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Emerging Technologies

Demonstration and M&V: Commercial Heat Pump Water Heating System using the Mitsubishi HEAT2O in Origin by Steffes Plug-and-Play Package at Bayview Tower, Seattle WA

March 2022

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ABSTRACT

This study focuses on the installation and initial monitoring of a new commercial heat pump water heater (CHPWH) system based around the Mitsubishi QAHV or "HEAT2O" CO2 air-to-water heat pump water heater. The system was designed by Ecotope as a retrofit at Bayview Tower, a 100-unit, low-income senior housing building in Seattle, WA, where it replaced the existing electric resistance system as the primary source for generating domestic hot water. The CHPWH system was preassembled as a plug-and-play skid-mounted package by Steffes and branded as the Origin. This project was the first installation of the HEAT2O and Origin products in the US.

Initial monitoring provided valuable insights into the design and field operations which were used to improve on-site operations and provided to the manufacturing team for packaged system refinements (when applicable). Over the study period, the CHPWH system operated more than two times as efficiently as the original electric resistance system during initial operations, with a coefficient of performance (COP) of 2.4. The overall system COP, for the monitoring period, including swing tank operation, is estimated to be 2.3. Preliminary estimates suggest the CHPWH system will save over 136,875kWh/yr or about $15,000 in operational savings annually (using $0.11/kWh electrical rate) compared to the electric resistance system it replaced. This savings estimate is anticipated to increase with the system improvements made based on real world findings and how the system is expected to operate during warmer ambient conditions which will be measured in continued monitoring.

ACKNOWLEDGEMENTS

The study team is indebted to the broader project team. This project would not have been possible without:

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- The efforts of the installation team: Burton Construction, Seahurst Electric, and Vital Mechanical.
- Mechanical engineering and overall project leadership by Scott Spielman, Ecotope.

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Acronyms

BPA – Bonneville Power Administration

BtuH – British Thermal Units per Hour

SysCOP – Coefficient of Performance of the Domestic Hot Water System

COP – Coefficient of Performance

CO2 – Carbon dioxide

DHW – Domestic Hot Water

F – Fahrenheit

GPD – Gallons per Day

GWP – Global Warming Potential

HPWH – Heat Pump Water Heater

kBTU – Thousand British Thermal Units

kW – Kilowatt(s)

kWh – Kilowatt-hour(s)

kWh/yr – Kilowatt-hour(s) per Year

METUS – Mitsubishi Electric Trane United States

M&V – Measurement and Verification

MXV – Mixing Valve

OAT – Outdoor Air Temperature

EXECUTIVE SUMMARY

On July 26, 2021, a fully packaged commercial heat pump water heater (CHPWH) system was installed at Bayview Tower in Seattle, WA, as a demonstration project to evaluate its performance. The CHPWH system, based around the Mitsubishi QAHV or "HEAT2O", was preassembled as a plug-and-play skid-mounted package by Steffes and branded as the Origin. This demonstration project, as well as the measurement and verification (M&V) of it, is part of the Technology Innovation Model process for introducing energy efficient products into the built environment market. This report on M&V initial findings indicate that, during the monitoring period, the CHPWH plant at Bayview Tower operated with a coefficient of performance (COP) of 2.4 during the monitoring period; and, with minimal electric resistance operation from the swing tanks, the system COP was 2.3.

While the system performed over twice as efficiently as the original electric resistance water heating system, several opportunities for improvement were identified during the monitoring period from August to December. The most significant opportunity uncovered was the inconsistent control of the secondary loop pump. As a result, the pump at Bayview Tower will be replaced in February 2022 with a different model that should more consistently meet setpoint and Mitsubishi Electric Trane U.S. (METUS) will use the updated pump model on all future installations.

In addition to being the first installation of Mitsubishi's HEAT2O and Steffes' Origin in the U.S., the Bayview project is the first single-pass heat pump water heating system designed by Ecotope with parallel-piped primary thermal storage. The 15 temperature sensors used to monitor stratification in the primary storage indicated that the three thermal storage tanks piped in parallel were well-stratified, giving validity to this design practice.

At ~11 tons, the HEAT2O is ideally sized to serve multifamily buildings with more than about 75 occupants and large commercial buildings. While there are a few minor opportunities to improve the fully packaged CHPWH system[i], it is well positioned to successfully enter the market and provide significant energy savings.

This report focuses on the efficiency and consistency of hot water delivered by the CHPWH system. However, the installation also provides demand response capability through an EcoPort (CTA-2045). As part of a future study, Ecotope will conduct longer-term monitoring to test the demand response capability of the system, using this retrofit to demonstrate the value of demand response capable CHPWH systems.

Background

The HEAT2O uses carbon dioxide, a natural refrigerant with a global warming potential of 1, as the refrigerant. Ecotope worked with METUS to develop a fully packaged system around the HEAT2O, including all the parts and controls necessary for a fully functional CHPWH system. The system was packaged into an Origin skid manufactured by Steffes in North Dakota, shipped to Seattle, and installed by local contractors at Bayview Tower.

The demonstration project at Bayview Tower is the culmination of several steps in the Technology Innovation Model including:

1. QAHV Feasibility Study[ii]
2. QAHV Load Shift Feasibility Study[iii]
3. QAHV System Development and Applications Testing[i]

Figure 1 shows the major components in the packaged system. The QAHV System Development and Applications Testing report describes the system in detail.

Bayview Tower is a 13-story, 100-unit, low-income senior apartment building. It is an all-electric building, built in 1968, with a pre-existing electric resistance domestic hot water (DHW) system. The primary focus of this demonstration project is the retrofit of the electric resistance water heating system to a CHPWH DHW system and measurement and verification (M&V) of the system performance. However, the Origin at Bayview is also the first demand response capable CHPWH system installed in the United States. The study team will continue monitoring at the site to understand long term system operation, performance and test demand response capability.

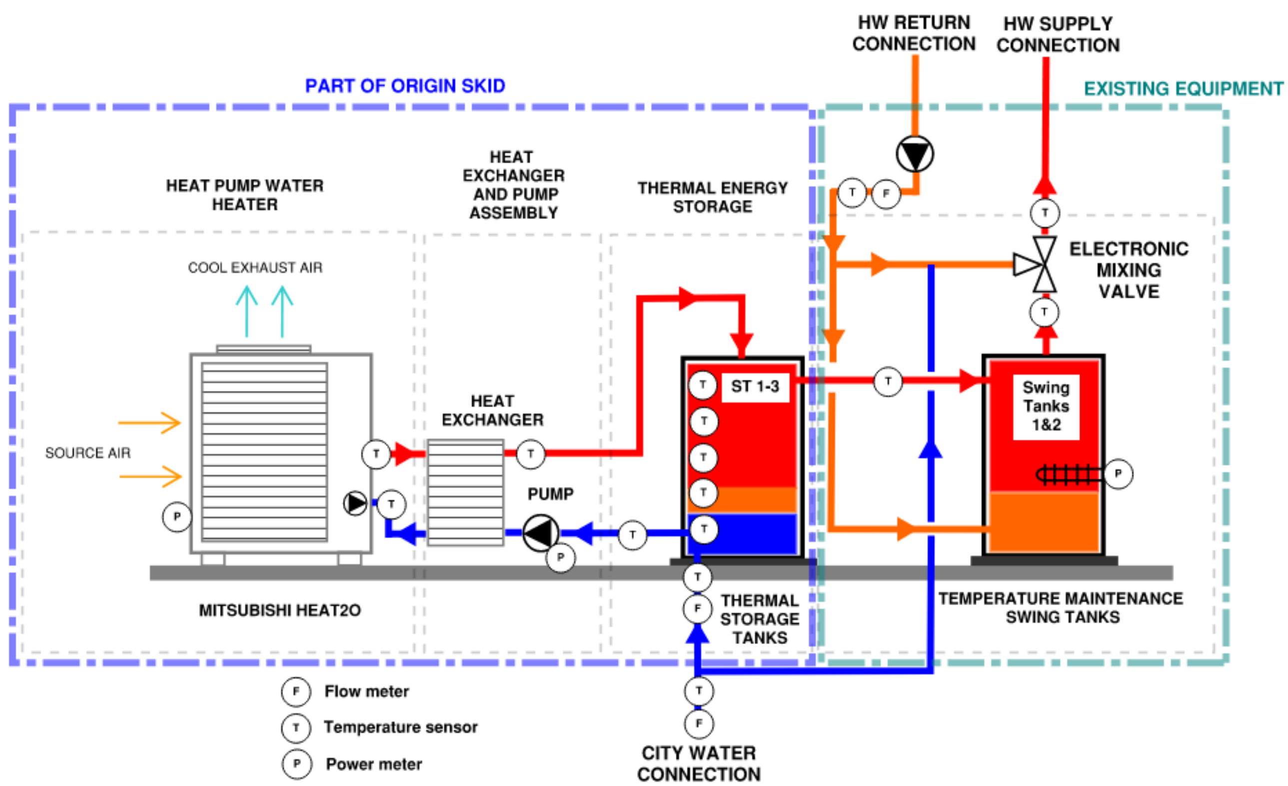

Figure 1. Origin fully packaged system simplified schematic (with monitoring points)

Retrofit HPWH System

The retrofit system required an appropriate location for the Origin skid. In the existing hot water room electronic mixing valves were added and two of the existing electric water heaters were removed. Many of the original DHW system components were maintained, providing some cost savings for the installation.

Site considerations / Equipment location

Structural, electrical, acoustical, and architectural requirements were considered when choosing a building and location for the demonstration project. The rooftop of a meter room adjacent to the building was selected to keep the system near the existing hot water equipment and out of the way of traffic in and out of the building. A structural engineer was hired to determine a weight limit for the Origin at Bayview Tower – the weight limit drove the maximum primary thermal storage volume. The study team confirmed electrical capacity was available on existing panels to support the new system.

The rooftop location has no windows near the system and therefore minimized acoustical disruption to tenants. It also allows expensive equipment to be installed off-grade in an inaccessible location to prevent potential theft and vandalism. The location was also ideal for a skid-mounted solution, which decreased cost and disruption to building tenants.

Swing Tanks

Two of the six existing electric resistance (ER) tanks were removed to provide sufficient electrical capacity for the HPWH installation. The remaining four 119-gallon ER tanks (which range in capacity from 6 to 23kW) were retained to serve as swing tanks to serve the temperature maintenance load in the building (two ER tanks per swing tank system[1]). Each swing tank system serves a different recirculation loop.

This design minimized the disruption to tenants, and only required hot water to be shut off for a few hours, not for multiple days of construction.

Piping Connections

Installation of the Origin skid means that the primary DHW storage is now located outside the building. Pipes from the primary storage to the swing tanks were outfitted with heat-trace tape for freeze protection. Inside the mechanical room, sets of paired valves were installed to facilitate the transition to a CHPWH system. This allowed the building's DHW needs to be met by the ER tanks until the CHPWH was installed and the primary storage charged with hot water. This design minimized the disruption to tenants, and only required hot water to be shut off for a few hours, not for multiple days of construction.

[1] Swing tank 1 is ER tank 1 (6kW) and ER tank 6 (10kW). Swing tank 2 is ER tank 2 (23kW) and ER tank 5 (11kW).

Mixing Valves

A swing tank design requires water above delivery temperature to be provided to the swing tank. Due to the hotter temperatures, mixing valves (MXV) were installed on each of the two recirculation loops so that water can be tempered to the appropriate recirculation loop supply temperature.

Photographs

The following photographs show details of the retrofit CHPWH system, including the HEAT2O and piping, details of the storage tanks, secondary loop heat exchanger, and controls system housed on the Origin skid. Images are from the skid-manufacturer, Steffes', manufacturing location and from the installation at Bayview Tower.

Figure 3. Secondary loop heat exchanger before pipe insulation was installed. Photo credit: Steffes.

Figure 2. Storage tanks and piping during initial skid assembly. Photo credit: Steffes.

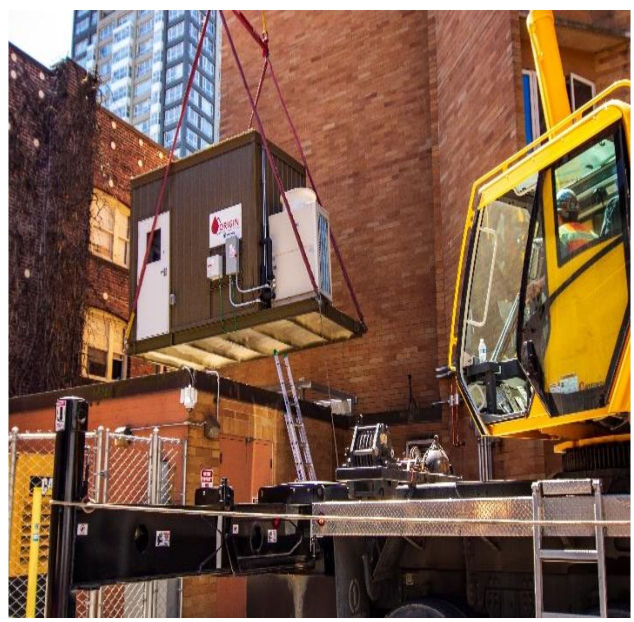

Figure 4. Origin skid being lifted to final install location at Bayview Tower. Photo credit: Blue Fern Productions.

Figure 5. Origin skid installed at Bayview Tower with HEAT2O external to skid enclosure. Photo credit: Blue Fern Productions.

Figure 6. View inside rooftop skid shed with storage tanks (left) and secondary loop heat exchanger assembly (right). Photo credit: Blue Fern Productions.

Figure 7. New piping in mechanical room connecting to existing electric resistance water heaters (during insulation installation).

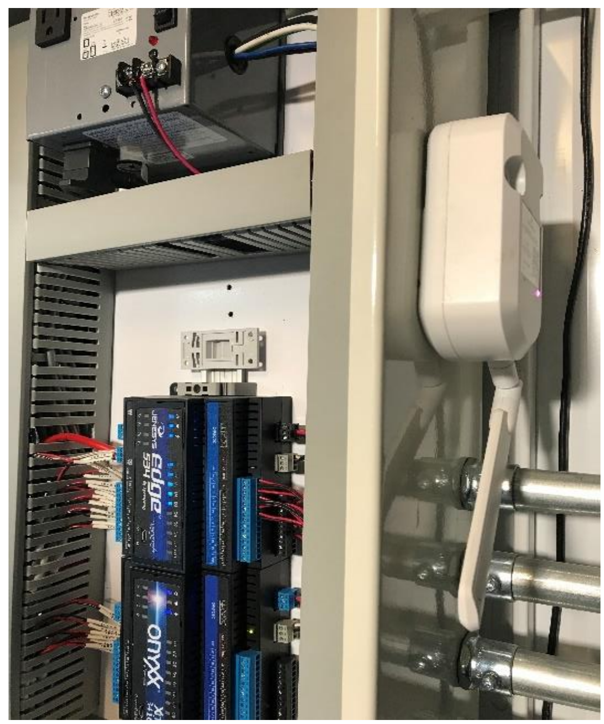

Figure 8. Partial view of Mitsubishi Diamond Controls panel with side-mounted SkyCentrics EcoPort (right). Photo credit: Blue Fern Productions.

Methods

The M&V system for the demonstration project was integrated into the Mitsubishi Diamond Control Package. This control panel is used in addition to the HEAT2O's internal controls for more nuanced command of the system components and to enable its monitoring. In addition, the control panel communicates with a SkyCentrics EcoPort (CTA-2045) interface that will also eventually be used in future load shift testing.

Monitoring points are displayed in Figure 1. Data was delivered hourly to the study team's servers and compiled daily. The study team set up an online tool to view the monitored points from the CHPWH system, as well as calculated values like COP and heat output. This data was automatically updated nightly, allowing the engineers and installers commissioning the project to quickly receive feedback on initial system operation. Partial data has been collected and was available through the online tool[2] beginning August 2021, with the full suite of data points initiated in September 2021.

Findings

This section contains summaries of system operations and M&V observations over the study period from August through early December 2021.

M&V Commissioning and Timeline

The Origin skid was installed at Bayview on July 26th, 2021. It was lifted onto the rooftop structural platform and mechanical, electrical, communication and structural connections were made. The startup team ran the HEAT2O through a setup procedure and configured the system per the controls sequence. After the system was set up, a series of tests were run to make sure it controlled as intended.

Although MXVs had to be installed before the HEAT2O could be initiated, partial data was available almost immediately. Once the MXVs were installed, the primary water heating was switched from electric resistance to the CHPWH on August 5, 2021.

As additional data streams became available, commissioning of the data collection began, and the study team worked with SkyCentrics and METUS staff to resolve data collection and communication issues as promptly as possible.

Appendix A includes a timeline of notable monitoring and system optimization events to date.

System Operation

This section contains subsections that briefly describe initial operation of the CHPWH system.

[2] https://ecotope.shinyapps.io/qahvviewer/

Primary Plant (Skid)

The primary plant at Bayview consists of a single HEAT2O, heat exchanger and pump assembly, and three 285-gallon storage tanks. The single HEAT2O unit is the sole-source of primary heating in the HPWH system. This section focuses on the primary heating temperatures and operation of the CHPWH system components.

HEAT EXCHANGER AND PUMP ASSEMBLY

Potable DHW is heated by the HEAT2O through a secondary heat exchanger[3]. A secondary loop pump is used to pump city water through the heat exchanger to charge the thermal storage tanks. The heat exchanger and pump assembly are designed to operate with a 10°F temperature lift on each side of the heat exchanger (HEX) shown in Figure 9.

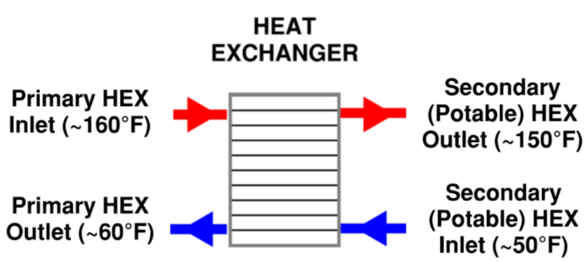

Figure 9. Design temperatures for heat exchanger inlet and outlet.

Secondary loop pump internal controls are meant to control flow of city water through the HEX to target a hot water outlet temperature of 150°F. However, a setpoint limitation on the specified pump did not allow for outlet temperature to be controlled above 86°F. Another, less optimal control strategy was used during the M&V timeframe to achieve secondary HEX outlet temperatures between 135 and160°F.

In addition, the original secondary pump, an Ecocirc XL N 20-25, turned out to have a manufacturing defect that caused it to fail on five separate occasions. Each failure required a manual restart. The Ecocirc will be replaced by a Grundfos Magna3 in February 2022. The Grundfos pump is expected to have improved control capabilities.

Figure 10 shows the daily average temperatures for the HEX inlet/outlet from August through December. During this time, modes and settings adjustments were made to get the system to operate as designed. Effectively the monitoring period encompassed several control optimizations to make the HEX pumping arrangement work optimally. During that time the pump failed and is being replaced. A summary of original and adjusted HEAT2O control points and settings can be found in Appendix B.

[3] The secondary heat exchanger is used to protect the HEAT2O internal heat exchanger from variable potable water quality.

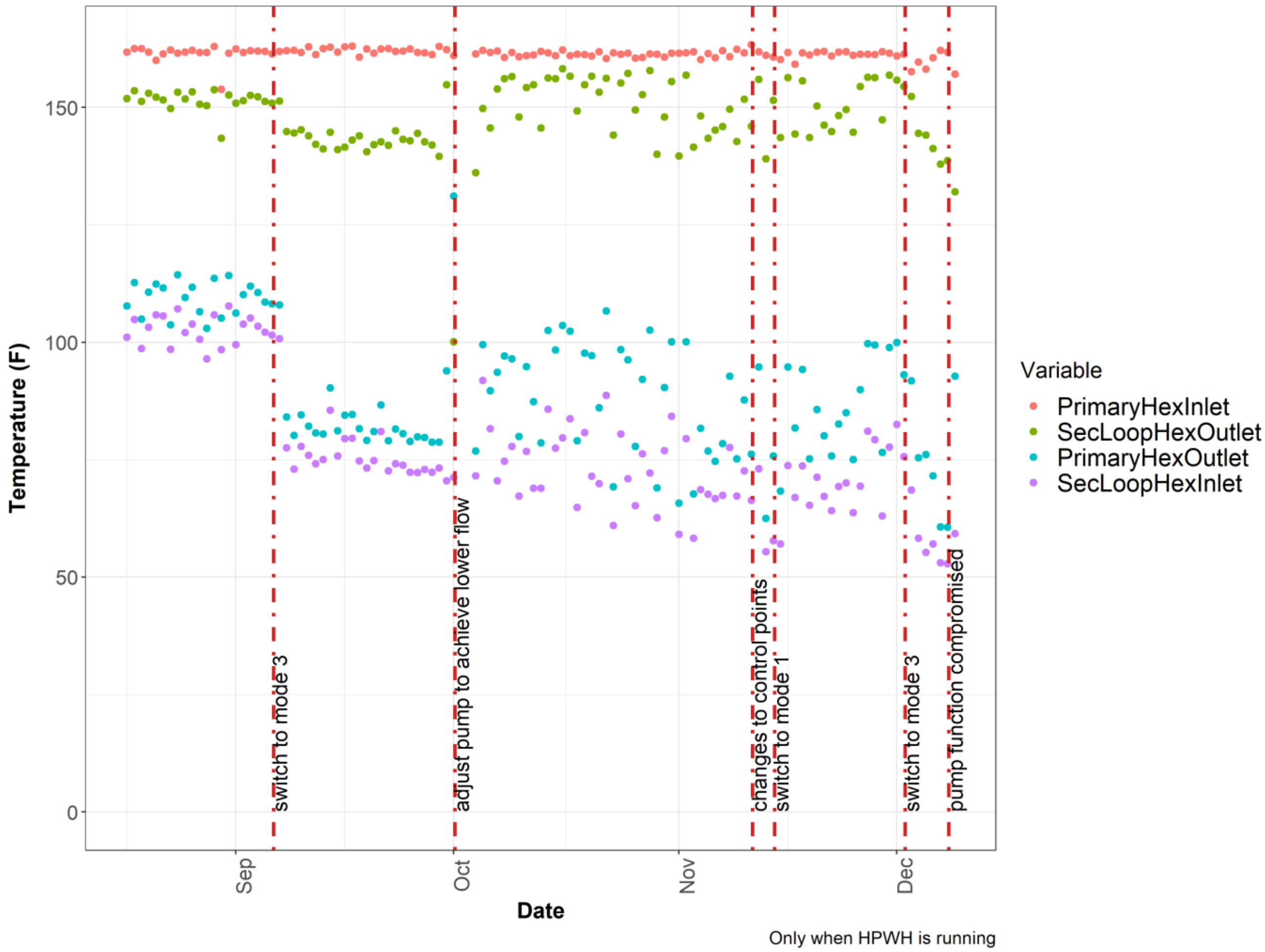

Figure 10. Daily average HEX inlet and outlet temperatures.

Figure 11 shows more detail for several heating calls before and after the controls-point changes on November 12 and before the heating mode was changed again. Note that temperature run-ups, visible in the increased PrimaryHexOutlet / HPWH inlet temperature at the end of a heating cycle, are much briefer in duration after November 12, which was the aim of controls points adjustments. This mode testing and controls and flow rate adjustments helped optimize the operations of the CHPWH at this site and increased understanding about the key points to improve real-world operations.

System alterations were attempted to improve an already well-performing system. And further refinements on the secondary loop HEX side will continue to improve the primary heating performance.

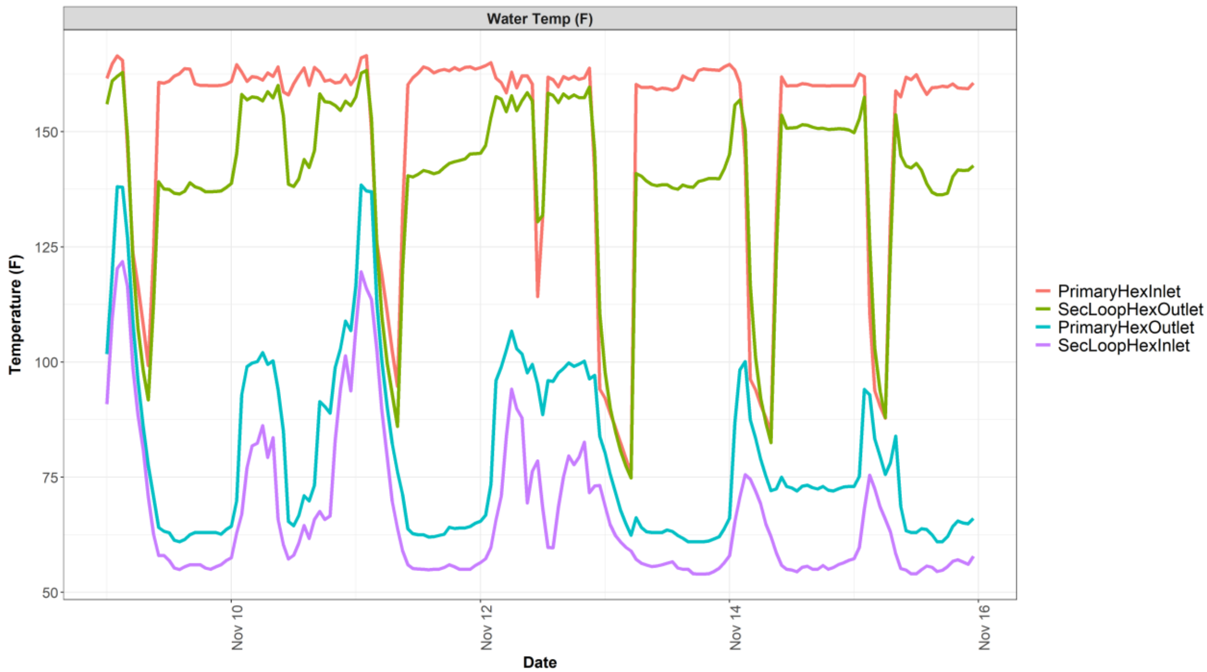

Figure 11. Detail of hourly inlet and outlet temperatures in November 2021

Overall, as will be discussed in the Performance and Energy Usage section, the CHPWH performed very well. The HEAT2O produced reliable 160°F water with inlet temperatures down to 60°F. System alterations were attempted to improve an already well-performing system. And further refinements on the secondary loop HEX side will continue to improve the primary heating performance.

Figure 12. Snapshot of temperatures in thermal storage system

PRIMARY STORAGE / STRATIFICATION

The primary storage for this system consists of three 285-gallon storage tanks (ST) piped in parallel for 855-gallons of thermal storage intended to work as a single stratified volume. Each tank has five temperature sensors installed at equivalent tank heights in each tank, which provides excellent insights into thermal storage.

The study team observed that the parallel-piped storage design worked well and delivered consistent hot water to building occupants, suggesting that well-designed parallel-piped storage approaches are viable in HPWH system applications. Figure 12 shows a snapshot of the thermal storage system as shown by the METUS control panel interface. Although the figure can only show one moment in time, the tank was observed to be well-balanced throughout the monitoring period. The system was also observed to be well-stratified. More detailed analysis on stratification is included in a separate report on thermal storage performance[iv].

Unfortunately, the bottom temperature sensors of storage tanks ST-2 and ST-3 did not give accurate readings but balancing and stratification could be determined from the 13 working sensors.

THERMOSIPHONING

High temperatures were observed in the thermistor recording the city water and water entering the primary storage at the skid. Temperatures as high as 145°F were observed at least once a day at the city water inlet at the skid, with temperatures up to 120°F detected at the city water sensor in the mechanical room. This appeared to be happening during periods of low flow, and it may be that hot storage water is

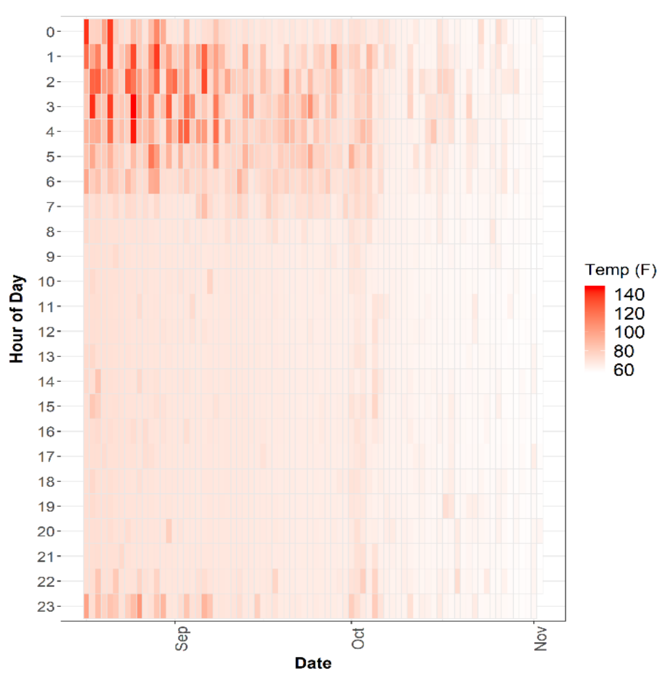

Figure 13. Peak water temperatures measured at the skid inlet

infiltrating the pipe where the sensor is installed, until cold incoming water (with increased DHW usage) flushes cooler water into the pipes. Figure 13 shows the daily trend of these temperature anomalies at the skid during early monitoring, and their co-occurrence during hours when there is typically little water use in multifamily buildings.

The parallel-piped storage design worked well and delivered consistent hot water to building occupants, suggesting that well-designed parallel-piped storage approaches are viable in HPWH system applications.

While this phenomenon decreased with system adjustments in October, and the study team determined that the daily temperature anomalies at the study site had negligible performance impact, future designs should incorporate check valves or heat traps on incoming cold-water lines to prevent thermosiphoning from hot water storage tanks.

HPWH Duty Cycle

The duty cycle of the HPWH is the sum of hours that the equipment is operational over a day. In the first several months of operation, several factors influenced a variable duty cycle. Initially, the average duty cycle for the HEAT2O was 11 hours per day. Typical manufacturer guidance is that systems should be designed such that equipment does not typically run for more than 16 hours per day. Over the course of this initial phase of monitoring, design day conditions or extreme cold conditions were not captured; however, during favorable ambient conditions, the system was operating at approximately a 70% duty cycle indicating an available capacity buffer for cold weather operation. Figure 14 shows the average temperatures from a nearby weather station (Boeing Field, King County International Airport).

Beyond ambient conditions, DHW usage in the building and operating mode will also influence equipment duty cycle. All three of these factors changed over the study period, and variable duty cycle is visible in Figure 15.

As daily temperatures changed and occupant water usage increased, additional system adjustments resulted in increased duty cycle to over fifteen hours per day. Since October 1, the average duty cycle has been closer to 19 hours/day.

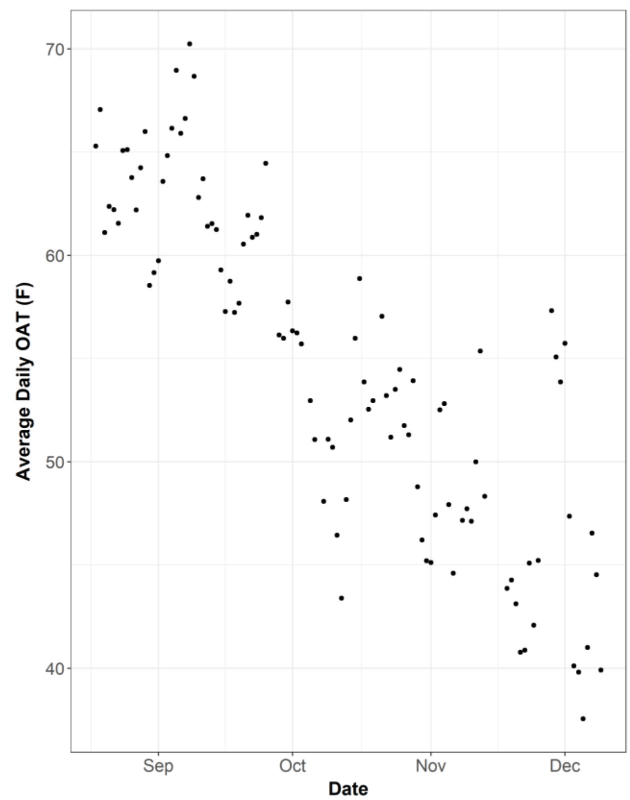

Figure 14. Average daily outside air temperature over the study period

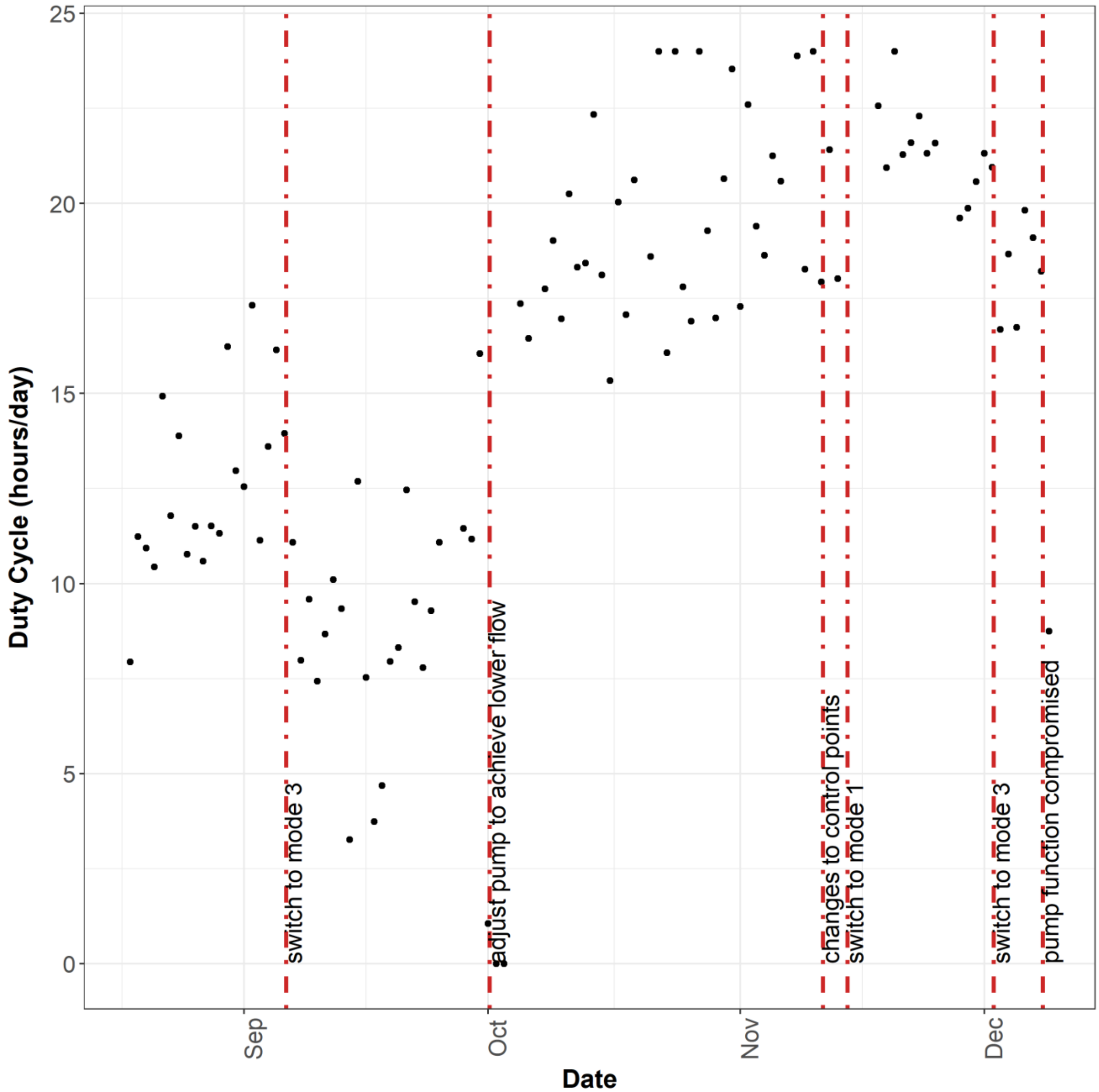

Figure 15. Daily duty cycle

Another way to measure equipment operation is to add up the cumulative hours of operation for a given heating cycle. While a sum-per-day will yield maximum run times of 24 hours, this alternative metric can reveal consecutive run times > 24 hours. As seen in Figure 16, multi-day heating cycles were observed in October and November.

Also, of note is the increased prevalence of short-duration (<2-hour) heating cycles. Those occurrences are an artifact of the heat pump briefly stopping operation when inlet temperatures exceeded 147°F.

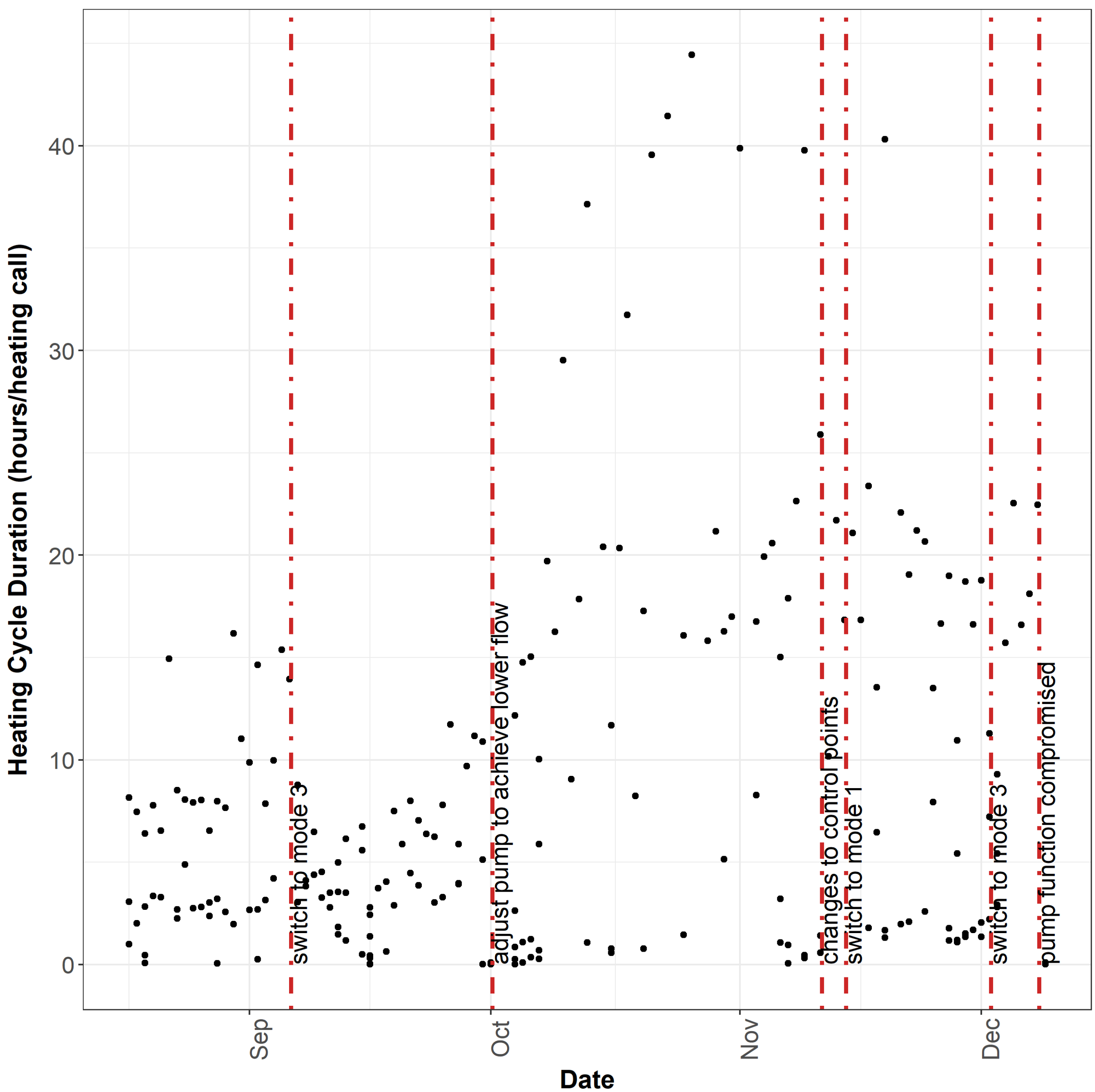

Figure 16. Heating cycle duration

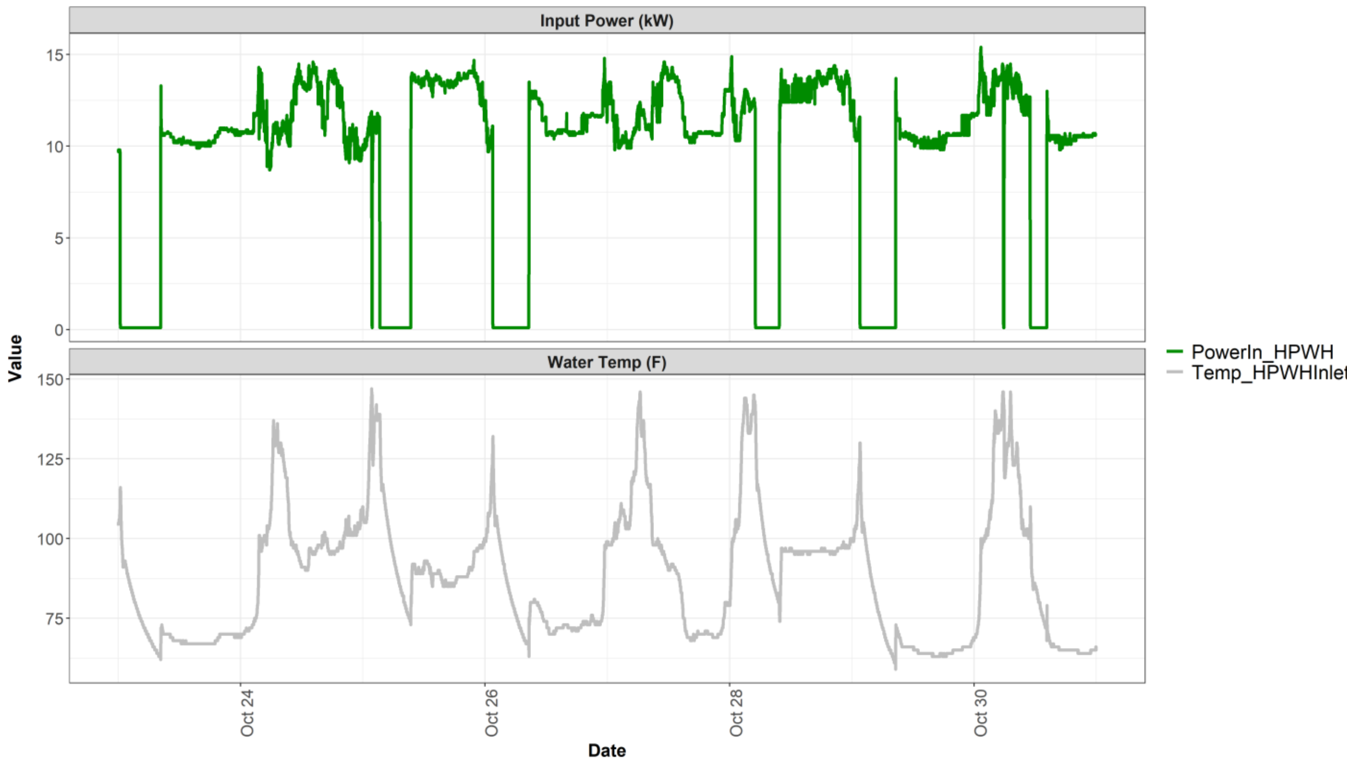

Figure 17. Heating cycle detail

Figure 17 shows both:

- Heating cycles > 36 hours of duration on October 23-25 and October 26-28
- HEAT2O stop-restart behavior the morning of October 25 and October 30, correlated with elevated inlet temperatures near the end of a heating call. Note, there are occasions when similarly elevated temperatures did not result in this behavior. In most cases, the secondary loop flow was also paused under these conditions, and it is possible that this was driven by secondary loop pump operation. The study team expects these instances to be resolved with the replacement pump.

From these early findings, it is clear that the HEAT2O has ample capacity to serve the water heating needs at this site during mild ambient conditions. Additional system refinements and cold-weather testing will be useful to understand design day operations and annual duty cycle operations.

From these early findings, it is clear that the HEAT2O is operating as expected with ample capacity to serve the water heating needs at this site during mild ambient conditions.

Swing Tanks

The swing tank concept relies on very hot water from the primary storage being drawn into the swing tank(s) as occupants use water in the building. This temperature-charged water is then tempered down for delivery to the recirculation loop. When hot water usage is low (typically during overnight periods), the swing tank can be cooled by returning recirculation water and some ER may be required until increased occupant usage brings in hotter water from the primary storage again.

Initial monitoring at the study site showed substantial ER energy usage and high temperatures at the MXV inlets. On-site investigations showed that the original ER setpoints were higher than necessary, and, in consultation with facility staff, the study team reduced the setpoints to ~120°F. Subsequently, ER usage was reduced and coincided with expected pattern of minimal support of the DHW load during periods of low DHW usage. This can be seen in Figure 18.

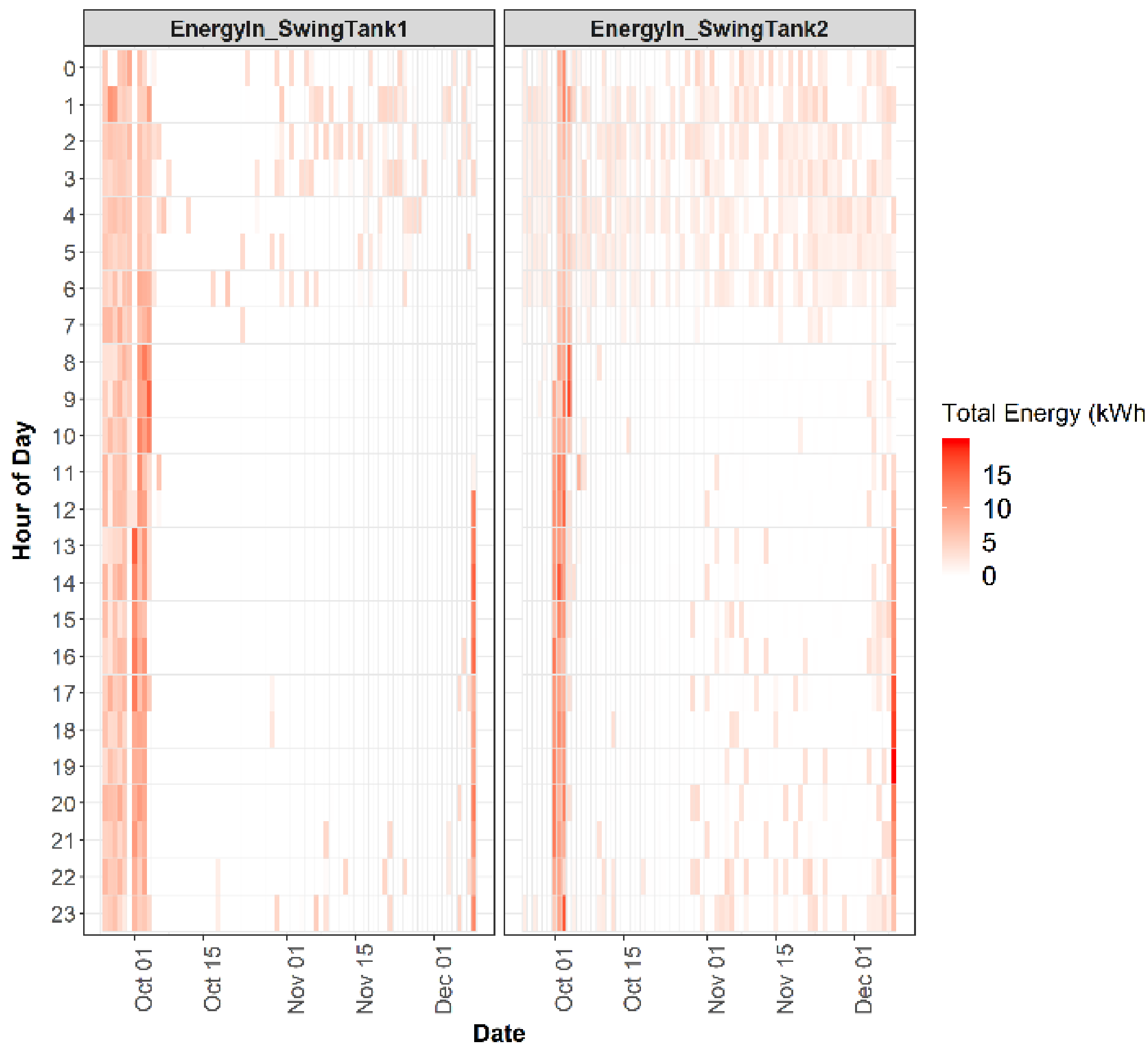

Figure 18. Total hourly electric resistance energy (kWh) for swing tanks 1 and 2

Early monitoring (in September) showed ER use during all hours (particularly in Swing Tank 1). Setpoints were reduced on September 30. Coincidentally, the secondary loop pump lost communications and the building's DHW needs were supplied solely by ER equipment over the weekend until the pump could be cycled – apparent in elevated usage throughout the day in both swing tanks. When the secondary loop pump was restarted, there was a more typical swing tank pattern of overnight temperature maintenance load support. These tanks have different total capacities (Swing Tank 2 > Swing Tank 1) and serve different zones within the building. In early December, the secondary loop pump went into error again, and we see the ER support increase at the end of monitoring. This gives us confidence that the existing ER capacity is adequate to provide full emergency back-up in the case of heat pump failure or maintenance.

Temperature Maintenance/Recirculation Losses

During early commissioning of the M&V data the study team noted several factors complicating accurate calculation of recirculation losses. This calculation requires three measurements:

1. Recirculation supply temperature
2. Recirculation return temperature
3. Recirculation return flow rate

The temperature drop across the recirculation loop and flow rate are used to calculate the energy losses in the distribution loop. These measurements were taken for each of the building's two recirculation loops and M&V data revealed two main concerns:

- While the flow rate returning to MXV 2 was fairly constant, about 13 GPM, the flow rate through MXV 1 was highly variable, from 12.5 to < 5 GPM. These fluctuations also coincided with the valve position in the MXV. When the valve was more closed there was a coincident flow rate reduction.
- The temperature drop across loop 1 was also highly variable and correlated with the flow fluctuations. Loop 2, on the other hand, had almost no temperature drop.

These issues meant there was very little confidence in an accurate recirculation-loss calculation. Temporary instrumentation and on-site investigation into original plumbing and pressure zone configuration was determined to be too time- and cost-intensive and of limited value to the project aims of CHPWH demonstration / operation and primary plant performance.

Temperature-maintenance losses are, however, an input into the calculation of the system coefficient of performance (SysCOP). Due to monitoring issues, an alternative calculation was used; this is discussed further in the Performance and Energy Usage section of this report.

Domestic Hot Water Load

Short-term monitoring in May 2020 was conducted in Bayview Tower in preparation for the design phase of the HPWH retrofit. It suggested an average daily hot water usage of 3,150 gallons per day (GPD) by building occupants. Initial findings from the current M&V project, suggest somewhat lower average water-usage of ~2,744 GPD or 18 GPD per person. Peak daily DHW usage (95^{th} percentile) values are closer to 21 GPD per person. Seasonal peak usage typically occurs over the winter months, so higher average and peak day usage may be observed during continued monitoring at this site.

Performance and Energy Usage

A primary aim of this M&V study was understanding the field performance of the Origin skid (including the HEAT2O and primary storage), which serves as the primary plant. SysCOP, is an important metric to understand, as it quantifies the performance of the entire DHW system, including temperature-maintenance losses, and provides a metric for comparing performance across different technologies, climates, and designs.

Due to monitoring issues on the recirculation loops at this site, an alternative calculation was used to arrive at SysCOP for this swing tank configuration. At Bayview Tower the majority of the DHW load (including recirculation losses) is intended to be served by the CHPWH, with minimal ER input. To determine what fraction of the system was being supported by the CHPWH versus the ER tanks, the CHPWH daily energy usage was divided by the total daily energy use of all components. This provided the proportion that was the CHPWH energy input, and one less that amount was the ER fraction. Estimated SysCOP is calculated as:

SysCOP_est = (proportion CHPWH * COP_PrimaryPlant) + (proportion ER * 1)),

where the electric resistance efficiency is assumed to be one.

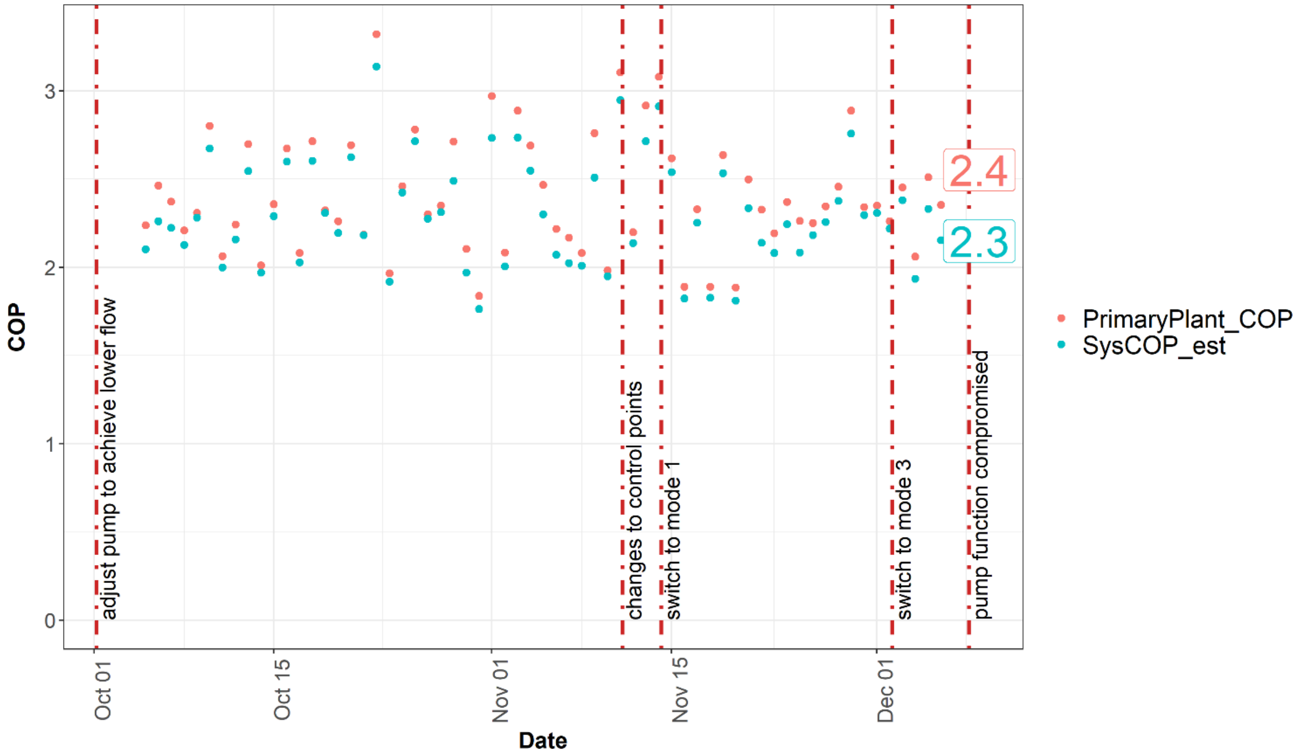

Figure 19. Primary plant and DHW system (estimated) coefficient of performance

The primary plant and estimated system COPs[4] after swing tank temperature settings were adjusted are depicted in Figure 19.

The average COPs were 2.4 for the primary plant and 2.3 for the entire system, demonstrating that the HEAT2O supported the primary heating needs and the overall DHW system load over two times more efficiently than the original ER DHW equipment (assuming perfect ER performance).

This phase of the monitoring was intended to determine initial operations and performance. With continued monitoring, annual estimates will be available once system refinements are finalized. For example, a replacement pump, which better matches the flow range achievable by the HEAT2O will allow for improved heat transfer to primary storage and increased primary plant performance. Based on these system changes, continued monitoring should be used to assess annual SysCOP at this site.

Energy usage

Overall DHW system energy usage is, of course, related to system performance. Reduced energy usage is also of interest to utilities (to manage peak demand) and to utility customers (to lower utility bills). The pump failure in early December 2021 meant

[4] Another approach using original distribution losses measured during the design preparation phase was attempted, but due to changes to the ER setpoints, and the addition of mixing valves (and the apparent influence on recirculation loop flow rates), the previously measured losses were not useful for retrofit SysCOP calculations.

that the water heating had to be switched to full ER heating until the pump could be replaced with a new part. Figure 20 shows the total daily DHW system energy usage compared to the daily HPWH energy usage.

There are two important takeaways:

- Over the study period (until early December), the ER energy draw was minimal (represented by the difference between the total energy less the HPWH energy usage). On average, ER was 8% of the total daily system energy usage.
- The average daily energy usage after the pump failure was 566 kWh/day versus 255 kWh/day over the study period – indicating the CHPWH operations offered an approximate 55% reduction compared to ER-only operation post-retrofit.

However, savings compared to the original ER DHW system is higher as two ER tanks were removed as part of the retrofit. DHW electrical usage monitored pre-retrofit showed average daily energy usage was closer to 630 kWh/day. Based on initial operations during the monitoring period, compared to the original ER system, preliminary savings at this site could be close to 136,875kWh/yr or $15,000/yr

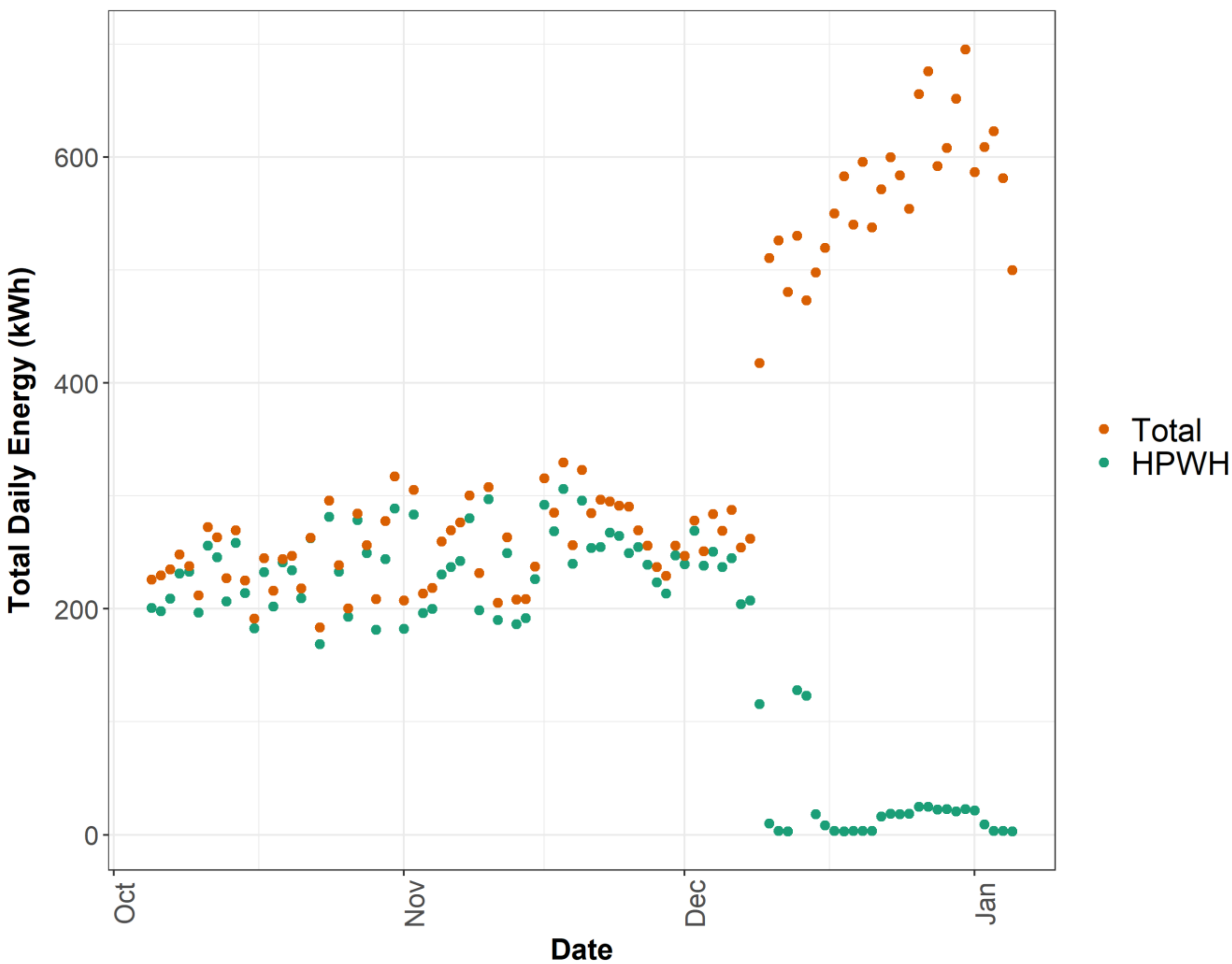

Figure 20. Daily total and HPWH energy usage

(assuming a residential electrical rate of $0.11/kWh). However, with the pump control topics addressed and the system operating as designed, increased annual savings may be achieved.

As more energy demands are placed on the electrical grid, efficient systems are an incomparable tool to meet utility peak demand reductions. Another grid management tool being piloted by regional utilities is the development of rate structures to encourage off-peak usage. DHW systems in multifamily buildings offer a tremendous resource for utility peak management, as the DHW load is typically 25% of total energy usage in multifamily buildings[v]. Known as load shifting, or demand response, customers with demand response-capable equipment can opt to receive utility signals that reduces or stops DHW system energy usage during peak demand/peak price periods for additional operational savings. The CHPWH system at Bayview Tower is demand response-capable and this added operational savings needs to be tested in a future phase of monitoring at this site.

The information collected at Bayview Tower has demonstrated successful deployment of the first HEAT2O and Origin skid. And a retrofit CHPWH system that is performing over twice as efficiently as an ER-only system.

Future Studies

The information collected at Bayview Tower has demonstrated successful deployment of the first HEAT2O and Origin skid. And a retrofit CHPWH system that is performing over twice as efficiently as an ER-only system.

Bayview Tower continues to offer important future study opportunities:

- Ongoing monitoring to verify annual performance and retrofit savings, including financial analysis of Origin retrofit projects.
- Collection of M&V data on freeze protection components will be important for understanding implications for cold-climate applications.
- Comparison of operations and efficiency with the replacement pump component.
- How continued refinements to controls improve system operation.
- Design and completion of testing to quantify added value from demand response capability.
- Exploration of thermal storage performance during load shift testing.

The system at Bayview Tower offers a unique opportunity for field testing load shift controls, and these last two topics are of particular importance in understanding and optimizing load shift protocols for CHPWH systems.

Conclusion and Recommendations

Valuable information was gained from the first five months of operation, from August to December 2021:

- Based on initial findings, the installed CHPWH system reduced the DHW energy usage at Bayview Tower by approximately 55% demonstrating that HPWHs are a valuable energy efficiency measure.
- Increased performance and savings may be achievable once the pump control issues are resolved with a replacement part.
- Fully packaged CHPWH skid products are an easily implementable retrofit solution and can significantly speed up on-site construction times.
- Well-designed parallel-piped storage designs are viable in CHPWH system applications.
- M&V helps field demonstration projects identify issues early and provides valuable feedback on system operation for site operations, as well as product and design development.
- M&V can be successfully integrated into manufacturer's product offerings.
- Certain system design elements, such as secondary loop heat exchangers, may require post-installation refinements. This may extend the commissioning period, but these activities benefit performance optimization.
- Careful consideration of on-site conditions is important for retrofit projects to be completed with minimal disruption to tenants.

Based on early operations at this site, the study team has the following recommendations:

- Early in the monitoring period, the study team communicated initial secondary loop pump operations issues to the manufacturer. As a result, the METUS team has conducted applications testing on alternative pumps for inclusion in their packaged product.
- Given the secondary loop pump failure, continued monitoring at this site post-pump replacement will be valuable to understand operations with a pump that is intended to better match the HEAT2O flow range.
- With this update, continued testing and refinements of heating modes at this site may improve typical performance and overall retrofit savings.
- Component updates are also anticipated to improve the system's operations and load shift capabilities. For example, more efficient heat transfer to storage may reduce equipment duty cycles, and create the conditions for more optimal thermal storage, allowing more of the DHW load at Bayview Tower to be shifted to off-peak hours.
- As discussed in the Future Studies section, the CHPWH system and integrated load-shift capabilities offer a unique opportunity for further studies at this site.

Works Cited

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Appendix A

Event	Year	Month	M&V Observation	Event Cause	Resolution
1	2021	Aug 5	HEAT2O operations initiated in Mode 1[5] after mixing valves are installed.		
2	2021	Sept 8	In Mode 1 HEAT2O observed to be processing high inlet temperatures. Decision to test another operating mode.	N/A	Study team shifted operation to Mode 3.
3	2021	Sept 20	Power metering incomplete. Not all data channels had data present.	Likely incomplete set-up initially.	Study team visit site to resolve power metering issues.
4	2021	Sept 21	Heat exchanger outlet temp noticeably lower than HPWH outlet temperature in Mode 3 operation.	System operation refinements required.	Study team increases heat exchanger set point. Additional pump adjustments occurred through 9/30.
5	2021	Aug-Sept	Hot inlet to mixing valves determined to be higher than necessary.	High set-points on electric resistance swing tanks.	Study team decreased swing tank set points on 9/30.
6	2021	Sept 30	Secondary loop pump stops operating.	Pump error indication lost communications.	Study team visit site with pump service tech staff to re-start and re-configure pump on 10/6.

[5] More information on heating Modes can be found in Appendix B.

7	2021	Nov 12	Study team observes large temperature run-ups in HEAT2O heating cycles.		Study team works with Mitsubishi to edit the operating mode temperature differentials to reduce temperature run-ups.
8	2021	Nov 15	N/A	N/A	Study team switches to Mode 1 operations with new control point temperatures.
9	2021	Dec 3	Although reduced, some high inlet temperatures still observed at end of HPWH heating cycles.	N/A	Study team switches to Mode 3 operations with new control point temperatures.
10	2021	Dec 8	Secondary loop pump stops operating.	Pump error indicates lost communications.	Facility staff cycle power to the pump on 12/13. System resumes operation.
11	2021	Dec 14	Secondary loop pump stops operating.	Pump error indicates lost communications.	Study team contacts manufacturer and determines pump should be replaced.

Appendix B

Sequence of operations control points and temperatures for original and current controls settings.

Original Settings		
	ON Sensor/F	OFF Sensor/F
Mode 1	Mid-16/81	Low-17/135
Mode 2	Mid-16/120.6	Low-17/135
Mode 3	High-15/120.6	Mid-16/135
Current Settings		
	ON Sensor/F	OFF Sensor/F
Mode 1	Mid-16/101.4	Low-17/105
Mode 2	Mid-16/107.6	Low-17/109.4
Mode 3	High-15/122	Mid-16/122

The high-, mid-, low- locations are approximate. In the storage configuration at Bayview Tower, these correspond to:

- High = 82% up storage volume
- Mid = 11% up storage volume
- Low = in storage outlet pipe

A reduced Mode 1 THERMO-OFF setting of 95°F was attempted in the current settings, but the HEAT2O logic would not accept a setting that low, so 105°F was used.