BONNEVILLE POWER ADMINISTRATION

Emerging Technologies

Mitsubishi QAHV Load Shift Feasibility Study

February 2022

Mitsubishi QAHV Load Shift Feasibility Study

Prepared for

Karen Janowitz, Project Principal Investigator

Washington State University Energy Program on behalf of Bonneville Power Administration

Prepared by

Scott Spielman

Ecotope Inc.

The following report was funded by the Bonneville Power Administration (BPA) to assess emerging technology topics that have the potential to increase energy efficiency. BPA is committed to identify, assess and develop emerging technologies with significant potential for contributing to efficient use of electric power resources in the Northwest.

ABSTRACT

This Feasibility Study focuses on load shifting with the packaged Mitsubishi QAHV CO2 HPWH system which includes heat pumps, thermal storage, and controls. Control strategies, pilot project testing, and results from an Ecosizer Analysis are discussed. The QAHV uses both built-in equipment controls and a custom Mitsubishi control board to accomplish the necessary flexibility for load shifting. The pilot project will test the system's ability to shed load during morning and evening peaks, operate to optimize COP efficiency, and respond to CTA-2045 demand response requests. CTA-2045 is an open platform defining a port and machine-to-machine communication for utility signals to appliances. The importance of using CTA-2045 for demand response, how the QAHV demand response system is set up, and how it reacts to demand response requests are included. Lastly, back-end Ecosizer code was run parametrically to investigate how a QAHV system, with one or two heat pumps and thermal storage, could support load shifting in multifamily buildings with more than 50 apartments. The Ecosizer is a web calculation tool, developed by Ecotope, to size heat pump water heating systems. The exercise initiated a load shape modification to improve Ecosizer load shift sizing methodology. Engineers using the Ecosizer to estimate load shift volumes will now be provided a less conservative tank volume that will still consistently provide load shifting but reduce installation cost.

Table of Contents

Table of Figures

Acronyms

DHW- Domestic Hot Water

OAT – Outdoor Air Temperature

HPWH – Heat Pump Water Heater

EAT – Exhaust Air Temperature

IWT – Incoming Water Temperature

COP – Coefficient of Performance

DR – Demand Response

SGD – Smart Grid Device

UCM – Universal Communication Module

Background

Each of the following topics provide a context for the importance of developing a load shift capable QAHV system that communicates through a CTA-2045 interface.

Market Landscape

For over 100 years, customers in the United States have used electricity with the expectation that the grid will always provide power, regardless of time of day or amount of use. As the United States population grew through the early 20th century, electric energy usage increased. In early years, abundance of fossil fuels drove down electric costs and many users where encouraged by utilities to increase their usage. The Reddy Kilowatt character was created in the 1920s to assure customers that electricity would always be available. Utilities would add generation resources to meet the demands of their customers, regardless of the amount or time of use. However, fossil fuel availability is linked to cheap electricity, and in the 1960's utilities began incurring increased cost from capital investments and higher fuel costs. Peak loads continued to rise, and utilities began to look to load management to reduce costs.[1] Load management strategies included both total energy use reduction and peak load reduction by shifting when energy is used – also called load shifting or demand response.

A peak load is the electrical load the utility must supply during the highest demand time of day. For example, in California a peak load occurs during summer afternoons when AC systems are working hardest. In the PNW, a peak load occurs on winter mornings, when buildings are warming up for occupants and residents are using hot water to shower. During peak hours, peaker power plants must turn on to meet demand. Operating peaker plants is expensive and CO2 intensive. Reducing the use of peaker plants is both financially and environmentally beneficial. Shifting load from one time of day to another is a way to reduce peak loads and minimize the use of peaker plants. This is called load shifting.

A need to load shift to periods of surplus renewable energy production will be the defining feature of the 21st century electric grid.

In the future load shifting will not only be used to reduce the use of peaker plants. A need to load shift to periods of surplus renewable energy production will be the defining feature of the 21st century electric grid. Today, renewable energy and the Internet have created a landscape that demands and will allow for wide scale adoption of load shifting. The inherent variability of renewable energy will require extensive energy storage systems. For example, energy storage systems can load up during peak solar hours and discharge energy back onto the grid after the sun has set. Similar, storage can charge at night during heavy wind, and discharge the next morning residents are using hot water for morning showers. The internet will allow nearly instantaneous communication from utilities to remote equipment and for widespread, on demand, energy storage.

By mid-century, to meet electric demand with renewable energy, many electric loads and distributed generating devices must become *alonetic*, meaning to support the larger electric grid network. Alonetic devices, along with grid scale energy storage systems, will provide flexibility needed to meet future demand with renewable energy.

Domestic Hot Water Load-Shifting

Domestic hot water (DHW) is one of the largest energy uses in residential buildings and its energy use is relatively constant throughout the year, making it an ideal source for shifting during all seasons. Load shifting with DHW thermal storage is not a new concept. In the 1960s, Michigan electric utilities installed time clocks on water heaters to turn off electric resistance elements during four daily peak load periods.[2]

From 2015 to 2018 Bonneville Power Administration (BPA) and Portland General Electric (PGE) performed an innovative pilot project by equipping unitary single-family waters heaters with demand response capability. The study focused on demand response using a CTA-2045 interface and found that 26.9% market adoption by 2039 would create and energy source equivalent to a 301MW peaking plant.[3] CTA-2045 allows utilities to send signals directly to remote equipment and is described in detail under the section *Importance of CTA-2045*.

In commercial buildings, well-designed packaged DHW systems, like the QAHV packaged system, can store large amounts of energy at a relatively low cost. The ability to store energy, when combine with appropriate controls, gives the system the ability to load shift. Water heating is the largest energy use in multifamily new construction buildings in the PNW and central systems allow for investment in advanced controls to enhance load shifting capability.

Economically, DHW has some advantages over other sources of energy storage. High temperature lift could allow it to be far less expensive, per kWh stored, than traditional battery storage. Additionally, the simplicity of thermal storage tanks means they require minimal maintenance, have nearly infinite cycle lives, and should last over 30 years. By comparison, lithium-ion batteries require temperature and depth-of-discharge control to maximize cycle life. Even with additional maintenance and controls, grid-scale lithium-ion batteries may only last 7-10 years.[4] Grid-scale battery systems almost certainly have a place in solving the 21st century grid. However, domestic hot water thermal storage offers a more economical energy storage solution for a significant portion electric demand.

QAHV Packaged System

A feasibility study, performed on the QAHV Heat Pump Water Heater, was published in June of 2020.[5] Since then, Mitsubishi has been working with Ecotope toward creating a packaged system for DHW heating. A QAHV packaged system will include all the parts and controls necessary for a fully functional central HPWH system. Figure 1 shows the major components and connections needed.

The QAHV packaged system is being developed with integrated controls for load shifting. This feasibility study focuses on load shifting using the QAHV packaged system. A pilot project in Seattle Washington, planned to be the first QAHV installation in the United States, will test QAHV load shifting on a 100-unit apartment building.

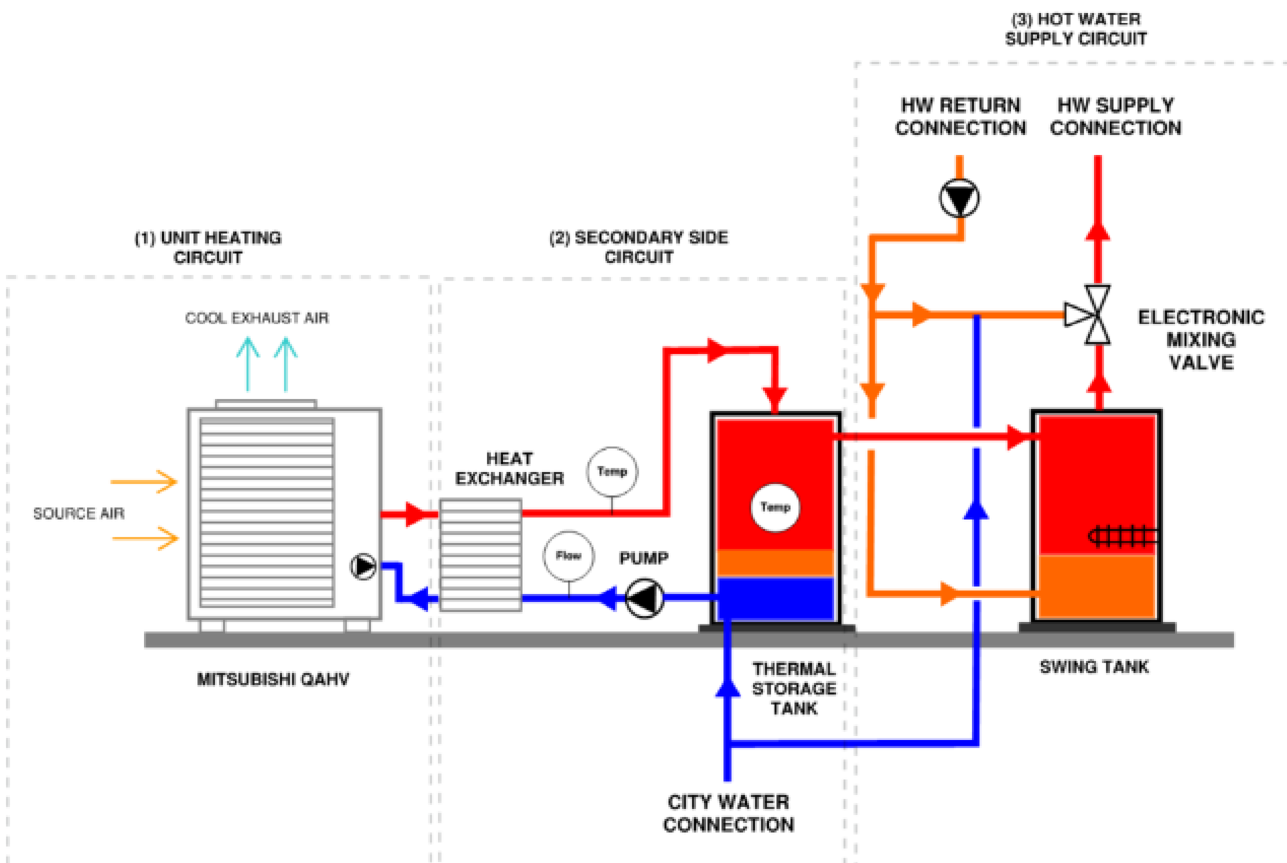


Figure 1. QAHV packaged system

Importance of CTA-2045

The market for demand response is defined by over 2,000 utilities and ~40 major appliance manufacturers. A single, open standard, allowing utilities to communicate directly with equipment within their service territory, is critical for cost effectiveness and customer experience. Without this, fewer flexible loads will be part of demand response programs.

A single, open standard, allowing utilities to communicate directly with equipment within their service territory, is critical for cost effectiveness and customer experience.

CTA-2045 refers to a standard published by the Consumer Technology Association (CTA) and double-listed by the American National Standards Institute (ANSI). It defines a device-to-device interface, like a USB connection, that allows for communication between a Smart Grid Device (SGD), referred hereinafter as a smart device, and a Universal Communication Module (UCM), referred to hereinafter as a CTA-module. Figure 2 below shows a CTA-Module from SkyCentrics – AC CTA-2045 USNAP Wifi Module. The port and method of passing information from the CTA-module to the smart device are defined by CTA-2045.

Figure 2. AC CTA-2045 USNAP WiFi module Courtesy of SkyCentrics

This approach has several advantages:

- Defining the port and method of passing information to the smart device allows for any form of external communication to be used. The utility can decide between Wifi, Zigbee, 4G LTE, Z-Wave, Bluetooth, FM broadcast, or any future method how it wants to communicate with the CTA-Module. Similarly, the service provider can choose any DR language – OpenADR, BacNet, SEP 2.0, etc.
- It puts the service provider and customer, not the manufacturer, in charge of how communication with the smart device occurs.
- It will never become obsolete. The open standard will work the same in 20 years as it does today. The customer may change the CTA-module, but the smart device will receive the same signals and respond the same way to grid requests.
- A single standard means CTA-modules can be produced in volume to lower prices.

Control System

To provide alonetic, grid-interactive response, the QAHV needs heat pump controls that can be adjusted, logic to adjust heat pump controls based on a grid signal, and a device to interface between the heat pump and the grid.

The two sections below address heat pump controls and the Skycentrics CTA-2045 interface between the heat pump and grid. The SkyCentrics CTA-2045 interface contains logic to adjust heat pump controls. Several logic schemes will be analyzed during pilot testing. The Pilot Study section describes these potential strategies.

Heat Pump Controls

QAHV controls can adjust staging, heat output, and temperature setpoint. As part of the product launch, Mitsubishi has developed an additional control board, (the Mboard), that will be used for control of auxiliary system components, system monitoring, and load shifting. Some control features are initiated through internal QAHV controls; others are signaled by the Mboard.

Staging adjustment is done by altering the sensor location in the thermal storage used to initiate operation of the heat pump. Three thermistors in the thermal storage system are wired directly back to the QAHV and used to set a Thermo-ON and Thermo-OFF position. The QAHV can be programmed with a maximum of three modes, allowing for different Thermo-ONs, Thermo-OFFs, and temperature differentials. In Figure 3 TH15 is the temperature sensor used for Thermo-ON

QAHV controls can adjust staging, heat output, and temperature setpoint.

and TH17 is Thermo-OFF. The water heater will engage when TH15 drops below the Set Water temperature minus the Thermo Differential Value and Stop when TH17 reaches the Set Water Temperature. Set Water Temperature should not be confused with Setpoint temperature. Set Water Temperature is the temperature at which the unit will shut-off. Setpoint Temperature is the temperature of the hot water produced by the QAHV.

The QAHV can provide heating output capacity at three settings: 40 kW, 50 kW, and 60 kW. Varying unit output capacity also varies its electrical consumption. Internal QAHV controls use this capacity control for *Peak-Demand Control Operation*. However, when sufficient thermal storage is

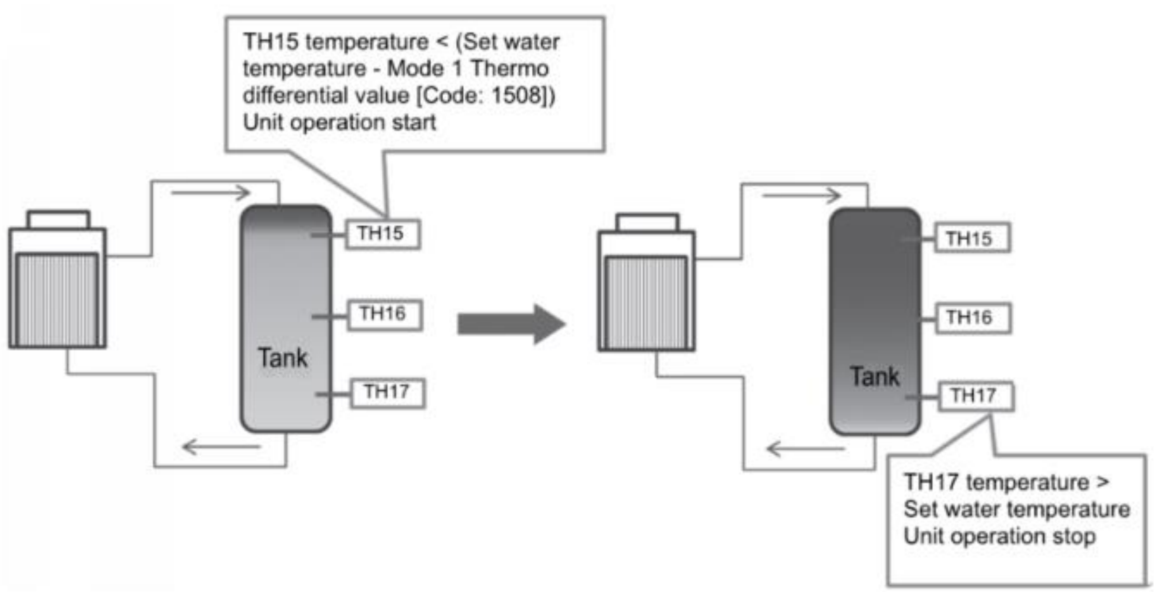


Figure 3. QAHV control mode example

provided, Demand-Control can and should be done with staging adjustments, not capacity adjustments. Using staging adjustments will prevent the unit from turning on entirely during shed events. Therefore, output capacity adjustment in the QAHV will be engaged through logic built into the Mboard and it will not use built in *Peak-Demand Control Operation*. Capacity setting changes are used to both increase tank charging speed during load up and when the storage tank is low on hot water to prevent the system from being depleted.

Setpoint Temperature can be adjusted through the Mboard. However, because the QAHV packaged system uses a common heat pump configuration called a "swing tank"[6] (see Figure 1), increasing temperature setpoint does not have the same effect on load shift capability as it would in other configurations. Water draw from the thermal storage tanks heats up the swing tank. Therefore, increasing the thermal storage tank setpoint will provide additional heat to the swing tank. This will offset recirculation losses, but not significantly increase load shifting capability. In a swing tank system, thermal storage should be kept as hot as possible without reducing equipment COP to offset recirculation losses.

SkyCentrics CTA-2045 Interface

The SkyCentrics CTA-2045 interface consists of two parts: (1) A control board plugged into the Mboard, referred to hereinafter as the Sboard, (2) a CTA-module.

The Sboard provides logic to convert CTA-2045 signals into actionable commands for the QAHV to carry out. A preliminary version of this logic is described in the controls sequence outlined in Appendix A. Those actionable commands are then sent from the Sboard to the Mboard. The Sboard contains all the logic to decide whether or not the QAHV system can comply with a grid request. In the future, Mitsubishi will develop their own version of the Sboard. However, for pilot testing it was determined that SkyCentrics could more quickly produce this interface. The Sboard is what makes the QAHV system a smart device. It allows for the QAHV system to read in utility signals and determines how to act upon those signals.

The CTA-Module and Sboard together create a complete interface between the QAHV controls and the SkyCentrics cloud. From the SkyCentrics cloud, utility requests can be sent directly to the QAHV. The Sboard then interprets those signals, determines what control changes must be made, and relays the commands to the Mboard. The Mboard then relays those commands to the QAHV system. The figure below is a diagram on the QAHV pilot system for demand response communication.

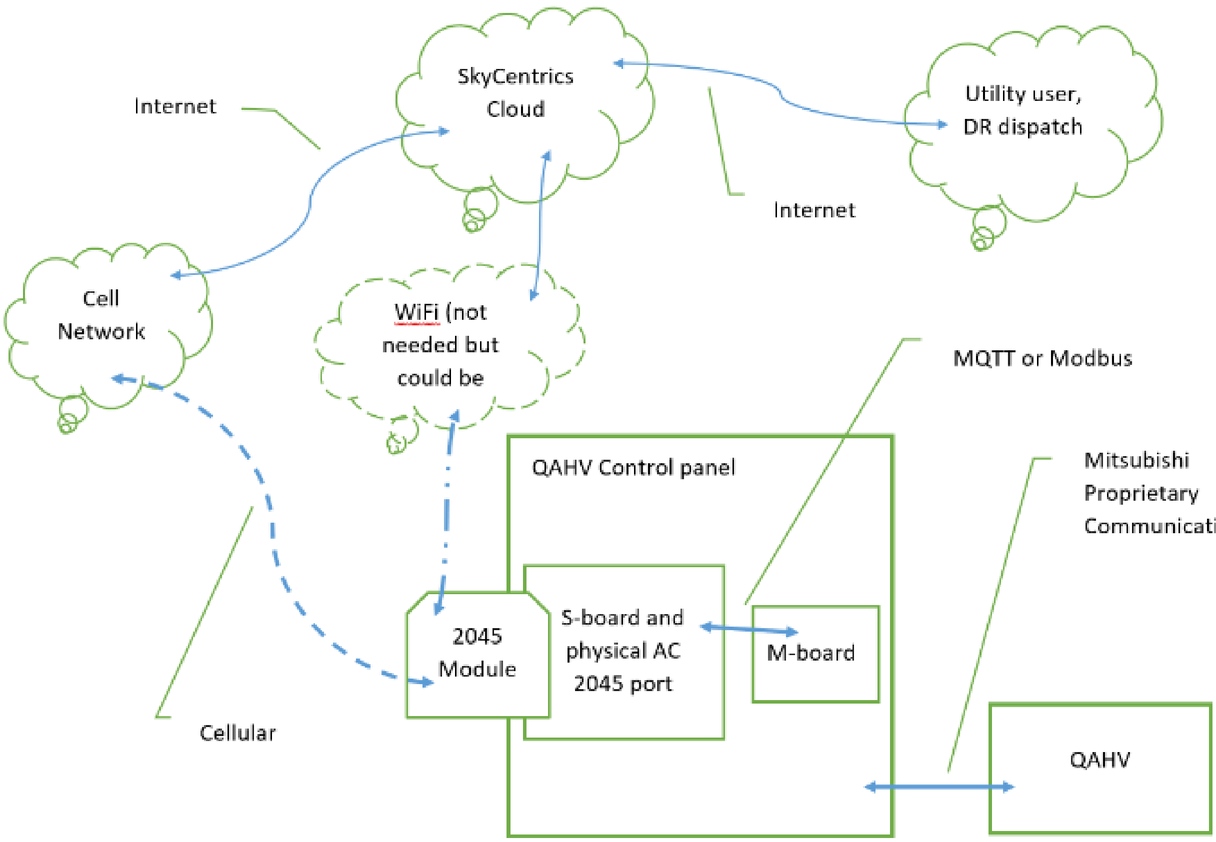


Figure 4. Demand response communication diagram

Pilot Study

During the pilot study, several control strategies will be tested to explore demand response using the QAHV system. First, standard operation will be used as a control for experimentation. Then the team will test methods for operating the unit to optimize grid peak demand. Then the team will test operating the unit to maximum efficiency based on outdoor air temperature. As a last step, using the SkyCentrics Cloud to send CTA-2045 grid requests will be tested.

Standard Operation

The pilot project will use standard operation as a control for observing load shifting capabilities. During standard operation, the unit will function similarly to other heat pump water heaters designed by Ecotope. A single aquastat (AQ) will initiate the unit to start. The unit will run until the tank is filled with hot water. The AQ, or Thermo-On, will be located 30% up the tank volume.

Standard operation has several disadvantages. The storage tank will always be kept hot, increasing thermal losses to ambient air and the unit will naturally turn on during morning and afternoon, times which may correspond with utility peaks.

Daily Grid Shift

To accomplish a daily, grid-friendly, load shift, the QAHV will operate on a set schedule to load up every day before morning and evening peaks and turn off during those peaks. This operation aims to reduce morning and evening utility peaks, prove the future need to absorb energy during mid-day PV generation, and demonstrate the design storage volume's ability to handle shifting daily in both morning and evening.

Storage volume at the Seattle Pilot Project has only been sized to fully handle evening load shifting (see appendix C for sizing summary based on meter data). However, load shifting is still possible during morning hours. If the tanks become depleted during a morning load shift, the QAHV will simply break its shed state and turn on to fulfill the hot water needs of the tenants later in the day.

Three Daily Grid Shift options will be tested: Morning only shift, Evening only shift, and Morning and Evening shift. Testing all three operations will give the team an understanding of the different volume requirements for each shifting scenario and the ability of the system to recover.

Diurnal COP Optimization

The third test, Diurnal COP Optimization, will aim to operate the unit during the warmest outdoor air conditions. Up to a certain temperature, HPWH efficiency is correlated with outdoor air temperature. So, at higher outdoor air temperatures the unit should operate more efficiently. Pairing a piece of equipment, like a heat pump, with thermal storage to allow it to operate under the most favorable outdoor air conditions is called *Diurnal Storage*[1]. This test will operate the HPWH as if it is connected to a diurnal storage system. The tank be charged as much as possible between 10am and 6pm. During all other hours, the unit will operate as little as possible. Ecotope anticipates Diurnal operation will be most effective in high desert climate were temperature swings are large throughout the day. In Seattle, little efficiency increase is expected from this operation, but it will be tested to demonstrate functionality.

Unfortunately, with Diurnal COP Optimization, the HPWH will likely turn on during morning and evening peaks. The pilot project storage volume is not sized large enough to allow for both Daily Grid Shift and Diurnal COP Optimization.

Testing Diurnal COP optimization will allow the team to compare energy savings from operating the unit during the most favorable outdoor air conditions with energy increase from loading up the unit before morning load shifts.

Demand Response Testing

After testing the system's ability to provide Grid Shifting and Diurnal COP Optimization, the team will test the system's ability to receive signals directly from the utility. As described above, the QAHV has been designed with a custom control board that

[1] Siegenthaler, J. (2017). *Heating with renewable energy: Practical, hydronic-based combisystems for residential and light commercial buildings* (pp. 556-560). Stamford, CT, USA: Cengage Learning.

allows for a SkyCentrics CTA-2045 plug in. The preliminary controls sequence in Appendix A describes how the unit will respond to each signal.

In the future, after Mitsubishi moves through a product launch, energy codes adopt the use of heat pumps for multifamily hot water heating, and the QAHV is installed at sites around the country, demand response with CTA-2045 will likely be the primary means of load shifting. Demand response allows for each utility to operate the QAHV system as it sees fit to meet its needs. For one day the utility may choose to charge the tanks overnight using excess wind energy, while on the next day the tank is charged during peak solar hours. The flexibility allowed through CTA-2045 demand response will significantly increase the system value to
the utility.

Ecosizer Analysis

Ecotope used Ecosizer back-end code to plot sizing for QAHV systems in four climate zones
on the West Coast. When designing with the QAHV, engineers should run their specific design conditions on the Ecosizer website, and not base sizing off these results. Results were used
to assess how thermal storage and heat pump capacity interact in projects with and without load shifting.

Mitsubishi plans to offer three standard tanks sizes – 175-, 285-, and 500-gallon. However, the 175-gallon tank will mostly be used in retrofit projects and not new construction. Thermal storage will consist of up to three tanks piped in parallel to increase stratification. Ecosizer analysis determined the maximum number of apartments that could be served using 285- and 500-gallon tanks for no load shifting, morning load shifting, and evening load shifting in climate zones 3B, 3C, 4C, and 5B. A full table of findings is included in Appendix B. High level findings are included below:

- In most cases, evening load shifting can be applied without increasing storage volume.
- Morning load shift requires a storage increase of approximately 5 to 6 gallons per apartment. Pressurized thermal storage typically costs between $15 and $25 per gallon. Therefore, designing for morning load shifting in 100-unit apartment will add approximately $15,000. However, some amount of morning load shift can be applied without increasing storage volume.
- Up to three 500-gallon tanks (1,500 gallons of storage), is well-suited to pair with two QAHV and serve most multifamily buildings. In climate zones 3B and 3C up over 200 units and in 4C and 5B about 130 units could be supplied hot water and provide evening load shifting. Only in very large buildings, where morning load shift is desired, is more than 1,500 gallons of storage required. 2,000 gallons could be used to provide morning load shifting for 180 apartments in 3B and 3C.

Ecosizer Update

The Ecosizer[7] originally used overly conservative methods for load shift sizing. The analysis reported in Appendix B used a modified load shape to represent a more typical day instead of a day with unusually heavy use in the mornings and evenings. This resulted in a 400-gallon reduction when providing morning load shifting for 150 apartments corresponding to about a $10,000 cost reduction. Ecotope has determined the new methodology will provide sufficient sizing at a reduce cost and plans to integrate it into the Ecosizer website.

When functionally sizing a system, to ensure tenants will always have hot water, it is important to size conservatively. However, thermal storage can be costly, and having a sizing methodology that is too conservative may lead projects to install unnecessarily large and expensive thermal storage systems. Additionally, the increased size may cause building owners to choose not to design for load shifting or avoid load shifting all together.

In the Ecosizer, two inputs are used to size a system: (1) an hourly load shape and (2) daily total usage in gallons. The hourly load shape is used to account for variation in hot water usage throughout the day. The more peaky the shape, meaning more water used during peak usage hours, the more thermal storage is needed to consistently provide hot water to the building. When sizing a system, to be conservative, the most peaky load shape is used coincidently with the highest volume day. This design point is referred to as the sizing design day.

Originally, the Ecosizer used the sizing design day for sizing load shifting as well. Users are given the option to adjust a slider for "Percent of Load Shift Captured". However, the slider only adjusts for design day water usage volume and does not adjust load shape. Ecotope's analysis of metered data found that there is significant difference between load shapes for the

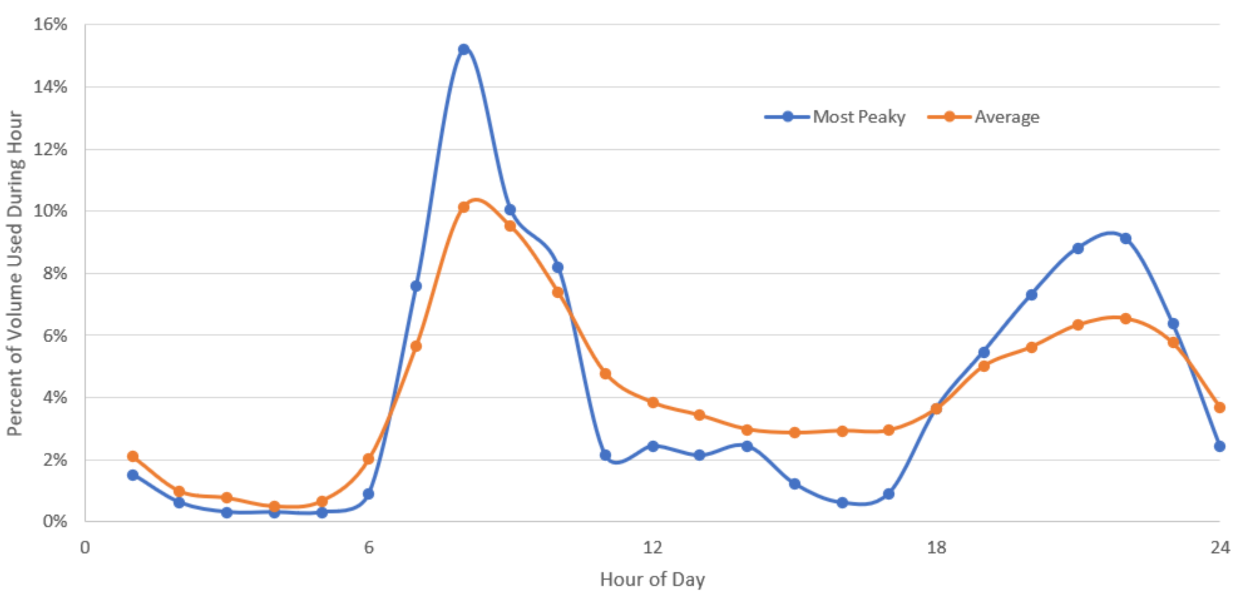


Figure 5. Multifamily hot water usage load shapes, most peaky vs. average.

design day and average day. The most peaky and average load shapes are shown in the figure below.

To reduce oversizing for load shift, the average load shape is used instead of the most peaky load shape. This design point is called the load shift design day.

Ecotope created the factor "peak norm" to compare load shapes from metered data while developing the Ecosizer. The peak norm is the fraction of total volume used during the three hours of heaviest use. It can be used to compare the peakyness of different load shapes. The figure below illustrates how sizing changes relative to the peak norm.

Each blue dot is a data point, collected at one of Ecotope's metered sites. The x-axis is the total number of gallons used on that day, and the y-axis is the peak norm for that day. The design point in the top right corner is what Ecotope uses to conservatively size systems with the Ecosizer. However, for reasons discussed previously, a less conservative approach is needed for load shifting. By changing the load shape, the load shift design day was moved down to the center right. By changing the load curve used in load shift sizing, the peak norm drops from ~0.5 to ~0.35. The slider on the Ecotope site will now cut directly through the center of the data collected, and more accurately depict the percent of days captured.

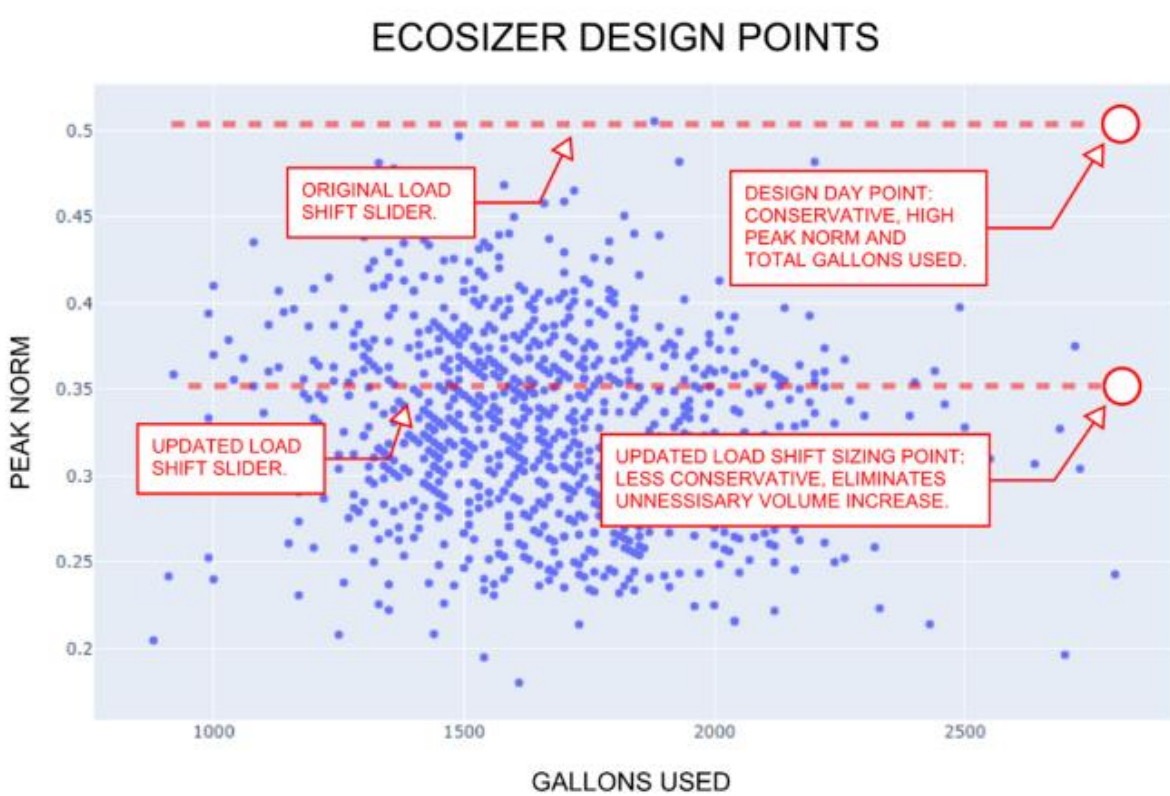


Figure 6. Load shift sizing design point change

Conclusion and Recommendations

As stated previously, load shifting will be a defining characteristic of the 21st century electric grid. To overcome future energy challenges, including electrification and adoption of renewable energy, *when* energy is used will become increasingly important. Domestic hot water systems, because they require built in, energy-dense thermal storage, are ideal for load shifting.

The QAHV packaged system being developed by Mitsubishi and Ecotope will provide load shifting controls through CTA-2045. The Seattle pilot project will be used to test load shifting control strategies in a real world setting and set the stage for adoption of CTA-2045 grid-integrated central heat pump water heating.

The future is bright for demand response, but many challenges remain. Ecotope can play an important role in helping to bring load shift capable products to market and develop algorithms to control those products based on CTA-2045 utility signals. Thought must be put into developing robust controls for activating demand response resources to get the most value out of the investment. With connections and expertise in engineering, product development, and utility needs, Ecotope is well-suited to play that role.

Works Cited

[1] Eckert, Andrew, 1983, Load Management – Methods to Reduce Electric Utilities Peak Loads. University of Florida.

[2] Ibid.

[3] Bonneville Power Administration, 2018, "CTA-2045 Water Heater Demonstration Report Including a Business Case for CTA-2045 Market Transformation", *BPA Technology Innovation Project 336*, https://www.bpa.gov/EE/Technology/demand-response/Documents/20181118_CTA-2045_Final_Report.pdf.

[4] Smith, K., Saxon, A., Keyser, M., Lundstrom, B., Cao, Z., and Roc, A., 2017, "Life Prediction Model for Grid-Connected Li-ion Battery Energy Storage System", NREL, 2017 American Control Conference, Paper No.NREL/CP-5400-67102.

[5] Spielman, S., Grist, C., and Heller, J., 2019, "Mitsubishi QAHV CO2 Heat Pump Water Heater Feasibility Study", Prepared by Ecotope for BPA.

[6] Kintner, P., Banks, A., Spielman, S., Grist, C., and Heller, J., 2020, "Manual: Ecosizer – Central Heat Pump Water Heating Sizing Tool," https://ecosizer.ecotope.com/static/pdfs/ecosizer-chpwh-sizing-tool-manual.pdf, Ecotope.

[7] Ibid.

Appendix A

Bayview Tower – Heat Pump Water Heater Retrofit

SECTION 23 0994

CONTROLS SEQUENCE

PART 1 - GENERAL

1.1 SUMMARY

A. The domestic hot water heating system retrofit is comprised of existing electric resistance water heaters, used as swing tanks, and the new Mitsubishi QAHV heat pump skid. Water heating is separated into two systems, the primary heating system consisting of the heat pump skid, and the secondary system consisting of existing electric resistance water heater swing tanks. The primary system heats incoming city water, and the secondary system reheats recirculation losses.

B. The heat pump skid is comprised of two (2) 500 gallon hot water storage tanks, one Mitsubishi single-pass heat pump, one secondary side loop with heat exchanger, circulation pump, a custom Mitsubishi controls panel with Diamond Controls System, ancillary piping and equipment, and controls points.

1. Two (2) 500-gallon hot water storage tanks, manufactured by Niles, are piped in parallel with custom internal sparge outlets to provide improved thermal storage.
2. The Mitsubishi single pass heat pump has two operating modes: default efficiency mode (40kW, ~11 tons), and high capacity mode (60kW, ~17 tons). It can switch back and forth between the two modes based on hot water demand.
3. The heat pumps internal heat exchangers is not rated for city water quality, and therefore a secondary side loop heat exchanger and circulating pump are required. A brazed plate heat exchanger is used to achieve the high lift requirement. The circulator has the capability to modulate down to low flows (2.5 GPM), to achieve high lift through the heat exchanger.
4. The Mitsubishi control panel with Diamond Controls System is used to both provide enhanced controls for the single pass heat pump and collect data for measurement and verification.

C. The existing building contains two (2) sets of electric resistance water heaters, set at different pressures, with separate recirculation pumps to serve different parts of the building. The single heat pump skid will serve two swing tank systems in the hot water room, each serving a different pressure zone. Two (2) electronic mixing valves will be added, one to each swing tank system to mix water down to 120°F before supplying to the building.

1. Each swing tank system consists of two existing electric resistance water heaters.
2. Swing Tank System A includes two 27kW electric resistance heaters for a total of 54 kW. A pressure reducing valve at the inlet of this system reduces pressure to ~65 PSI.
3. Swing Tank System B includes one 27 kW and one 9 kW electric resistance heater, for a total of 36 kW. It supplies water at ~75 PSI, the same pressure as cold city water.

1.2 SUBMITTALS

A. Ongoing coordination between Mitsubishi, Ecotope and Skycentrics.

ECOTOPE

PART 2 - CONTROL LOGIC

2.1 PRIMARAY DOMESTIC HOT WATER SYSTEM

A. HWPH-1 shall be configured in a single-pass arrangement to deliver ~150°F water to hot water storage tanks ST-1 and ST-2. HPWH shall be configured to handle entering water temperatures from 45-120°F.

1. Delivery water shall be configured for a secondary side loop. The unit shall control output temperature, output flowrate, and secondary side loop flowrate, based on a temperature sensor and flow sensor provided as part of the secondary side loop kit. In controlling temperature and flow, the unit shall deliver ~150°F water in the secondary loop requiring the heat pump loop to operate at ~160°F.

B. HPWH controls shall be configured using both built in QAHV controls and controls from a custom Mitsubishi Electric Control Panel, referred to herein as the "Mboard". The Mboard will also be responsible for logging M&V data, alarming, and load shift controls. Additionally, Skycentrics will provide a third control board, referred to herein as the "Sboard", which is responsible for CTA-2045 communication. The Sboard will be used to adjust operation and change control schedules implemented by the Mboard. Additionally, Skycentrics will provide Ecotope access to M&V data, as indicated on the points list, through their FTP push feature.

C. Configure HPWH-1 to use the internal QAHV controls to turn the unit ON and OFF based on three temperature sensors within the thermal storage system. Temperature sensors shall be 15kOhm sensors per Mitsubishi compatible with QAHV. Sensor are referred to as TH15, TH16, and TH17 in installation documentation. Configure HPWH-1 with three operating modes as shown in the table below. See QAHV IOM manual for instructions. Configure setpoint adjustments for each Operating Mode through the Mboard. All the values in this table, except for each modes setpoint temperature, are hard configured into the QAHV and cannot be altered remotely through the Sboard.

1. Configure Mboard such that setpoints for Modes 1, 2, and 3 are lifted by 8°C (14.4°F) during an Advanced Load Up. The amount lifted shall be able to be configured remotely through the Sboard.

QAHV Control Input	Selection
Mode 1 Thermo-ON thermistor	ST-2 TEMPERATURE T-2 (TH16)
Mode 1 Thermo-OFF thermistor	ST-2 TEMPERATURE T-1 (TH17)
Mode 1 Thermo differential value	30°C (54°F)
Mode 1 Set Water Temperature (Set with Mboard)	58°C (135°F)*
Mode 2 Thermo-ON thermistor	ST-2 TEMPERATURE T-2 (TH16)
Mode 2 Thermo-OFF thermistor	ST-2 TEMPERATURE T-1 (TH17)
Mode 2 Thermo differential value	8°C (14.4°F)
Mode 2 Set Water Temperature (Set with Mboard)	58°C (135°F)*
Mode 3 Thermo-ON thermistor	ST-2 TEMPERATURE T-6 (TH15)
Mode 3 Thermo-OFF thermistor	ST-2 TEMPERATURE T-2 (TH16)
Mode 3 Thermo differential value	8°C (14.4°F)
Mode 3 Set Water Temperature (Set with Mboard)	58°C (135°F)*

**Setpoint change under Advanced Load Up CTA-2045 Command.*

ECOTOPE

D. Configure Mboard such that the QAHV will change its operating mode, setpoint temperature, and capacity setting based on CTA-2045 signal.

System Change	*CTA-2045-A Command to QAHV Operation*					
	NORMAL OPERATION	*SHED*	*CRITICAL PEAK EVENT*	*GRID EMERGENCY*	*LOAD UP*	*ADVANCED LOAD UP*
Operating Mode	1	3	3	OFF	2	2
Setpoint Temperature [°F]	140	140	130	OFF	140	160
Capacity Setting [kW]	40	40	40	OFF	40	60

E. Skycentrics cloud service shall be used to pass CTA-2045 commands to the QAHV.

2.2 SECONDARY DOMESTIC HOT WATER HEATING – SWING TANKS

A. Existing electric resistance swing tank controls shall not be adjusted. Electric resistance heaters maintain a temperature of 120°F +/-4°F.

B. Hot water is delivered to the apartments after being tempered by an electronic thermostatic mixing valves (TMV-1 and TMW-2) set at 120°F.

2.3 ALARMING

A. Control system to provide alarms for all temperatures and flows specified in the points list, loss of communications with monitoring devices, and equipment faults

B. System controller to send email to multiple email addresses for the for the following alarm states:

1. HPWH-1 Equipment Fault.
2. MXV-1: Mixed Outlet Temperature LOW ALARM, below 110°F
3. MXV-2: Mixed Outlet Temperature LOW ALARM, below 110°F

END OF SECTION

Appendix B

Single QAHV, No Load Shift	Tank Configuration	Total Volume	Maximum Number of Apartments Served			
			CZ 3B	CZ 3C	CZ 4C	CZ 5B
	Single 500-gallon Tank	500	90	80	70	60
	Two 285-gallon Tanks	570	95	90	NA	NA
	Three 285-gallon Tanks	855	105	100	NA	NA

Sinlge QAHV, Evening Load Shift	Tank Configuration	Total Volume	Maximum Number of Apartments Served			
			CZ 3B	CZ 3C	CZ 4C	CZ 5B
	Single 500-gallon Tank	500	90	80	70	60
	Two 285-gallon Tanks	570	95	90	NA	NA
	Three 285-gallon Tanks	855	105	100	NA	NA

Single QAHV, Morning Load Shift	Tank Configuration	Total Volume	Maximum Number of Apartments Served			
			CZ 3B	CZ 3C	CZ 4C	CZ 5B
	Three 285-gallon Tanks	855	80	80	70	60
	Two 500-gallon Tanks	1,000	90	90	NA	NA
	Three 500-gallon Tanks	1,500	105	100	NA	NA

Two QAHVs, No Load Shift	Tank Configuration	Total Volume	Maximum Number of Apartments Served			
			CZ 3B	CZ 3C	CZ 4C	CZ 5B
	Single 500-gallon Tank	500	155	150	110	100
	Two 285-gallon Tanks	570	165	160	120	110
	Three 285-gallon Tanks	855	185	180	130	125
	Two 500-gallon Tanks	1,000	195	170	NA	NA
	Three 500-gallon Tanks	1,500	220	205	NA	NA

Two QAHVs, Evening Load Shift	Tank Configuration	Total Volume	Maximum Number of Apartments Served			
			CZ 3B	CZ 3C	CZ 4C	CZ 5B
	Three 285-gallon Tanks	855	155	140	130	125
	Two 500-gallon Tanks	1,000	190	175	NA	NA
	Three 500-gallon Tanks	1,500	220	205	NA	NA

Two QAHVs, Morning Load Shift	Tank Configuration	Total Volume	Maximum Number of Apartments Served			
			CZ 3B	CZ 3C	CZ 4C	CZ 5B
	Three 500-gallon Tanks	1,500	140	140	**130**	**130**

Appendix C

Ecotope, Inc.
1917 1st Avenue, Suite 300
Seattle, WA 98101
P: 206-322-3753
F: 206-325-7270

Appendix C

From: Scott Spielman, Ecotope

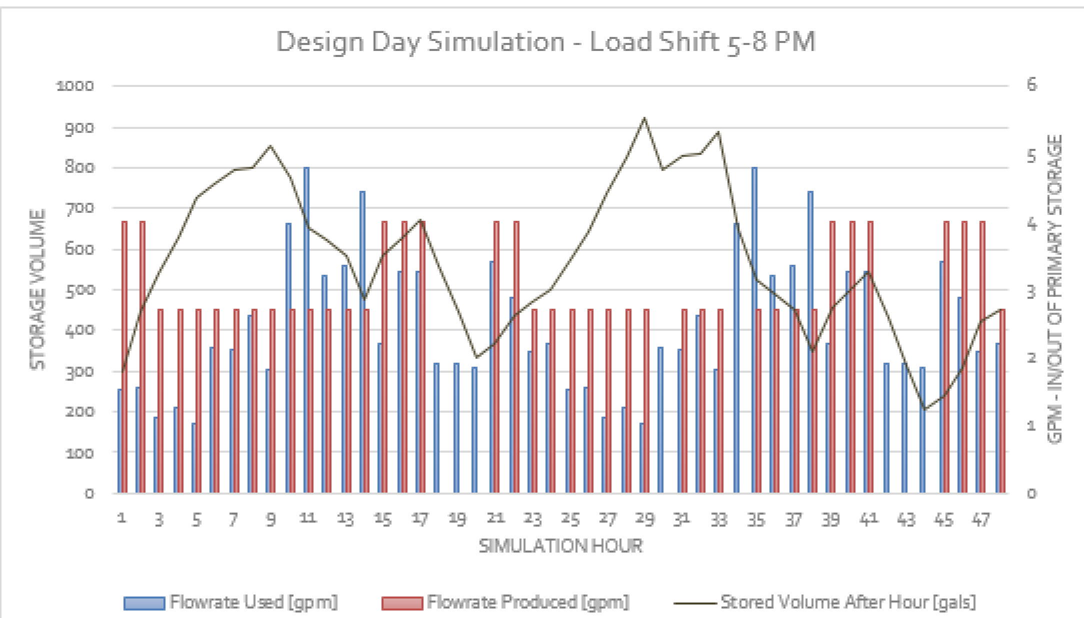
Subject: QAHV Pilot Load Shift Sizing Summary

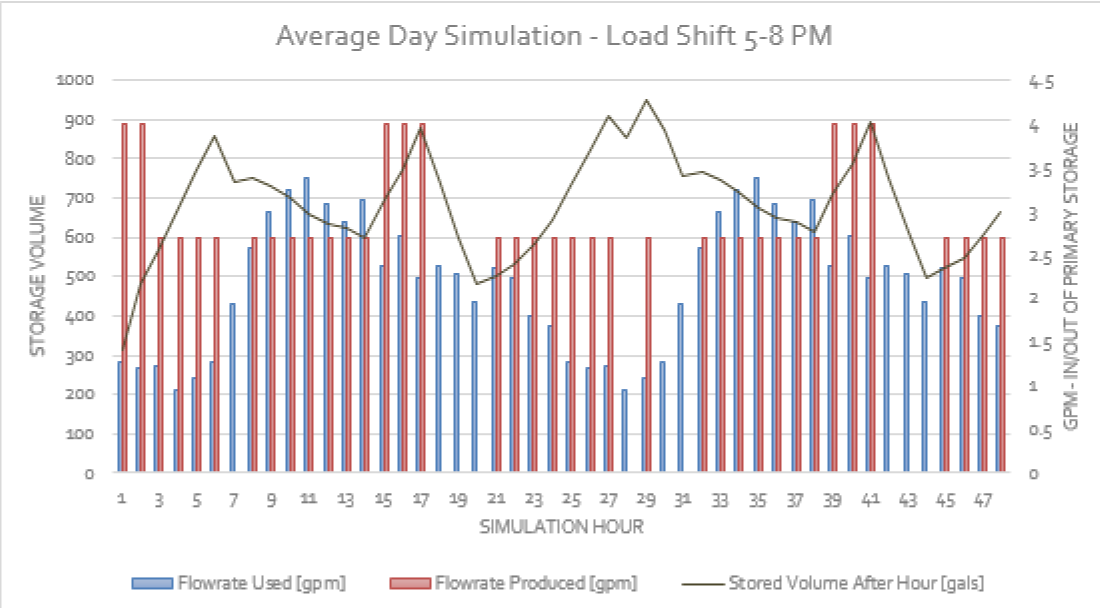
Date: August 31, 2020

The following information was calculated based on metering in May 2020.

- Peak Daily Gallons = 3600
- Average Daily Gallons = 3150
- Approx. Gallons Per Person (assuming ~150 ppl in the 100 apts) = ~20 gal/per/day
- Recirc Losses = 80 W/apt (~40% of total system energy usage)

The plots below show hourly storage volumes on simulated design days and average days with load shifting between 5 and 8 PM. Each simulation shows two consecutive days.





Load shift simulations make use of the QAHV's high capacity mode, in which it can increase its output capacity from 40 kW to 60 kW. The simulation assumes there are three temperature sensors in the tank: (1) THERMO-ON in standard efficiency mode, (2) THERMO-ON in high capacity mode, and (3) THERMO-OFF. The simulation also assumes the QAHV will use high capacity mode to charge the tank during the three hours prior to the load shift period.

Between 5 and 8 PM the average flowrate is 2.5 GPM. Therefore, if the QAHV does not produce any water, 450 gallons of hot water will be drained from the storage system during the load shift period.

The site was only metered for one month, during the covid-19 pandemic, and therefore the ability to fine-tune the design based on metered data is limited. The system should be able to provide load shifting on the worst-case day recorded. It was important to not overdesign the storage volume due to cost implications of having to reinforce the structure and foundation. The pilot project will serve as an opportunity to test all aspects of the QAHV – it's ability to perform in a variety of outdoor air conditions, the secondary side loop HEX's affect on performance, it's ability to alternate between modes to prepare for load shift periods, and the tank designs ability to maintain stratification for high quality storage.