ($/KBtuh)	Labor Cost ($/KBtuh)	Total Measure Cost ($/KBtuh)
97% Condensing Boiler	$42.99	$8.95	$51.94
EHPWH	$160.44	$23.91	$184.35
GAHP v.1	$150.63	$170.30	$320.92
GAHP v.2	$150.63	$170.30	$320.92

Energy Use and Operation Costs

Annual energy consumption and costs based on the tariffs analysis are used considering the 2025 values. A summary of these annual costs and energy consumption for each system is given in Table 14 and Table 15. Detailed analysis can be found in "ET24SWG0005 (MS04b) TSB and Simple Payback Analysis (2024-11-20).xlsx". These savings for each system with respect to the 84% efficient boiler is used in the CET input file.

Table 14: Annual Energy Cost

	Annual Energy Cost ($)				
Climate Zone	84% Condensing Boiler	97% Condensing Boiler	EHPWH	GAHP v.1	GAHP v.2
CZ01	$23,824.03	$19,679.36	$49,467.64	$15,136.29	$16,067.54
CZ02	$22,416.42	$18,504.51	$43,962.15	$15,971.22	$16,684.22
CZ03	$22,351.14	$18,452.38	$42,621.72	$15,547.69	$16,310.90
CZ04	$21,771.03	$17,965.03	$41,460.81	$15,953.85	$16,595.05
CZ05	$22,340.86	$18,442.75	$43,013.41	$15,740.81	$16,487.80
CZ06	$13,253.39	$10,933.35	$32,545.03	$9,973.94	$10,324.35
CZ07	$16,991.37	$13,999.68	$40,729.04	$12,921.77	$13,343.74
CZ08	$13,116.40	$10,819.25	$32,621.99	$10,158.56	$10,469.12
CZ09	$12,978.83	$10,704.43	$32,141.44	$10,227.06	$10,509.43
CZ10	$12,905.50	$10,645.56	$33,838.95	$10,730.63	$10,929.35
CZ11	$20,818.91	$17,179.58	$41,455.29	$17,067.63	$17,343.91
CZ12	$21,251.73	$17,535.19	$41,013.34	$16,756.65	$17,191.63
CZ13	$20,363.74	$16,801.05	$38,799.77	$17,079.48	$17,271.18
CZ14	$12,331.78	$10,172.35	$36,654.49	$11,056.59	$11,022.57
CZ15	$11,308.45	$9,322.77	$28,639.27	$10,357.01	$11,030.58
CZ16	$13,959.76	$11,528.04	$48,710.82	$11,103.79	$11,333.38

Table 15: Annual Energy Consumption

	Annual Energy Consumption				
	84% Condensing Boiler	97% Condensing Boiler	EHPWH	GAHP v.1	GAHP v.2
Climate Zone	Therm Usage	Therm Usage	kWh Usage	Therm Usage	Therm Usage
CZ01	9,218.57	7,628.35	10,2273.40	5,885.28	6,242.58
CZ02	8,652.80	7,151.89	9,1093.81	6,179.93	6,453.49
CZ03	8,624.35	7,128.49	8,8147.99	6,014.03	6,306.86
CZ04	8,405.18	6,944.91	8,5948.83	6,173.26	6,419.28
CZ05	8,623.81	7,128.20	8,9142.36	6,091.53	6,378.13
CZ06	8,114.53	6,701.51	7,6316.12	6,117.19	6,330.60
CZ07	8,041.61	6,640.78	7,5571.03	6,136.06	6,333.64
CZ08	8,031.10	6,632.02	7,6494.19	6,229.63	6,418.77
CZ09	7,947.31	6,562.09	7,5585.79	6,271.35	6,443.32
CZ10	7,902.66	6,526.24	7,9580.35	6,578.05	6,699.08
CZ11	8,029.50	6,633.18	8,6165.79	6,590.22	6,696.23
CZ12	8,200.15	6,774.20	8,5180.63	6,475.49	6,642.38
CZ13	7,854.86	6,487.94	8,0703.67	6,594.77	6,668.32
CZ14	7,553.23	6,238.03	8,6075.74	6,776.57	6,755.85
CZ15	6,929.97	5,720.59	6,8125.86	6,350.49	6,760.74
CZ16	8,544.75	7,063.71	11,3852.34	6,805.32	6,945.15

TSB Results

The TSB and TRC values resulting from the CET tool are shown in Table 16 and Table 17. The full analysis and CET output file can be found in "ET24SWG0005 (MS04b) TSB and Simple Payback Analysis (2024-11-20).xlsx".

Table 16: TSB Results

	TSB ($)			
Climate Zone	**97% Condensing Boiler**	**EHPWH**	**GAHP v.1**	**GAHP v.2**
CZ01	$183	$469	$487	$435
CZ02	$173	$458	$361	$321
CZ03	$172	$470	$381	$339
CZ04	$168	$456	$326	$290
CZ05	$172	$454	$370	$328
CZ06	$164	$418	$292	$261
CZ07	$167	$397	$286	$256
CZ08	$163	$408	$263	$236
CZ09	$161	$406	$245	$220
CZ10	$160	$378	$194	$176
CZ11	$161	$415	$210	$195
CZ12	$164	$430	$252	$228
CZ13	$158	$417	$184	$173
CZ14	$153	$298	$113	$117
CZ15	$141	$332	$85	$25
CZ16	$172	$288	$254	$234

Table 17: TRC Results

	TRC and TRC Ratio							
	97% Condensing Boiler		EHPWH		GAHP v.1		GAHP v.2	
Climate Zone	TRC	TRC Ratio	TRC	TRC Ratio	TRC	TRC Ratio	TRC	TRC Ratio
CZ01	$3,984	6.79	$164,280	1.45	$26,209	2.3	$26,209	2.05
CZ02	$3,984	6.41	$152,318	1.46	$26,209	1.71	$26,209	1.51
CZ03	$3,984	6.39	$148,640	1.50	$26,209	1.80	$26,209	1.60
CZ04	$3,984	6.23	$146,315	1.48	$26,209	1.54	$26,209	1.37
CZ05	$3,984	6.39	$152,521	1.46	$26,209	1.74	$26,209	1.55
CZ06	$3,992	6.07	$148,601	1.41	$26,263	1.37	$26,263	1.23
CZ07	$3,992	6.17	$157,654	1.35	$26,267	1.35	$26,267	1.21
CZ08	$3,992	6.01	$148,842	1.39	$26,263	1.24	$26,263	1.11
CZ09	$3,992	5.95	$147,272	1.39	$26,263	1.15	$26,263	1.03
CZ10	$3,992	5.91	$152,992	1.33	$26,263	0.91	$26,263	0.83
CZ11	$3,984	5.96	$147,062	1.41	$26,209	0.99	$26,209	0.92
CZ12	$3,984	6.09	$147,724	1.43	$26,209	1.19	$26,209	1.07
CZ13	$3,984	5.84	$141,914	1.43	$26,209	0.87	$26,209	0.82
CZ14	$3,992	5.65	$163,994	1.19	$26,263	0.53	$26,263	0.55
CZ15	$3,992	5.20	$139,398	1.28	$26,263	0.40	$26,263	0.12
CZ16	$3,992	6.36	$192,015	1.15	$26,263	1.20	$26,263	1.10

Simple Payback

The simple payback analysis uses the measure costs and annual operation costs to determine how many years of operational savings it takes to pay off the cost of the system. The simple payback of each system is shown in Table 18.

It was discovered in a previous section of this project that the operational costs of the EHPWH were significantly greater than the baseline 84% efficient boiler. For that reason, it was expected that the EHPWH would have no payback period due to negative cost savings. The 97% efficient condensing boiler has the lowest simple payback periods of all the systems. It does not have the most operational energy savings; however, its installation cost is much lower than the GAHP systems. The GAHP systems perform well in certain climate zones and have simple payback periods as low as four years; however, there are certain climate zones where the payback is poor. Cells in Table 18 that are marked red indicate payback periods greater than the expected useful life (EUL) of the GAHP. This indicates that the GAHP will not save any money in its life in these regions and should not be installed for financial benefit. The EUL for the gas boilers is assumed to be 25 years while the EHPWH and GAHP systems are assumed to have an EUL of 20 years.

Table 18: Simple Payback

	Simple Payback (Years)			
Climate Zone	97% Condensing Boiler	EHPWH	GAHP v.1	GAHP v.2
CZ01	1.85	N/A	4.56	5.11
CZ02	1.96	N/A	6.15	6.91
CZ03	1.97	N/A	5.83	6.56
CZ04	2.01	N/A	6.81	7.66
CZ05	1.97	N/A	6.01	6.77
CZ06	3.30	N/A	12.09	13.53
CZ07	2.56	N/A	9.74	10.87
CZ08	3.34	N/A	13.40	14.97
CZ09	3.37	N/A	14.40	16.05
CZ10	3.39	N/A	18.22	20.06
CZ11	2.11	N/A	10.57	11.41
CZ12	2.06	N/A	8.82	9.76
CZ13	2.15	N/A	12.07	12.82
CZ14	3.55	N/A	31.08	30.27
CZ15	3.86	N/A	41.66	142.64
CZ16	3.15	N/A	13.88	15.09

Conclusions

This study conducted a comprehensive analysis of various DHW systems, such as high efficiency condensing gas boilers, EHPWHs, and gas absorption heat pumps, across California's 16 diverse climate zones. The analysis compared the performance of these systems to the baseline 84% efficient gas boiler system.

Based on the modeling results, all measure cases have outperformed the baseline in terms of energy consumption and GHG emissions, though not in terms of fuel costs. The results of the cost analysis indicate that the contrast between electric and gas-fueled systems will only grow, making gas-fueled systems much more economically viable over time. While the EHPWH consumes the least site energy among the evaluated systems, its operational cost is at least three times higher than that of equipment running on gas.

In terms of source emissions, the GAHP systems do compete with the EHPWH in certain climate zones. However, there are several climate zones where the EHPWH produces significantly lower emissions. It is important to understand that electric system emissions will only improve over time as the grid introduces more renewable and clean energy sources.

The EHPWH's significantly higher operational costs compared to the baseline 84% efficient boiler resulted in negative cost savings and no discernible payback period. In contrast, the 97% efficient condensing boiler offered the shortest payback period due to its lower initial cost, despite lower energy savings compared to GAHP systems. Fuel cost outlooks for electricity and gas indicate that prices for both sources will continue to increase, making gas equipment less costly to operate than electric equipment.

While GAHP systems demonstrated promising performance in specific climate zones, with payback periods as low as four years, its viability was significantly reduced in less favorable climates. In such cases, GAHP systems may not yield financial benefits over their lifetime and should be avoided for cost-saving purposes. The high installation labor cost for GAHP systems introduces a significant benefit reduction over the lifetime of the system for all climate zones. It is possible, if GAHP systems become more common, that installation costs are reduced due to being less specialized.

Recommendations

Gas Absorption Heat Pump systems, particularly the GAHP-v2 model, which preheats make-up water and reheats recirculation water, offer a promising solution for balancing energy efficiency and economic viability in domestic hot water applications. These systems demonstrate lower source emissions than EHPWHs in certain regions and provide competitive operational costs compared to other gas-fueled systems. Their ability to perform well in specific climate zones makes them an attractive option for reducing utility costs and greenhouse gas emissions.

The increasing penetration of renewable energy onto the grid could significantly impact the performance and cost-effectiveness of electric systems like EHPWHs. As renewable energy sources become more prevalent, the emissions and operational costs associated with EHPWHs may improve, potentially making them a more competitive option. Monitoring grid electricity trends and their influence on the economics of these systems is essential for future planning and decision-making.

Further research is needed to evaluate the long-term performance and maintenance and electric energy costs of GAHP systems. Understanding factors such as operational reliability, service life, and ongoing maintenance expenses will provide critical insights for determining their suitability in multifamily buildings and other applications. This research will help building owners and stakeholders make informed decisions about investing in these systems.

Policymakers should consider implementing incentives to promote the adoption of energy-efficient DHW systems, such as GAHPs. Incentive programs could help offset the higher upfront costs of these systems, making them more accessible to building owners and developers. Supporting energy-efficient technologies through policy measures can drive sustainable building practices and reduce environmental impacts.

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Appendices

Model Challenges

This section addresses the challenges encountered during the EnergyPlus modeling of the proposed base and measure cases in the industry practice. For each case, the details and features of the industry physical system architecture are discussed, followed by the presentation of the corresponding EnergyPlus-translated architecture. Additionally, the challenges faced in modeling the translated architecture are highlighted.

Boiler -Base Case and Measure Case 1

The proposed baseline architecture includes these three features:

- Recirculation water mixes with water from the storage tank before entering the boiler.
- Make-up water combines with hot water from the boiler and is sent to the storage tank.
- The output from the storage tank (supply water) is delivered to the water fixtures.

Figure 14: Base Case and Measure 1 Industry Architecture

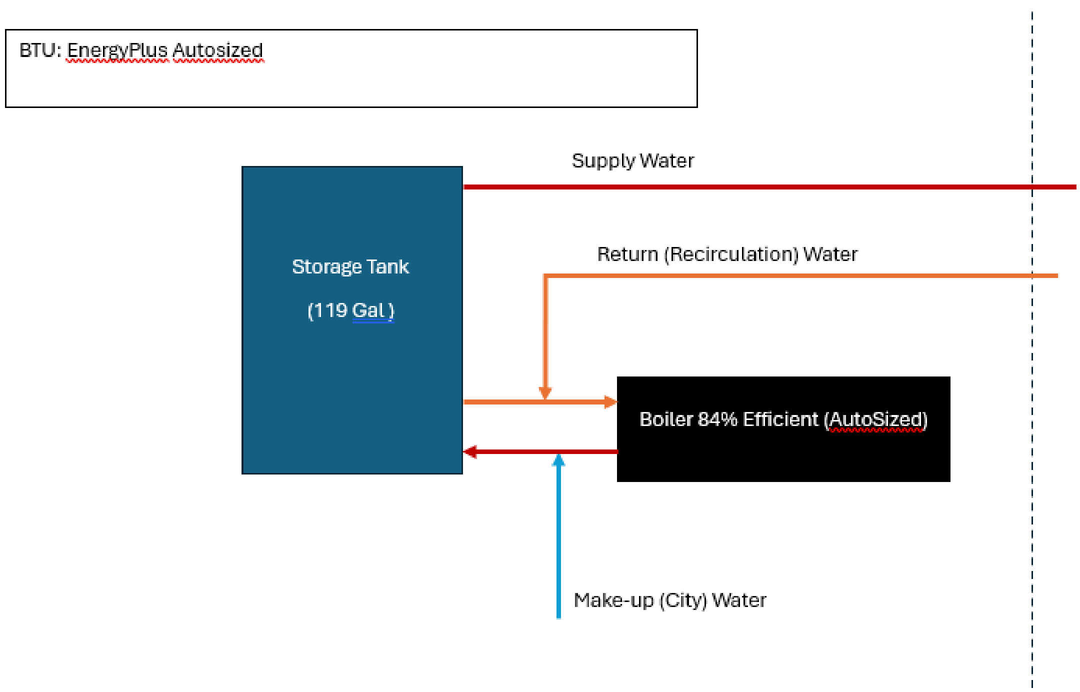
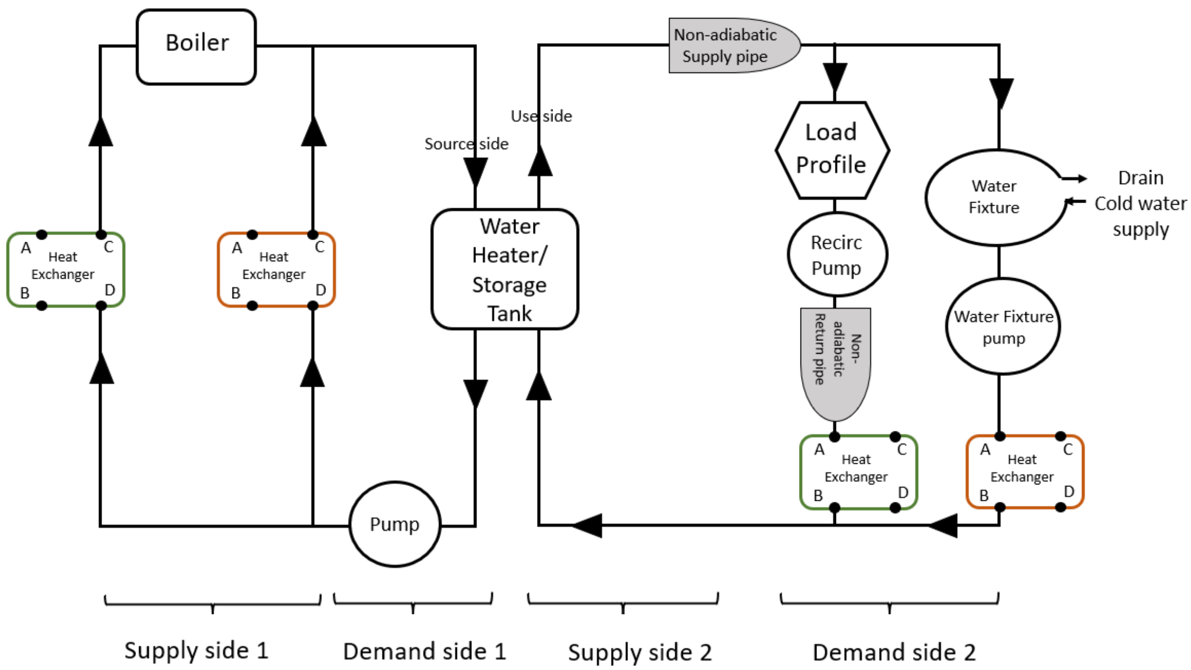


Figure 15's schematic illustrates the EnergyPlus-translated architecture for the baseline. Since loops in EnergyPlus must be closed and cannot be directly connected, a heat exchanger (green) was defined to simulate the mixing of recirculation water with water from the storage tank before it enters the boiler. Additionally, a red heat exchanger represents the combination of make-up water with hot water from the boiler, which is then sent to the storage tank.

A significant challenge in this architecture is that heat exchangers in EnergyPlus function as active components, overriding flow dynamics. Even with Energy Management System (EMS) controls, it was not possible to manage and equalize the flow on both sides of the heat exchangers to accurately simulate the proposed architecture. As a result, in the simplified architecture, the loops were modeled without incorporating heat exchangers.

Figure 15: EnergyPlus Translated Architecture of Base Case and Measure Case 1 Industry Architecture

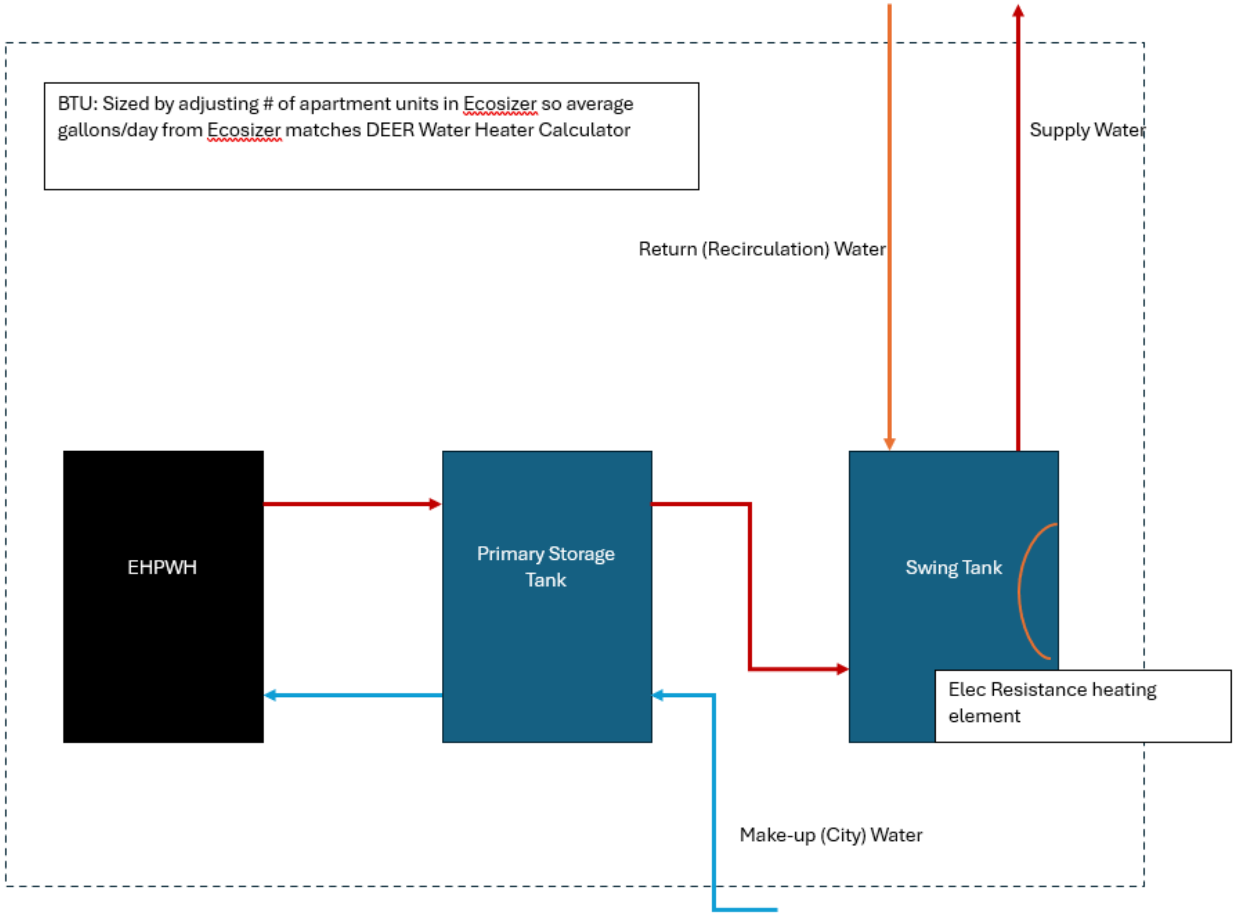


Measure Case 2- Electric Heat Pump Water Heater:

The proposed EnergyPlus architecture includes these three features:

- Recirculation water flows to the swing tank.
- Make-up water is directed to EHPWH, then storage tank and finally to the swing tank.
- The output from the swing tank (supply water) is delivered to the water fixtures.

Figure 16: Measure Case 2 Industry Architecture



The primary challenge with Figure 16's architecture is that EnergyPlus does not include a swing tank object. To address this, the swing tank and storage tank were combined into a single storage tank equipped with electric resistance. This configuration allows both make-up and recirculation water to mix before entering the tank. The revised architecture and its corresponding EnergyPlus representation are presented in Figure 17.

Figure 17: Simplified Industry Architecture of Measure Case 2

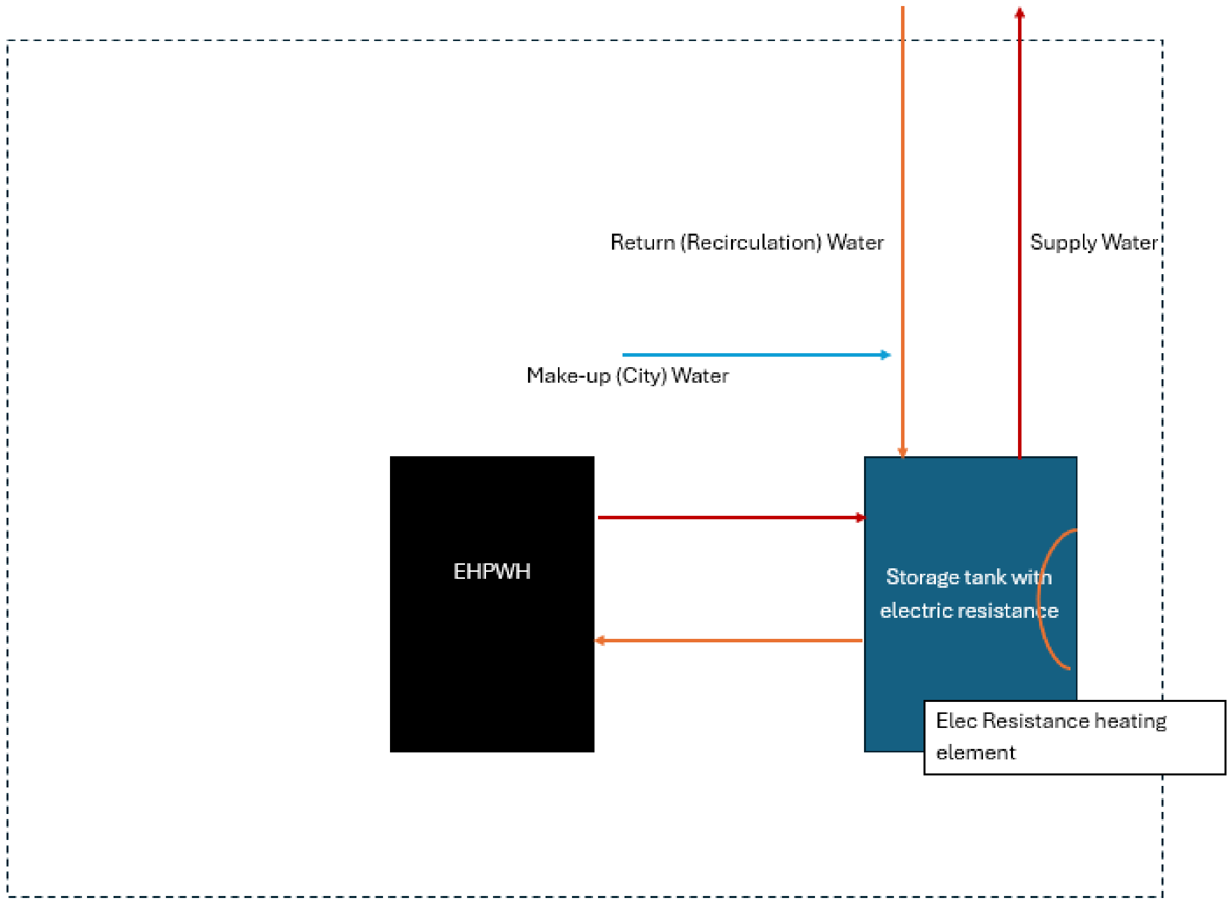
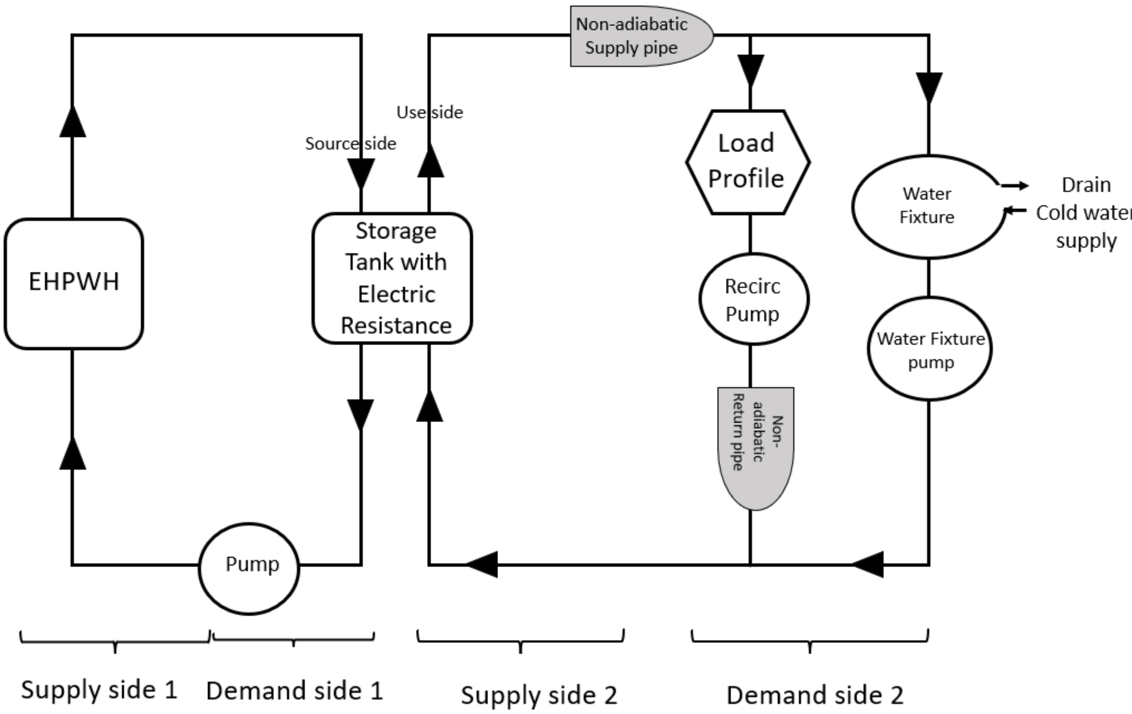


Figure 18: Energy Plus Translated Architecture of Measure Case 2



Measure 3- GAHP Acting as Preheat and Reheating Recirculation Water

The proposed architecture includes these three features:

- Recirculation water mixes with make-up water before entering the heat exchanger and GAHP.
- GAHP and Boiler work in parallel with respect to the storage tank to heat up the water.
- The output from the storage tank (supply water) is delivered to the water fixtures.

Figure 19: Industry Architecture of Measure Case 3

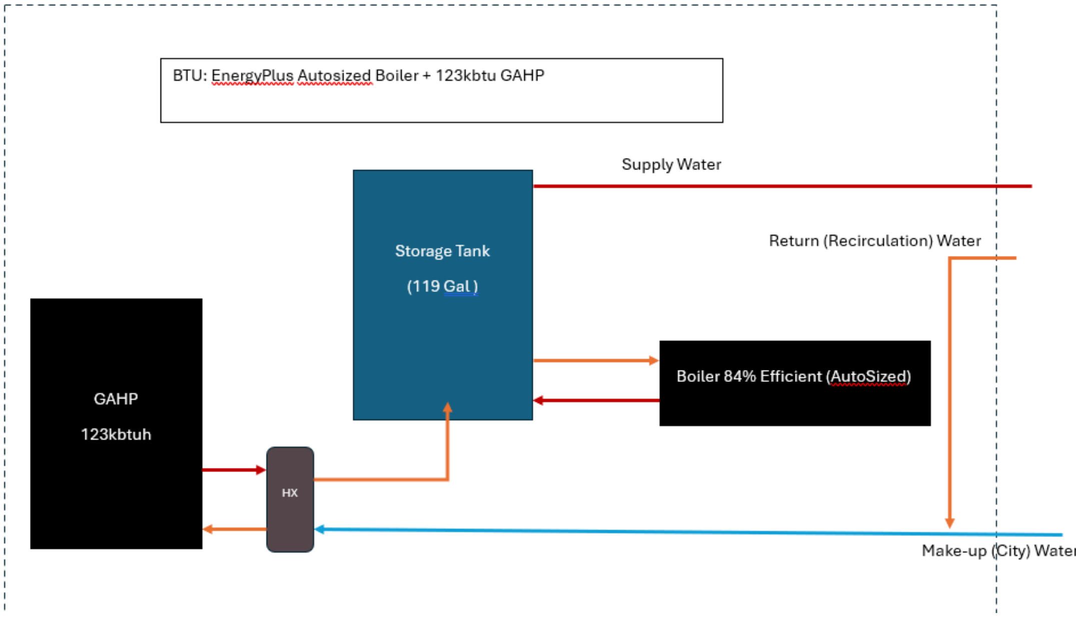
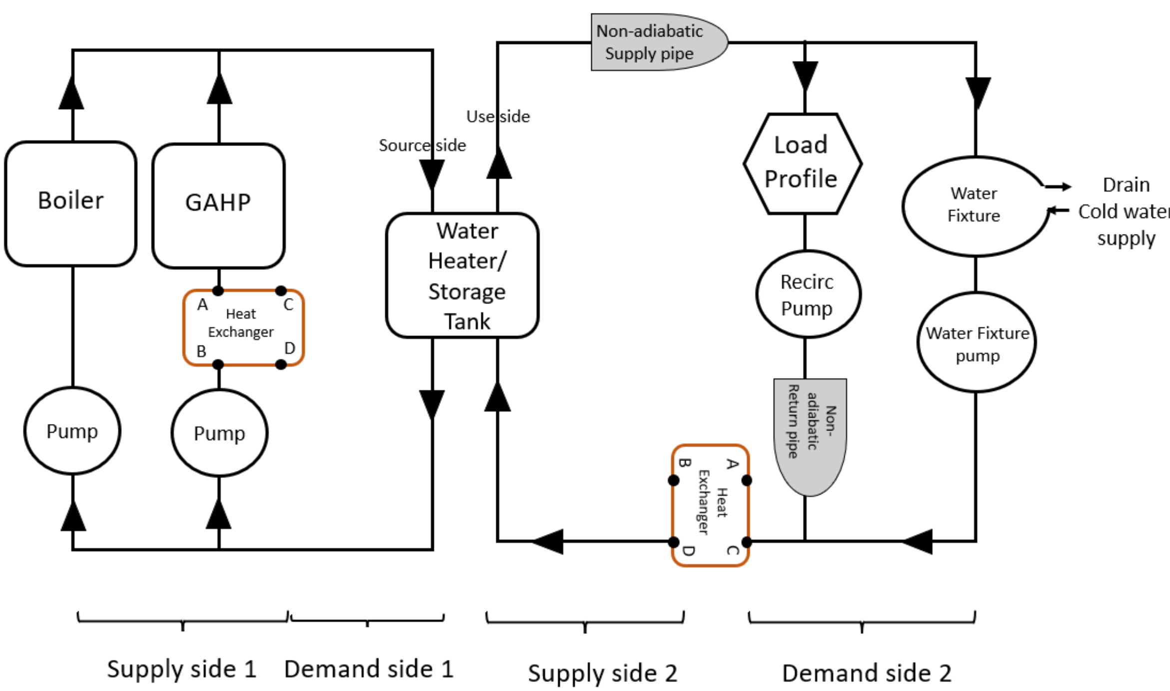


Figure 20 illustrates the EnergyPlus-translated architecture for Figure 19. As discussed in the previous section on GAHP modeling, the simplified architecture is modeled without incorporating heat exchangers.

Figure 20: Energy Plus Translated Architecture of Measure Case 3

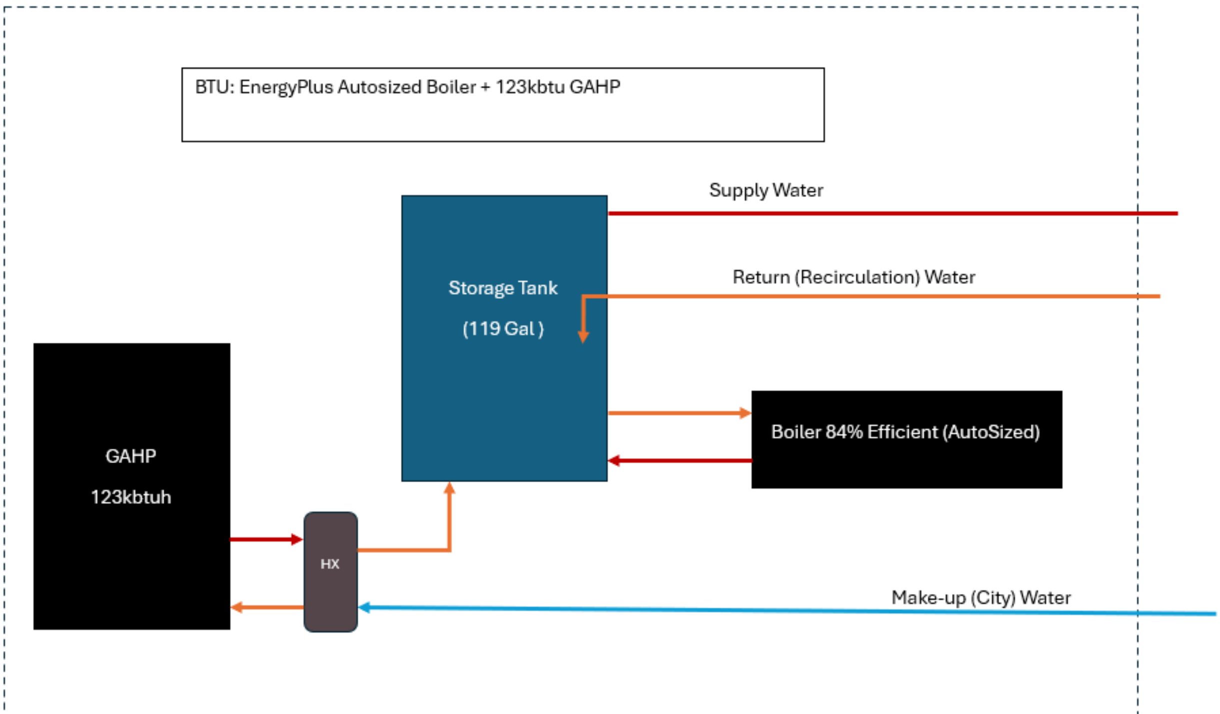


Measure 4 - GAHP Acting as Preheat

The proposed Energy Plus architecture includes these three features:

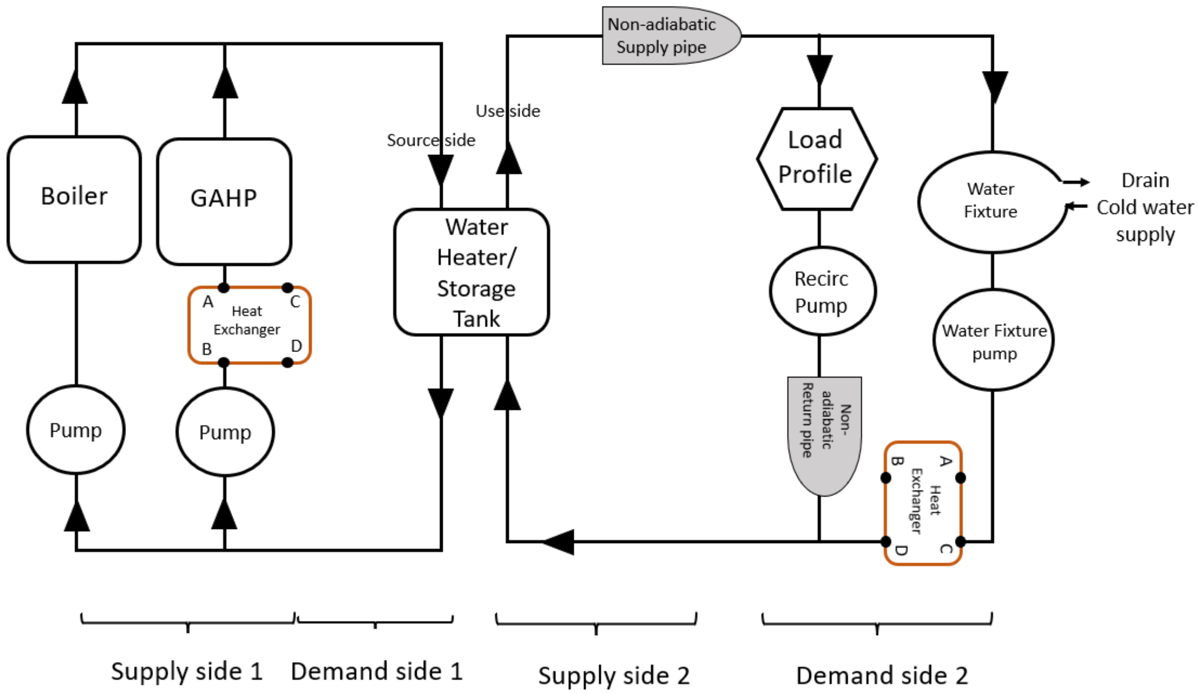
- Make-up water pre-heated by heat exchanger and GAHP
- Recirculation water flows to the storage tank.
- GAHP and Boiler work in parallel with respect to the storage tank to heat up the water.
- The output from the storage tank (supply water) is delivered to the water fixtures.

Figure 21: Industry Architecture of Measure Case 4



The EnergyPlus-translated architecture of the piping system is illustrated in Figure 22. As mentioned earlier regarding the challenges in the base case, incorporating heat exchangers will override the flow rates in the branches. In EnergyPlus, it is not feasible to equalize the flow rates in two branches connected to heat exchangers. Therefore, in the simplified architecture, the loops were modeled without including heat exchangers.

Figure 22: Energy Plus Translated Architecture of Measure Case 4



ET24SWG0005 (MS02b) Fuel Tariff Write-up (2024-08-27).xlsx

The tool requires a year of hourly gas and electric consumption data as well as a (2) dropdown selections of the climate zone and service type (tiered, time-of-use). Lastly, it requires the start year to determine the data from the ACC. Individual outputs of certain tariffs can be found on each tab of the tool, however, a summary of the monthly and annual operation costs and emissions for the inputs chosen can be found on the first tab.

ET24SWG0005 (MS04c) - RACC-FSC_v3.1_EHPWH (2024-11-20).xlsx

One line was inputted into RACC version 3.1 on the RACC tab of the excel tool. The same inputs used for the SWWH028 measure package were used and the outputs from the eTRM export tab were taken for this analysis.

ET24SWG0005 (MS04b) TSB and Simple Payback Analysis (2024-11-20).xlsx

Capital costs were summarized on the first three tabs of the workbook for boilers, EHPWHs, and the GAHP. Along with these static charges as inputs, the operational costs from the previous task were inputted, considering a start year of 2025. A CET input file was created within the workbook and ran on CEDARS. The outputs of the workbook are the TSB, TRC, and simple payback.