BONNEVILLE POWER ADMINISTRATION

Emerging Technologies

Mitsubishi Heat2O Hot Water Load Shift Demonstration and Simulation Analysis: at Bayview Towers, Seattle, WA

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Glossary

Commercial Heat Pump Water Heating (HPWH) System: Commercial heat pump water heating systems are defined as central domestic water heating plants serving more than four dwelling units or serving commercial loads needing more than a total of 119 gallons of storage volume and/or 6 kW of input power. These systems can be unitary or split systems and contain multiple equipment components to create a fully functioning system.

Coefficient of Performance (COP): The Coefficient of Performance (COP) is a dimensionless ratio used to measure the efficiency of a heat pump or a refrigeration system. It represents the amount of heat energy transferred (output) to the desired location divided by the amount of electrical or mechanical energy consumed (input) to drive the system. In simpler terms, COP indicates how much heating or cooling a system can provide per unit of energy it consumes.

Demand Response: (DR) Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.

Domestic Hot Water (DHW): Domestic hot water (DHW) refers to the hot water supplied to residential, commercial, and institutional buildings for various daily uses, such as bathing, washing, cooking, and cleaning.

Event: A period of time in which the utility notifies the customer of an upcoming request in advance, and then sends a signal to a control module that automatically to reduce load.

Grid Peak Period: Period of highest electrical power demand that occurs over a specified time period and is typically characterized as annual, daily, or seasonal and has the unit of power. The highest period of demand may occur twice a day, daily, monthly, or seasonally. For a utility, the actual point of peak demand is a single half-hour or hourly period which represents the highest point of customer consumption of electricity.

Load Shifting: Moving electric demand from one time of day to another, usually to an adjacent period, either prior or after to avoid peak hours, or highest demand, of energy use.

Time of Use (TOU) Pricing: A variable electricity rate structure in which the cost of electricity changes based on the time of day it is consumed. This pricing model reflects the fluctuating costs of generating and delivering electricity, which can vary due to factors such as demand, availability of resources, and grid conditions.

Load Up: The Load Up command is a signal sent from the utility to the device to charge its thermal storage before a Shed period. This command is typically used during periods of low energy demand or when there's a surplus of power supply. The device receiving the Load Up command will respond by increasing its energy use. For example, a water heater may increase its setpoint by a few degrees during a sunny period in the summer with excess solar, pre-charging it to remain off during the afternoon peak period.

Equipment COP: The equipment COP represents the efficiency of a single peak of equipment.

System COP: The System COP represents the efficiency of the entire domestic hot water system—the combined efficiency of the primary plant and temperature maintenance plant. It includes all the heat energy put into the system to heat and maintain hot water over all the electrical energy used to heat and maintain hot water. System COP is typically described as an average annual value that accounts for climate conditions and entering and leaving water conditions. All COPs referred to in this report are System COP.

Shed: The shed command is a signal sent from the utility to the device to reduce its electricity consumption. This command is typically used during periods of high energy demand or when there's a shortage of power supply. The device receiving the shed command will respond by lowering its energy use. For example, a smart thermostat may raise the set temperature a few degrees during a summer afternoon peak load event, reducing the power used by air conditioning.

Decarbonization: Decarbonization is the process of reducing carbon dioxide emissions, a necessity to mitigate climate change and transition towards cleaner, sustainable energy sources.

CTA-2045: CTA-2045, also known as ANSI/CTA-2045, is a standard set by the Consumer Technology Association. This standard, officially titled "Modular Communications Interface (MCI) for Energy Management", describes a physical port and a command set for enabling appliances to communicate with demand response systems to provide load shifting.

EcoPort: EcoPort is the brand name for CTA-2045 certified products.

OpenADR: Open Automated Demand Response (OpenADR) is a standard for electricity providers to communicate with customers for demand response to provide load shifting. It is an open and standardized way for electricity providers to send information about the current and future state of the electrical grid, particularly regarding the supply and demand balance.

Executive Summary

The Bayview Tower project retrofitted an aging electric resistance water heating system in an occupied, 100-unit, affordable housing high-rise located in Seattle. The new commercial heat pump water heating system at Bayview Towers marked the first United States installation of Mitsubishi's HEAT2O (QAHV) system – the country's first large-capacity CO2 refrigerant-based domestic water heating system. It is also the first installation of a load shift capable commercial HPWH system nationwide.

Findings Summary:

- In its first 18 months of operation, the system operated at a COP of 2.3 and saved about 180,000 kWh. The research team identified opportunities to improve COP on future installations.
- During Jun and July 2022, the HPWH shifted electric load twice a day – 6-9AM, 6-9PM – with 100% success. The HEAT2O is a valuable utility asset for shifting or shaping loads.
- HPWH controls design and implementation are critical to load shifting. Utility programs should require proper controls on future installations.
- System thermal storage and heating capacity are critical for effective load shifting and utility programs should require proper sizing of both.
- The industry needs specifications for testing the HPWH defrost to provide better information for designers on heating capacity reduction from defrost (defrost derate).
- The industry needs additional load shift studies to develop best practices for load shift controls.

The Bayview HPWH system uses a Swing Tank design – defined in the Northwest Energy Efficiency Alliance (NEEA) Advanced Water Heating Specification (AWHS). The Swing Tank design includes a primary system for heating cold incoming municipal water and a temperature maintenance swing tank for trim heating the recirculation loop during periods of low water usage. The primary system which includes the HEAT2O, a heat exchanger assembly, and thermal storage tanks, was pre-packaged in a plug-and-play, skidded assembly for fast, simple installation by Steffes in North Dakota. This skid-style design minimized the disruption of hot water supply to residents during installation.

The pre-retrofit system was a 93kW electric resistance system. The new HEAT2O, only draws 10 to 19 kW, and satisfies all the heating of cold incoming municipal water and most all of the recirculation heating. A portion of the existing electric resistance system was left in place to use as swing tanks and provide backup heat.

Depending on the season, the system achieved a Coefficient of Performance (COP) between 2 and 3, averaging a full system COP of 2.3. However, the project identified potential enhancements to elevate the system's average COP above 3 in Seattle's climate. Mitsubishi is acting on these insights to advance its product offering.

Bayview Tower has an atypical load shape. Instead of the traditional market rate multifamily load shape with a morning and evening peak, Bayview has a single morning peak and remains flatter throughout. The difference in load shape allowed the Bayview system to shift load more easily in the morning hours but made it more difficult for the system to sufficiently load up for an evening load shift.

The project team tested load shifting from March 2022 to June 2023. The yearlong testing revealed that: (1) during summer, the system performed exceptionally, and provided hot water through the shed periods each day without using electricity; and (2) during winter, the HEAT2O capacity was reduced more than expected by defrost, which, when combined with other factors, resulted in approximately a 35% capacity reduction. The capacity reduction prevented the Heat2O from fully charging the primary storage tank between shed periods and limited the evening shed. This meant that the HEAT 2O used more energy during the winter and could not complete shed periods. Despite this, the anticipated improvements and appropriate design controls can enable consistent year-round load shifting on future installations.

The research team used Ecosizer – an open-source HPWH sizing and simulation software – for simulating the load shift. The simulation results indicated that, contrary to common industry knowledge, the ability to load shift is not only correlated to storage volume. When well-designed load shift controls are included, significant load shift can be provided without adding additional storage volume.

The Bayview Tower project marks a significant milestone in market transformation of load shift capable water heating systems. The monitoring and studying of the system have yielded valuable insights, which will be used to improve the product and inform future large-scale implementation of load shifting HPWH systems. The findings prove that commercial HPWH systems can realize consistent load reduction during peak periods. This ability will play a role in supporting the transition to renewable energy, drive electrification, and help with grid stability.

Background

This report culminates several years of collaborative work between BPA, Ecotope, Mitsubishi, SkyCentrics, and Steffes to introduce the first load shift capable commercial HPWH system to the United States, featuring the HEAT2O. The research team worked with Mitsubishi using the Technology Innovation Model (TIM) to bring the HEAT2O to market through a series of stage gates. The TIM outlines a repeatable process, illustrated in **Figure 1**.

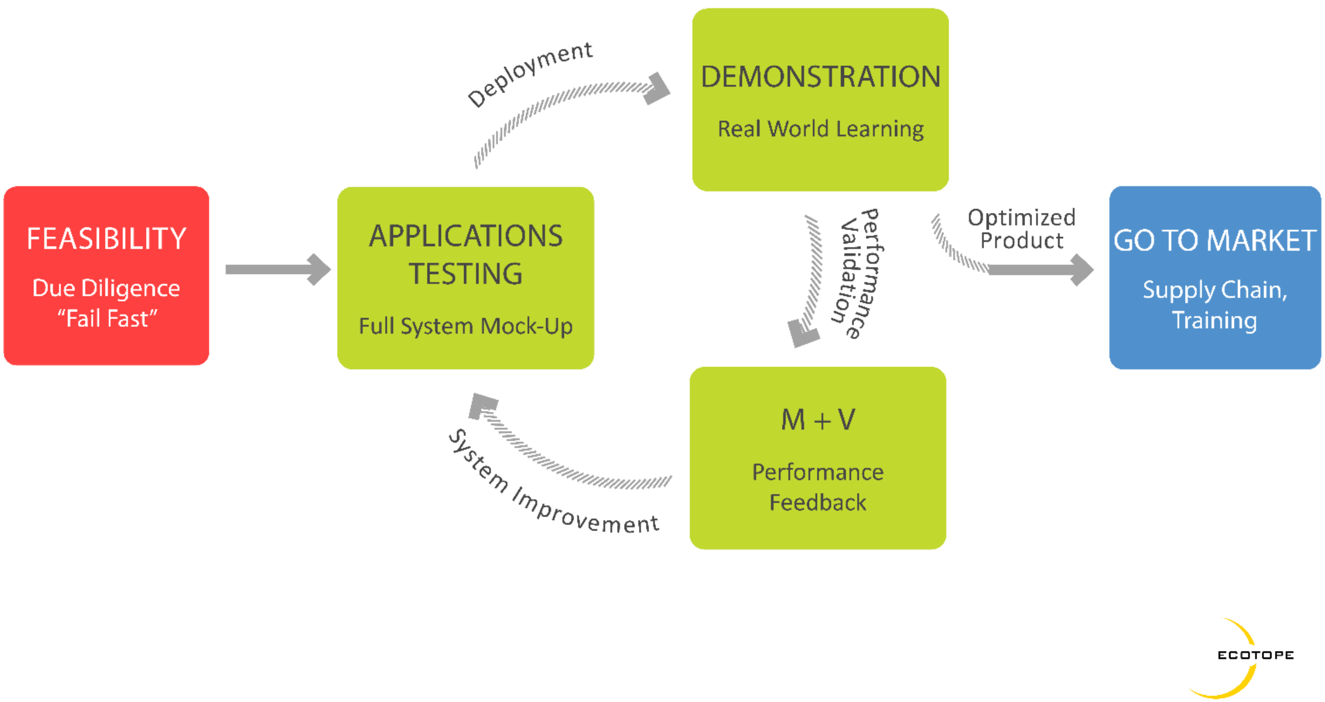

Figure 1. Technology Innovation Model

As part of the TIM, BPA produced several key documents: a Feasibility Study[i], Load Shift Feasibility Study[ii], Applications Test Report[iv], and a Measurement and Verification Study (M&V)[iii].

The retrofit hot water system at Bayview Tower was completed in August 2021. A skid package, constructed by Steffes in South Dakota, was shipped to Seattle, installed at Bayview Tower, and connected to the building infrastructure – water, power, and physical structure.

At Bayview, the load shift communication was tested through the SkyCentrics EcoPort (CTA-2045) and OpenADR Virtual End Node, which interacted with the SkyCentrics SkyKit integrated into the Mitsubishi Heat2O control panel. This setup allows the system to receive signals for two levels of load up and three levels of shed, consistent with CTA-2045-B standards. The CTA-2045 protocol, an open standard which describes a physical port and a command set for demand response to enable load shift, simplifies grid-to-device communication, fostering a more efficient implementation of load flexibility programs for a sustainable and reliable electric grid.

Figure 2 shows the system schematic at Bayview Tower. The left side shows the skid, which includes the Primary HPWH (HEAT2O), heat exchanger, and primary storage tanks. The right side is located in the building's existing hot water room and includes existing electric resistance tanks which are repurposed as swing tanks

Additional details on system sizing and design are included in Appendix A.

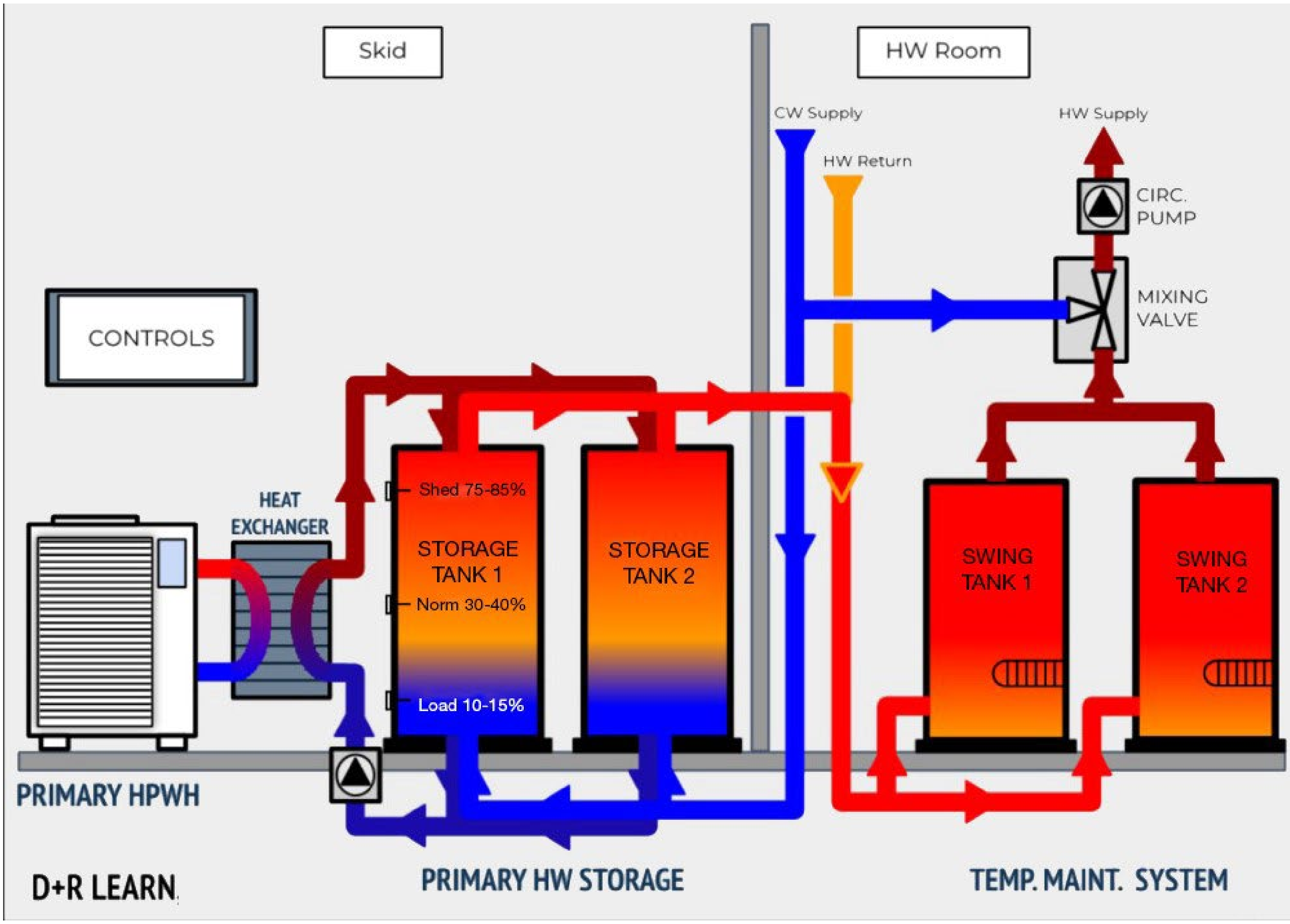

Figure 2. Bayview System Schematic

HEAT2O System Equipment Summary:
- One (1) HEAT2O 40 kW nominal output capacity; 36 kW output capacity indicated at Seattle design outdoor temperature.
- Three (3) 285-gallon thermal storage tanks.
- Four (4) 119-gallon swing tanks with 81 kW capacity (also used for backup)
- Two (2) electronic mixing valves.

In a swing tank design, the recirculation water is piped back to a separate, smaller tank in series with the primary storage tanks called a swing tank. The HPWH heats the primary storage and does not heat the swing tank directly. However, as the hot water from the primary storage (typically between 140 and 180°F) flows to the swing tank, it heats up the swing tank and offsets the heat loss that occurs as water recirculates around the building. The swing tank design supports HPWHs that operate most efficiently on cold incoming water from needing to heat recirculation water directly.

Load Shift Demonstration

Load shift control schedules for the HPWH system at Bayview were set and updated every 1.5-2 months, with adjustments made as necessary. The system performed exceptionally during the summer. The winter presented challenges and impacted the HEAT2O system's load shift capability. A summary of the results from each schedule can be found in **Table 1**. A more detailed summary of load shift and COP data is available in Appendix B along with a description of the test ran during each time period. During the coldest winter months, December 2022 through February 2023, testing was paused due to cold conditions and reduced equipment capacity.

Start Date	End Date	Total Shed Hours Scheduled	Percent Shed Met	Avg Outdoor Air Temp (°F)	Avg COP[4]
5/2/2022	6/19/2022	168	91%	55	2.33
6/20/2022	7/27/2022	132	100%	66	2.63
8/18/2022	10/2/2022	208	85%	66	2.82
10/3/2022	12/15/2022	336	62%	47	2.24
12/16/2022	1/1/2023	0	-	39	2.1
1/2/2023	2/5/2023	0	-	43	2.34
2/6/2023	2/19/2023	0	-	43	2.24
2/20/2023	3/5/2023	56	53%	38	1.97
3/6/2023	3/19/2023	56	54%	44	2.13
3/20/2023	4/20/2023	54	88%	46	2.32

Table 1. Summary of Results from Demand Response Testing Period

Figures 3 and 4 illustrate the comparative energy use during the 3-hour period for three different scenarios: the pre-retrofit electric resistance system (calculated from water usage), an uncontrolled Heat2O commercial HPWH system (data collected on control days – T, Th, Sat), and a load shift capable Heat2O commercial HPWH system (data collected on load shift days – M, W, F, Sun).

Figure 3 shows summary data, gathered from May through July 2022. The figure demonstrates a substantial average demand reduction. First, replacing the electric resistance system with the HEAT2O system reduced peak demand and provided significant energy savings (from ~70 kWh to ~25 kWh). Then, the load shifting further reduced peak demand from ~25 kWh to ~2 kWh.

Figure 4 shows the average energy use per hour by each system over a 24-hour period. The figures were created using uncontrolled energy usage data from Tuesdays, Thursdays, and Sundays (no load shift) and controlled energy usage data from Monday, Wednesdays, Fridays, and Saturdays (with load shift).

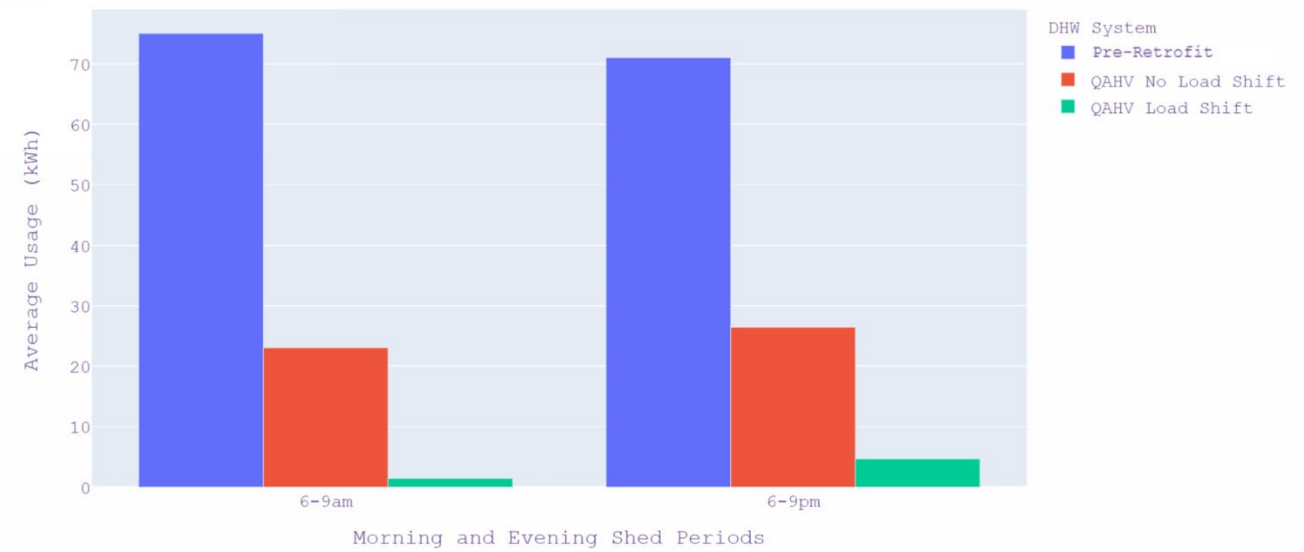

Figure 3. Average Demand Reduction during Peak Periods by Hot Water System

Figure 4. Average Daily Energy Use Profiles for Hot Water Systems

Figures 3 and 4 clearly demonstrate the substantial peak demand reduction (~97%) potential of commercial HPWHs equipped with load shift controls. When combined across numerous buildings, this could translate to a significant demand reduction resource. Additionally, the demand reduction observed at Bayview likely underestimates the potential in other multifamily buildings. Bayview is a senior affordable housing building. Unlike most multifamily buildings, Bayview's load shape features a single, less pronounced mid-day peak. (Refer to **Figures 5 and 6** for comparison.) In most multifamily buildings the peak hot water usage aligns with peak electricity use periods in the morning and evening, which creates a greater opportunity for load shifting.

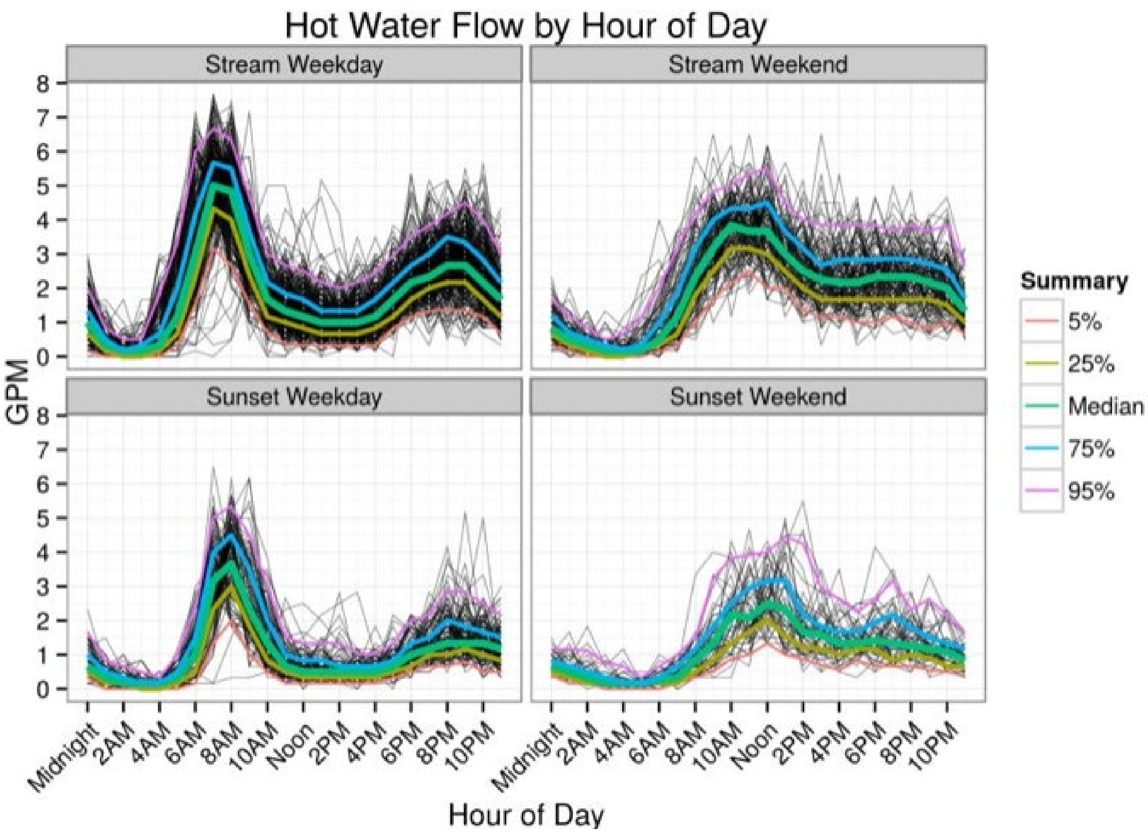

Figure 5. Common Seattle Market Rate Load Shapes

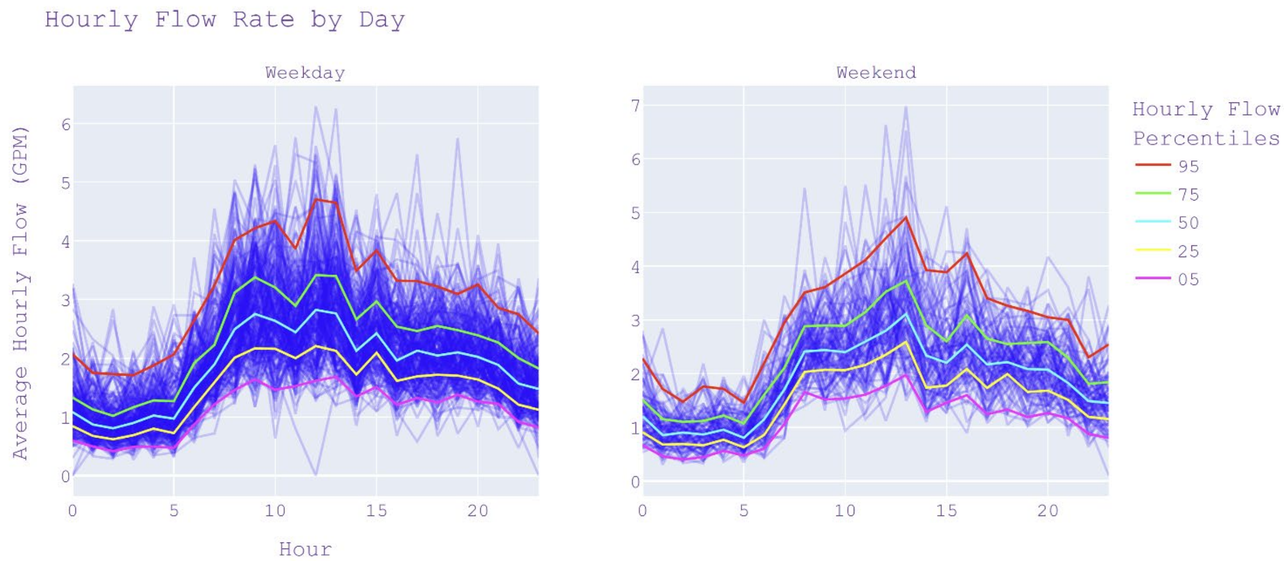

Figure 6. Bayview Tower Load Shapes

Controls

At Bayview, the load shift controls are straightforward: (1) use a load up command to fully charge the thermal storage tanks ahead of expected grid peak periods, and (2) keep the HPWH system idle as long as possible during peak periods using a shed command. However, the HPWH will turn on during a shed to provide uninterrupted hot water delivery to the building occupants. The substantial storage volume of commercial HPWH systems facilitates load shifting. The large storage tanks can store large volumes of water prior to peak events and allow storage to deplete during shed periods. This enables the system to not use electricity during shed and maintain hot water supply to residents.

To enable load shift, the research team identified three control strategies:

Strategy #1: Altering which location in the storage tank is used to turn the HPWH on and off: HPWHs are controlled to turn on and off with temperature sensors located in the storage tank. Installing three temperature sensors—at the top (82%), middle (46%), and bottom (11%) of the tank allowed for effective management of the HPWH's operations during shed, normal, and load up operating modes respectively. Refer to **Figure 2** for temperature sensor locations.

During load-up, the HPWH controller was set to heat the water until the bottom temperature sensor (11%) met setpoint, maximizing the stored hot water volume. During shed periods, the HPWH controller was set to satisfy a setpoint at the top (82%) of the tank. This allows the HPWH to remain off for long periods of time between load up and shed as the middle of the tank – full of hot water – could be used to ride through long periods without the need for electricity. During normal operation, the middle sensor (46%) is used to provide long compressor cycles while maintaining a large amount of hot water storage.

Altering which storage tank sensor was used for HPWH on/off control was the most significant contributor to Bayview's successful load shift demonstration. Bayview's monitoring system allowed the research team to analyze the tank stratification through temperature data while designing the control sequence. In order for manufacturers, engineers, and contractors to design and implement load shift while ensuring consistent hot water supply, standardized guidance on placing tank temperature sensors to achieve load shift is needed. While the Bayview research suggests a HPWH sensor location at 75-85% for shed, and a 5-15% location for load up, more studies, both field and simulation, are needed to provide guidance on temperature sensor placement for load shifting.

Strategy #2: Increasing the temperature of hot water produced by the HPWH during load up: Increasing HPWH outlet temperature increases primary storage temperature which generates denser energy storage. Denser energy storage allows the same storage tank volume to provide more hot water (increasing thermal storage capacity) when provided through a mixing valve. However, increasing HPWH outlet temperature has not been successfully tested at Bayview due to complications with controls around the secondary heat exchanger. This is described Appendix D.

Strategy #3: Adjusting the output capacity of the HPWH: During load up with the HEAT2O system, the heating capacity of the HPWH can be increased to speed up hot water recovery in the thermal storage tanks. This was done by requesting high-capacity output from the HEAT2O during load up periods via control signal from the control panel – which receives load shift commands – to the HEAT2O. However, this capacity increase only works when outdoor air temperatures are above ~45°F and the higher the air temperature, the more the capacity will increase. Capacity adjustment strategy is limited to certain HPWH models and seasons.

Currently, the research team does not see significant value in decreasing capacity of a single HPWH during shed for commercial HPWH systems. The existing HPWH technology does not significantly increase COP through capacity reduction, and the added complexity with marginal value makes this strategy unfeasible at this stage of commercial HPWH load shift technology maturity. However, when multiple HPWHs are used, using simple staging controls to turn HPWHs on one at a time can be implemented.

A detailed description of setpoints, temperatures sensor locations, and control modes is described in appendix E.

Ideal Operation and Tuning

Load shift testing initiated on March 21, 2022, encompassing two 3-hour shed events from 6AM-9AM and 6PM-9PM on Monday, Wednesday, Friday, and Saturday. Initially, a 1-hour load up was implemented before each shed event. Most morning shed events were successfully executed without turning on the HPWH, but evening shed events were less successful.

High midday water usage at Bayview prevented the HPWH from fully recovering in its standard capacity mode. Three control modifications made by May 2 2022, enhanced the system's ability to meet both morning and evening shed events consistently:

1. The hot storage water temperature setpoint was raised from 138°F to 150°F.
2. HPWH capacity during load up was increased from 40kW to 60kW nominal heat output.
3. Load up duration was extended from a 1-hour period (5PM-6PM) to a 6-hour period (Noon-6PM).

These changes resulted in the system successfully meeting hot water demand during sheds without the use of electricity 90% of the time. Further control modifications on June 20, 2022 expanded *load up* to an 8-hour period from 10AM to 6PM, enabling the HPWH to meet all shed events without needing to use electricity to heat water.

More studies – both field and simulation – would offer better insight into optimal locations for various building sizes and types, system storage and HPWH combinations, and system configurations.

Figure 7, on the following page, provides a snapshot of the system's optimal performance in May 2022, where the system successfully fulfilled two 3-hour shed periods. The chart's background colors highlight the scheduled events, with load up denoted in blue and shed in green.

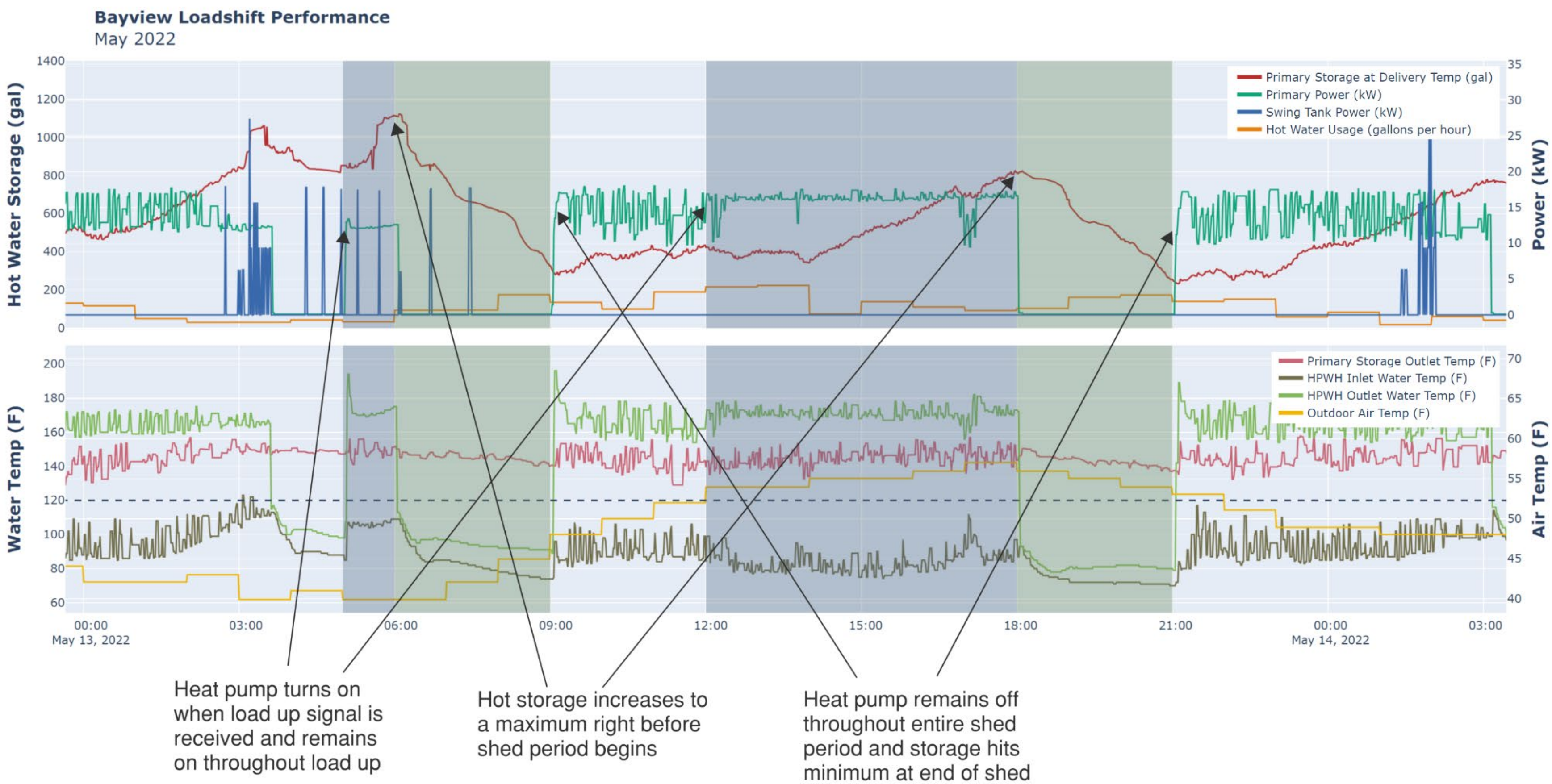

Figure 7. Ideal Control Day

Hot Storage at Delivery Temperature (subsequently referred to as Vsupply), shown in red on **Figure 7**, is calculated from fifteen temperature sensors installed in Bayview's three storage tanks. The calculation generates a temperature profile for the tanks and estimates the volume of hot water stored at the delivery temperature. Essentially, Vsupply is the total volume of 120°F water available if the storage tanks were drained through a mixing valve with cold municipal water at any given moment. Although the tanks at Bayview have a volume of 855 gallons, with elevated temperature they can effectively store over 1200 gallons of 120°F Vsupply.

The Vsupply line on **Figure 7** clearly shows the system's capability to store sufficient hot water during both load up periods. The power input to the Heat2O remains zero during both shed periods, reflecting a successful shed.

Opportunities for Improvement

The research team identified several opportunities to improve the HPWH system and the need to develop better industry standards to support high quality future installations. These opportunities included, controls improvements, better sizing guidance for engineers, clear maintenance requirements, and the development of control strategies to load shift swing tanks.

Secondary Heat Exchanger

The secondary heat exchanger, which is required to protect the HEAT2O internal heat exchanger from variable municipal water quality, controls inlet water temperature to the HPWH. Inlet water temperature is a critical determinant of the HPWH operating efficiency and capacity. Transcritical CO_2 HPWHs, like the Mitsubishi HEAT2O, require cool inlet water temperatures to perform optimally. Ideally, the secondary heat exchanger should supply inlet water to the HPWH within 10°F of the incoming cold municipal water (~60°F), while supplying outlet water temperatures above 150°F. The high temperature lift (from 60°F to 150°F) requires low flowrates, outside the stable control envelope of currently available stock equipment. A lack of control stability results in high (80°F to 120°F) and fluctuating inlet water temperatures which negatively impacted performance.[iv]

This was particularly observed in the winter, when high inlet water temperature compounded with cold ambient temperatures reduced the HEAT2O's capacity and COP. **Figure 8** demonstrates how variations in inlet water temperature influence the input power of the heat pump. Input power oscillations to adjust for inlet water temperature are hard on the equipment and reduce the heat output. Given the impact to system performance, it is critical that designers precisely control the inlet water temperature.

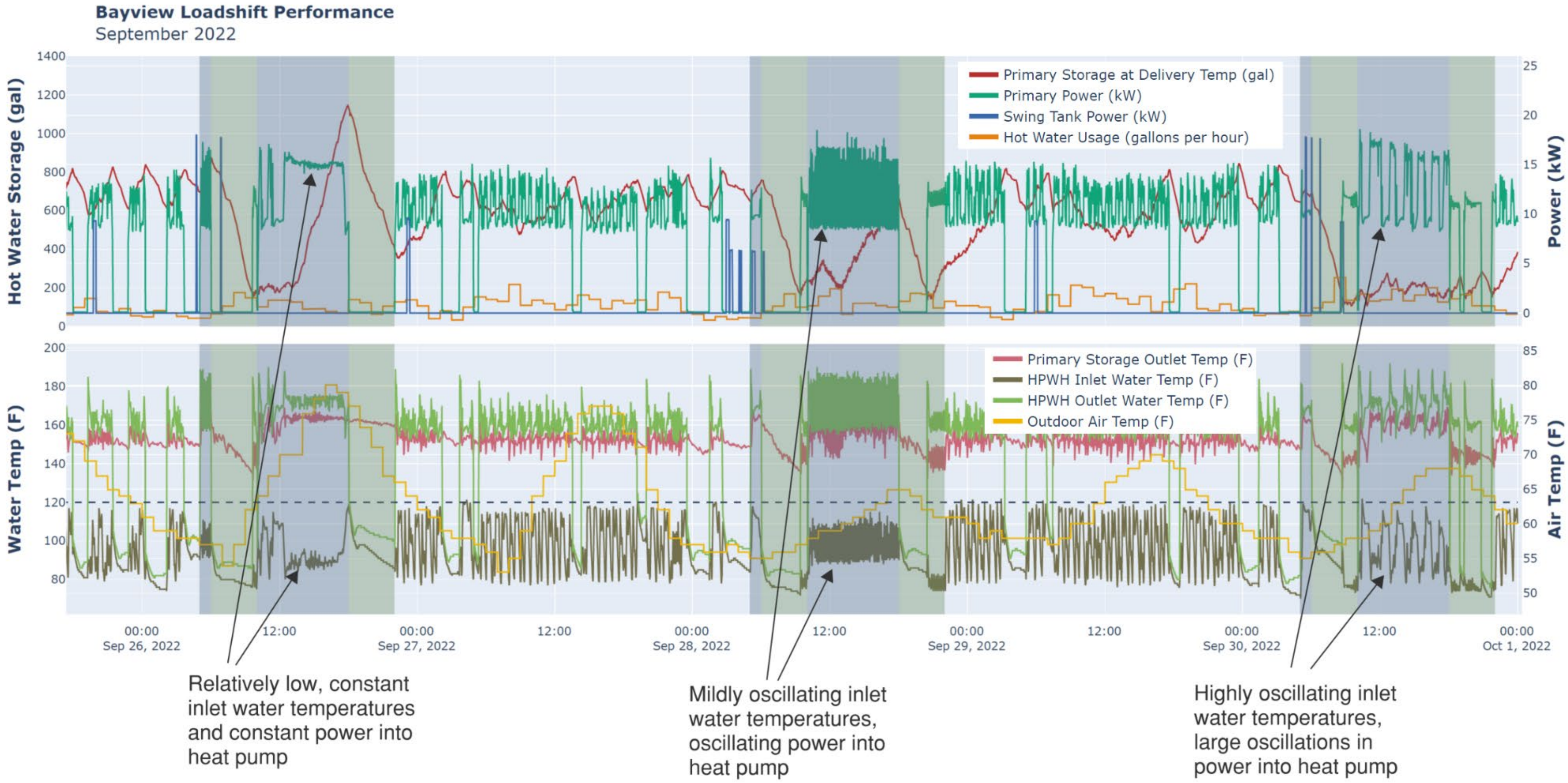

Figure 8. Inlet Water Temperature

To gain better control and consistency over the performance of the secondary heat exchanger, Mitsubishi Electric Trane HVAC US (METUS) is developing a pre-packaged heat exchanger and pump assembly with specialized components – shown in **Figure 8**. Mitsubishi already manufactures a similar Thermal Exchange Module sold in France. The findings at Bayview underscore the importance of improving the control of these features.

Figure 9. Prototype heat exchanger skids being tested at Mitsubishi Facility.

Defrost Derate

When the outdoor temperature drops below a certain point (often within 10°F of freezing), the moisture in the outdoor air can freeze on the outdoor unit's evaporator coil. This frost or ice buildup insulates the evaporator, reducing heat transfer, and the ability of the unit to pull heat from the outdoor air. The defrost cycle is a process designed to remove this frost or ice buildup from the outdoor unit. However, when the unit is in a defrost cycle, it is not producing hot water. The percentage of time the unit is in defrost cycle, when it would otherwise be heating, is referred to as the defrost derate.

Another opportunity for improvement identified at Bayview is improving the manufacturer guidance on the defrost derating. Quantifying defrost derate is important for both sizing and energy usage simulations. This finding applies industry wide, not just to the HEAT2O. Currently, manufacturers do not provide the data needed to understand defrost derate.

Near freezing temperatures with high humidity in December and January severely impacted the system's ability to maintain adequate levels of storage and the system was prevented from load shifting. Mild disruptions to hot water supply from the primary system were observed in December, with the most extreme event illustrated in **Figure 10**. The large oscillations of heat pump outlet water temperatures and resulting dips in supply water leaving the primary storage tank indicated that the system was in defrost mode. On cold, humid days in December, the heat pump operated in defrost mode as much as 20% of the day, severely limiting its hot water generation. During this time, the system was unable to meet demand. During this period, the load shift controls were turned off to allow the system to maintain hot water. The electric resistance heater functioned accordingly as a backup, ensuring the consistent delivery of hot water to occupants. If a 20% defrost factor was used during sizing, the system would not have initiated the electric resistance backup.

Testing standards must be developed to standardize and understand defrost derate impact across manufacturers and equipment models.

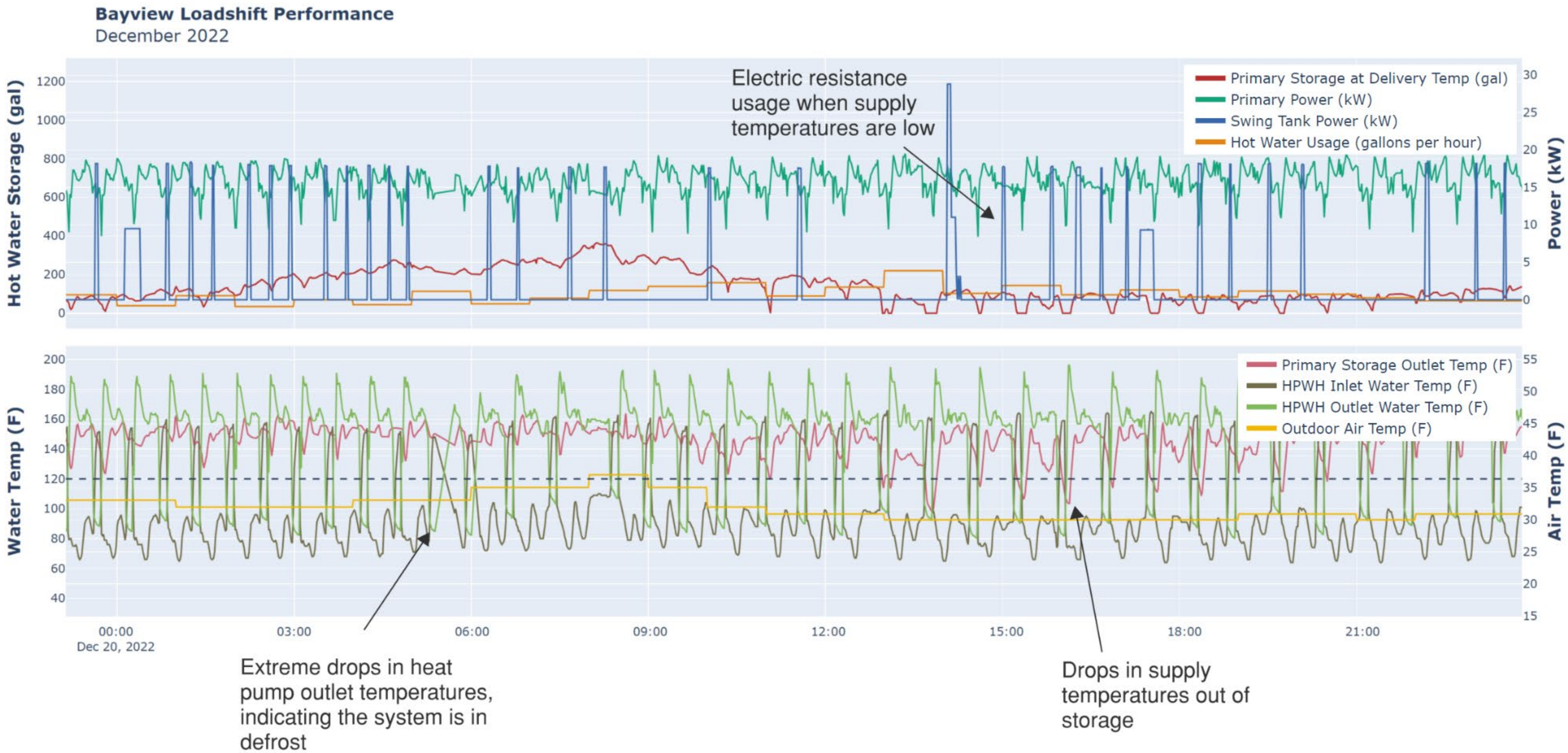

Figure 10. Defrost Mode

Maintenance

Another factor that may be contributing to more defrost time is the condition of the HEAT2O evaporator coil – which absorbs heat from the ambient air. The coil has not been cleaned since the HEAT2O was installed over a year ago. Evaporator coils should be cleaned annually to prevent buildup of dust and pollen. The Bayview Tower HEAT2O installation has been operating for a year and requires maintenance to continue to operate effectively and avoid equipment degradation. This cleaning should include cleaning on the evaporator coil, the secondary heat exchanger, the tank anodes, strainers, T&P valves, etc.

Typically, the equipment manufacturer (OEM) provides an operation and maintenance guide (O&M) to the building operator so they can provide maintenance or hire a third party to provide maintenance. Commercial HPWHs are a new technology to the US market, and the industry would benefit from training contractors and building owners on the importance of HPWH system maintenance. Requiring a full system warranty through the manufacturer or distributor is a potential avenue utilities can explore to guarantee savings for programs. A system warranty should guarantee systems are installed and maintained properly.

Swing Tank Load Shift

At Bayview, the existing electric resistance water tanks were preserved with their own independent controls to function as temperature maintenance heaters and backup. The controls at Bayview didn't allow the temperature maintenance system to fully shut off during shed periods, but the research team has designed two methods to implement load shifting for temperature maintenance at future sites. Appendix C provides M&V data and details on swing tank usage patterns in both swing and backup operation.

The first method: Increase the setpoint of the swing tank prior to shed periods. This strategy is analogous to loading up the primary storage tanks, and it would allow the swing tank to store more energy before entering shed periods.

The second method: Implement a new design concept called a pumped swing tank. A pumped swing tank includes an instantaneous water heater piped in parallel with the swing tank and primary storage. In this case, the swing tank does not include electric elements – it is just a tank. This allows a controller to heat the swing tank by turning on the pump which allows swing tank setpoints to be easily adjusted for load up and shed. Refer to the Applications Test Report for more details on pumped swing tanks (also called parallel electric resistance water heater).[iv]

Load Shift Simulations

In addition to field testing and monitoring, the research team conducted and compared load shift data to another previous simulation study prepared for Seattle City Light at the White Center Hub. The energy results from the White Center study align with the findings in this report, but the need to increase storage outlined in the White Center Study may not be necessary in many cases. When the controls demonstrated at Bayview were simulated, the research team was able to show that storage volume does not typically need to be increased to achieve significant load shifting.

The hot water simulation tool used in Ecosizer was modified to simulate the load shift controls used at Bayview – including altering the location and number of sensors in the storage tank which turns the HPWH on and off during load up and shed. Then, the research team performed a parametric simulation study, varying load shapes, daily hot water usage, HPWH heating capacity, and storage volume. For the simulations, HPWH heating and capacity were sized using Ecosizer standard sizing methodology for a building the same size as Bayview Tower.

Load Shape: Market Rate Shed: 6-9 AM, 6-9 PM						
	Gallons Per Day Per Person	17	19	21	23	25
	Percentile Day	50%	69%	84%	93%	98%
Storage, Capacity	(210 gal, 320kBTU/hr)	0.61	0.55	0.5	0.5	0.46
	(270 gal, 280kBTU/hr)	0.57	0.52	0.49	0.45	0.43
	(330 gal, 260kBTU/hr)	0.52	0.48	0.43	0.39	
	(410 gal, 240kBTU/hr)	0.61	0.55	0.51		
	(490 gal, 220kBTU/hr)	0.65	0.61	0.57		
	(590 gal, 200kBTU/hr)	0.73	0.68	0.65	0.61	
	(690 gal, 190kBTU/hr)	0.78	0.76	0.75	0.71	
	(780 gal, 180kBTU/hr)	0.81	0.79	0.77	0.72	
	(860 gal, 170kBTU/hr)	0.87	0.83	0.81	0.79	0.77
	(930 gal, 160kBTU/hr)	0.92	0.87	0.83	0.81	0.79
	(1000 gal, 150kBTU/hr)	0.96	0.91	0.87	0.83	0.81
	(1050 gal, 140kBTU/hr)	0.99	0.94	0.89	0.85	0.82
	(1100 gal, 130kBTU/hr)	1	0.97	0.92	0.88	0.85
	(1150 gal, 130kBTU/hr)	1	0.99	0.94	0.9	0.87
	(1190 gal, 120kBTU/hr)	1	1	0.97	0.93	
	(1230 gal, 120kBTU/hr)	1	1	0.98	0.95	

Load Shape: Market Rate Shed: 5-9 PM						
	Gallons Per Day Per Person	17	19	21	23	25
	Percentile Day	50%	69%	84%	93%	98%
Storage, Capacity	(210 gal, 320kBTU/hr)	0.74	0.71	0.68	0.63	0.59
	(270 gal, 280kBTU/hr)	0.71	0.64	0.59	0.56	0.52
	(330 gal, 260kBTU/hr)	0.7	0.65	0.63	0.6	0.57
	(410 gal, 240kBTU/hr)	0.56	0.53	0.47	0.47	0.48
	(490 gal, 220kBTU/hr)	0.63	0.58	0.53	0.55	0.49
	(590 gal, 200kBTU/hr)	0.75	0.7	0.65	0.59	0.55
	(690 gal, 190kBTU/hr)	0.85	0.79	0.74	0.67	0.63
	(780 gal, 180kBTU/hr)	0.93	0.86	0.82	0.78	0.78
	(860 gal, 170kBTU/hr)	1	0.98	0.92	0.72	0.73
	(930 gal, 160kBTU/hr)	0.98	0.87	0.84	0.83	0.81
	(1000 gal, 150kBTU/hr)	1	0.97	0.95	0.91	0.88
	(1050 gal, 140kBTU/hr)	1	1	1	0.97	0.93
	(1100 gal, 130kBTU/hr)	1	1	1	1	0.98
	(1150 gal, 130kBTU/hr)	1	1	1	1	1
	(1190 gal, 120kBTU/hr)	1	1	1	1	0.97
	(1230 gal, 120kBTU/hr)	1	1	1	1	0.98

Table 2. Market Rate Housing Load Shift Simulations

Load Shape: Senior Affordable (Bayview) Shed: 6-9 AM, 6-9 PM						
	Gallons Per Day Per Person	17	19	21	23	25
	Percentile Day	50%	69%	84%	93%	98%
Storage, Capacity	(120 gal, 180kBTU/hr)	0.69	0.64	0.6	0.57	0.54
	(200 gal, 170kBTU/hr)	0.67	0.66	0.67	0.65	0.62
	(270 gal, 160kBTU/hr)	0.71	0.68	0.59	0.55	0.5
	(340 gal, 160kBTU/hr)	0.99	0.9	0.85	0.78	0.72
	(410 gal, 150kBTU/hr)	1	0.96	0.9	0.82	0.78
	(480 gal, 140kBTU/hr)	1	1	0.97	0.82	0.64
	(550 gal, 130kBTU/hr)	1	1	0.97	0.78	
	(610 gal, 130kBTU/hr)	1	1	0.98	0.77	0.58
	(680 gal, 120kBTU/hr)	1	1	0.95	0.71	
	(855 gal, 130kBTU/hr)	1	1	1	0.97	0.79

Load Shape: Senior Affordable (Bayview) Shed: 5-9 PM						
	Gallons Per Day Per Person	17	19	21	23	25
	Percentile Day	50%	69%	84%	93%	98%
Storage, Capacity	(120 gal, 180kBTU/hr)	0.7	0.65	0.62	0.55	0.51
	(200 gal, 170kBTU/hr)	0.76	0.7	0.64	0.57	0.53
	(270 gal, 160kBTU/hr)	0.6	0.54	0.51	0.44	0.43
	(340 gal, 160kBTU/hr)	0.59	0.65	0.63	0.59	0.5
	(410 gal, 150kBTU/hr)	0.83	0.78	0.7	0.63	0.55
	(480 gal, 140kBTU/hr)	0.86	0.79	0.75	0.66	0.62
	(550 gal, 130kBTU/hr)	0.9	0.85	0.92	0.72	0.58
	(610 gal, 130kBTU/hr)	0.98	0.91	0.92	0.77	0.84
	(680 gal, 120kBTU/hr)	1	0.99	0.96	0.78	0.54
	(855 gal, 130kBTU/hr)	1	1	1	0.94	0.73

Bayview Sizing

Table 3. Senior Affordable Housing Load Shift Simulations

Tables 2 and 3, above, show the results of the parametric simulation for Market Rate (typical non-low income) and Senior Affordable (based on Bayview load shape) housing load shapes respectively. The upper section of each table describes the load up and shed periods used in the simulation runs. The first row represents the volume of hot water used per day in the simulation, while the second row signifies the percentile that corresponds to this hot water usage. The indicated storage and capacity, in subsequent rows, are derived from Ecosizer's standard (no load shift) sizing curve, depicted in **Figure 11.**

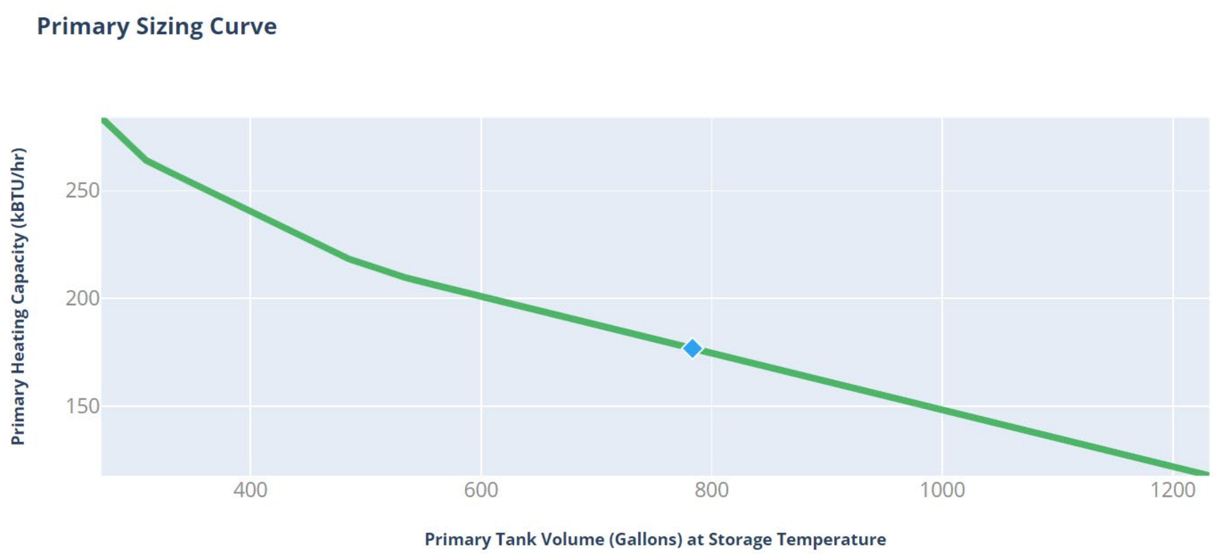

Figure 11. Ecosizer's Primary Sizing Curve

The following columns contain decimal values that represent the fraction of the load shift met for each combination of system size (both heating capacity and storage), load shape, shed period, and daily hot water use. These fractions provide an understanding of how effectively different system configurations are able to meet the shed period indicated at different hot water usage levels. A blank cell indicates the simulated system ran out of hot water during the simulation.

Findings from Simulation

- When a higher storage to heating ratio market rate system is installed, it will provide as good or better load shift performance as Bayview.
- Sizing combinations with larger storage volumes and lower heating capacities provide more consistent load shifting.
- A significant amount of load shifting can be accomplished without upsizing thermal storage system.
- The less peaky load shape of low-income housing allows for more consistent load shifting when sized with the standard Ecosizer load shape.
- Load shifting capability depends on controls and capacity as well as storage.

Market rate systems performed well for systems sized with storage greater than or equal to the recommended size, which corresponds to a 16 hour per day runtime, and fair even better with the once daily time of use shed. Senior housing buildings fared slightly worse overall. However, it's important to note that these simulations were sized using the less peaky, senior housing, load shape and were thus sized smaller despite equivalent volume of water consumed. The Ecosizer tool available online only includes the market rate load shape, so senior housing buildings sized using the online Ecosizer's standard inputs may be sized with larger storage and capacity.

Conclusion

The Bayview Tower project marks a significant milestone by successfully implementing the country's first load shift capable commercial HPWH system. This achievement, along with the valuable practical lessons and insights gained from monitoring and studying the site, showcases the potential of such systems to consistently reduce load during peak periods and support the adoption of renewable energy, electrification, and grid stability.

Load shift simulations and field monitored data also revealed that strategically designed and placed controls may allow for smaller sized storage volumes and still meet resident hot water needs. Smaller hot water storage volumes will drive down the first costs of these systems and support adoption. However, more case studies are required to understand equipment capacity derate during winter, the impact of any defrost derate. Improving the derate understanding will optimize the system sizing and modeling assumptions as well as enhance system performance.

Economically, domestic hot water (DHW) systems offer numerous advantages over other energy storage source, making them a cost effective with a lifespan over 30 years. These systems provide high temperature lift, require minimal maintenance and have nearly infinite cycle lives. To maximize the benefits of these systems and implement load shifting and TOU pricing, additional research and industry guidance on system control logic are needed.

However, DHW's vast energy storage potential can provide further benefit when aggregated across various installations and applications, testing at Bayview Tower suggests that the key to leveraging TOU pricing lies in determining when the system should begin a load up to achieve a fully charged state at the beginning of the peak period or shed event. To maximize utility and customer benefits, control logic is needed to automate the decision of when to begin load up. Control logic must be researched and developed to optimize heat pump operations because commercial building draw profiles vary and CHPWH systems will be built with varying storage and heating capacity.

The Bayview Tower project represents a significant success. However, further efforts are necessary to facilitate rapid market transformation. This includes improving sizing and system modeling assumptions and tools, standardizing equipment control guidance, and establishing supportive energy codes. These next steps will optimize CHPWH system performance and may reduce first costs thereby accelerating the market rate of adoption.

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