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Modeling Commercial Water Heating System

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TASK 2 FINAL REPORT

Energy Modeling Analysis of Commercial Service Water Heating Systems

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EXECUTIVE SUMMARY

GTI Energy completed an energy-modeling study of commercial service water heating (SWH) systems for the Northwest Energy Efficiency Alliance (NEEA). The study evaluated hybrid SWH plants that integrate gas absorption heat pump (GHP) and electric heat pump water heater (HPWH) technologies with conventional gas-fired baseline equipment such as non-condensing boilers, condensing tankless water heaters, and storage water heaters in three representative commercial building archetypes: Full-Service Restaurant, Multifamily, and Large Hotel. Annual whole-building energy simulations were performed using EnergyPlus 25.1.0¹ across four Pacific Northwest cities spanning three climate zones: Portland, OR and Seattle, WA (CZ 4C Mixed Marine), Boise, ID (CZ 5B Cold Dry), and Missoula, MT (CZ 6B Cold Dry). Building models were derived from the Department of Energy's (DOE) commercial prototype buildings² (1980–2004 vintage). Hot-water demand patterns for Full-Service Restaurants and Multifamily buildings were characterized from real-world GTI Energy field-monitored draw data using the Moving Window sizing methodology; while demand patterns for Large Hotels were sourced from Ecosizer³ and scaled to the EnergyPlus average and peak demand loads for the Large Hotels building.

The parametric modeling matrix evaluated three heat pump technology types - modulating GHP, non-modulating GHP, and electric HPWH (in both all-electric and dual-fuel configurations) combined with three conventional baseline systems, two heat pump sizing fractions relative to peak demand, two main storage tank sizes, and buffer tank setpoint temperatures of 120°F and 140°F, across simulated building types and climate locations. In all evaluated hybrid configurations, the heat pump and associated buffer tank were sized to address the baseload SWH demand, generally 30% to 60% of peak load, while the conventional gas-fired baseline system was retained to serve short-duration peak draws and maintain the main storage tank at 140°F. This design philosophy enabled the maximization of high-efficiency heat pump operation. City water entering the system was preheated by the GHP or HPWH prior to feeding into the buffer tank, after which additional heating was supplied by the baseline water heater as needed to maintain the main storage tank setpoint. Custom Energy Management System (EMS) scripts⁴ within EnergyPlus were used to implement supervisory control strategies governing load sharing between the heat pump and the backup baseline system.

Across all three building types and climate zones, modulating GHP systems delivered the most consistent and favorable annual operating cost savings.

- For the Full-Service Restaurant prototype, a 5,502 sq. ft. facility with a peak SWH demand of 7,000 Gallons Per Day (GPD), modulating GHP configurations achieved operating cost savings ranging from 22.5% to 42.0% relative to the respective gas-fired baseline, with the highest SWH plant-level Coefficient of Performance (COP) reaching 1.43. The SWH

¹ EnergyPlus, EnergyPlus v25.1.0, <https://energyplus.net/>

² <https://www.energycodes.gov/prototype-building-models>, DOE Prototype Building Models

³ Ecosizer, <https://ecosizer.ecotope.com/sizer/> (Accessed July 2025)

⁴ EMS Application Guide, EnergyPlus v25.1.0, <https://energyplus.readthedocs.io/en/stable/ems-application-guide/ems-application-guide.html> (Accessed July 2025)

plant-level COP was calculated as the ratio of total hot water delivered to the total gas and electricity used by the SWH systems. It is being calculated on a site energy basis.

- For the Multifamily prototype, a 33,740 sq. ft. building with a peak demand of 2,000 GPD and the steadiest daily hot-water demand profile among the three archetypes, modulating GHP configurations produced the highest cost savings results of any building type modeled, with operating cost savings of 36.8% to 48.9% and maximum SWH plant COPs reaching 1.62.
- The Large Hotel prototype, a 122,120 sq. ft. facility with a peak SWH demand of 26,500 GPD and the highest absolute hot-water throughput, yielded modulating GHP savings of 18.4% to 39.7%, with peak plant COPs of 1.17.

Non-modulating GHP configurations consistently underperformed relative to their modulating counterparts due to on/off cycling losses, return water temperature constraints, and increased backup SWH heating system reliance to meet the 140°F setpoint, delivering cost savings in the range of 5.1% to 32.2% depending on building type and baseline system.

Electric HPWH systems achieved the highest annual SWH plant-level efficiencies across all building types, with overall plant COPs reaching 2.08 for Full-Service Restaurant, 2.04 for Multifamily, and 2.02 for Large Hotel. However, their annual operating cost economics varied substantially by region because the electricity-to-gas price ratios differ significantly across the modeled Pacific Northwest cities. As a result, electric HPWH operating cost outcomes ranged from strongly positive to strongly negative: -37.4% to +20.1% for Full-Service Restaurants, -45.5% to +8.2% for Multifamily, and -14.3% to +22.2% for Large Hotels.

All-electric HPWH SWH plants also introduced significant electric resistance backup operation within the main storage tank, which reduced their overall system efficiency. Dual-fuel HPWH configurations achieved very high overall efficiencies when the gas backup system was properly integrated, but annual economics remained sensitive to local utility pricing. On a non-baseload Greenhouse Gas (GHG) emissions basis, the recommended metric for energy efficiency retrofits that add incremental electrical load to the grid, modulating GHPs delivered the most GHG reductions: 36,600 to 86,600 lbs CO₂e per year for Full-Service Restaurants, 16,900 to 28,300 lbs CO₂e per year for Multifamily, and 220,600 to 497,900 lbs CO₂e per year for Large Hotels.

As expected, GHPs and HPWHs were seen to have a wide variation in COPs with outdoor ambient temperatures. Subsequently, colder climates gained less benefit due to the increased operating time of the heat pumps at lower temperatures. Although cold climate reliance and impacts on overall performance were observed, the impact of part-load ratio and return water temperatures on the overall efficiencies were much higher. The results also showed that there is a fine balance between sizing your SWH for peak loads and the storage tank. This finding, coupled with sizing the heat pump to roughly 30% to 60% of peak demand, allowed the heat pump to address most of the annual base load while the conventional water heater handled short-duration peaks. The approach helps avoid both severe under sizing, which limits decarbonization impact, and oversizing, which increases cycling and reduces cost-effectiveness. For Full-Service Restaurants, the sizing sweet spot was seen to be around 50-60% of the peak load; for Multifamily and Hotels, it was closer to 30-35% of the peak load.

Three consistent themes emerge across the modeling analysis-

- 1) The load pattern and magnitude of the service hot-water demand matters
 - a) the 'steadier' and less 'peaky' loads through the day offered the greatest opportunity for a hybrid heat pump to operate at a high annual load factor and to effectively displace baseline SWH gas-use.
 - b) Periods of low demand and inactivity led to standby losses in the main storage tank that was supplemented by the baseline SWH system. A potential workaround could be to investigate SWH configurations with the recirculation load fed back to the GHP/HPWH. However, it's possible that this has detrimental impacts on their COPs owing to higher return water temperatures.
- 2) Modulating GHPs consistently outperformed non-modulating GHPs in annual economics because they were better able to track part-load operation while minimizing backup SWH system use.
- 3) Electric HPWHs in a dual-fuel setting achieved very high overall efficiencies, but annual operating-cost benefits remain region specific because electric prices and gas prices differ substantially among the modeled cities, and generally across the US. All-electric HPWHs also achieved high overall COPs, however, were impacted by significant electric resistance operation in the main storage tank.

The main storage tank was modeled to maintain a tank temperature of 140°F even during periods of low usage. System integrations with on-demand heating could provide significant energy savings by avoiding energy delivered but not utilized. Commercial applications with recirculation requirements could be challenging to implement on-demand water heating without sacrificing user experience and convenience. Future control strategies that can better leverage the dynamic dual-fuel operation between electric HPWHs and backup gas water heaters should be explored to fully realize the interoperability for maximum efficiency and economic benefits.

Based on the modeling results, GTI Energy recommends that program designers and building owners prioritize high-SWH-demand building types, particularly Full-Service Restaurants, Multifamily residential, and Large Lodging facilities for GHP and HPWH retrofit screening, as these applications consistently demonstrate the strongest and most persistent annual savings opportunities. Heat pumps should be sized to address the baseload rather than the full peak demand, and storage volumes should be conservatively specified using field-measured or high-quality representative hot-water demand data rather than fixture-count or legacy demand-curve methods. Future research priorities could include

- laboratory validation of electric HPWH performance curves to calibrate the modeled performance mapping
- lab and field calibration of the developed EnergyPlus modeling framework against measured SWH system performance
- investigation of advanced dual-fuel control strategies to better leverage interoperability between electric HPWHs and gas backup systems, and

- sensitivity analyses varying recirculation loads and on-demand heating configurations to quantify their impact on overall SWH plant efficiency.

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INTRODUCTION

In the U.S. Pacific Northwest today, natural gas is the primary energy source for water heating in existing commercial buildings, often by low-efficiency tank-type water heaters or boilers⁵.

To mitigate the emissions in these buildings, it is critical to apply energy efficiency and heat pump technology retrofits where feasible. Hot water loading patterns are diverse across commercial building types, ranging from 100s to 10,000s of gallons per day and with widely varying usage patterns, much less a direct function of occupancy patterns. Similarly commercial building baseline water heating technologies are heterogeneous, with wide diversity in gas-fired versus electricity-driven (38% gas water heating in warehouses versus 94% in hospitality) and technology-type (17% storage/83% boiler in hospitals versus 86% storage/14% tankless in restaurants) (EIA CBECS). Finally, the diversity of conventional and emerging water heating technologies and installation types are compounding as well, including boilers with or without indirect storage tank(s), storage water heaters (condensing/non-condensing), tankless water heaters (racked or central-type), thermally-driven heat pumps (modulating & non-modulating), and central heat electric heat pump water heaters (standard and natural refrigerants), among others.

As part of this project, the GTI Energy team performed a modeling study to compare conventional (boiler, storage, tankless) to emerging (thermally-driven & central electric heat pumps) commercial water heating systems in hybrid configurations over a range of Pacific Northwest building types. Covering Climate Zones spanning 4C, 5B, and 6B, the model simulated the equipment responding to realistic hot water loading patterns from seven building types: Full-Service Restaurants, Multi-family, and Large Hotels. The respective findings and trends can also potentially be extended to other building types that are somewhat similar from a service hot water demand pattern perspective such as Quick-Service Restaurants, Smaller Hotels, and/or Motels. This report summarizes the loading patterns used, derived from a combination of prior GTI Energy administered field studies within these building types and performance curves for the conventional and emerging technologies, derived from prior laboratory or field-based studies. Findings include comparison amongst different system sizing strategies within a SWH plant, both for the heat pumps and for the main storage tanks, with particular focus on the impact of cycling/part-load losses and nuances amongst different heat pumping based water heating systems. Energy savings potential across technologies, region, and building types are summarized, as well as baseload and non-baseload full-fuel cycle GHG emission reductions and operating cost savings.

To accomplish this, the project team performed a detailed building energy modeling analysis to investigate the potential of integrating commercial heat pump-based water heaters to an existing service water heating plant. Owing to the emerging nature of hybrid commercial water heating plants as a high efficiency technology solution, there is a lack of understanding regarding their potential. Moreover, controlled laboratory scale testing across all the different possible equipment configurations, building types, and ambient conditions is yet to be published by researchers and stakeholders. This makes energy modeling simulations crucial in

⁵ <https://neea.org/wp-content/uploads/2025/03/CBSA-4-2019-Final-Report.pdf>

the evaluation of this technology. Currently, stakeholders do not have the means to compare these systems and predict the expected seasonal performance specific configurations or climate regions.

The project team used building energy modeling in EnergyPlus and OpenStudio⁶ with custom-building modeling scripts to inform the evaluation of different combinations of high efficiency commercial water heating systems. This effort performed an energy modeling analysis of GHPs and electric HPWH retrofits in a commercial building SWH system, detailing the existing SHW system configuration, integration of the GHP/HPWH into the existing SHW system, and performance assessment of the heat pumps and the overall retrofit system. The HPWH system was investigated in both an all-electric capacity and in a dual-fuel capacity. The Results section presents the overall energy, emission, and operating cost benefits of the GHP/HPWH based retrofit system relative to the existing baseline. Baseline water heating systems considered ranged from a gas boiler with a storage tank, a tankless water heating system with a storage tank and a storage tank water heater.

In reviewing results, the report highlights the challenges in one-size-fits-all solutions across the commercial building stock, the best fits for heat pump technologies, and opportunities for dual-fuel and 'gas-hybrid' combinations of conventional and emerging technologies.

Background

Gas-fired commercial water heaters represent a major portion of the non-residential "duty" commercial water heating market⁷ with approximately 77 percent of storage type, 14 percent are boilers coupled with indirect storage tanks (IST), and 9 percent are tankless.

When the report was written, the U.S. federal standard currently requires a minimum thermal efficiency⁸ (TE) 80% for commercial gas-fired storage water heaters and has planned to increase this requirement to 95% for equipment to be manufactured on and after October 2026. While current gas-fired condensing water heaters can certainly meet the 95% TE requirement, the building owners and energy efficiency stakeholders are looking beyond condensing water heaters and are looking at advanced heat pump technologies that have the potential to further improve operating efficiencies. This project involved evaluation of two different GHP technologies (modulating and non-modulating) with rated COPs of up to 1.4, for service water heating in a commercial building application. The project also evaluated an electric HPWH with rated COPs of 4.0 in an all-electric and a similar integrated dual-fuel SWH application.

The evaluated GHP systems were air source, air to water GHPs, based on the vapor absorption refrigeration cycle, using an ammonia-water working fluid pair, in which an absorbent (water) is used as a carrier for the refrigerant (ammonia). The refrigeration cycle moves heat from ambient air at the evaporator to provide hot water output at the condenser, which can be utilized for

⁶ OpenStudio, <https://openstudio.net/>

⁷ DOE. 2016. Technical Support Document: Commercial Water Heating Equipment. U.S. Department of Energy, Docket No. EERE-2014-BT-STD-0042, April 18, 2016.

⁸ <https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-431/subpart-G/subject-group-ECFR58ec6007f45fca3/section-431.110>

space heating and/or domestic water heating applications. The modeled HPWH system was also an air source, air to water HPWH, based on a vapor compression cycle using a low GWP R513A refrigerant.

In commercial applications, high efficiency water heating equipment such as GHPs/HPWHs are expected to be an efficient technology to replace more conventional gas-fired SWH equipment such as boilers and water heaters. Per a recent study from NEEA, the greatest potential for GHPs and by extension HPWHs is expected to be in the replacement and new construction markets, due to installation complexities and high costs associated with retrofits. Building types with large annual SHW demand present a unique opportunity and a great target application for these systems owing to potentially steady water heating loads throughout the year that can serve as a means to extract high COPs from the systems due to extended runtimes. This final report presents the completed Task 2 study as part of this broader NEEA project that quantifies the modeled performance of these SWH plants across three representative building archetypes, along with recommendations for future research.

Project objectives

The primary objective was to provide decision-makers with a modeling analysis of the performance of GHP/HPWH systems integrated into existing SWH plants with a traditional gas-fired water heating system. Specifically, the objectives of Task 2 were to:

- Investigate the modeled performance from retrofitting a commercial water heating plant with heat pump-based water heating systems while keeping all the existing SWH equipment in place and adding a GHP/HPWH
- Develop EnergyPlus-based custom commercial SWH plant models derived from DOE commercial building prototypes.
- Integrate emerging heat-pump water-heating technologies with conventional gas-fired baseline systems in hybrid plant loops.
- Use realistic service hot-water demand patterns in the simulation to ground the analysis in real-world assumptions to then determine optimal storage and heating capacities; and
- Compare annual efficiency, operating cost, and GHG emissions across climates, building types, and baseline SWH configurations.

Lastly, a secondary objective was to create a modeling framework for these complex SWH systems that can be leveraged for future research efforts, and design guidance.

MODELING

Modeling Methodology

This was accomplished by developing detailed energy models to simulate the SWH plant configurations in different buildings and climates. The modeled simulations were run for multiple building models and climate zones. The simulations in this study were performed using EnergyPlus 25.1.0. It is an open-source tool developed by the U.S. DOE and the National Lab of the Rockies (NLR) to estimate and optimize the energy consumption of buildings on an annual basis. EnergyPlus is commonly used on its own or on the backend of other building energy simulation software, such as OpenStudio. It allows the simultaneous simulation of an entire building's energy consumption and interaction with the surrounding environment. Table 1 lists the commercial building types, and Table 2 lists the cities and associated climate zones covered in this study.

The building models used were based on existing, well-established reference buildings representing the existing population of code-compliant buildings. The U.S. DOE, in conjunction with three of its national laboratories, developed residential and commercial reference buildings, formerly known as building benchmark models. The suite of commercial prototype buildings covers 75% of the commercial building floor area in the United States for new construction, including both commercial buildings and mid- to high-rise residential buildings, and across all U.S. climate zones. For this project, the DOE prototype models reflecting a 1980-2004 vintage were used for Full-Service Restaurant, Multifamily, and Large Hotel.

The HeatPump:AirToWater:FuelFired:Heating⁹ object in EnergyPlus was used to model the GHP systems in this study. By design, this object allows practitioners to model a gas-fired (or fuel fired) air-to-water absorption heat pump that can be used for space heating and/or DHW.

The HeatPump:PlantLoop:EIR:Heating¹⁰ object in EnergyPlus was used to model the HPWH systems in this study. By design, this object can be configured as either a water-source or air-source heat pump object. In this study, performance curves for an air to water HPWH were fed into this object to simulate the HPWH.

Building Characteristics

The major modeling inputs were building geometry from the U.S. DOE commercial building prototype models, climate/weather files, hourly peak and average hot-water draw patterns, baseline SWH system sizing assumptions, storage-tank sizing assumptions, retrofit GHP/HPWH sizing and efficiency assumptions, utility prices, and GHG emission factors. There were three demand-pattern sources used for this study - GTI Energy field data from a prior CEC demonstration for the Full-Service Restaurant model, GTI Energy administered field data from a

⁹ https://bigladdersoftware.com/epx/docs/25-1/input-output-reference/group-plant-equipment.html#plhp_fuelfired

¹⁰ https://bigladdersoftware.com/epx/docs/25-1/input-output-reference/group-plant-equipment.html#plhp_eir_heating

demonstration in multifamily buildings in MN for the multifamily prototype, and Ecosizer/EnergyPlus SWH demand data for the hotel prototype. Utility electric and gas prices were sourced from Energy Information Administration (EIA)¹¹, while grid-related GHG emission factors were derived from GTI Energy's Carbon Management Information Center¹² (CMIC) tools that leverage eGRID to quantify baseload and non-baseload full-fuel cycle emission factors.

Table 1 Simulated Building Energy Models

Commercial Building Type	Vintage
Full-Service Restaurant	DOE Prototype 1980-2004
Multifamily	DOE Prototype 1980-2004
Large Hotel	DOE Prototype 1980-2004

Table 2 Simulated Cities and Climate Zones

Climate Zone	City
4C Mixed Marine	Seattle, WA
4C Mixed Marine	Portland, OR
5B Cold Dry	Boise, ID
6B Cold Dry	Missoula, MT

Table 3 Building Characteristics, SWH Demand Data, and Baseline Equipment Sizes

Building type	Representative size	Peak demand (GPD)	Peak demand (GPH)	Peak baseline sizing output (Btu/h)
Full-Service Restaurant	5,502 sq. ft.	7,000	635	470,375
Multifamily	33,740 sq. ft.	2,000	296	197,308
Large Hotel	122,120 sq. ft.	26,500	7,624	3,766,430

Building internal loads, schedules, furnishings, lighting, and occupancy were assumed to be consistent with the DOE Reference models. The default SWH equipment in these DOE reference building models were storage tank water heaters. They were modified to represent the applicable SWH system being simulated. Annual simulations of the building energy

¹¹ Natural Gas Prices, https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm
Electric Prices, <https://www.eia.gov/electricity/data/browser/>

¹² Source Energy and Emissions Analysis Tool, Commercial Module, CMIC, <https://cmic.gti.energy/commercial>

consumption were performed for the Typical Meteorological Year (TMY3) weather data¹³ in each location. Key performance indicators of this project included answering the following research questions for effective retrofits of GHP/HPWH based SWH systems in NEEA's climate zones:

- What is the ideal sizing of a GHP and an HPWH relative to the peak load when integrated into a SWH system with a traditional gas-fired SWH system?
- How does a dual-fuel based SWH plant compare to a gas-hybrid SWH plant on an efficiency, economics and emissions basis?

EnergyPlus' whole-building energy modeling engine was used in conjunction with custom scripts to simulate hourly SWH loads, hot water delivery, setpoint management in the storage tanks, and load management control strategies between the GHP/HPWH and the baseline boiler. The EMS feature in EnergyPlus and provides a way to develop custom control and modeling routines for EnergyPlus models. EMS provides supervisory control to override selected aspects of EnergyPlus modeling. An internal programming language intrinsic to EnergyPlus called Erl is used to read these control algorithms. The software interprets and executes the custom Erl programs while the model is being run. The programs work by overriding existing features and operating parameters within the model rather than adding a new set of controls and component models.

Table 4 Summary of the Modeling Approach

	Summary/Approach
Representative building types in final report	Full-Service Restaurant; Multifamily; Large Hotel
Technologies	Modulating GHP; non-modulating GHP; electric HPWH
Traditional baseline technologies	Boiler; Tankless water heater; Storage tank water heater
Primary simulation platform	EnergyPlus with custom service-water-heating plant configurations
Sizing principle	Heat pumps sized to approximately 30%–60% of peak demand with baseline equipment serving peak draws
Key input sources	DOE prototype models; GTI Energy field SWH datasets for Restaurants and Multifamily; Ecosizer/EnergyPlus data for Hotels; EIA utility prices; GHG emission factors from GTI Energy's CMIC tool [leverages eGRID data]

¹³ TMY3 weather files, <https://energyplus.net/weather>

Service Water Heating Demand Patterns

There were three demand-pattern sources used for this study - GTI Energy field study data from a prior California Energy Commission (CEC) demonstration¹⁴ for the Full-Service Restaurant model, GTI Energy administered field study data from a demonstration in multifamily buildings in MN¹⁵ for the multifamily prototype, and Ecosizer/EnergyPlus SWH demand data for the hotel prototype.

For the modeled Restaurants and Multifamily buildings, SWH demand patterns were characterized using real-world GTI Energy monitored draw data to establish representative daily use levels, hourly demands, and short-duration peak events relevant to storage and recovery performance. With a means of assessing “worst-case” water heater sizing, referred to as the “Moving Window” analysis, the project team used the detailed field derived Domestic Hot Water (DHW) draw information to ‘right size’ the baseline SWH system. This sizing analysis was first described for residential applications in the 1990s by Hiller (Hiller 1998) and provides a conservative approach to analyzing detailed field hot water consumption data to estimate compatible water heater storage volumes and heating output rates. Using aggregated SWH draw patterns from the multiple field sites, GTI developed real-world service water heating demand patterns that are outlined in Figure 3 and Figure 4, Table 5, and Table 6.

Essentially, in this approach, high-resolution draw data is used to identify the most demanding rolling hot water use sequences and to estimate compatible storage volume and heating output requirements for those events. This method is generally understood to be a conservative basis for assessing storage-based system adequacy under realistic, clustered demand conditions. This analysis takes a large dataset, several months in the case of this study, and determines the largest volume of SHW drawn for a given duration of time. For example, at the smallest duration of 15 seconds, the analysis ranks all 15-second durations by volumes of SHW drawn. The same is performed for a slightly larger duration, 30 seconds for example, and so on with windows increasing up to a 24-hour period. For each duration of time, 15 seconds up to 24 hours in this example, the 1st highest, 2nd highest, and 3rd highest volumes drawn are assembled together into a cumulative hot water draw for a 24-hour period. Each sequence of durations do not represent actual 24-hour periods of SHW drawn, as recorded, but hypothetical worst-case sequences of SHW draws. Each worst-case sequences of draw volumes are compared for the 1st, 2nd, 3rd, and 4th and so on.

¹⁴ Demonstrating Natural Gas Heat Pumps for Integrated Water Heating and Air Conditioning in Restaurants, <https://www.energy.ca.gov/publications/2024/demonstrating-natural-gas-heat-pumps-integrated-water-heating-and-air>

¹⁵ Demonstration of Packaged Central Condensing Tankless Water Heating Systems in Multifamily Buildings, https://mn.gov/commerce-stat/energy/data-reports/138324_GTI_Tankless-Central-WH_Report_Final%20SECURE.pdf

Baseline Equipment Sizing

This analysis is used for sizing by assessing the balance between heating output and available SHW storage. Each hot water volume consumed in a duration window implies a necessary heating rate if a temperature difference is known, for this the maximum temperature difference observed for each site is used for conservative estimates. When charted against the volumes drawn for each duration window, a curve like Figure 2 can be developed for acceptable heating outputs and storage volumes for a given hot water consumer. The analysis is inherently conservative, sizing water heater heating output and storage volume for a hypothetical worst-case series of events, thus sizing guidance does not require use of “safety factors” commonly used in specifying of equipment.

It is important to note that average daily use alone does not adequately describe service water heating capacity requirements. Substantial variation may be observed in the number of daily draws, the size of individual draw events, and the degree of clustering within short time periods. Relationships between the number of draws per day and total daily hot water volume, as well as between maximum draw volume and daily volume, indicated that materially different short-term recovery requirements could be imposed even where daily totals appeared similar.

Previously published GTI Energy research¹⁶ indicates that SWH demand should be evaluated using both average and hourly usage characteristics and worst-case rolling draw events, with the latter serving as the primary indicator of capacity risk for storage-based systems. Accordingly, this SWH demand-pattern derivative methodology was used in this project to inform interpretation of SWH performance and to provide a more robust basis for assessing storage adequacy than would be provided by daily-average consumption alone.

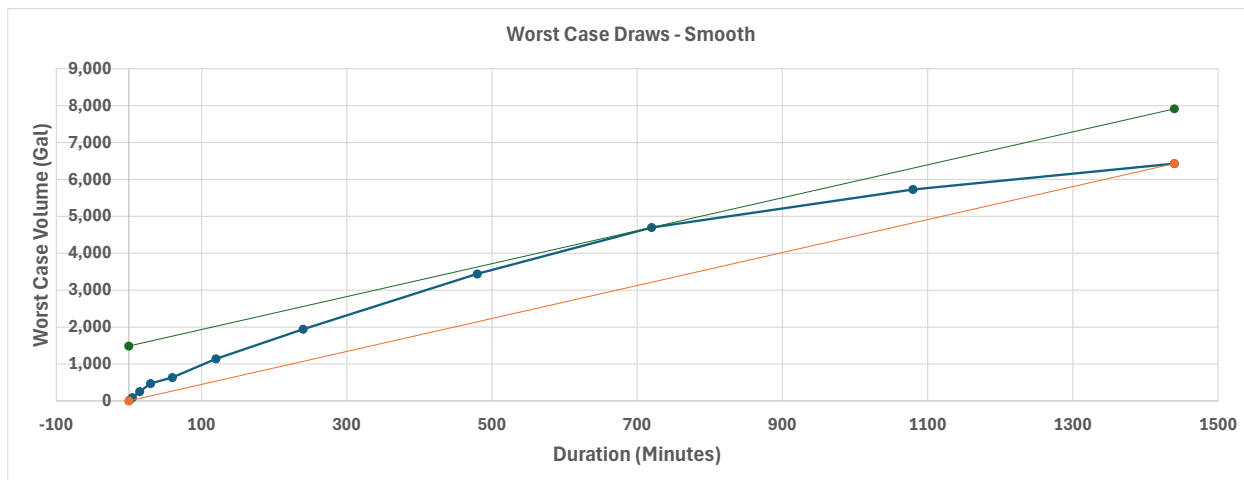


Figure 1 Worst Case draw volume vs duration for Full-Service Restaurant

¹⁶ Demonstrating Natural Gas Heat Pumps for Integrated Water Heating and Air Conditioning in Restaurants, <https://www.energy.ca.gov/publications/2024/demonstrating-natural-gas-heat-pumps-integrated-water-heating-and-air>

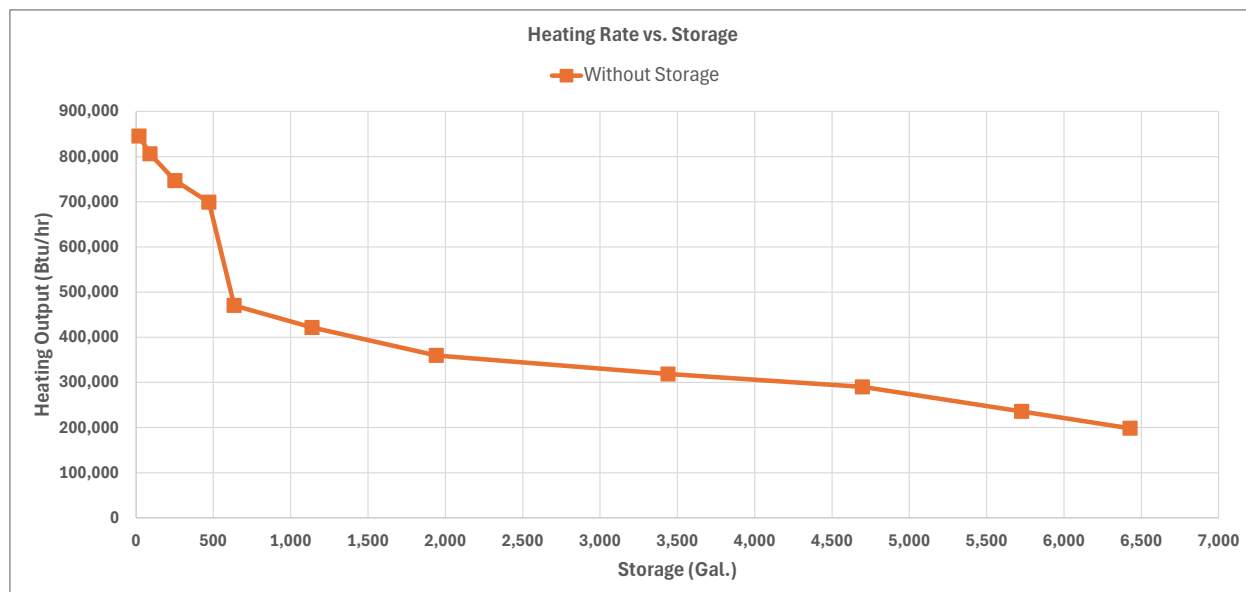


Figure 2 Heating Rate vs Storage Volume design for Full-Service Restaurant

For example, for the Full-Service Restaurant in this study, Figure 2 and Figure 1 provide a basis for selecting a practical combination of water-heating capacity and storage. Figure 2 uses measured rolling-window data to characterize short-duration peaks, sustained intermediate loads, and total daily demand under a selected recurring worst-case condition. Figure 1 converts this demand profile into a boundary of feasible heating-output and storage combinations, allowing designers to evaluate high-capacity/low-storage, balanced, and low-capacity/high-storage options based on site constraints, cost, efficiency, and system type. For the Full-Service Restaurant, the balanced design point corresponds to approximately 634.8 gallons of reference storage and 470,375 Btu/h of useful heating output, resulting in a practical selection of a 600-gallon tank and a 588,000 Btu/h input boiler at 80% thermal efficiency. The selected 600-gallon tank is the practical nominal size that preserves substantial peak-shaving storage while avoiding an unnecessarily larger nominal tank. Actual equipment could consist of one or more staged units and can account for usable rather than nominal storage, redundancy, recirculation losses, entering-water temperature, controls, and equipment performance. This sizing is intentionally based on the measured load shape and storage-recovery tradeoff, rather than on the single highest instantaneous flow or the 7,000-gallon peak daily total alone.

The same analysis can also guide 'hybrid' SWH heat-pump designs by assigning baseload demand to the heat pump, transient demand to storage, and peak or recovery demand to the backup boiler.

Peak flow alone can substantially oversize heating capacity

Sizing the water heater to serve the maximum short-duration flow without storage treats the plant almost like a tankless system. This can lead to excessive boiler capacity, short cycling, high first cost, and poor part-load efficiency.

Daily gallons alone can underestimate short-term demand

Two facilities can use the same gallons per day but have very different capacity requirements:

- One facility may spread consumption evenly over 24 hours.
- Another may use most of the water during a two-hour dinner cleanup period.

Daily consumption does not distinguish between the two.

Moving Window analysis captures draw better

The method reflects the actual temporal characteristics of the load in the restaurant, including:

- Consecutive dishwasher cycles
- Simultaneous fixture draws
- Meal-service and cleanup peaks
- Recovery opportunities between peaks
- Sustained multi-hour demand

It produces multiple valid equipment combinations

The method does not imply that only one boiler-and-tank combination can work. Instead, it establishes a boundary of acceptable combinations. A designer can select a point based on:

- Available mechanical-room space
- Equipment cost
- Desired recovery time
- Heat-pump capacity
- Boiler modulation range
- Standby losses
- Retrofit constraints
- Redundancy requirements

The selected 600-gallon tank does not independently cover the entire peak event, and the 588,000 Btu/h boiler does not independently follow every instantaneous draw. The two components work together:

- The tank handles short-duration demand exceeding the boiler recovery rate.
- The boiler supplies heat during the draw and recharges the tank afterward.
- The Moving Window calculation verifies that the combined storage and recovery capability is sufficient for the critical draw intervals.

That makes it particularly useful for sizing commercial boiler-storage systems and 'hybrid' heat-pump systems, where balancing equipment capacity and storage is essential to achieving reliable service without unnecessary oversizing.

Full-Service Restaurant

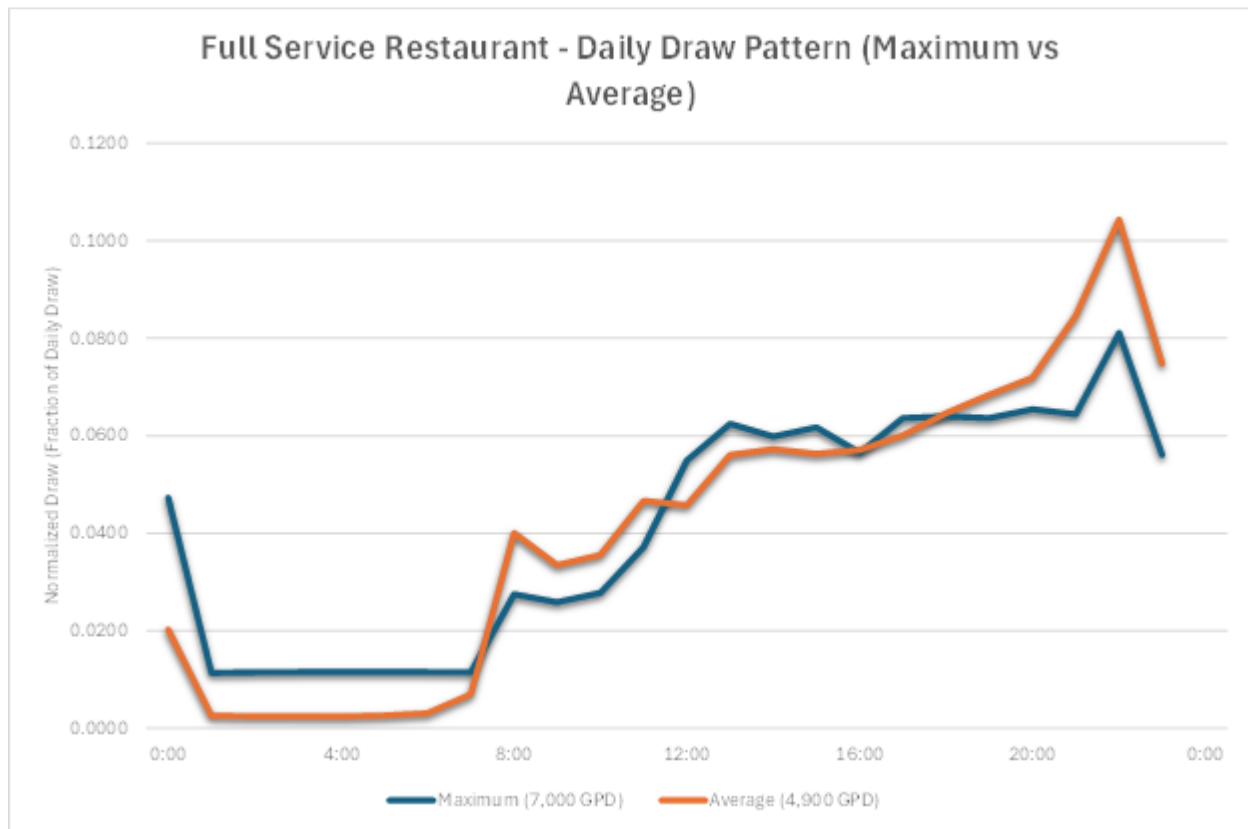


Figure 3 Full-Service Restaurant building Daily Draw Pattern

Table 5 Hourly peak and average SWH daily draw for Full-Service Restaurant building

Daily Draw	Maximum	Average
	7,000	4,900
0:00	0.0473	0.0203
1:00	0.0114	0.0025
2:00	0.0115	0.0024
3:00	0.0116	0.0024
4:00	0.0115	0.0024
5:00	0.0115	0.0026
6:00	0.0115	0.0031
7:00	0.0115	0.0070
8:00	0.0275	0.0400
9:00	0.0259	0.0335
10:00	0.0278	0.0356

Daily Draw	Maximum	Average
11:00	0.0372	0.0467
12:00	0.0549	0.0458
13:00	0.0625	0.0561
14:00	0.0599	0.0573
15:00	0.0617	0.0563
16:00	0.0565	0.0571
17:00	0.0636	0.0601
18:00	0.0640	0.0646
19:00	0.0636	0.0685
20:00	0.0655	0.0720
21:00	0.0644	0.0847
22:00	0.0812	0.1044
23:00	0.0561	0.0748

Figure 3 shows the representative daily SWH draw profile for the Full-Service Restaurant prototype. Hot-water demand is concentrated during meal-preparation and meal-service periods, with relatively low overnight use and sustained daytime activity. The profile indicates a strong recurring baseload with short periods of elevated demand, which supports the use of a hybrid system in which the heat pump serves most routine load while the backup heater responds to peak draws.

Multifamily

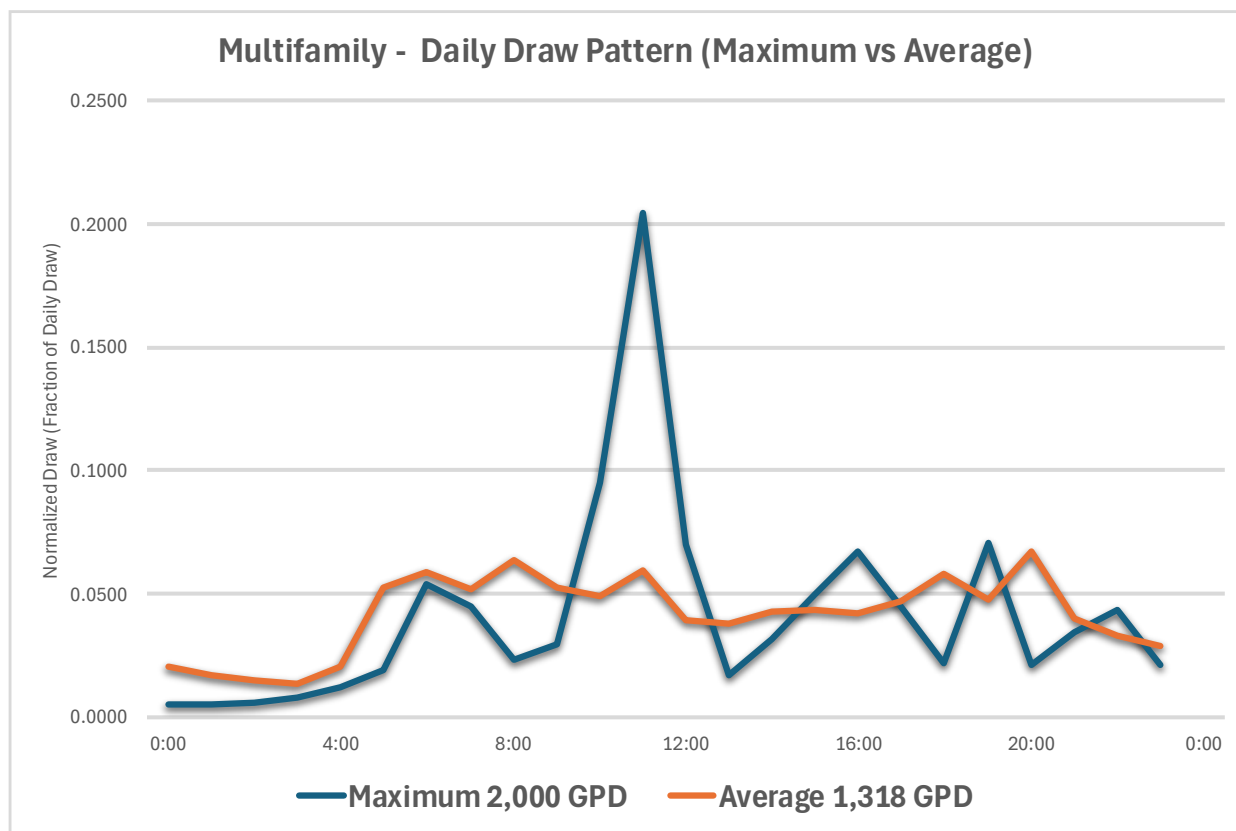


Figure 4 Multifamily building Daily Draw Pattern

Figure 4 presents the daily service water draw pattern used for the Multifamily building prototype. Demand is more distributed than in the restaurant case, with characteristic morning and evening peaks associated with occupant showering, laundry, and general DHW use. The steadier profile and lower peak intensity make this building type well suited to storage-based hybrid service water heating systems sized to cover the majority of annual baseload demand.

Table 6 Hourly peak and average SWH daily draw for Multifamily building

Daily Draw	Maximum	Average
	2,000	1,318
0:00	0.0051	0.0205
1:00	0.0049	0.0167
2:00	0.0061	0.0151
3:00	0.0080	0.0135
4:00	0.0123	0.0205
5:00	0.0192	0.0523

Daily Draw	Maximum	Average
6:00	0.0538	0.0585
7:00	0.0445	0.0518
8:00	0.0234	0.0635
9:00	0.0295	0.0523
10:00	0.0951	0.0492
11:00	0.2047	0.0595
12:00	0.0698	0.0394
13:00	0.0171	0.0376
14:00	0.0316	0.0425
15:00	0.0500	0.0437
16:00	0.0671	0.0423
17:00	0.0449	0.0469
18:00	0.0221	0.0578
19:00	0.0706	0.0474
20:00	0.0213	0.0674
21:00	0.0346	0.0397
22:00	0.0431	0.0333
23:00	0.0212	0.0288

Large Hotel

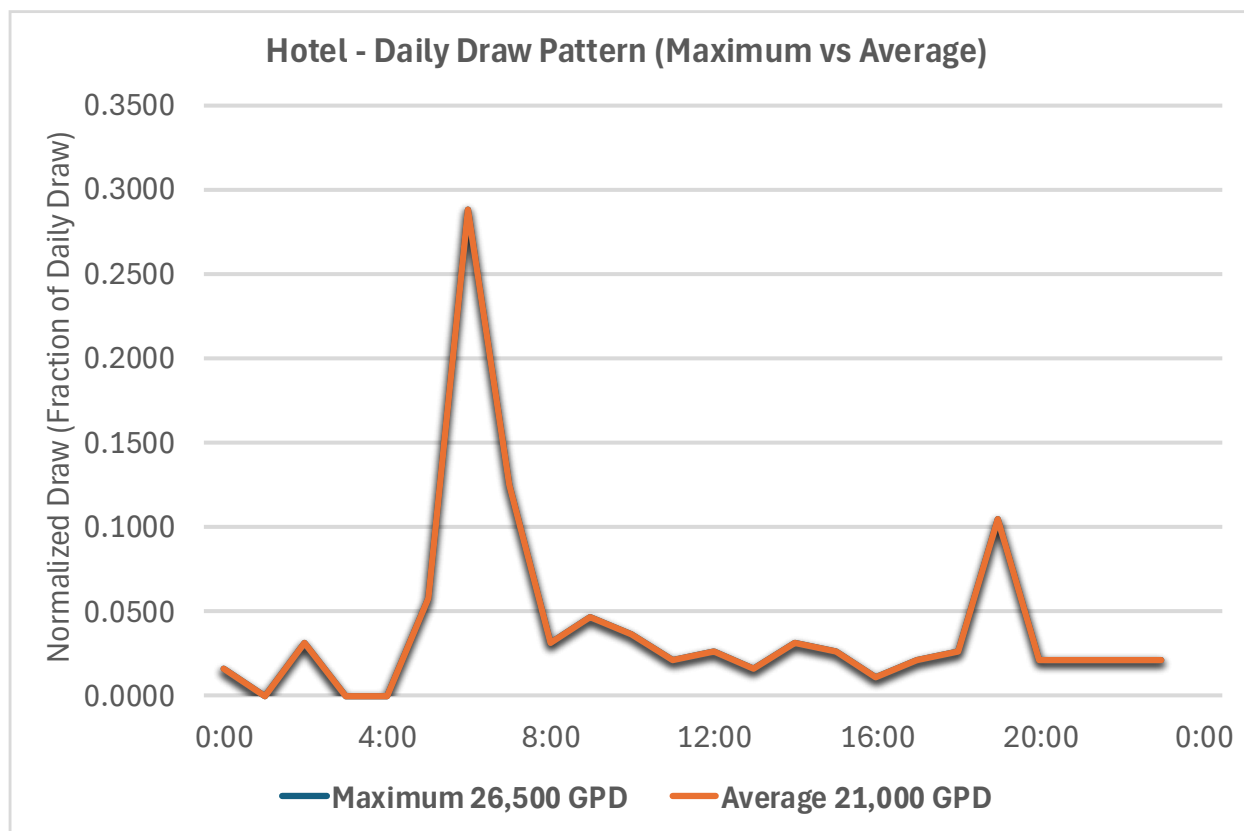


Figure 5 Large Hotel building Daily Draw Pattern

Figure 5 illustrates the representative daily draw pattern for the Large Hotel prototype. The profile reflects high total hot-water use with pronounced occupancy-driven peaks and a substantial underlying baseload created by guest rooms, laundry, and common-area service demands. Because demand remains high for much of the day, this building type provides a favorable application for large-capacity hybrid systems that can achieve high annual heat-pump utilization. This dataset is not based on field data but rather on demand data pattern for Hotels listed in Ecosizer, scaled to the EnergyPlus average and peak demand loads for the Large Hotels building. Future efforts could include leveraging actual field demonstration demand data into this modeling analysis specific to Hotels, to quantify impacts and a sensitivity analysis.

Table 7 Hourly peak and average SWH daily draw for Large Hotel building

Daily Draw	Maximum	Average
	26,500	21,000
0:00	0.0156	0.0157
1:00	0.0000	0.0000

Daily Draw	Maximum	Average
2:00	0.0311	0.0313
3:00	0.0000	0.0000
4:00	0.0000	0.0000
5:00	0.0576	0.0576
6:00	0.2882	0.2882
7:00	0.1256	0.1257
8:00	0.0311	0.0313
9:00	0.0467	0.0470
10:00	0.0363	0.0364
11:00	0.0207	0.0207
12:00	0.0259	0.0258
13:00	0.0156	0.0157
14:00	0.0311	0.0313
15:00	0.0259	0.0258
16:00	0.0104	0.0106
17:00	0.0213	0.0212
18:00	0.0265	0.0262
19:00	0.1049	0.1050
20:00	0.0213	0.0212
21:00	0.0213	0.0212
22:00	0.0213	0.0212
23:00	0.0213	0.0212

Equipment Performance Curve Fits

For the GHPs, equipment performance curves were leveraged from previously published datasets. The parsed datasets used performance correlations between heating capacity and gas use relative to ambient conditions and return water temperatures for modeling real-time GHP performance. Additional incorporations were made for cycling of the equipment, defrost penalties and electrical power consumption of the equipment. This approach was followed for both the modulating and non-modulating GHPs.

For the HPWH, manufacturer specified datasets for a representative HPWH in NEEA's Qualified Product List¹⁷ (QPL) were used. The parsed datasets used performance correlations between

¹⁷ NEEA's Commercial HPWH Qualified Products List, <https://neea.org/resource/commercial-hpwh-qualified-products-list/>

heating capacity and compressor power draw relative to ambient conditions and return water temperatures for modeling real-time compressor modulation effects. Representative defrost penalties and cycling penalties were used from existing EnergyPlus data. It is recommended that future research potentially looks at using laboratory/field validated HPWH performance data to generate modeling results that are calibrated.

To model the baseline systems, GTI Energy leveraged previously developed models for condensing tankless water heaters and storage tank water heaters, and default performance curves in EnergyPlus for non-condensing boilers. To summarize, performance curves used in the completed analysis included: previously published GTI Energy work for modulating GHPs¹⁸, GTI Energy published work through the California Gas Emerging Technology (GET) Program for non-modulating GHPs¹⁹, and manufacturer-based performance curves for a representative electric HPWH. For modeled scenarios which had multiple systems installed, the equipment performance was scaled as needed to those additional units assumed to be in an array. Complex control strategies such as simultaneous modular operation between GHP/HPWH units was not assumed here.

Parametric Modeling Matrix

The parametric modeling analysis was designed to inform utilities and other stakeholders on when and where GHPs/HPWHs can provide meaningful efficiency, GHG emission and operating cost benefits when integrated into existing gas-fired SWH plants. The simulation matrix was structured to capture the primary drivers of SWH plant design. Simulations were then conducted across pacific northwest climate zones (4C, 5B, and 6B) and included three commercial building types to reflect real-world differences in SWH demand patterns.

Key parameters varied in the modeling matrix included:

- Climate and location (4C, 5B, 6B)
- Baseline water heating system
- Storage tank sizes
- GHP and HPWH sizes relative to peak demand
- Buffer tank temperature setpoint

Results are reported by climate zone, building type and SWH system type i.e. baseline, all electric HPWH or variations of GHP/HPWH integrated with the baseline SWH system. This type of parametric study can highlight key sweet spots for heat pump based SWH systems that can

¹⁸ Pathways to Decarbonization of Residential Heating, <https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1353&context=ihpbc>

¹⁹ Gas Absorption Heat Pump (GAHP) #1 Performance Mapping, <https://ca-etp.com/sites/default/files/reports/ET23SWG0015%20%28MS06a%29%20Final%20Report%20Addendum%20%282025-02-04%29.pdf>

aid development of adaptive program strategies rather than a single uniform parameter set across all conditions.

Table 8 Parametric Modeling Analysis permutations

Building Type	Heat Pumps	Sizing Variations	Baseline Equipment	Climate Locations	Tank Variations	Buffer Tank setpoint
Full-Service Restaurant	Modulating GHP	Heat pump capacities ranging between 30% and 60% of peak load	Boiler with a storage tank	4C	Storage tank capacities between 50% and 100% of peak load	120°F and 140°F
Multifamily	Non modulating GHP		Tankless water heater with a storage tank	5B		
Large Hotel	Electric HPWH		Storage tank water heater	6B		

Figure 6 shows the modeled integration schematic for adding a GHP/HPWH to an existing SWH plant. Conceptually, in all evaluated 'hybrid' configurations, the heat pump and associated buffer tank are sized to meet the routine baseload requirement, while the conventional gas-fired equipment remains available to satisfy short-duration peaks and maintain a main storage tank temperature of 140°F. This configuration is central to the study because it enables high-efficiency operation without requiring full replacement of the baseline system. All cold city water and SHW return flow was routed directly to the main storage tank, with the GHP/HPWH adding energy only when the tank temperature dropped below the aquastat setpoint.

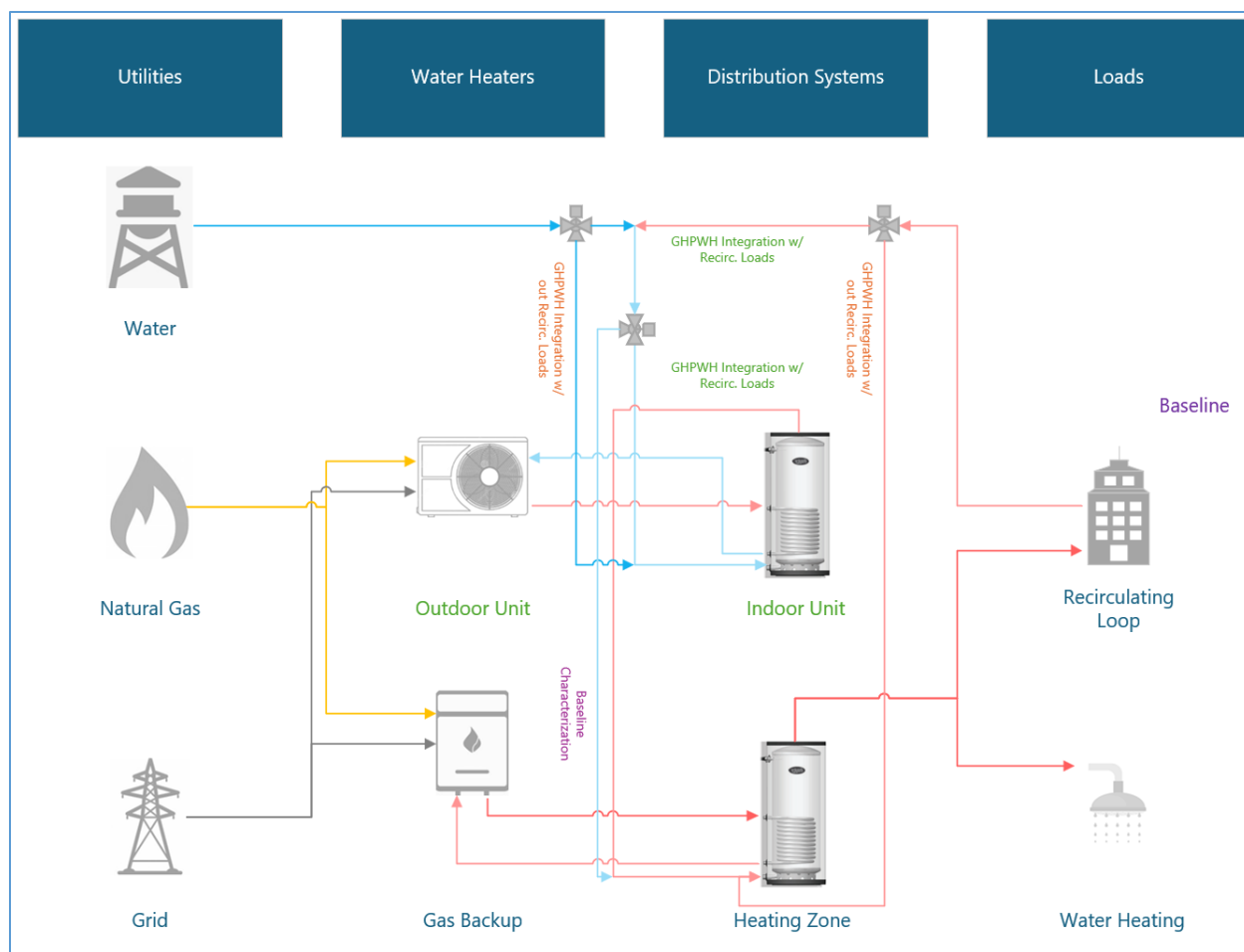


Figure 6 GHP/HPWH integration and schematic of modeled representative SWH plant

Custom SWH plant loops were created in EnergyPlus to examine the hybrid SWH designs in which a GHP/HPWH is integrated with a conventional baseline water-heating system. The modeled technology pairings include modulating GHPs, non-modulating GHPs, and electric HPWHs with buffer tanks combined with baseline boiler, tankless water-heater, or storage tank water-heater systems paired with a main storage tank. The heat pumps were generally sized between 30% to 60% of the peak load, with the baseline equipment retained to meet peak draws and maintain temperature control.

This configuration enabled effective SHW system operation as follows - city water entering the system is first preheated by the GHP/HPWH prior to feeding into the system with the buffer tank (indoor unit) setpoint of either 120°F or 140°F. The heat pump-based systems offer a more efficient and cost-effective means to preheat the city water, with relatively higher COPs at lower return temperatures, well above condensing and non-condensing baseline levels. The GHPs were modeled as multi-pass systems whereas the electric HPWH was modeled as a single pass system. The all-electric HPWH configurations were modeled with electric resistance backup heating within the main storage tank. Recirculation loads were assumed to be minimal in these

simulations, about 5% of the SWH loads. Future research efforts could look at the impact of differing recirculation loads to the overall SWH plant efficiencies.

Hot water from the buffer tank is then circulated to the main storage tank where additional heating is supplied by the baseline water heater as needed to meet the existing storage tank aquastat setpoint (140°F). By preheating most of the temperature lift (from about 50-60°F city water to 120/140°F) at a higher efficiency, less demand is needed from the existing baseline DHW systems (remaining temperature lift to 140°F), delivering higher overall system efficiency.

Table 9 Electric and Gas Utility Rates used for the Modeling

Cities	Electric Utility Rates²⁰ (\$/kWh)	Gas Utility Rates²¹ (\$/therm)
Seattle, WA	0.13	1.43
Portland, OR	0.11	1.09
Boise, ID	0.11	0.95
Missoula, MT	0.12	0.75

Table 10 Full-fuel Cycle Conversion Factors²² used for the Modeling

Cities	Source to Site Conversion Factor (Electric)	Source to Site Conversion Factor (Gas)	Baseload Emission Factors (lb/MMBtu)	Non-baseload Emission Factors (lb/MMBtu)	Gas Emission Factors (lb/MMBtu)
Seattle, WA	2.52	1.09	68.30	376.86	145.6
Portland, OR	2.76		109.15	351.71	
Boise, ID	2.76		93.5	345.27	
Missoula, MT	2.21		344.52	672.08	

²⁰ Electric Prices, <https://www.eia.gov/electricity/data/browser/>

²¹ Natural Gas Prices, https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm

²² Source Energy and Emissions Analysis Tool, Commercial Module, CMIC, <https://cmic.gti.energy/commercial>

RESULTS

The project results, including the modeled results, are presented in this section, with a summary of the key results and trends listed in Table 11 and more detailed outputs in subsequent sections for each building type. The SWH plant-level COP was calculated as the ratio of total hot water delivered to the total gas and electricity used by the SWH systems. It is being calculated on a site energy basis. Overall system power consumption used here to compute efficiencies includes just the boiler/tankless water heater/storage water heater for the baseline configurations. For the GHP retrofit configurations, it includes the GHP, sorption pump and circulation pump. Similarly, for the HPWH retrofit configurations, it includes the HPWH and the circulation pump.

Table 11 Summary of key modeling results

Building type	Heat Pump being integrated	Operating cost-savings range (%)	Highest Annual Overall SWH plant efficiency	Highest Hourly Peak Heat Pump efficiency	Non-baseload GHG emissions-reduction range (1,000 lbs of CO₂e)
Full-Service Restaurant	Modulating GHP	22.5 to 42.0%	1.43	1.62	36.6 to 86.6
Full-Service Restaurant	Non-Modulating GHP	5.1 to 17.6%	1.04	1.27	8.3 to 37.7
Full-Service Restaurant	Electric HPWH	-37.4 to 20.1%	2.08	3.4	-60.4 to 53.4
Multifamily	Modulating GHP	36.8 to 48.9%	1.62	1.68	16.9 to 28.3
Multifamily	Non-Modulating GHP	9.9 to 28.6%	1.10	1.31	5.6 to 16.4
Multifamily	Electric HPWH	-45.5 to 8.2%	2.04	3.37	-3.5 to 9.3
Large Hotel	Modulating GHP	18.4 to 39.7%	1.17	1.42	220.6 to 497.9
Large Hotel	Non-Modulating GHP	9.9 to 32.2%	1.03	1.26	135.3 to 404.2
Large Hotel	Electric HPWH	-14.3 to 22.2%	2.02	3.37	58.4 to 346.6

Modeling Results - Full-Service Restaurant

Table 12 lists all the different permutations of system types, sizes and sensitivities that were modeled for the Full-Service Restaurant building type. As detailed in the earlier sections, the Full-Service Restaurant was a representative 5,502 sq. ft. prototype with peak SWH demand of 7,000 GPD and average daily demand of 4,900 GPD. The modeled hybrid configurations retain the baseline system as a supplement to meet peak draws and to meet supply water temperatures in the main storage tank. The GHP/HPWHs were modeled to be located outdoors whereas the existing SWH system, buffer tank and main storage tank was located indoors.

Table 12 Parametric modeling done for Full-Service Restaurant

Simulation-matrix	Sensitivities modeled
Cities	Portland, OR, Seattle, WA, and Missoula, MT
Baseline systems	Boiler with storage tank; tankless with storage tank; storage tank water heater
Modulating GHP sizes	160,000 and 240,000 Btu/h
Non-modulating GHP sizes	123,000 and 246,000 Btu/h
Electric HPWH sizes	203,069 and 272,762 Btu/h
Baseline SWH system	470,000 Btu/h output
Main storage tank	600 gal and 300 gal
Buffer tank	120 gal at 120°F or 140°F
Total combinations	186

The modeled results illustrate that restaurants can serve as favorable hybrid/SWH applications owing to high SWH demand, steady daily draw diversity, and that a right-sized modulating GHP can serve the base load for much of the year. The summary charts show that best-case modulating GHP cost savings range from about 22.5% to 42.0% depending on climate and baseline system, while best-case electric HPWH economics vary widely from strongly positive to strongly negative depending on the local electric to gas price ratios and baseline configuration.

Modeling results for Portland with a backup boiler

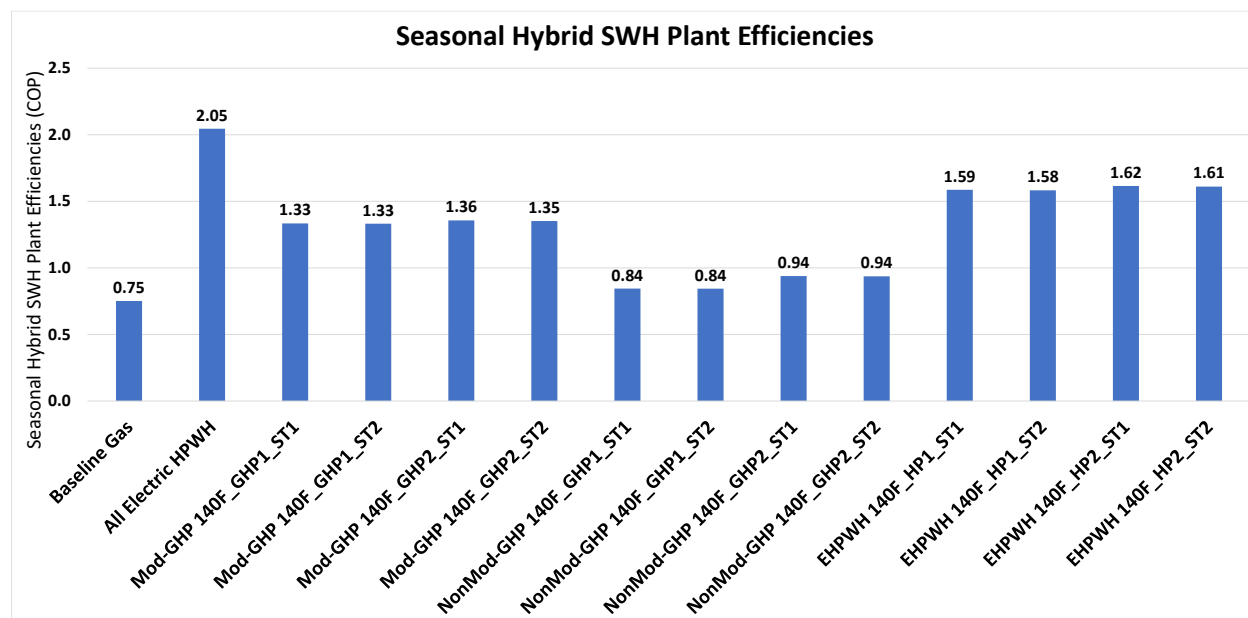


Figure 7 Full-Service Restaurant Annual SWH Plant Efficiencies for Portland with a backup gas boiler

Figure 7 compares annual hybrid SWH plant efficiencies for the Full-Service Restaurant prototype in Portland with a backup gas boiler. Modulating GHP and electric HPWH use cases show the highest overall plant-level efficiencies because they displace more boiler operation over the year, whereas non-modulating GHP cases show lower values due to cycling effects and return-water-temperature related constraints on GHP operation that reduce part-load and overall performance. Results also demonstrate the efficiency advantage of controllable heat-pump operation in a high-demand restaurant application. Overall system power consumption used here to compute efficiencies includes just the boiler for the baseline configurations. For the GHP retrofit configurations, it includes the GHP, sorption pump and circulation pump. Similarly, for the HPWH retrofit configurations, it includes the HPWH and the circulation pump. Broadly speaking, these integration results also encompass standby losses from the storage tanks and from recirculation losses.

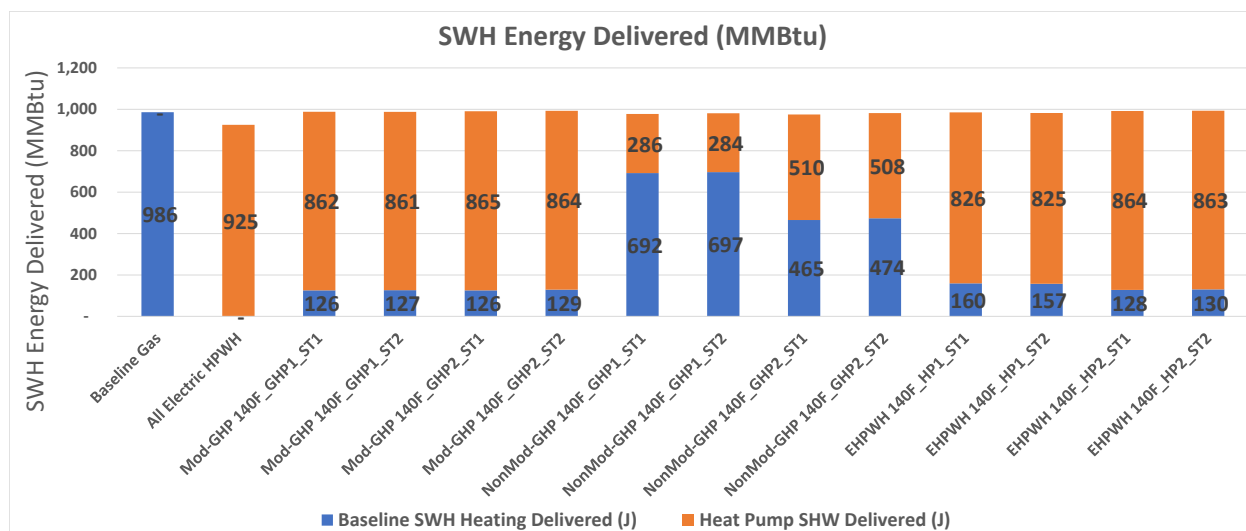


Figure 8 Full-Service Restaurant Annual SWH Energy Delivered for Portland with a backup gas boiler

Figure 8 presents the breakdown of the annual SWH energy delivered between the baseline boiler and the GAHP/HPWH system for the Full-Service Restaurant prototype in Portland with a backup gas boiler. Delivered energy remains broadly similar across cases because each configuration is required to satisfy the same hot-water load, but differences among technologies reflect varying storage losses, control behavior, and the split between heat-pump and back-up-boiler contribution. The results visualize that the hybrid systems meet the restaurant hot-water demand while shifting how the thermal load is served.

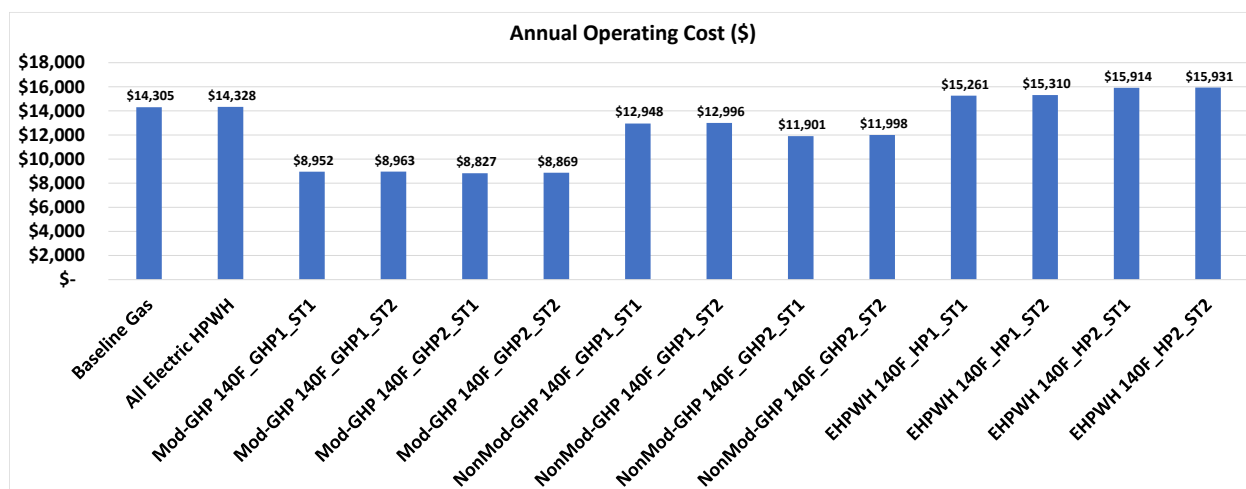


Figure 9 Full-Service Restaurant Annual Hybrid Operating Cost for Portland with a backup gas boiler

Figure 9 compares the annual operating cost for the Full-Service Restaurant prototype in Portland with a backup gas boiler. Lower annual cost is generally associated with configurations that maximize useful heat-pump contribution while minimizing reliance on the boiler during

periods of high demand. The results show that modulating GHP configurations are typically among the most economical options, while electric HPWH outcomes depend more strongly on the local electricity-to-gas price ratios. Utility natural gas and electric rates were applied from 2024 annual averages from EIA.

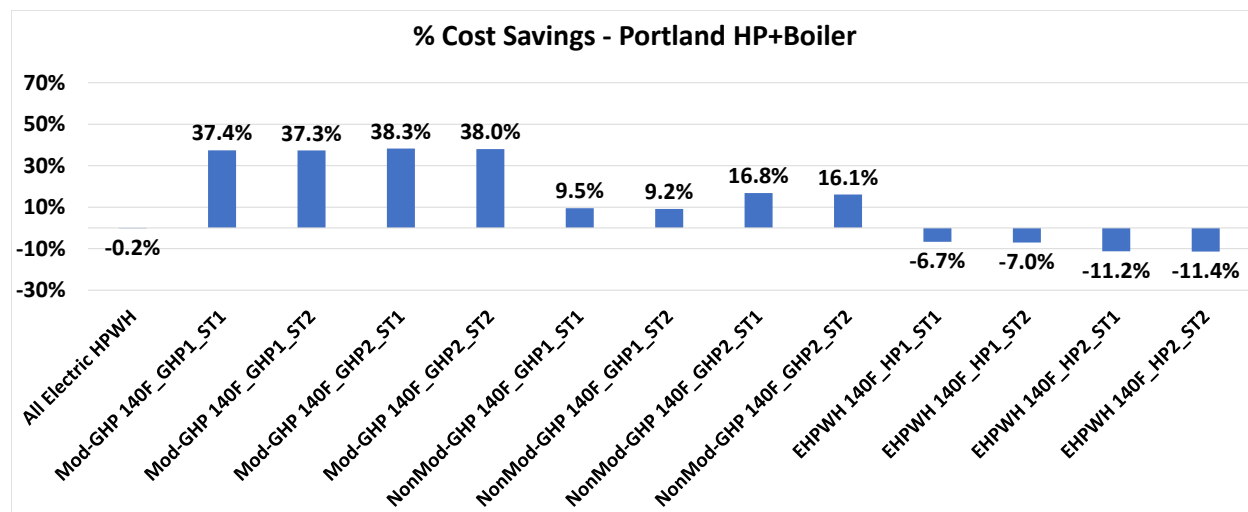


Figure 10 Full-Service Restaurant Operating Cost Savings % for Portland with a backup gas boiler

Figure 10 shows the relative annual operating-cost savings for the Full-Service Restaurant prototype in Portland with a backup gas boiler, expressed relative to the corresponding baseline SWH plant. Modulating GHP configurations deliver the most consistent savings because they maintain efficient part-load operation and reduce backup-boiler use across much of the year. Results also highlight that cost effectiveness is driven not only by equipment efficiency, but also by fuel pricing and how well the GHP/HPWH technology is sized to keep up with building SWH load profile.

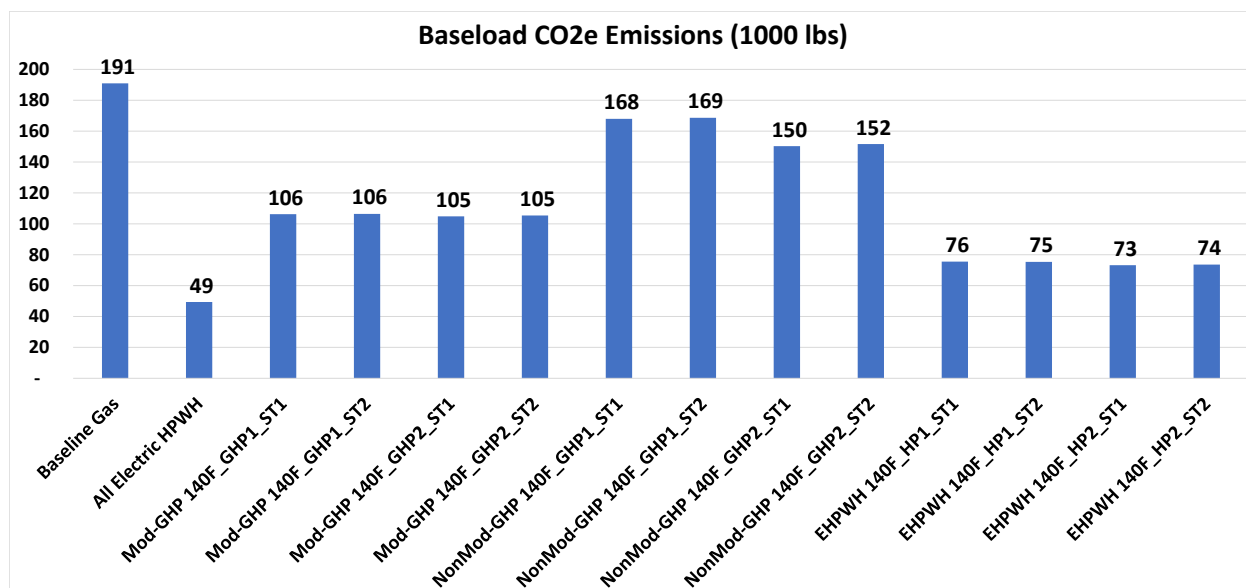


Figure 11 Full-Service Restaurant Annual Baseload CO₂e Emissions for Portland with a backup gas boiler

Figure 11 compares annual baseload CO₂e emissions for the Full-Service Restaurant prototype in Portland with a backup gas boiler. Applications with greater heat pumping contribution generally reduced direct gas consumption from the boiler and therefore had lower annual emissions relative to conventional gas-only non-condensing boiler operation. The chart illustrates how improved plant efficiency can translate into meaningful emissions benefits even when the baseline system remains in place to serve peaks. It must be noted that while this result visualizes GHG emissions impact on a baseload basis, typically for energy efficiency retrofits or added load to the grid, a non-baseload GHG emissions comparison is recommended. Figure 12 quantifies this comparison on a non-baseload basis.

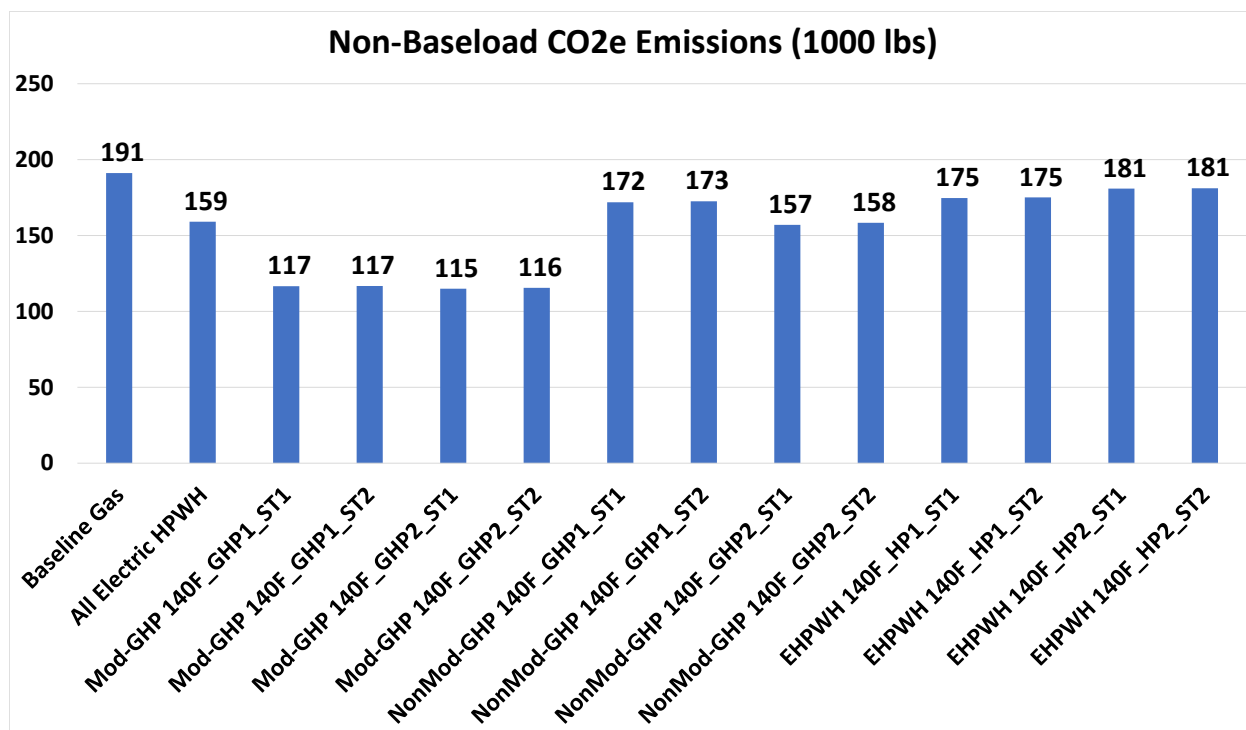


Figure 12 Full-Service Restaurant Annual Non-Baseload CO₂e Emissions for Portland with a backup gas boiler

Figure 12 presents annual non-baseload CO₂e emissions for the Full-Service Restaurant prototype in Portland with a backup gas boiler. Under this GHG emissions approach, results are more sensitive to the emissions intensity of incremental electricity use, so the relative ranking of technologies are seen to differ from the baseload emissions case. The figure therefore provides an important marginal-emissions perspective on the same hybrid configurations and reinforces that emissions outcomes depend on both system efficiency and grid conditions.

Modeling results for Portland with a backup tankless water heater

Table 13 Full-Service Restaurant Cost Outputs for Portland with a backup tankless gas water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$12,137			\$12,137

All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	2.05	\$14,328	-18.1%	\$14,328	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.39	\$8,701	28.3%	\$1,364	\$7,336
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.39	\$8,733	28.0%	\$1,365	\$7,368
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.42	\$8,541	29.6%	\$1,341	\$7,200
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.41	\$8,574	29.4%	\$1,342	\$7,232
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.97	\$11,498	5.3%	\$499	\$10,999
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.97	\$11,525	5.0%	\$499	\$11,026
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.96 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	1.03	\$11,063	8.8%	\$851	\$10,212
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.96 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	1.03	\$11,044	9.0%	\$878	\$10,166

EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.68	\$15,020	-23.8%	\$13,056	\$1,964
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.68	\$15,051	-24.0%	\$13,057	\$1,994
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.70	\$15,722	-29.5%	\$14,224	\$1,497

Table 14 Full-Service Restaurant GHG Outputs for Portland with a backup tankless gas water heater

Case	Overall Efficiency	Source Energy (MMBtu)	Non-baseload Emissions	Reduction in Non-Baseload Emissions	Reduction in Baseload Emissions	Baseload Emissions
Baseline Gas	0.89	1281	162			162
All Electric HPWH	2.05	1248	159	3	113	49
Mod-GHP 140F_GHP1_ST1	1.39	853	113	49	59	103
Mod-GHP 140F_GHP1_ST2	1.39	856	114	49	59	103
Mod-GHP 140F_GHP2_ST1	1.42	837	111	51	61	101
Mod-GHP 140F_GHP2_ST2	1.41	840	112	51	61	101
NonMod-GHP 140F_GHP1_ST1	0.97	1144	153	10	13	149

NonMod-GHP 140F_GHP1_ST2	0.97	1146	153	9	13	149
NonMod-GHP 140F_GHP2_ST1	1.03	1096	146	16	23	139
NonMod-GHP 140F_GHP2_ST2	1.03	1093	146	17	23	139
EHPWH 140F_HP1_ST1	1.68	1334	171	(9)	91	71
EHPWH 140F_HP1_ST2	1.68	1337	172	(9)	91	72
EHPWH 140F_HP2_ST1	1.70	1389	178	(16)	93	69

Table 13 and Table 14 summarize the modeled outputs for the Full-Service Restaurant prototype in Portland when the baseline system is a tankless gas water heater with storage. Taken together, the tables compare overall efficiency, operating cost, cost savings, and GHG emissions across the identified heat-pump technologies. The results indicate that the main technology trends remain similar to the boiler-baseline case, with modulating GHP options generally providing the strongest balance of efficiency improvement and annual cost savings.

Modeling results for Portland with a backup storage water heater

Table 15 Full-Service Restaurant Cost Outputs for Portland with a backup storage gas water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$15,155			\$15,155
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	2.05	\$14,328	5.5%	\$14,328	\$-

Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.36	\$8,974	40.8%	\$1,408	\$7,566
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.32	\$9,111	39.9%	\$1,365	\$7,746
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.35	\$8,900	41.3%	\$1,341	\$7,558
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.35	\$8,941	41.0%	\$1,342	\$7,600
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.81	\$13,634	10.0%	\$499	\$13,134
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.81	\$13,734	9.4%	\$474	\$13,261
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.67 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	0.91	\$12,481	17.6%	\$878	\$11,603
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.67 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	0.91	\$12,511	17.4%	\$878	\$11,633
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.56	\$15,510	-2.3%	\$13,056	\$2,454

EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.56	\$15,550	-2.6%	\$13,057	\$2,493
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.60	\$16,134	-6.5%	\$14,225	\$1,909

Table 16 Full-Service Restaurant GHG Outputs for Portland with a backup storage gas water heater

Case	Overall Efficiency	Source Energy (MMBtu)	Non-baseload Emissions	Reduction in Non-Baseload Emissions	Reduction in Baseload Emissions	Baseload Emissions
Baseline Gas	0.72	1599	202			202
All Electric HPWH	2.05	1248	159	43	153	49
Mod-GHP 140F_GHP1_ST1	1.36	879	117	86	97	106
Mod-GHP 140F_GHP1_ST2	1.32	894	119	84	94	108
Mod-GHP 140F_GHP2_ST1	1.35	873	116	87	97	106
Mod-GHP 140F_GHP2_ST2	1.35	877	116	86	96	106
NonMod-GHP 140F_GHP1_ST1	0.81	1357	181	21	25	177
NonMod-GHP 140F_GHP1_ST2	0.81	1368	182	20	24	179
NonMod-GHP 140F_GHP2_ST1	0.91	1237	165	38	44	158

NonMod-GHP 140F_GHP2_ST2	0.91	1240	165	37	44	158
EHPWH 140F_HP1_ST1	1.56	1383	178	25	125	78
EHPWH 140F_HP1_ST2	1.56	1387	178	24	124	78
EHPWH 140F_HP2_ST1	1.60	1430	183	19	128	75

Table 15 and Table 16 summarize the modeled outputs for the Full-Service Restaurant prototype in Portland when the baseline system is a storage gas water heater. The combined tables show how technology choice affects overall plant efficiency, annual energy use, operating cost, relative savings, and GHG emissions. Meaningful performance gains are still obtainable with hybrid heat-pump integration, although the magnitude of savings depends on the balance between storage volume, control strategy, and backup SWH system operation.

Modeling Results - Multifamily

Table 17 lists all the different permutations of system types, sizes and sensitivities that were modeled for the Multifamily building type. As detailed in the earlier sections, the Multifamily building was a representative 33,740 sq. ft. prototype with peak service hot-water demand of 2,000 GPD and average daily demand of 1,318 GPD. The modeled hybrid configurations retain the baseline system as a supplement to meet peak draws and to meet supply water temperatures in the main storage tank. The GHP/HPWHs were modeled to be located outdoors whereas the existing SWH system, buffer tank and main storage tank was located indoors.

Table 17 Parametric modeling done for Multifamily

Simulation-matrix	Sensitivities modeled
Cities	Seattle, Portland, Boise
Baseline systems	Boiler with storage tank; tankless with storage tank; storage tank water heater
Modulating GHP sizes	80,000 and 160,000 Btu/h
Non-modulating GHP sizes	123,000 Btu/h
Electric HPWH sizes	66,688 and 136,381 Btu/h
Main storage tank	250 gal and 150 gal

Simulation-matrix	Sensitivities modeled
Buffer tank	120 gal at 140°F
Total combinations	90

Among the three representative building types, multifamily shows the strongest and most stable operating-cost outcome for modulating GHPs. The best modulating-GHP cases provided approximately 36.8% to 48.9% operating-cost savings across the reported climates and baselines. The multifamily case also highlights how storage affects design heating rate and annual performance, reinforcing the value of the conservatively sizing the storage tank sizes and the baseline systems in this study (based on the moving-window sizing method).

Modeling results for Portland with a backup boiler

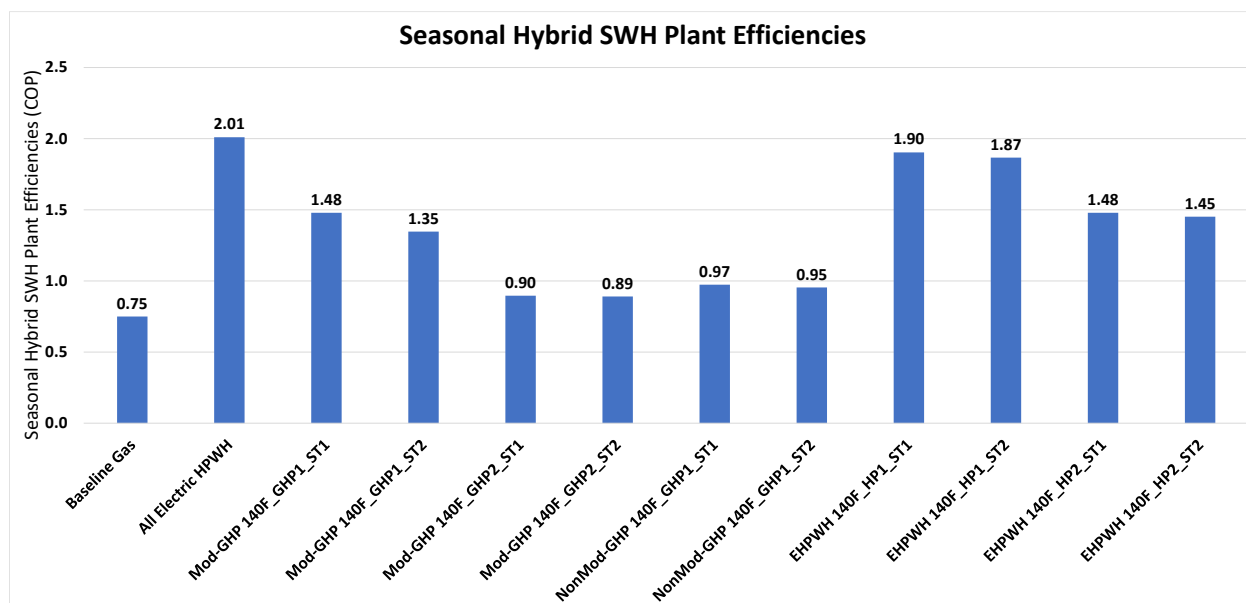


Figure 13 Multifamily Annual SWH Plant Efficiencies for Portland with a backup gas boiler

Figure 13 compares the annual SWH plant efficiency for the multifamily prototype in Portland with a backup gas boiler. Multifamily loads are steadier than restaurant loads, which tends to improve heat-pump runtime characteristics and supports strong performance from modulating GHP and electric HPWH configurations. The results show that non-modulating GHP options remain less effective under these conditions because part-load cycling reduces seasonal plant efficiency.

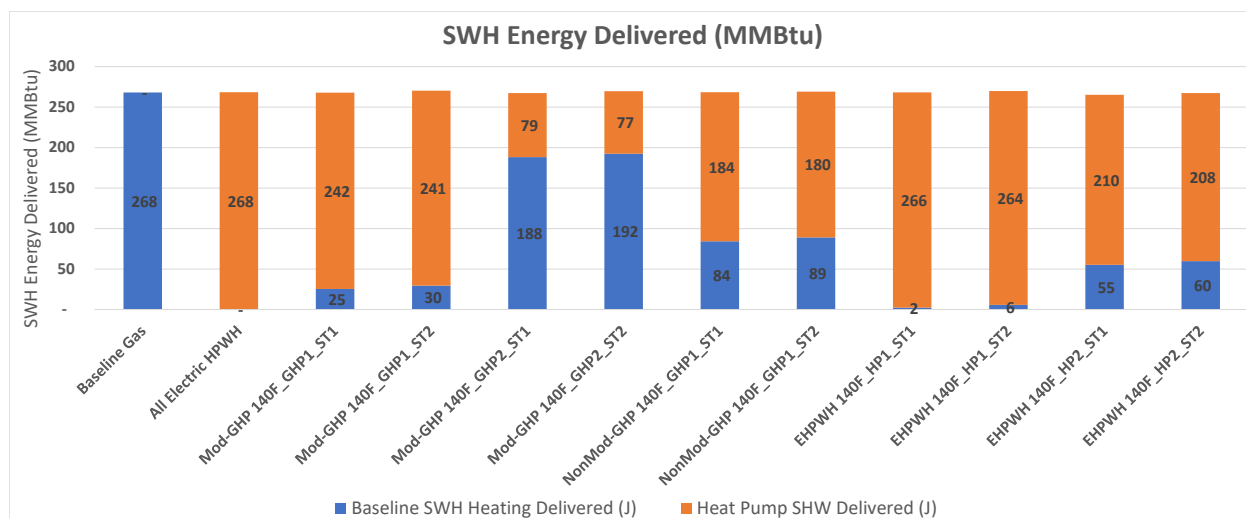


Figure 14 Multifamily Annual SWH Plant Energy Delivered for Portland with a backup gas boiler

Figure 14 presents the annual SWH energy delivered for the multifamily prototype in Portland with a backup gas boiler. Because all modeled systems serve the same domestic hot-water demand, total delivered energy is relatively consistent, while remaining differences reflect storage losses and the relative share carried by the heat pump and backup heater. The graph confirms that the hybrid systems can satisfy the multifamily load while changing the annual energy distribution among plant components. With more sophisticated control strategies, it could be beneficial to explore different optimization approaches leveraging different the different fuel sources in a dual-fuel SWH configuration to address overall operating cost, demand charges, grid constraint issues or overall GHG emissions.

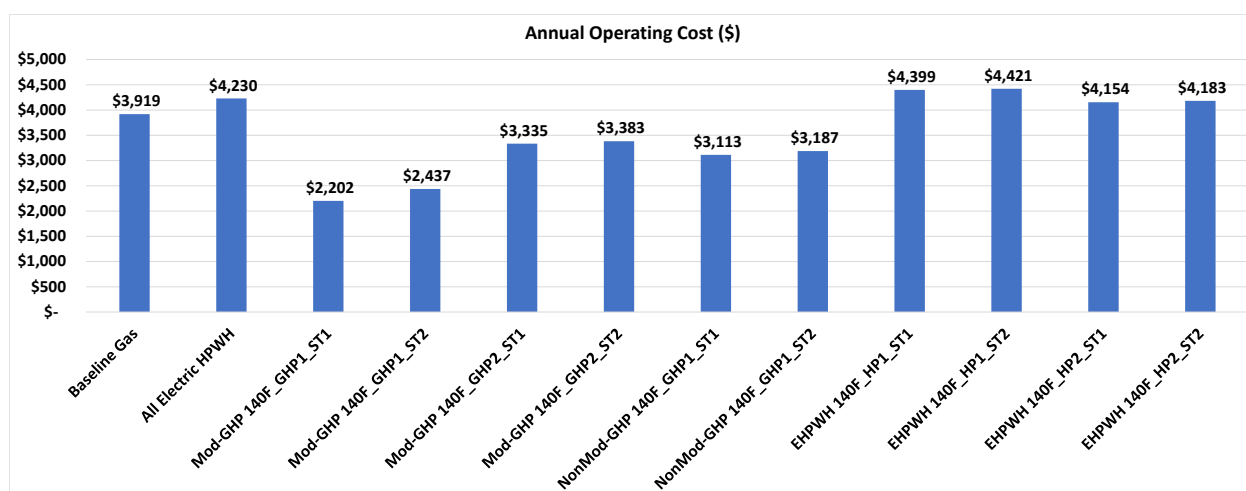


Figure 15 Multifamily Annual SWH Plant Operating Cost for Portland with a backup gas boiler

Figure 15 compares the annual operating cost for the multifamily prototype in Portland with a backup gas boiler. The steadier daily demand profile favors technologies that can operate efficiently for long periods at different modulation ratios, which tends to improve the economics of modulating GHP systems. The results also show that electric HPWH operating cost remains more sensitive to utility pricing, even when plant efficiency is high.

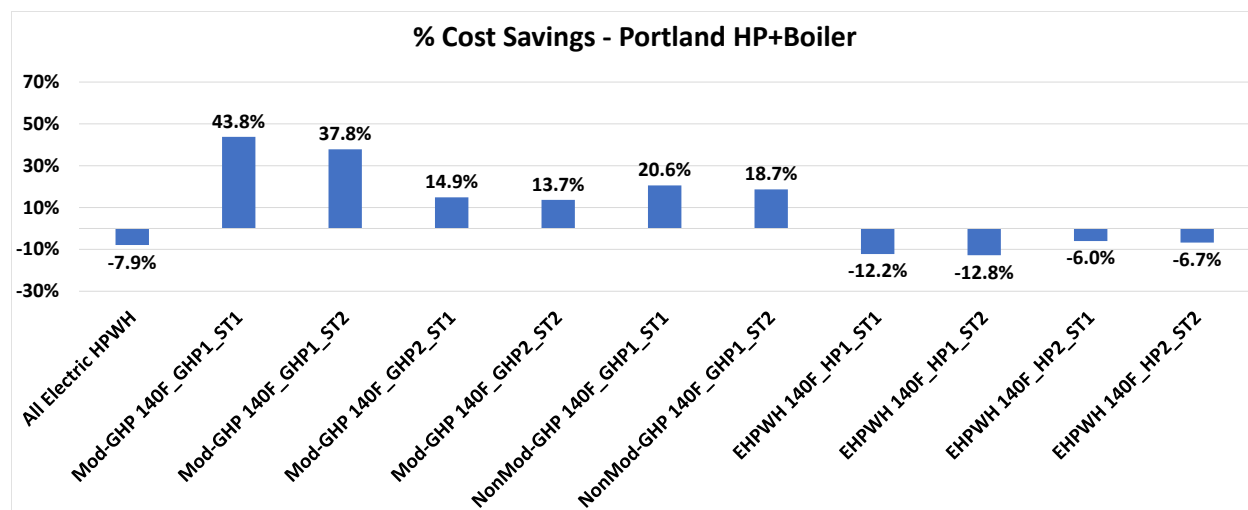


Figure 16 Multifamily SWH Plant Operating Cost Savings % for Portland with a backup gas boiler

Figure 16 shows the relative annual operating-cost savings for the multifamily prototype in Portland with a backup gas boiler. Among the three representative building types, multifamily produces some of the strongest and most stable savings for modulating GHP configurations because the load profile supports sustained efficient operation. The graph reinforces that appropriate sizing and storage selection are important to capturing these savings opportunities.

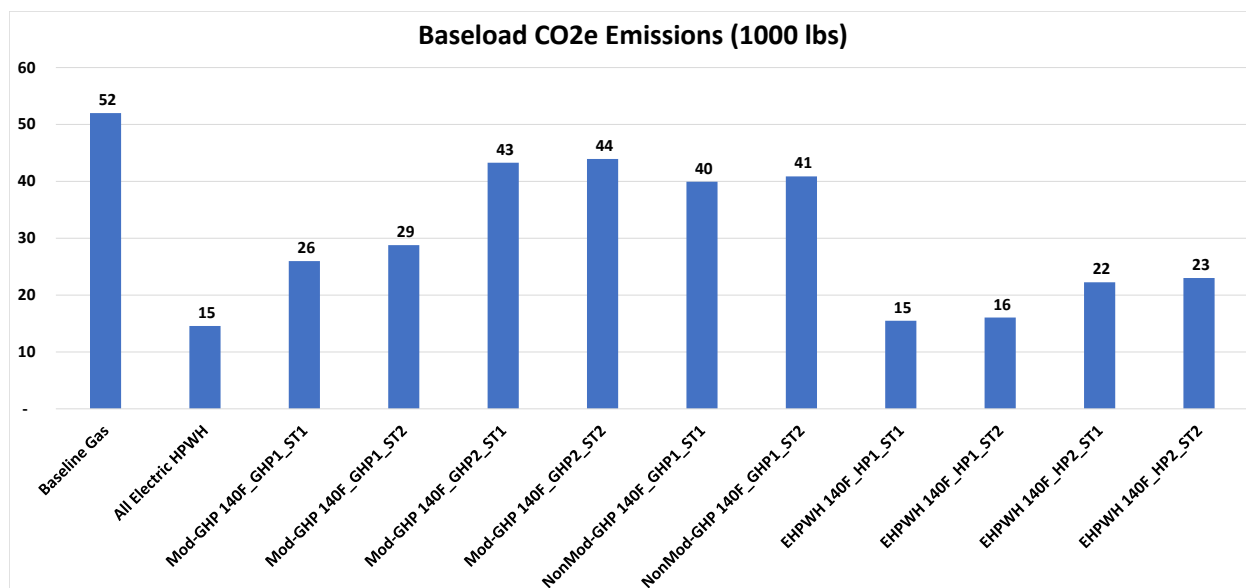


Figure 17 Multifamily Annual Baseload CO₂e Emissions for Portland with a backup gas boiler

Figure 17 compares the annual baseload CO₂e emissions for the multifamily prototype in Portland with a backup gas boiler. Emissions are reduced when heat-pump operation displaces baseline gas use while maintaining the required hot-water service loads. The chart shows that the multifamily application can achieve meaningful annual emissions improvements because its relatively smooth demand profile allows efficient use of the hybrid plant. As detailed in the previous section, while this result visualizes GHG emissions impact on a baseload basis, typically for energy efficiency retrofits or added load to the grid, a non-baseload GHG emissions comparison is recommended.

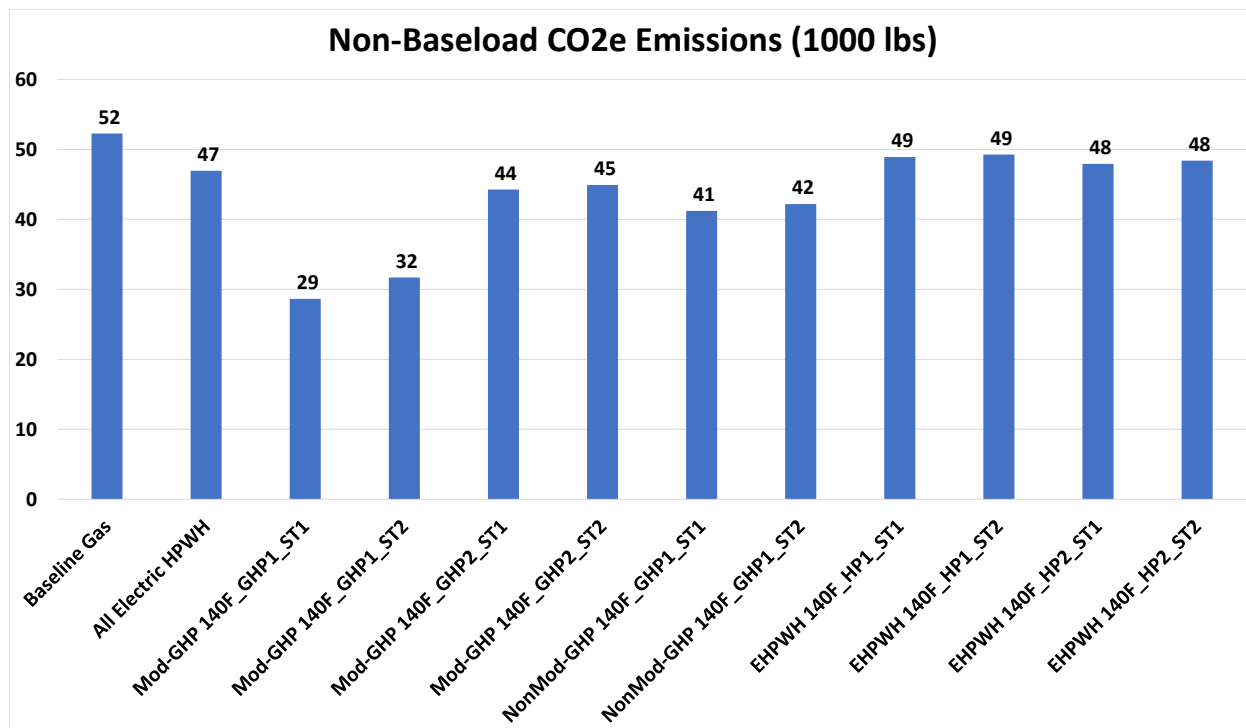


Figure 18 Multifamily Annual Non-Baseload CO₂e Emissions for Portland with a backup gas boiler

Figure 18 presents the annual non-baseload CO₂e emissions for the multifamily prototype in Portland with a backup gas boiler. The marginal or non-baseload emissions results depend on both equipment performance and the GHG emissions intensity of the electricity used by the heat pump.

Modeling results for Portland with a backup tankless water heater

Table 18 Multifamily Cost Outputs for Portland with a backup tankless gas water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$3,410		\$-	\$3,410
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	2.01	\$4,230	-24.0%	\$4,230	\$-

SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.50	\$2,253	33.9%	\$357	\$1,895
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.62	\$2,081	39.0%	\$326	\$1,755
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (250-gal main tank)	1.08	\$2,892	15.2%	\$152	\$2,740
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (150-gal main tank)	1.09	\$2,896	15.1%	\$154	\$2,742
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	1.09	\$3,083	9.6%	\$500	\$2,583
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	1.09	\$3,073	9.9%	\$496	\$2,577
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.83	\$4,555	-33.6%	\$4,429	\$126
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.80	\$4,587	-34.5%	\$4,416	\$171
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.46	\$4,712	-38.2%	\$3,635	\$1,077

EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.87	\$4,343	-27.4%	\$3,662	\$681
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Table 19 Multifamily GHG Outputs for Portland with a backup tankless gas water heater

Case	Overall Efficiency	Source Energy (MMBtu)	Non-baseload Emissions	Reduction in Non-Baseload Emissions	Reduction in Baseload Emissions	Baseload Emissions
Baseline Gas	0.89	360	46			46
All Electric HPWH	2.01	369	47	(1)	31	15
SMTI 140F_GHP1_ST1	1.50	221	29	16	19	27
SMTI 140F_GHP1_ST2	1.62	204	27	19	21	25
SMTI 140F_GHP2_ST1	1.08	287	38	7	8	37
SMTI 140F_GHP2_ST2	1.09	288	38	7	8	37
Robur 140F_GHP1_ST1	1.09	302	40	6	9	36
Robur 140F_GHP1_ST2	1.09	301	40	6	9	36
EHPWH 140F_HP1_ST1	1.83	398	51	(5)	29	17
EHPWH 140F_HP1_ST2	1.80	402	51	(6)	28	17

EHPWH 140F_HP2_ST1	1.46	424	55	(9)	19	27
EHPWH 140F_HP2_ST2	1.87	387	50	(4)	24	22

Table 18 and Table 19 summarize the modeled outputs for the multifamily prototype in Portland when the baseline system is a tankless gas water heater with storage. The grouped tables provide a consolidated view of efficiency, delivered energy, operating cost, cost savings, and GHG emissions outcomes for the evaluated SWH options. Results show that the overall technology ranking is consistent with the boiler-baseline case, although the absolute savings values shift with the efficiency and operating characteristics of the tankless baseline.

Modeling results for Portland with a backup storage water heater

Table 20 Multifamily Cost Outputs for Portland with a backup storage gas water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$4,212		\$-	\$4,212
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	2.01	\$4,230	-0.4%	\$4,230	\$-
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.48	\$2,292	45.6%	\$378	\$1,914
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.57	\$2,154	48.9%	\$337	\$1,817
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (160KBtu, 67% of Peak Load) (140F	0.91	\$3,415	18.9%	\$151	\$3,263

	swing tank) (250-gal main tank)					
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (150-gal main tank)	0.92	\$3,415	18.9%	\$153	\$3,262
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	1.02	\$3,050	27.6%	\$127	\$2,923
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	1.03	\$3,005	28.6%	\$124	\$2,882
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.91	\$4,541	-7.8%	\$4,537	\$3
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.91	\$4,556	-8.2%	\$4,551	\$4
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.50	\$4,381	-4.0%	\$3,612	\$769
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.50	\$4,394	-4.3%	\$3,634	\$760

Table 21 Multifamily GHG Outputs for Portland with a backup storage gas water heater

Case	Overall Efficiency	Source Energy (MMBtu)	Non-baseload Emissions	Reduction in Non-Baseload Emissions	Reduction in Baseload Emissions	Baseload Emissions
Baseline Gas	0.72	444	56			56
All Electric HPWH	2.01	369	47	9	42	15
SMTI 140F_GHP1_ST1	1.48	224	30	27	29	27
SMTI 140F_GHP1_ST2	1.57	211	28	28	31	25
SMTI 140F_GHP2_ST1	0.91	340	45	11	12	44
SMTI 140F_GHP2_ST2	0.92	340	45	11	12	44
Robur 140F_GHP1_ST1	1.02	303	40	16	17	39
Robur 140F_GHP1_ST2	1.03	299	40	16	17	39
EHPWH 140F_HP1_ST1	1.91	396	50	6	41	16
EHPWH 140F_HP1_ST2	1.91	397	51	6	41	16
EHPWH 140F_HP2_ST1	1.50	392	50	6	34	23
EHPWH 140F_HP2_ST2	1.50	393	50	6	34	23

Table 20 and Table 21 summarize the modeled outputs for the multifamily prototype in Portland when the baseline system is a storage gas water heater. The results demonstrate how the selected heat-pump technology changes annual performance across several key indicators while still meeting the same service water heating demand.

Modeling Results - Large Hotel

Table 22 lists all the different permutations of system types, sizes and sensitivities that were modeled for the Large Hotel building type. As detailed in the earlier sections, the Large Hotel building was a representative 122,120 sq. ft. prototype with peak service hot-water demand of 26,500 GPD and average daily demand of 21,000 GPD. The modeled hybrid configurations retain the baseline system as a supplement to meet peak draws and to meet supply water temperatures in the main storage tank. The GHP/HPWHs were modeled to be located outdoors whereas the existing SWH system, buffer tank and main storage tank was located indoors.

Table 22 Parametric modeling done for Large Hotel

Simulation-matrix	Sensitivities modeled
Climates	Seattle, Portland, Boise
Baseline systems	Boiler with storage tank; tankless with storage tank; storage tank water heater
Modulating GHP sizes	1,200,000 and 2,160,000 Btu/h
Non-modulating GHP sizes	1,230,000 and 2,091,000 Btu/h
Electric HPWH sizes	1,357,800 and 2,036,700 Btu/h
Main storage tank options	5,450 gal and 3,500 gal
Swing tank	500 gal at 140°F
Combinations	108

Large Hotel prototype had the largest absolute SHW demand and consequently the largest absolute GHG emissions reductions. Best-case modulating-GHP cost savings range from about 18.4% to 39.7%, while the best electric HPWH cases can still achieve positive savings in some baselines but remain highly sensitive to climate-specific utility rates. Because the SWH load demand is large, the absolute emissions-reduction values are much larger than those for Full-Service Restaurant and Multifamily.

Modeling results for Portland with a backup boiler

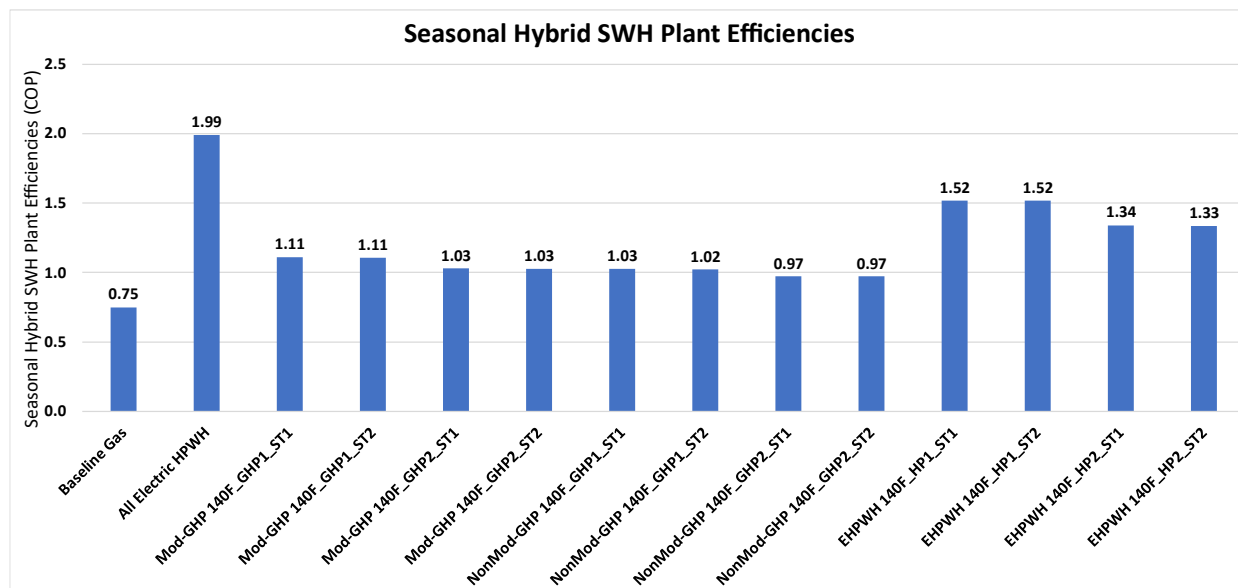


Figure 19 Hotel Annual SWH Plant Efficiencies for Portland with a backup gas boiler

Figure 19 compares annual SWH plant efficiency for the Large Hotel prototype in Portland with a backup gas boiler. Because the hotel building had the highest sustained hot-water demand of the modeled archetypes, even moderate differences in plant efficiency translate into large absolute energy impacts. The figure shows that modulating GHP and electric HPWH configurations provide the highest annual efficiencies, while non-modulating GHP performance is limited by less favorable part-load behavior.

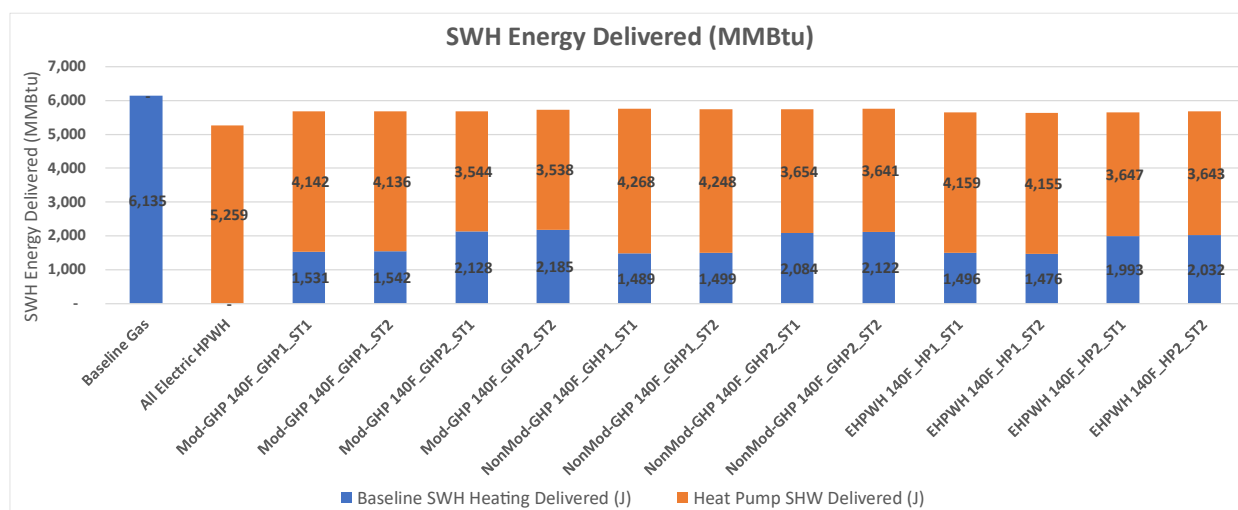


Figure 20 Hotel Annual SWH Plant Energy Delivered for Portland with a backup gas boiler

Figure 20 presents the annual SWH energy delivered for the hotel prototype in Portland with a backup gas boiler. All use cases are required to meet a very large and persistent hot-water load, so the chart mainly illustrates how the thermal delivery requirement is distributed among technologies with different loss characteristics and backup-heater usage.

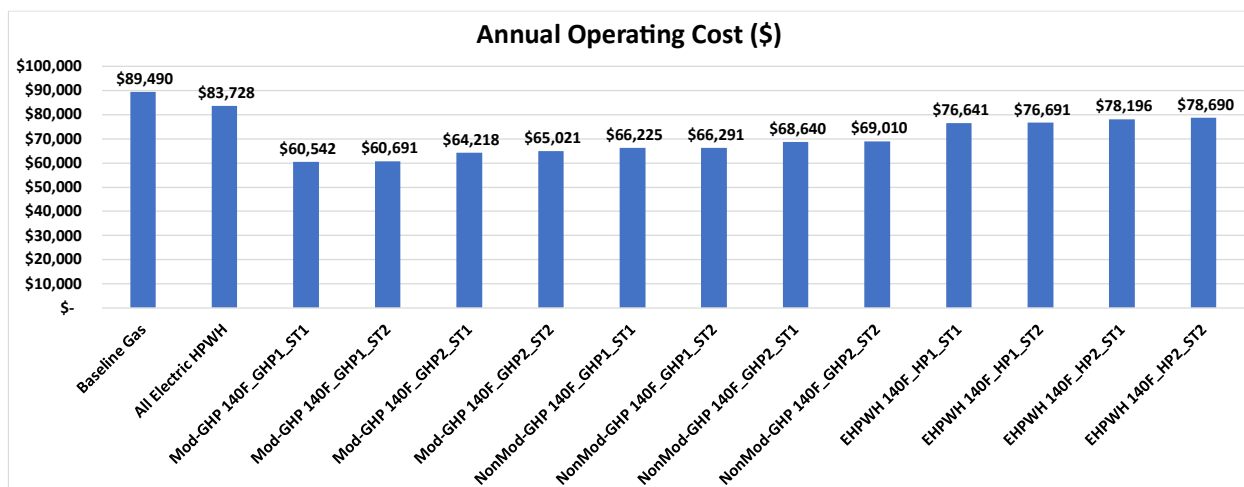


Figure 21 Hotel Annual SWH Plant Operating Cost for Portland with a backup gas boiler

Figure 21 compares the annual operating cost for the hotel prototype in Portland with a backup gas boiler. Given the very large annual hot-water load, differences in plant efficiency and fuel mix have a substantial effect on total operating cost. The figure shows that modulating GHP configurations generally offer the most favorable cost outcome, whereas electric HPWH economics depend more strongly on the local balance between electricity and gas prices.

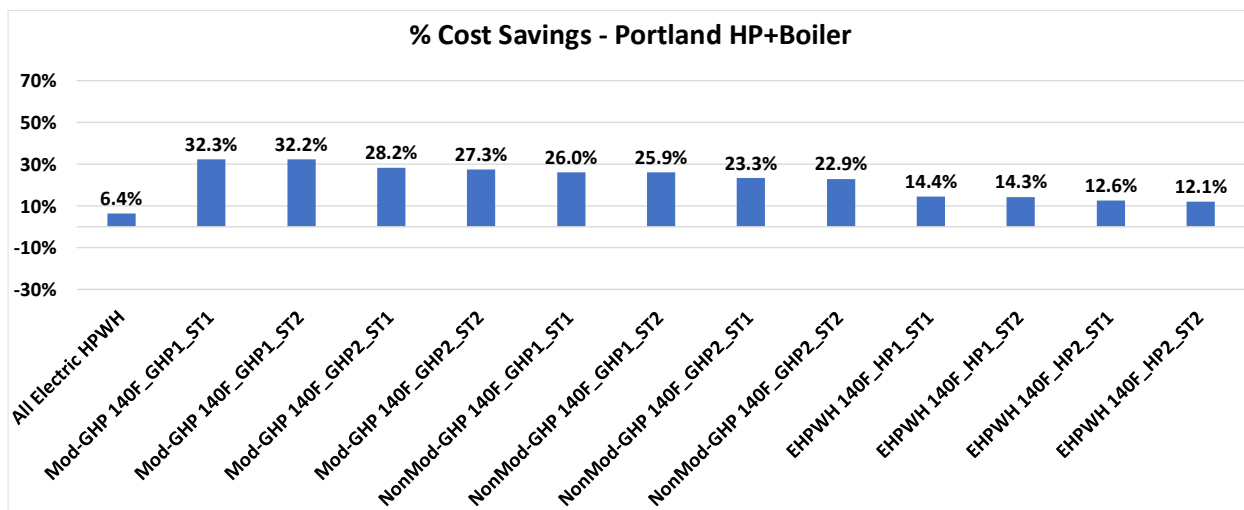


Figure 22 Hotel Annual SWH Plant Operating Cost Savings % for Portland with a backup gas boiler

Figure 22 shows the relative annual operating-cost savings for the hotel prototype in Portland with a backup gas boiler. The savings trends demonstrate that large, high-load lodging applications can be strong candidates for hybrid heat-pump retrofits, particularly when the technology is able to carry a large share of baseload demand. As in the other building types, modulating GHP cases are generally the most consistent performers from an operating-cost perspective. These results can also potentially be extended to motels or smaller hotels with similar SWH demand patterns.

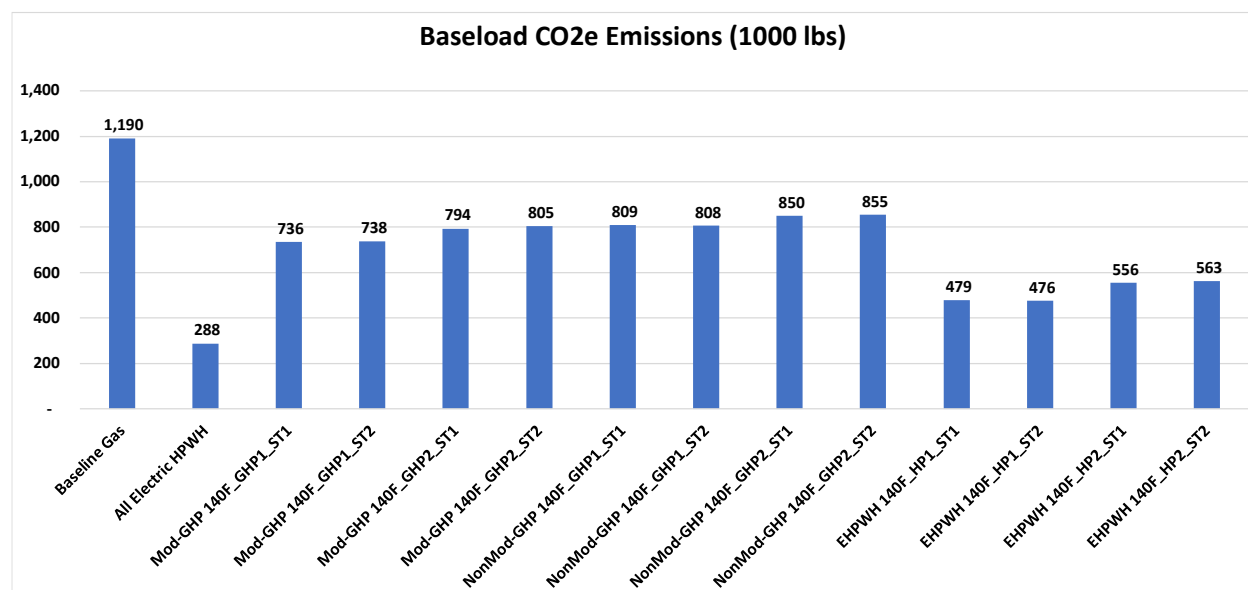


Figure 23 Hotel Annual Baseload CO₂e Emissions for Portland with a backup gas boiler

Figure 23 compares annual baseload CO₂e emissions for the hotel prototype in Portland with a backup gas boiler. Because annual service water heating demand is very high in this prototype, GHG emissions differences among configurations are larger in absolute terms than those observed for the restaurant or multifamily cases. As detailed in the previous sections, while this result visualizes GHG emissions impact on a baseload basis, typically for energy efficiency retrofits or added load to the grid, a non-baseload GHG emissions comparison is recommended.

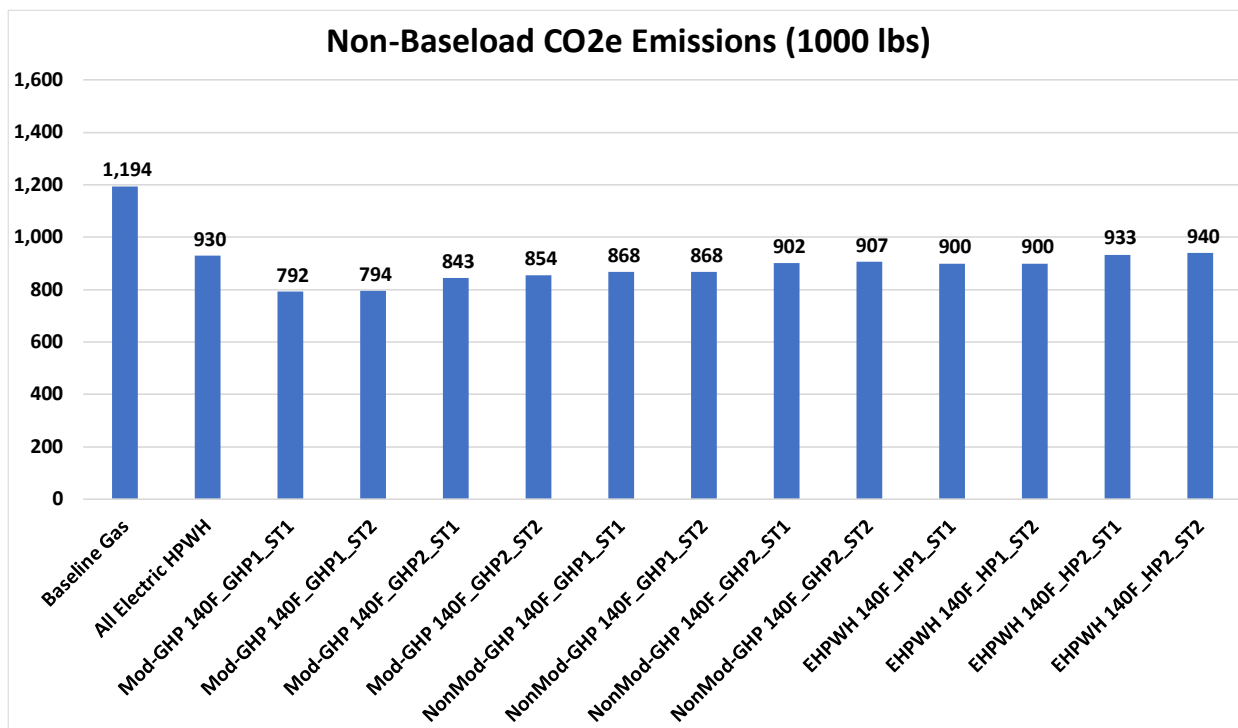


Figure 24 Hotel Annual Non-Baseload CO₂e Emissions for Portland with a backup gas boiler

Figure 24 presents annual non-baseload CO₂e emissions for the hotel prototype in Portland with a backup gas boiler. The marginal-emissions view is especially important for this building type because the large annual energy throughput amplifies the effect of the assumed electric-grid emissions factor. The figure shows that hybrid heat-pump systems can still provide major emissions benefits, but the relative magnitude depends on both technology performance and the local non-baseload electricity emissions assumption.

Modeling results for Portland with a backup tankless water heater

Table 23 Hotel Cost Outputs for Portland with a backup tankless gas water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$75,681		\$-	\$75,681
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing)	1.99	\$83,728	-10.6%	\$83,728	\$-

	tank) (5,450-gal main tank)					
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.12	\$60,065	20.6%	\$7,313	\$52,752
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.12	\$60,510	20.0%	\$7,315	\$53,195
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.04	\$62,557	17.3%	\$6,354	\$56,203
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.04	\$63,167	16.5%	\$6,357	\$56,810
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.02	\$66,732	11.8%	\$7,537	\$59,195
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.02	\$67,058	11.4%	\$7,798	\$59,260
Robur 140F_GHP2_ST1	(1.3 COP GHP, 0.96 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.96	\$69,188	8.6%	\$6,329	\$62,859

Robur 140F_GHP2_ST2	(1.3 COP GHP, 0.96 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.97	\$69,698	7.9%	\$6,652	\$63,046
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.53	\$76,731	-1.4%	\$54,816	\$21,915
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.52	\$77,406	-2.3%	\$55,156	\$22,250
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.37	\$76,885	-1.6%	\$49,118	\$27,767
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.36	\$77,373	-2.2%	\$49,053	\$28,320

Table 24 Hotel GHG Outputs for Portland with a backup tankless gas water heater

Case	Overall Efficiency	Source Energy (MMBtu)	Non-baseload Emissions	Reduction in Non-Baseload Emissions	Reduction in Baseload Emissions	Baseload Emissions
Baseline Gas	0.89	7987	1,011			1,011
All Electric HPWH	2.01	7294	930	82	723	288

SMTI 140F_GHP1_ST1	1.50	5914	786	225	281	730
SMTI 140F_GHP1_ST2	1.62	5959	792	219	275	736
SMTI 140F_GHP2_ST1	1.08	6176	822	190	238	773
SMTI 140F_GHP2_ST2	1.09	6237	830	182	230	781
Robur 140F_GHP1_ST1	1.09	6578	875	137	194	817
Robur 140F_GHP1_ST2	1.09	6607	878	133	193	819
EHPWH 140F_HP1_ST1	1.83	6839	910	101	150	862
EHPWH 140F_HP1_ST2	1.80	6886	916	95	146	865
EHPWH 140F_HP2_ST1	1.46	6968	901	110	530	482
EHPWH 140F_HP2_ST2	1.87	7031	910	102	524	487

Table 23 and Table 24 summarize the modeled outputs for the hotel prototype in Portland when the baseline system is a tankless gas water heater with storage. The combined tables compare efficiency, delivered energy, operating cost, cost savings, and emissions across the candidate hybrid technologies for this demanding service water heating application.

Modeling results for Portland with a backup storage water heater

Table 25 Hotel Cost Outputs for Portland with a backup storage gas water heater

Case	Case Description	Seasonal Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$93,374		\$-	\$93,374
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	1.99	\$83,728	10.3%	\$83,728	\$-
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.15	\$57,530	38.4%	\$7,546	\$49,983
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.12	\$60,550	35.2%	\$7,315	\$53,235
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.04	\$62,540	33.0%	\$6,355	\$56,184
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.04	\$63,189	32.3%	\$6,357	\$56,832
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.02	\$66,726	28.5%	\$7,537	\$59,189

Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.02	\$64,894	30.5%	\$7,343	\$57,552
Robur 140F_GHP2_ST1	(1.3 COP GHP, 0.67 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.97	\$69,587	25.5%	\$6,657	\$62,930
Robur 140F_GHP2_ST2	(1.3 COP GHP, 0.67 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.97	\$69,707	25.3%	\$6,653	\$63,054
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.53	\$76,718	17.8%	\$54,816	\$21,902
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.53	\$76,767	17.8%	\$55,156	\$21,611

Table 26 Hotel GHG Outputs for Portland with a backup storage gas water heater

Case	Overall Efficiency	Source Energy (MMBtu)	Non-baseload Emissions	Reduction in Non-Baseload Emissions	Reduction in Baseload Emissions	Baseload Emissions
Baseline Gas	0.72	9855	1,248			1,248
All Electric HPWH	1.99	7294	930	318	959	288

SMTI 140F_GHP1_ST1	1.15	5657	752	496	554	694
SMTI 140F_GHP1_ST2	1.12	5963	793	455	511	737
SMTI 140F_GHP2_ST1	1.04	6174	821	426	475	773
SMTI 140F_GHP2_ST2	1.04	6239	830	418	466	781
Robur 140F_GHP1_ST1	1.02	6578	875	373	431	817
Robur 140F_GHP1_ST2	1.02	6397	851	397	453	794
Robur 140F_GHP2_ST1	0.97	6875	915	333	384	864
Robur 140F_GHP2_ST2	0.97	6887	916	331	382	865
EHPWH 140F_HP1_ST1	1.53	6966	901	346	766	482
EHPWH 140F_HP1_ST2	1.53	6967	901	347	769	479

Table 25 and Table 26 summarize the modeled outputs for the hotel prototype in Portland when the baseline system is a storage gas water heater. The multiple performance metrics allow direct comparison of the tradeoffs among efficiency, operating cost, and emissions for each candidate SWH configuration. The figure demonstrates that storage-based baseline systems can still benefit substantially from heat-pump integration, particularly in large lodging buildings where sustained hot-water demand supports high annual utilization of the heat pump.

DISCUSSION

This Task 2 effort combined a consolidation of real-world SWH demand patterns, calibrated performance maps for GHPs with a parametric EnergyPlus modeling effort to assess the economic, efficiency and emissions potential of integrating high efficiency heat pump-based water heating into existing commercial SWH plants.

Conclusions

The effort successfully demonstrated a modeling framework for comparing gas-hybrid, dual-fuel and all-electric SWH systems across different commercial building types and climates. The completed analysis indicated that modulating GHP systems offer the highest and most consistent operating cost savings across the modeled cases, while electric HPWH systems offer highest overall efficiencies and can be attractive in regions and times when electricity is relatively low cost and low carbon. The modeling framework, and results tables described in the earlier sections can lay the groundwork to support future screening, design guidance, and dissemination activities for NEEA and GTI Energy.

By design, GHPs and HPWHs were seen to have a wide variation in COPs with outdoor ambient temperatures and system operating conditions. Subsequently, colder climates gained less benefit due to the increased operating time of the heat pumps at lower temperatures. Although cold climate reliance and impacts on overall performance were observed, the impact of part-load ratio and return water temperatures on the overall efficiencies were much higher.

The results also showed that there is a fine balance between sizing your SWH for peak loads and the storage tank. This finding, coupled with sizing the heat pump to roughly 30% to 60% of peak demand, allowed the heat pump to address most of the annual base load while the conventional water heater handled short-duration peaks. The approach helps avoid both severe under sizing, which limits decarbonization impact, and oversizing, which increases cycling and reduces cost-effectiveness. For Full-Service Restaurants, the sizing sweet spot was seen to be around 50-60% of the peak load; for Multifamily and Hotels, it was closer to 30-35% of the peak load.

Three consistent themes emerge across the modeling analysis-

- 1) The load pattern and magnitude of the service hot-water demand matters;
 - c) the 'steadier' and less 'peaky' loads through the day offered the greatest opportunity for a hybrid heat pump to operate at a high annual load factor and to effectively displace baseline SWH gas-use.
 - d) Periods of low demand and inactivity led to standby losses in the main storage tank that was supplemented by the baseline SWH system. A potential workaround could be to investigate SWH configurations with the recirculation load fed back to the GHP/HPWH. However, it's possible that this has detrimental impacts on their COPs owing to higher return water temperatures.

- 2) Modulating GHPs consistently outperformed non-modulating GHPs in annual economics because they were better able to track part-load operation while minimizing backup SWH system use.
- 3) Electric HPWHs in a dual-fuel setting achieved very high overall efficiencies, but annual operating-cost benefits remain region specific because electric prices and gas prices differ substantially among the modeled cities, and generally across the US. All-electric HPWHs also achieved high overall COPs, however, were impacted by significant electric resistance operation in the main storage tank.

Lastly, the main storage tank was modeled to maintain a tank temperature of 140°F even during periods of low usage. System integrations with on-demand heating could provide significant energy savings by avoiding energy delivered but not utilized. Commercial applications with recirculation requirements could be challenging to implement on-demand water heating without sacrificing user experience and convenience. Future control strategies that can better leverage the dynamic dual-fuel operation between electric HPWHs and backup gas water heaters should be explored to fully realize the interoperability for maximum efficiency and economic benefits.

Recommendations and Future Work

- Use measured or high-quality representative hot-water demand data whenever possible rather than relying solely on fixture-count methods or legacy demand curves.
- Size thermally driven heat pumps and HPWHs to cover the base load rather than the full peak load and maintain adequate storage to prevent excessive cycling.
- Evaluate both baseload and non-baseload electric emission factors when screening technologies, because dispatch-sensitive electric emissions can materially affect technology ranking.
- Prioritize high-SWH-demand building types for deployment screening, because these applications show the strongest and most persistent annual savings opportunity.
- It was also noted that periods of lower hot water consumption resulted in diminished system performance and higher energy losses. Based on these observations, facilities with consistently high hot water demand are anticipated to derive greater advantages from this technology. Commercial properties with consistent hot water usage patterns may be especially well suited for GHP and HPWH retrofits.
- Laboratory validation of the electric HPWHs to calibrate and ground the performance mapping of the modeled system.
- Field evaluations and calibrations of the modeling with real-world performance.

GLOSSARY

The following list of acronyms, abbreviations, and terms are applicable for this report:

Acronym or Term	Definition
Btu/hr	British Thermal Units Per Hour
CEC	California Energy Commission
COP	Coefficient of Performance
CMIC	Carbon Management Information Center
DOE	Department of Energy
EIA	Energy Information Administration
EMS	Energy Management System
Erl	EnergyPlus Runtime Language
GET	Gas Emerging Technology
GHP	Gas Absorption Heat Pump
GPD	Gallons Per Day
GPH	Gallons Per Hour
GHG	Greenhouse Gas
HPWH	Heat Pump Water Heater
IST	Indirect Storage Tank
NLR	National Laboratory of the Rockies
NEEA	Northwest Energy Efficiency Alliance
QPL	Qualified Product List
SWH	Service Water Heating
TE	Thermal Efficiency
TMY3	Typical Meteorological Year
U.S.	United States

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APPENDICES

APPENDIX A: FULL-SERVICE RESTAURANT ADDITIONAL RESULTS

Modeling results for Seattle with a backup boiler with storage tank

Table 27 Full-Service Restaurant Cost Outputs for Seattle with a backup boiler

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(80% TE)	0.75	\$18,743		\$22	\$18,721
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	2.08	\$18,103	3.4%	\$18,103	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 80% TE) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.35	\$11,463	38.8%	\$1,596	\$9,867
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 80% TE) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.35	\$11,477	38.8%	\$1,595	\$9,882
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 80% TE) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.37	\$11,304	39.7%	\$1,567	\$9,736
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 80% TE) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.37	\$11,359	39.4%	\$1,566	\$9,793
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 80% TE) (123KBtu, 26% of Peak Load) (140F swing tank)	0.84	\$16,973	9.4%	\$614	\$16,359

	(600-gal main tank)					
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 80% TE) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.84	\$17,037	9.1%	\$610	\$16,427
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 80% TE) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	0.94	\$15,456	17.5%	\$1,062	\$14,394
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 80% TE) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	0.93	\$15,586	16.8%	\$1,056	\$14,530
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 80% TE) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.57	\$18,796	-0.3%	\$15,686	\$3,110
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 80% TE) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.56	\$18,852	-0.6%	\$15,783	\$3,069
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 80% TE) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.60	\$19,526	-4.2%	\$17,033	\$2,493
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 80% TE) (273KBtu, 58% of Peak Load) (140F swing tank) (300-gal main tank)	1.59	\$19,551	-4.3%	\$17,011	\$2,540

Modeling results for Missoula with a backup boiler with storage tank

Table 28 Full-Service Restaurant Cost Outputs for Missoula with a backup boiler

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(80% TE)	0.75	\$9,817		\$20	\$9,796
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	1.90	\$16,869	-71.8%	\$16,869	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 80% TE) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.33	\$6,739	31.3%	\$1,485	\$5,254
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 80% TE) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.32	\$6,738	31.4%	\$1,483	\$5,254
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 80% TE) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.35	\$6,653	32.2%	\$1,459	\$5,195
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 80% TE) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.34	\$6,667	32.1%	\$1,456	\$5,211
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 80% TE) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.85	\$9,075	7.6%	\$556	\$8,519

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 80% TE) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.85	\$9,112	7.2%	\$552	\$8,560
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 80% TE) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	0.94	\$8,512	13.3%	\$961	\$7,551
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 80% TE) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	0.94	\$8,560	12.8%	\$956	\$7,604
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 80% TE) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.50	\$15,741	-60.3%	\$13,820	\$1,920
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 80% TE) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.49	\$15,875	-61.7%	\$13,965	\$1,910
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 80% TE) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.53	\$17,616	-79.4%	\$16,310	\$1,306
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 80% TE) (273KBtu, 58% of Peak Load) (140F swing tank) (300-gal main tank)	1.53	\$17,609	-79.4%	\$16,298	\$1,310

Modeling results for Seattle with a backup tankless water heater with storage tank

Table 29 Full-Service Restaurant Cost Outputs for Seattle with a backup tankless water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$15,953		\$-	\$15,953
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	2.08	\$18,103	-13.5%	\$18,103	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.41	\$11,127	30.2%	\$1,615	\$9,513
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.41	\$11,170	30.0%	\$1,615	\$9,554
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.43	\$10,923	31.5%	\$1,587	\$9,336
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.43	\$10,966	31.3%	\$1,588	\$9,378
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.97	\$15,062	5.6%	\$600	\$14,462
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.97	\$15,098	5.4%	\$600	\$14,499

NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.96 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	1.03	\$14,361	10.0%	\$1,023	\$13,339
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.96 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	1.03	\$14,322	10.2%	\$1,054	\$13,268
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.66	\$18,448	-15.6%	\$15,805	\$2,643
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.66	\$18,490	-15.9%	\$15,807	\$2,683
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.68	\$19,234	-20.6%	\$17,220	\$2,014
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (300-gal main tank)	1.68	\$19,275	-20.8%	\$17,221	\$2,054

Modeling results for Missoula with a backup tankless water heater with storage tank

Table 30 Full-Service Restaurant Cost Outputs for Missoula with a backup tankless water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$8,340		\$-	\$8,340
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	1.90	\$16,869	-102.3%	\$16,869	\$-

Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.38	\$6,582	21.1%	\$1,502	\$5,079
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.38	\$6,601	20.9%	\$1,503	\$5,098
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.41	\$6,465	22.5%	\$1,477	\$4,988
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.40	\$6,482	22.3%	\$1,477	\$5,005
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.97	\$8,092	3.0%	\$543	\$7,548
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.97	\$8,105	2.8%	\$543	\$7,562
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.96 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	1.03	\$7,937	4.8%	\$928	\$7,009
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.96 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	1.04	\$7,916	5.1%	\$955	\$6,961
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.61	\$15,505	-85.9%	\$13,862	\$1,643
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (203KBtu, 43% of Peak Load)	1.60	\$15,523	-86.1%	\$13,863	\$1,660

	(140F swing tank) (300-gal main tank)					
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.61	\$17,572	-110.7%	\$16,486	\$1,086
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (300-gal main tank)	1.60	\$17,590	-110.9%	\$16,487	\$1,103

Modeling results for Seattle with a backup storage water heater

Table 31 Full-Service Restaurant Cost Outputs for Seattle with a backup storage water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.73	\$19,648		\$-	\$19,648
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	2.08	\$18,103	7.9%	\$18,103	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.38	\$11,483	41.6%	\$1,667	\$9,816
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.34	\$11,675	40.6%	\$1,616	\$10,060
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.37	\$11,402	42.0%	\$1,588	\$9,815

Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.37	\$11,457	41.7%	\$1,588	\$9,869
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.81	\$17,891	8.9%	\$600	\$17,291
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.80	\$18,035	8.2%	\$569	\$17,466
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.67 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	0.90	\$16,226	17.4%	\$1,055	\$15,171
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.67 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	0.90	\$16,266	17.2%	\$1,054	\$15,212
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.54	\$19,107	2.8%	\$15,805	\$3,301
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.54	\$19,160	2.5%	\$15,806	\$3,354
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.41	\$15,692	20.1%	\$8,797	\$6,895
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (300-gal main tank)	1.58	\$19,789	-0.7%	\$17,221	\$2,568

Modeling results for Missoula with a backup storage water heater

Table 32 Full-Service Restaurant Cost Outputs for Missoula with a backup storage water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$10,425		\$-	\$10,425
All Electric HPWH	(4 COP EHPWH) (470KBtu, Peak Load) (140F swing tank) (600-gal main tank)	1.90	\$16,869	-61.8%	\$16,869	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (600-gal main tank)	1.35	\$6,783	34.9%	\$1,550	\$5,233
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (160KBtu, 34% of Peak Load) (140F swing tank) (300-gal main tank)	1.32	\$6,863	34.2%	\$1,503	\$5,361
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (600-gal main tank)	1.34	\$6,712	35.6%	\$1,477	\$5,235
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (240KBtu, 51% of Peak Load) (140F swing tank) (300-gal main tank)	1.34	\$6,737	35.4%	\$1,477	\$5,259
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (600-gal main tank)	0.81	\$9,551	8.4%	\$543	\$9,007
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (123KBtu, 26% of Peak Load) (140F swing tank) (300-gal main tank)	0.81	\$9,572	8.2%	\$543	\$9,028

NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.67 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (600-gal main tank)	0.91	\$8,895	14.7%	\$956	\$7,939
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.67 UEF) (246KBtu, 52% of Peak Load) (140F swing tank) (300-gal main tank)	0.91	\$8,913	14.5%	\$955	\$7,958
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (600-gal main tank)	1.48	\$15,915	-52.7%	\$13,862	\$2,053
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (203KBtu, 43% of Peak Load) (140F swing tank) (300-gal main tank)	1.36	\$12,208	-17.1%	\$8,549	\$3,659
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (600-gal main tank)	1.52	\$17,842	-71.1%	\$16,486	\$1,357
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (273KBtu, 58% of Peak Load) (140F swing tank) (300-gal main tank)	1.51	\$17,866	-71.4%	\$16,487	\$1,379

APPENDIX B: MULTIFAMILY ADDITIONAL RESULTS

Modeling results for Seattle with a backup boiler with storage tank

Table 33 Multifamily Cost Outputs for Seattle with a backup boiler

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(80% TE)	0.75	\$5,180		\$61	\$5,120
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	2.02	\$5,076	2.0%	\$5,076	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 80% TE) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.49	\$2,823	45.5%	\$413	\$2,410
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 80% TE) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.36	\$3,124	39.7%	\$453	\$2,672
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 80% TE) (160KBtu, 67% of Peak Load) (140F swing tank) (250-gal main tank)	0.90	\$4,366	15.7%	\$154	\$4,211
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 80% TE) (160KBtu, 67% of Peak Load) (140F swing tank) (150-gal main tank)	0.89	\$4,429	14.5%	\$152	\$4,277
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 80% TE) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	0.97	\$4,067	21.5%	\$202	\$3,865

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 80% TE) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	0.95	\$4,164	19.6%	\$209	\$3,955
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 80% TE) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.88	\$5,362	-3.5%	\$5,315	\$48
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 80% TE) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.84	\$5,397	-4.2%	\$5,281	\$116
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 80% TE) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.45	\$5,188	-0.2%	\$4,084	\$1,104
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 80% TE) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.43	\$5,234	-1.0%	\$4,038	\$1,195

Modeling results for Boise with a backup boiler with storage tank

Table 34 Multifamily Cost Outputs for Boise with a backup boiler

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(80% TE)	0.75	\$3,451		\$51	\$3,399
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	1.96	\$4,423	-28.2%	\$4,423	\$-

Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 80% TE) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.45	\$2,011	41.7%	\$363	\$1,649
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 80% TE) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.43	\$2,051	40.6%	\$361	\$1,690
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 80% TE) (160KBtu, 67% of Peak Load) (140F swing tank) (250-gal main tank)	0.89	\$2,938	14.9%	\$134	\$2,804
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 80% TE) (160KBtu, 67% of Peak Load) (140F swing tank) (150-gal main tank)	0.89	\$2,979	13.7%	\$131	\$2,848
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 80% TE) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	0.97	\$2,749	20.3%	\$171	\$2,578
NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 80% TE) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	0.96	\$2,780	19.4%	\$177	\$2,604
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 80% TE) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.85	\$4,529	-31.3%	\$4,476	\$54
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 80% TE) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.82	\$4,551	-31.9%	\$4,458	\$93

EHPWH 140F_HP2_ST1	(4 COP EHPWH, 80% TE) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.36	\$4,262	-23.5%	\$3,393	\$868
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 80% TE) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.34	\$4,284	-24.2%	\$3,358	\$927

Modeling results for Seattle with a backup tankless water heater with storage tank

Table 35 Multifamily Cost Outputs for Seattle with a backup tankless water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$4,478		\$-	\$4,478
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	2.02	\$5,076	-13.4%	\$5,076	\$-
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.55	\$2,829	36.8%	\$414	\$2,415
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.55	\$2,837	36.6%	\$416	\$2,422
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (250-gal main tank)	1.09	\$3,756	16.1%	\$177	\$3,579
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (160KBtu, 67% of Peak Load) (140F	1.09	\$3,760	16.0%	\$180	\$3,580

	swing tank) (150-gal main tank)					
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	1.09	\$3,740	16.5%	\$151	\$3,589
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	1.09	\$3,712	17.1%	\$143	\$3,570
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.87	\$5,449	-21.7%	\$5,352	\$97
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.85	\$5,468	-22.1%	\$5,336	\$131
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.60	\$5,224	-16.7%	\$4,393	\$832
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	2.04	\$4,951	-10.6%	\$4,425	\$526

Modeling results for Boise with a backup tankless water heater with storage tank

Table 36 Multifamily Cost Outputs for Boise with a backup tankless water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$2,973		\$-	\$2,973

All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	1.96	\$4,423	-48.8%	\$4,423	\$-
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (250- gal main tank)	1.50	\$2,016	32.2%	\$364	\$1,652
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (150- gal main tank)	1.62	\$1,862	37.4%	\$331	\$1,530
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (250- gal main tank)	1.08	\$2,543	14.5%	\$154	\$2,389
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (150- gal main tank)	1.09	\$2,547	14.3%	\$156	\$2,390
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (250- gal main tank)	1.08	\$2,522	15.2%	\$128	\$2,394
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (150- gal main tank)	1.10	\$2,466	17.0%	\$120	\$2,346
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.83	\$4,617	-55.3%	\$4,507	\$110
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.83	\$4,610	-55.0%	\$4,504	\$105
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (136KBtu, 57% of Peak Load)	1.48	\$4,374	-47.1%	\$3,608	\$766

	(140F swing tank) (250-gal main tank)					
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.50	\$4,326	-45.5%	\$3,631	\$695

Modeling results for Seattle with a backup storage water heater

Table 37 Multifamily Cost Outputs for Seattle with a backup storage water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$5,530		\$-	\$5,530
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing tank) (250-gal main tank)	2.02	\$5,076	8.2%	\$5,076	\$-
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.53	\$2,872	48.1%	\$438	\$2,434
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.49	\$2,937	46.9%	\$430	\$2,507
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (250-gal main tank)	0.92	\$4,444	19.6%	\$177	\$4,267
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (150-gal main tank)	0.92	\$4,444	19.6%	\$179	\$4,264

Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	1.02	\$3,973	28.2%	\$152	\$3,820
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	1.02	\$3,970	28.2%	\$149	\$3,821
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.91	\$5,524	0.1%	\$5,519	\$4
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.91	\$5,542	-0.2%	\$5,536	\$5
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.49	\$5,417	2.0%	\$4,393	\$1,024
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.49	\$5,432	1.8%	\$4,420	\$1,012

Modeling results for Boise with a backup storage water heater

Table 38 Multifamily Cost Outputs for Boise with a backup storage water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$3,669		\$-	\$3,669
All Electric HPWH	(4 COP EHPWH) (190KBtu, Peak Load) (140F swing	1.96	\$4,423	-20.5%	\$4,423	\$-

	tank) (250-gal main tank)					
SMTI 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (250-gal main tank)	1.45	\$2,086	43.1%	\$376	\$1,710
SMTI 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (80KBtu, 34% of Peak Load) (140F swing tank) (150-gal main tank)	1.45	\$2,093	43.0%	\$377	\$1,715
SMTI 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (250-gal main tank)	0.89	\$3,082	16.0%	\$170	\$2,912
SMTI 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (160KBtu, 67% of Peak Load) (140F swing tank) (150-gal main tank)	0.89	\$3,082	16.0%	\$173	\$2,909
Robur 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (250-gal main tank)	1.02	\$2,679	27.0%	\$130	\$2,548
Robur 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (123KBtu, 52% of Peak Load) (140F swing tank) (150-gal main tank)	1.02	\$2,672	27.2%	\$127	\$2,546
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (250-gal main tank)	1.85	\$4,671	-27.3%	\$4,668	\$3
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (67KBtu, 28% of Peak Load) (140F swing tank) (150-gal main tank)	1.85	\$4,686	-27.7%	\$4,683	\$4
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (250-gal main tank)	1.46	\$4,399	-19.9%	\$3,716	\$683

EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (136KBtu, 57% of Peak Load) (140F swing tank) (150-gal main tank)	1.46	\$4,413	-20.3%	\$3,738	\$675
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APPENDIX C: LARGE HOTEL ADDITIONAL RESULTS

Modeling results for Seattle with a backup boiler with storage tank

Table 39 Hotel Cost Outputs for Seattle with a backup boiler

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(80% TE)	0.75	\$117,199		\$723	\$116,476
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	2.02	\$105,978	9.6%	\$105,978	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 80% TE) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.12	\$77,956	33.5%	\$8,716	\$69,240
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 80% TE) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.12	\$78,153	33.3%	\$8,714	\$69,439
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 80% TE) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.04	\$83,013	29.2%	\$7,663	\$75,351
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 80% TE) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.03	\$84,071	28.3%	\$7,662	\$76,408
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 80% TE) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.02	\$85,066	27.4%	\$9,242	\$75,825

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 80% TE) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.02	\$84,906	27.6%	\$9,187	\$75,720
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 80% TE) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.97	\$88,408	24.6%	\$8,001	\$80,407
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 80% TE) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.97	\$88,910	24.1%	\$7,969	\$80,942
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 80% TE) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.50	\$95,267	18.7%	\$66,103	\$29,165
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 80% TE) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.50	\$95,286	18.7%	\$66,509	\$28,778
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 80% TE) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.33	\$98,168	16.2%	\$59,309	\$38,858
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 80% TE) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.32	\$98,841	15.7%	\$59,236	\$39,605

Modeling results for Boise with a backup boiler with storage tank

Table 40 Hotel Cost Outputs for Boise with a backup boiler

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(80% TE)	0.75	\$78,189		\$613	\$77,575
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	1.88	\$90,180	-15.3%	\$90,180	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 80% TE) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.10	\$54,235	30.6%	\$7,557	\$46,679
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 80% TE) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.10	\$54,257	30.6%	\$7,550	\$46,707
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 80% TE) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.02	\$57,525	26.4%	\$6,644	\$50,881
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 80% TE) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.02	\$57,954	25.9%	\$6,637	\$51,316
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 80% TE) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.03	\$59,180	24.3%	\$7,818	\$51,362

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 80% TE) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.03	\$59,389	24.0%	\$8,076	\$51,312
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 80% TE) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.98	\$60,963	22.0%	\$7,000	\$53,962
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 80% TE) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.98	\$61,214	21.7%	\$6,983	\$54,231
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 80% TE) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.40	\$78,859	-0.9%	\$55,961	\$22,898
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 80% TE) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.40	\$79,078	-1.1%	\$56,305	\$22,773
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 80% TE) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.33	\$76,080	2.7%	\$50,186	\$25,894
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 80% TE) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.32	\$76,089	2.7%	\$50,120	\$25,969

Modeling results for Seattle with a backup tankless water heater with storage tank

Table 41 Hotel Cost Outputs for Seattle with a backup tankless water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$99,257		\$-	\$99,257
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	2.02	\$105,978	-6.8%	\$105,978	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.13	\$77,328	22.1%	\$8,655	\$68,673
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.13	\$77,914	21.5%	\$8,658	\$69,257
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.05	\$80,843	18.6%	\$7,521	\$73,323
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.05	\$81,646	17.7%	\$7,524	\$74,123
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.02	\$85,729	13.6%	\$9,064	\$76,665

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.02	\$85,877	13.5%	\$9,126	\$76,751
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.96 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.96	\$89,269	10.1%	\$7,407	\$81,862
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.96 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.97	\$89,820	9.5%	\$7,785	\$82,035
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.51	\$95,404	3.9%	\$65,922	\$29,483
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.50	\$96,263	3.0%	\$66,330	\$29,933
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.35	\$96,424	2.9%	\$59,068	\$37,356
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.35	\$97,089	2.2%	\$58,990	\$38,099

Modeling results for Boise with a backup tankless water heater with storage tank

Table 42 Hotel Cost Outputs for Boise with a backup tankless water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.96 UEF)	0.89	\$66,119		\$-	\$66,119
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	1.88	\$90,180	-36.4%	\$90,180	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.96 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.11	\$53,986	18.4%	\$7,507	\$46,479
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.96 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.11	\$54,313	17.9%	\$7,509	\$46,804
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.96 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.04	\$56,132	15.1%	\$6,524	\$49,608
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.96 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.03	\$56,534	14.5%	\$6,526	\$50,007
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.96 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.03	\$59,605	9.9%	\$7,670	\$51,935

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.96 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.03	\$60,001	9.3%	\$8,025	\$51,976
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.96 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.97	\$61,352	7.2%	\$6,469	\$54,883
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.96 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.98	\$61,776	6.6%	\$6,820	\$54,956
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.96 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.41	\$79,089	-19.6%	\$55,780	\$23,309
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.96 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.40	\$79,679	-20.5%	\$56,125	\$23,553
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.96 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.34	\$75,589	-14.3%	\$49,981	\$25,608
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.96 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.34	\$75,929	-14.8%	\$49,915	\$26,015

Modeling results for Seattle with a backup storage water heater

Table 43 Hotel Cost Outputs for Seattle with a backup storage water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$122,635		\$-	\$122,635
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	2.02	\$105,978	13.6%	\$105,978	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.17	\$73,994	39.7%	\$8,934	\$65,059
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.13	\$78,037	36.4%	\$8,660	\$69,377
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.05	\$80,906	34.0%	\$7,524	\$73,382
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.05	\$81,763	33.3%	\$7,526	\$74,237
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.02	\$85,715	30.1%	\$9,064	\$76,651

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.02	\$83,180	32.2%	\$8,593	\$74,587
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.67 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.97	\$89,664	26.9%	\$7,790	\$81,874
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.67 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.97	\$89,825	26.8%	\$7,786	\$82,039
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.51	\$95,390	22.2%	\$65,922	\$29,468
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.51	\$95,407	22.2%	\$66,330	\$29,078
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.34	\$98,331	19.8%	\$59,068	\$39,263
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.33	\$99,008	19.3%	\$58,990	\$40,018

Modeling results for Boise with a backup storage water heater

Table 44 Hotel Cost Outputs for Boise with a backup storage water heater

Case	Case Description	Overall Efficiency	Total Annual Cost \$	% Operating Cost Savings	Annual Elec \$	Annual Gas \$
Baseline Gas	(0.67 UEF)	0.72	\$81,558		\$-	\$81,558
All Electric HPWH	(4 COP EHPWH) (3,800 KBtu, Peak Load) (140F swing tank) (5,450-gal main tank)	1.88	\$90,180	-10.6%	\$90,180	\$-
Mod-GHP 140F_GHP1_ST1	(1.4 COP GHP, 0.67 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.15	\$51,708	36.6%	\$7,744	\$43,965
Mod-GHP 140F_GHP1_ST2	(1.4 COP GHP, 0.67 UEF) (1,200 KBtu, 32% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.11	\$54,364	33.3%	\$7,509	\$46,856
Mod-GHP 140F_GHP2_ST1	(1.4 COP GHP, 0.67 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.04	\$56,065	31.3%	\$6,525	\$49,540
Mod-GHP 140F_GHP2_ST2	(1.4 COP GHP, 0.67 UEF) (2,160 KBtu, 57% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.03	\$56,555	30.7%	\$6,526	\$50,029
NonMod-GHP 140F_GHP1_ST1	(1.3 COP GHP, 0.67 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.03	\$59,591	26.9%	\$7,670	\$51,921

NonMod-GHP 140F_GHP1_ST2	(1.3 COP GHP, 0.67 UEF) (1,230 KBtu, 33% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.03	\$59,997	26.4%	\$8,025	\$51,972
NonMod-GHP 140F_GHP2_ST1	(1.3 COP GHP, 0.67 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (5,450-gal main tank)	0.98	\$61,688	24.4%	\$6,824	\$54,863
NonMod-GHP 140F_GHP2_ST2	(1.3 COP GHP, 0.67 UEF) (2,091 KBtu, 56% of Peak Load) (140F swing tank) (3,500-gal main tank)	0.98	\$61,782	24.2%	\$6,822	\$54,960
EHPWH 140F_HP1_ST1	(4 COP EHPWH, 0.67 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.41	\$79,080	3.0%	\$55,780	\$23,301
EHPWH 140F_HP1_ST2	(4 COP EHPWH, 0.67 UEF) (1,357 KBtu, 36% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.40	\$79,299	2.8%	\$56,125	\$23,173
EHPWH 140F_HP2_ST1	(4 COP EHPWH, 0.67 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (5,450-gal main tank)	1.33	\$76,330	6.4%	\$49,981	\$26,349
EHPWH 140F_HP2_ST2	(4 COP EHPWH, 0.67 UEF) (2,036 KBtu, 54% of Peak Load) (140F swing tank) (3,500-gal main tank)	1.33	\$76,340	6.4%	\$49,915	\$26,425



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