



Emerging  
Technologies

# Mitsubishi QAHV CO<sub>2</sub> Heat Pump Water Heater Feasibility Study June 2020



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Prepared for:

Karen Janowitz, Project Principle Investigator

Washington State University Energy Program on behalf of Bonneville Power Administration

Prepared by:

Scott Spielman, Colin Grist, Jonathan Heller

Ecotope Inc.

The following report was funded by the Bonneville Power Administration, or 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 the efficient use of electric-power resources in the Northwest.

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## Abstract

This Feasibility Analysis of the Mitsubishi QAHV CO<sub>2</sub> Heat Pump Water Heaters evaluates performance in four categories: Codes and Certifications, System Components, Cost and Constructability, and Maintenance. The QAHV is promising; however, the current model has significant challenges with respect creating a simple plug-and-play system and compliance with Code and Certifications. The QAHV heat exchanger currently does not meet requirements to interact with municipal water, but a secondary heat exchanger can be used to provide heating. The next step for the QAHV is the development of a packaged system that includes this secondary heat exchanger. The QAHV design must be modified before it can meet the compliance requirements of the U.S. market. The manufacturer plans to have a U.S.-compliant product available in 2020. With these design adjustments, the Mitsubishi QAHV has significant potential to transform the Northwest multifamily water heating market.

# Table of Contents

- Abstract . . . . . 3
- Table of Contents . . . . . 4
  - Table of Figures . . . . . 5
- Executive Summary . . . . . 6
- Background . . . . . 7
  - Market Landscape . . . . . 7
  - Domestic Hot Water HPWH System Design . . . . . 7
  - Natural Refrigerants . . . . . 7
  - Transcritical Cycle . . . . . 9
  - Purpose . . . . . 9
  - Current Installations . . . . . 10
- Codes and Certifications . . . . . 10
  - Codes . . . . . 11
    - Federal Safe Drinking Water Act . . . . . 11
    - Energy Code . . . . . 11
    - Mechanical Code . . . . . 11
    - Plumbing Code . . . . . 12
  - Certifications . . . . . 12
- System Component Assessment . . . . . 12
  - Single-Pass Systems . . . . . 13
  - Secondary Heat-Exchanger Loop . . . . . 14
  - Multiple Units . . . . . 15
- Performance Assessment . . . . . 15
  - Architecture . . . . . 15
  - Space Requirements . . . . . 15
  - Acoustics . . . . . 16
  - Climate . . . . . 16
  - Engineering . . . . . 16
    - Structural . . . . . 16
    - Mechanical . . . . . 16
    - Electrical . . . . . 16
  - Owners . . . . . 19
  - End Users . . . . . 20



Cost and Constructability Assessment . . . . .	20
Availability . . . . .	20
Supporting Infrastructure . . . . .	20
Construction Schedule . . . . .	21
Installation Cost Impacts . . . . .	21
Retrofit Feasibility . . . . .	21
Maintenance Assessment . . . . .	21
Customer Service . . . . .	21
Maintenance . . . . .	22
Conclusions and Recommendations . . . . .	22
Conclusions . . . . .	22
Manufacturer Recommendations . . . . .	23
Utility Recommendations . . . . .	23
Applications Testing Topics for Investigation . . . . .	24
References . . . . .	25

## Table of Figures

Figure 1. Energy savings with heat pump water heaters for a typically multifamily installation. . . . .	7
Figure 2. Evolution of Refrigerants . . . . .	8
Figure 3. CO <sub>2</sub> Phase Diagram . . . . .	9
Figure 4. QAHV installed at hotel in Japan . . . . .	10
Figure 5. Mitsubishi QAHV . . . . .	11
Figure 6. Single-pass HPWH System Schematic . . . . .	13
Figure 7. QAHV with Secondary Heat Exchanger Loop . . . . .	14
Figure 8. Control of multiple QAHV operating in secondary side circuit design. . . . .	15
Figure 9. Capacity in Relation to Outdoor Air Temperature. . . . .	18
Figure 10. Refrigerant Temperature . . . . .	19
Figure 11. Rates of Corrosion . . . . .	22
Figure 12. Schematic of Envisioned Packaged QAHV System . . . . .	23
Table 1. Comparison of Common Refrigerants . . . . .	8
Table 2. Water Quality Standards . . . . .	21

## Executive Summary

Domestic water heating is the largest single use of energy in multifamily new construction in the Northwest. The Mitsubishi QAHV CO<sub>2</sub> heat pump water heater offers a cost-effective and energy-efficient option for heating domestic water. By reducing the water-heating load, BPA is able to address the system peaks identified in its Resource Plan. Redesigning the QAHV so it is packaged with a secondary heat exchanger may provide an affordable domestic water-heating solution in Northwest multifamily buildings.

This Feasibility Study has determined market adoption of the QAHV will require the following modifications.

- Obtain the UL listing for the product line.
- Develop a standardized potable-water solution that includes all components and controls necessary to integrate any heat exchangers.
- Provide full controls package, and engineering design and sizing support that results in standardized installations.

Application Testing will further assess the QAHV and result in a product performance map. It is anticipated that testing will occur in 2020. Additionally, the product is planned for demonstrations sites in Seattle and California.

This study is the first step in the Bonneville Technology Innovation Model, or TIM, and assesses the applicable certifications, system components performance, cost, constructability and maintenance.

**Certifications:** The Mitsubishi QAHV is undergoing UL testing and certification in 2020. Currently, the QAHV does not meet potable-water certifications. The packaged system will require the addition of secondary heat exchanger that is potable-water certified.

**Performance:** Sized at 60kW of capacity and with output temperatures up to around 180°F, the QAHV is an ideal heat pump for providing hot water and load shifting in multifamily buildings with 150-200 apartments.

**Cost:** Mitsubishi plans to move forward with delivering a packaged system. This will decrease the overall system cost for equipment and installation and improve the reliability and performance. Cost for the product is still to be determined, but it estimates the full package system will cost approximately \$50,000, plus labor for installation.

**Constructability:** Once a packaged product is completed, the system will be simple to design and construct.

**Maintenance:** Regular maintenance includes cleaning debris from equipment, ensuring proper airflow and checking the heat exchangers for scaling. Mitsubishi is still determining the U.S. customer-service plan for the QAHV.

## Background

### Market Landscape

Domestic water heating is the largest single use of energy in Northwest multifamily new construction, and is responsible for 25-30% of the energy use of a typical apartment building. In new apartments, domestic water heating typically has an Energy Use Intensity, or EUI, of 8-10 kBtu/SF/yr.

Water-heating load can be divided into two distinct loads: 1) the heating of entering water and 2) temperature maintenance. Approximately one-third of energy is used to maintain the water temperature in the distribution piping.

Heat pump water heaters, or HPWH, have the potential to reduce the energy used for water heating by approximately a factor of three if properly designed. Figure 1 shows an energy-use pie chart of a typical multifamily building, and the savings that can be expected from a correctly designed and operated HPWH system.

Heating domestic hot water with central heat pumps can reduce the total energy use by 7 kBtu/SF/yr EUI or roughly 17% total energy savings. (Ecotope; Heller, Jonathan, K. Geraghty, and S. Oram, 2009)

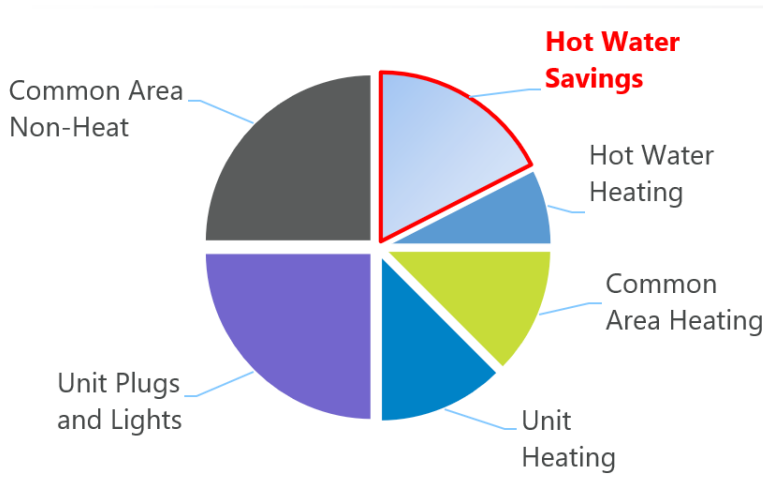
In addition to overall energy savings, HPWH systems naturally allow for load-shift capability. A typical HPWH system is designed with less capacity and more storage than a traditional electric or gas boiler system and runs 16 hours a day to meet the hot water demand. When sized and controlled corrected, the 16-hour run period can avoid peak times and flatten overall grid load.

### Domestic Hot Water HPWH System Design

HPWHs can be single-pass or multi-pass and come as a standalone unit or integrated into a tank as a unitary system. Single-pass systems heat water in a single pass and require a high-temperature lift to operate efficiently, whereas multi-pass units heat water in multiple passes with low lift and can accept warmer water temperatures.

### Natural Refrigerants

The most common refrigerants used in HPWHs are R-134a and R-410a. These are hydrofluorocarbons, or HFCs, with high Global Warming Potential, or GWP, and are scheduled for phase-out over the next several years by international accords. As markets shift toward lower GWP refrigerants, policy makers are promoting natural refrigerants with a GWP less than 3. Table 1 compares refrigerants.



**Figure 1. Energy savings with heat pump water heaters for a typically multifamily installation.**

	HYDROFLUOROCARBONS (R134A)	HYDROCARBONS Propane (R290)	CARBON DIOXIDE CO <sub>2</sub> (R744)	AMMONIA NH <sub>3</sub> (R717)
Refrigerant Type	Synthetic	Natural		
ODP	0			
GWP (100 year)	1430	3	1	0
Flammability	None	High	None	Low
Toxicity	Low (no identified toxicity at concentrations ≤ 400 ppm)			High (evidence of toxicity at concentrations below 400 ppm)
Typical Operating Pressure Range	0.6 - 6.7 bar	10 - 50 bar	10 - 50 bar	2.9 - 13.5 bar
Component Challenge		Flammability	High Pressure	Material Compatibility Corrosion
Pressure Switch Technology Solution		Explosion Proof Sealing	Heavy Duty Design	Hard Anodized

Table 1. Comparison of Common Refrigerants

Most early refrigerants were natural refrigerants including ammonia, CO<sub>2</sub> and hydrocarbons such as propane and butane. But as system outputs increased, the market transitioned to synthetic fluorinated gases.

These synthetic gases are known as f-gases or greenhouse fluorinated gases. Because of the detrimental global-warming impacts of these manmade gases, legislatures are shifting back to natural refrigerants. Figure 2 illustrates this evolution. (CoolingIndia)

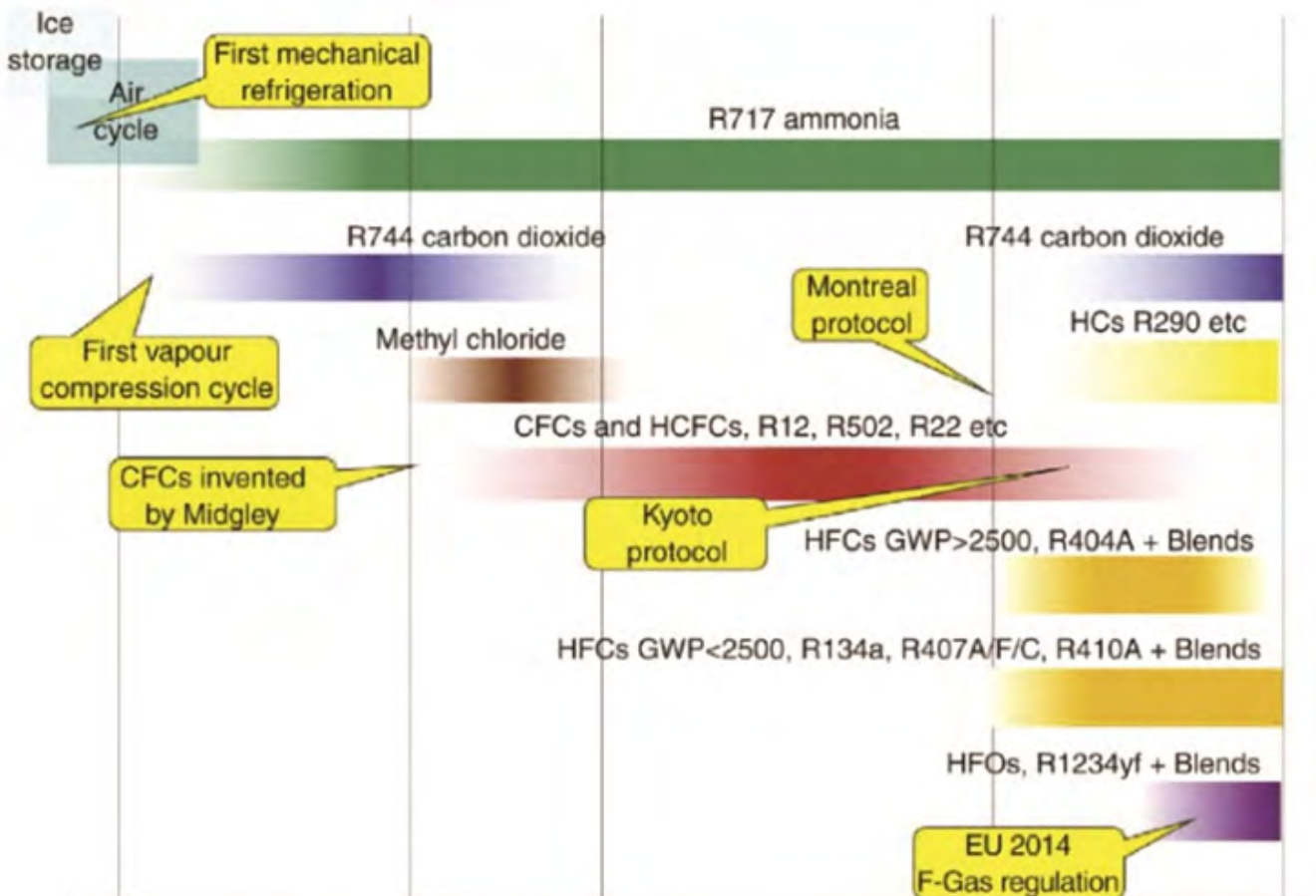


Figure 2. Evolution of Refrigerants



## Transcritical Cycle

The Mitsubishi QAHV uses the natural refrigerant R-744 (CO<sub>2</sub>) in a closed-loop transcritical refrigeration cycle. This cycle is a function of the unique phase-change properties of CO<sub>2</sub>. The critical point is the minimum temperature and pressure combination where a gas can no longer be liquefied. Figure 3 shows the critical point for CO<sub>2</sub> in a phase diagram.

The transcritical refrigeration cycle for heating water goes through the sub-critical (below the critical point) and super-critical (above the critical point) regions of the diagram. Transcritical operation is different than a typical HFC-based, which operates solely in the sub-critical region. A sub-critical system condenses the high-pressure gas refrigerant and transfers this energy into the incoming city water. A transcritical system does not require a condenser to condense the hot gas, but instead uses a hot-gas cooler (i.e. heat exchanger) to transfer heat to the incoming city water, while still being in a superheated gas state.

The transcritical CO<sub>2</sub>-cycle efficiency is highly dependent on the incoming water temperature at the hot-gas cooler (heat sink) and the entering air temperature, or EAT, to the outdoor evaporator coil (heat source). Both factors drive how much heat is transferred by the system.

CO<sub>2</sub> is an excellent solution for water heating. CO<sub>2</sub> refrigerant has a high-lift and it is an excellent technology match for domestic water heating. The inverter logic and feedback control optimize the CO<sub>2</sub> cycle to deliver very hot water with coefficient of performances, or COP, above 3.

## Purpose

The purpose of this Feasibility Analysis is to determine the suitability of the Mitsubishi QAHV CO<sub>2</sub> HPWH for multifamily water heating in the Northwest climate. To determine feasibility, the QAHV has been assessed for 1) Codes and Certification; 2) System Components; 3) Cost and Constructability; and 4) Maintenance. Each of the four assessments will inform the appropriateness of moving this product forward to the next stage gate of Application Testing.

The Feasibility Analysis is the first step in the TIM. The TIM is designed to take a technology through a series of stage-gates representing different areas of inquiry, to ensure the product can be safely and cost-effectively applied in a manner that ensures performance and savings in the marketplace.

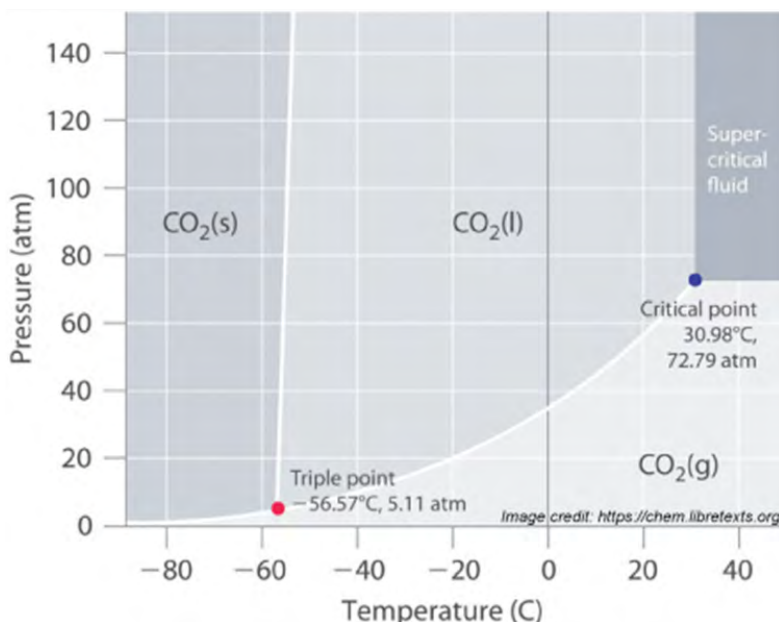


Figure 3. CO<sub>2</sub> Phase Diagram

Key stage-gates for the TIM include:

1. Feasibility Analysis.
2. Applications Testing.
3. Field Demonstration.
4. Measurement and Verification.
5. System Metrics.

The Mitsubishi QAHV is a CO<sub>2</sub> heat pump water heater. This new technology has the potential to improve hot-water heating efficiency and allow for hot-water load shifting.

## Current Installations

Although it has not yet entered the U.S. market, the QAHV has been sold in France, Sweden, Spain, Germany, New Zealand and Japan. It has been sold in Europe for two years, and longer in Japan. In France, it has been sold together with a secondary heat exchanger. The importance of a secondary heat exchanger is discussed later in the System Component Assessment.

Figure 4 is a photograph of the QAHV installed at a hotel in Japan to serve guest

rooms and the sauna during a facility upgrade in 2014. Other case studies have shown the QAHV used to provide base domestic hot water in a hospital, using steam as a peaker, and in a fitness center as part of a hot-water system that also uses solar and district sources.

## Codes and Certifications

This section reviews the Mitsubishi QAHV compliance with federal, state, and local energy codes and standards. The Energy Code addresses operational efficiencies and controls; the Mechanical Code addresses allowable refrigerant charge; the Plumbing Code addresses condensate management and drinking-water quality standards. The Electrical Code addresses the design of electrical connections.

Mitsubishi must comply with the following codes to be a viable product in the Northwest. This section identifies any unmet requirements and the manufacturer's plans for conformance.



Figure 4. QAHV installed at hotel in Japan

## Codes

### FEDERAL LAW

- The Safe Drinking Water Act, or SDWA, Section 1417.

### ENERGY CODE

- International Energy Conservation Code, or IECC. Includes Idaho and Montana.
- Washington State Energy Code, or WSEC.
- Oregon Energy Efficiency Specialty Code, or OEESC.
- Title 24, California.

### MECHANICAL CODE

- International Mechanical Code, or IMC.

### PLUMBING CODE

- Uniform Plumbing Code, or UPC.
- International Plumbing Code, or IPC.

### ELECTRICAL CODE

- National Fire Protection Agency, or NFPA
- 70 – National Electrical Code, or NEC.



Figure 5. Mitsubishi QAHV

## Federal Safe Drinking Water Act

The SDWA requires all products in contact with potable water be tested through NSF 372 to prove they are lead-free, meaning they contain less than 0.025% lead at wetted surfaces. The current Mitsubishi QAHV internal heat exchanger does not meet the current lead-free standard. Therefore, as currently configured, an NSF 372 secondary heat-exchanger loop must be incorporated to interface with potable water.

## Energy Code

Energy Codes based on IECC apply to water-heating systems for commercial buildings. See C404 Service Water Heating. C404 identifies the minimum efficiency of, and controls for, water-heating equipment and insulation piping. Minimum performance of water-heating equipment is covered in table C404.2. Heat pump equipment with less than or equal to 24 amperes must be tested by DOE 10 CFR Part 430 and show compliance with table C404.2.

With 33.8 maximum amperes, the QAHV is too large for the electric water heaters in table C404.2. Therefore, the IECC requirement does not apply to the QAHV, unless it is being used as a pool heater.

## Mechanical Code

IMC 918.2 requires heat pumps be tested in accordance with UL 1995. Therefore, the QAHV must be UL certified. UL certifications can be completed on the entire system in a lab, or by demonstrating that each individual component is UL certified. Mitsubishi has opted to test the entire equipment in a lab in 2020 for UL certification.

## Plumbing Code

Most major hurdles in the code compliance of a heat pump water-heating system using the QAHV are from the Plumbing Code. Most regional plumbing codes are based on the UPC. The UPC has two main requirements that apply to the QAHV. The first is (1) UPC 603.5.4, which requires double-wall heat exchangers to protect potable water from heat-transfer medium. The QAHV heat exchanger is double walled, but it is unclear whether the product is considered to be vented to the atmosphere. Venting determinations will be made by code officials on a case-by-case basis. The UPC also requires NSF certification for products in contact with potable water — UPC sections 415.1, 417.1, 604.1, 604.9, 606.1, 607.2 and 608.2.

NSF certification is required by the Plumbing Code for all products that touch potable water. NSF is used to show the product is lead-free and meets the federal SDWA Section 1417. While NSF does not apply to the QAHV directly, when operating as a secondary loop with a double-walled heat exchanger, it will apply to the heat exchanger and any other components Mitsubishi includes in a packaged hot-water system that come in contact with potable water. NSF certification on the QAHVs heat exchanger would considerably simplify systems designed with the QAHV and make it more marketable.

## Certifications

The QAHV requires UL certification, per IMC 918.2. The absence of UL certification, the product will not achieve market adoption. In addition, the QAHV requires NSF certification on its heat exchanger. The QAHV requires UL certification, per IMC 918.2. Although

on-site UL tests can be performed to certify individual pieces of equipment, those tests are expensive and the product line must be certified before it will be widely adopted in the U.S. Mitsubishi plans to carry out UL certification in 2020.

## System Component Assessment

System Component Assessment identifies the equipment needed for a complete product deployment. The product that will be released in the U.S. market will be the same as the product released worldwide. However, Mitsubishi is partnering with Trane to sell the product as a packaged system in the U.S.

The HPWH is a high-lift heat pump, which comprises a refrigerant circuit with an air-to-water evaporator, compressor, water-to-water condenser and expansions valve. It includes a fan to push air over the evaporator and a pump to move water through the condenser. When the product is provided as a packaged system, additional components — many from manufacturers other than Mitsubishi — will be provided. This additional equipment includes secondary heat exchangers and pumps, storage tanks, expansion tank, tempering valve, low-lift heating device and a fully integrated controls system. As part of the applications testing and pilot projects, Mitsubishi will receive the recommended designed packaged system, schematic piping designs, specifications for components, connections details and a sizing tool.

*The best system-design strategy for single-pass systems is to separate the primary and temperature-maintenance heating loads*

## Single-Pass Systems

The QAHV is designed to be a high lift — meaning the inlet and outlet water temperature delta is large — single-pass, machine. It operates extremely efficiently for heating incoming city water (~50°F to ~70°F) to a water-storage temperature of 140°F to 160°F. However, it does not work well heating water requiring a low lift, such as a temperature-maintenance loop, which requires heating from 115°F to only 125°F. This is because CO<sub>2</sub> operates with a transcritical refrigeration cycle that performs well with a high-lift and not well at low-lift. The best system-design strategy for single-pass systems is to separate the primary and temperature-maintenance heating loads, as shown in Figure 6.

Separating primary and temperature-maintenance heating loads refers to decoupling primary heating of city water from the heating required to maintain the water temperature in the distribution piping due to recirculation losses. As hot water recirculates through the building, the hot water pipe

loses heat to the air and the water cools. If hot water is sent to the building at 125°F, it may return at a temperature closer to 115°F. Separating these two loads allows the single-pass HPWH to only heat incoming city water to a storage temperature above the building's 125°F setpoint temperature. As water is used, the hotter storage water flows into the temperature maintenance side of the system and adds heat.

A temperature-maintenance tank and equipment are needed to maintain recirculating-loop temperature during periods of low hot water use. The temperature-maintenance tank also allows for secondary storage to isolate the primary storage and prevent recirculation temperature losses from disrupting thermal stratification. The temperature-maintenance equipment, either a multi-pass heat pump or electric resistance heater, keeps the water in the secondary storage warm during periods of low water use when hotter water from thermal storage tanks is not entering the temperature-maintenance tank.

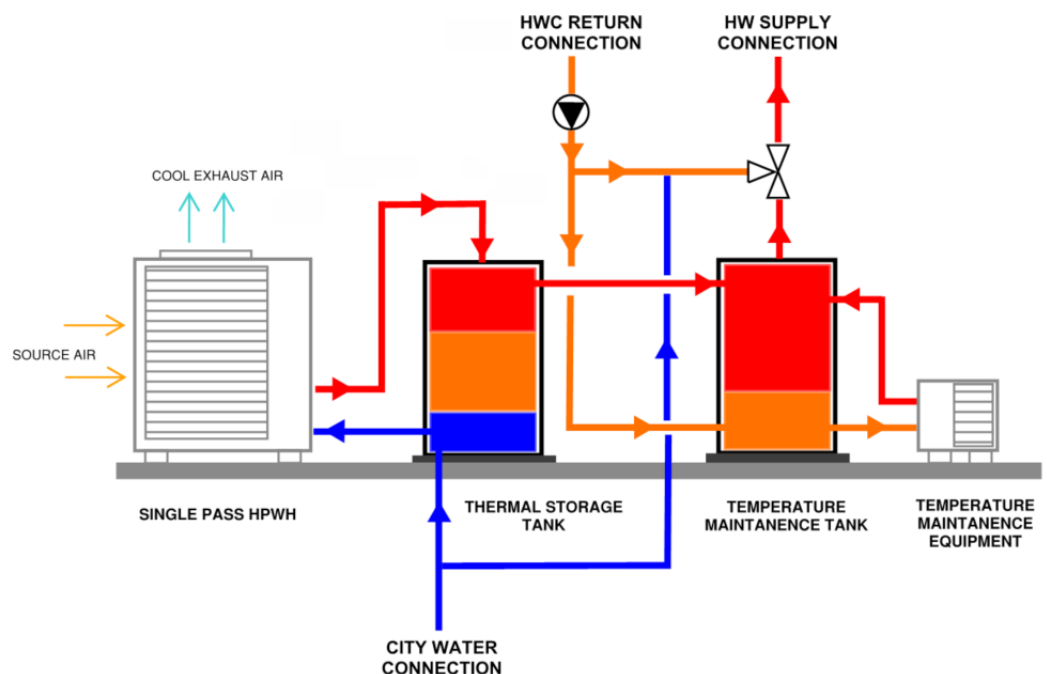


Figure 6. Single-pass HPWH System Schematic

Providing appropriately sized thermal storage and maintaining stratification in thermal storage tanks is another important aspect of designing HPWH systems. HPWH systems are expensive and complex. Appropriately sizing the system and thermal

storage is critical to realize energy savings and cost effectiveness. A tank design that ensures thermal storage remains stratified and prevents the degradation of water temperature and maximizes system efficiency.

## Secondary Heat-Exchanger Loop

Since the QAHV is not SDWA compliant, most Northwest jurisdictions will not permit the heat exchanger to interface with potable water. The QAHV water-quality standards are high and most municipal water supplies cannot meet the criteria. For example, Seattle, with superb water quality, typically has an 8.0 pH, which does not meet the QAHV standard. Therefore, the QAHV system design requires a secondary heat exchanger.

Figure 7 shows the QAHV with a secondary loop and heat exchanger. This design meets SDWA and the Mitsubishi water-quality standard requirements. Three circuits shown in Figure 5 make up the secondary loop system: (1) unit-heating circuit, (2) secondary

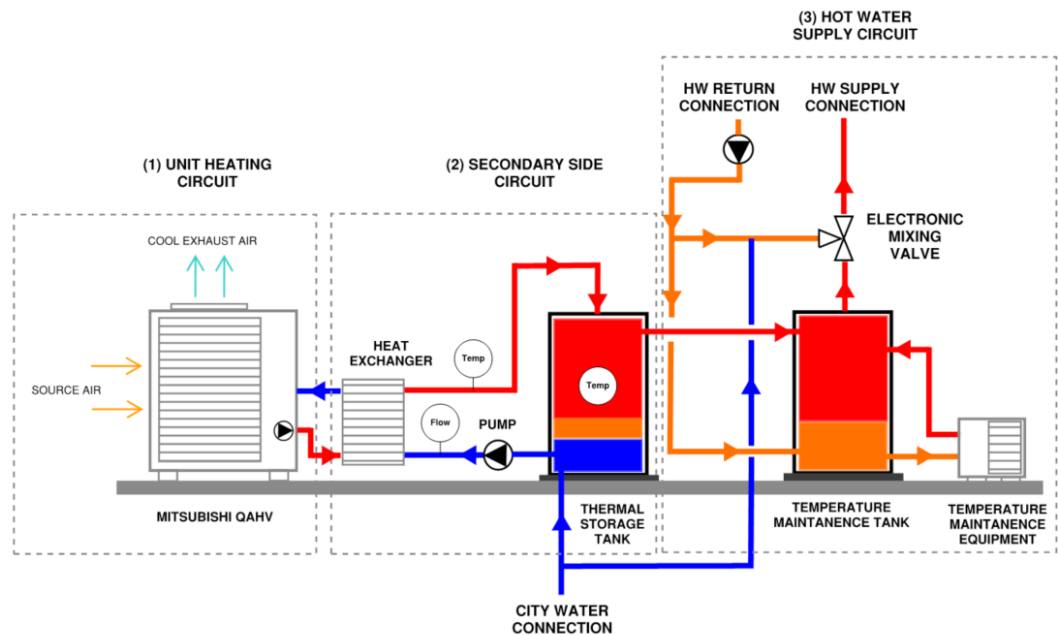


Figure 7. QAHV with Secondary Heat Exchanger Loop

side circuit, and (3) hot-water supply circuit.

The unit-heating circuit is made up of the QAHV and piping to the heat exchanger. The secondary side circuit is made up of the heat exchanger and storage. The hot-water supply circuit is the pumps, valves, piping and temperature-maintenance equipment required to deliver hot water to the building.

Mitsubishi documentation recommends a flow sensor and a temperature sensor be installed on the secondary side circuit to provide information used to control a pump and maintain tank temperature. The water pump to the primary loop is integrated into the QAHV. Applications Testing will be performed to assess the controls methodology for pumps in the unit-heating circuit and secondary circuit. Understanding pump controls, and modifying controls if required, is essential to developing a fully packaged system.

Three methods of control are provided as options for controlling secondary side-circuit flow: (1) a three-way valve, (2) a two-way valve, and (3) an inverter. Mitsubishi's documentation provides no guidance for

selecting from the three control options. Leaving this design to the plumbing engineer introduces a high level of risk and uncertainty for the performance of the product in the field. Mitsubishi has agreed to integrate a product offering that includes this secondary heat exchanger, pumps, and controls that provide a complete package to ensure a properly designed system is consistently installed.

## Multiple Units

Mitsubishi's QAHV's can meet higher hot water demands by using variable-speed pumps to control flow through the heat exchanger as shown in Figure 8. When the QAHV is provided as a package, the same pump can be provided for each QAHV with external static-pressure head limitations for piping. This would allow plumbing engineers to easily design larger HPWH systems in multifamily buildings using the QAHV.

## Performance Assessment

The Performance Assessment confirms the equipment will have adequate performance to gain acceptance of designers and users.

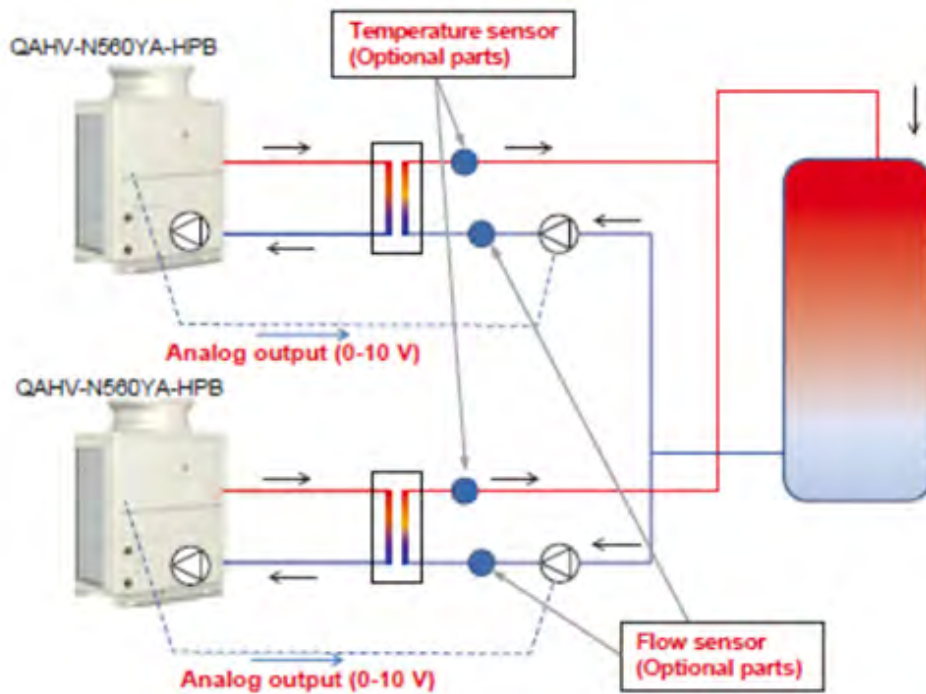


Figure 8. Control of multiple QAHV operating in secondary side circuit design.

## Architecture

Architectural design includes spatial and acoustic requirements. The QAHV is meant for outdoor installations only and looks like any other heat pump type of mechanical equipment. When installed in a visible location, the architect may want to provide a screen wall to obscure it from view. In large buildings in the Northwest, an allocated space in an open parking garage with sufficient airflow may be a suitable location and capture waste heat.

The installation location impacts the site's architectural design and acoustic requirements. Architects will need to coordinate with the mechanical or plumbing engineer to identify an appropriate location.

## Space requirements

The QAHV unit dimensions are 72.5" H X 48" W X 30" D. The QAHV Installation and Operations Manual, or IOM, provides the necessary clearances to allow for proper airflow and maintenance. The unit pulls air through the back and sides of the unit and discharges out the top. A one-foot (1') minimum clearance is required at all air

intakes and units cannot be stacked. The front of the unit has a service panel requiring one-and-a-half feet (1.5') of clearance for airflow; however, three feet (3') of clearance is required per NEC 110.26. Major components too large to fit through doors, such as larger storage tanks, should be identified early so architects and designers can plan building designs for installation and replacement equipment.

For full hot-water systems, Mitsubishi needs to provide a skid and/or layout sized for the number of apartment units being served. The custom layout needs to include different heat pump and storage tank arrangements. The architect and plumbing engineer will need to consult with Mitsubishi to ensure space is allocated for the equipment.

## Acoustics

Tested sound pressure levels are included in the product Data Book. The QAHV creates almost 60 dB of noise when operating, which is roughly the sound level of a conversation. The unit is not excessively loud, but it will preclude installations near windows in sleeping units or outdoor-amenity spaces, and should be located where it does not cause disruption to building tenants. When installed on a rooftop, an acoustic screen wall can be used to reduce sound transmission and obscure equipment.

## Climate

Other considerations when locating the QAHV outdoors include weather such as wind, rain and snow. Designers should refer to the Data Book when selecting a location. The unit can be provided with additional coil salt and corrosion protection for a marine environment. These considerations are typical of any heat pump product.

## Engineering

Engineering performance can be broken into structural, mechanical, electrical and plumbing performance. One of the biggest challenges for central HPWH systems is engineering a plug-and-play, reliable and cost-effective design. Although the packaged system described earlier under System Configuration has not yet been realized, its goal is to create a plug-and-play, reliable, cost-effective approach for Mitsubishi.

## Structural

The QAHV weighs 882 pounds. It includes a rotating compressor, which may require vibration isolation, depending on the

installation location and facility vibration requirements. Like other major mechanical components, the unit should be securely bolted to prevent it from falling in seismic or wind events. In most installations, the unit will be mounted on rubber isolators and fixed to a concrete slab with J-bolts. Refer to the Data Book for details on unit-bolting methods.

When the QAHV is provided as part of a package system that includes thermal storage and a temperature-maintenance system, the skid will weigh more than 15,000 pounds. Structural engineers should be notified where the thermal storage will be located early in the design process so they can design accordingly.

## Mechanical

Typically, plumbing engineers — not mechanical engineers — are responsible for selecting and designing systems for hot-water heating equipment. Therefore, details of equipment design, capacity and installation to meet hot-water loads is described under plumbing.

## Electrical

The QAHV will be available for 208/230V and 460/480V 60Hz power. No 120V versions will be available. It is best suited for larger buildings with three-phase voltage connections and hardwired applications, and the circuit feeding the device must comply with NFPA 70 (NEC). NFPA Article 440, Air Conditioning and Refrigeration Equipment,

*The Mitsubishi QAHV will be available for 208/230V and 460/480V 60Hz power.*



applies to all devices that include hermetic refrigerant compressors and will apply to the QAHV.

The installation manual indicates a minimum 8-gauge (10 mm<sup>2</sup>) cable connections to the unit and ground, in accordance with NEC Article 440.61. A thicker wire should be used if there will be a voltage drop greater than 10%. A minimum impedance of 0.21 Ohms is allowed between the panel (power service box) and equipment.

Overcurrent, short circuit, and/or ground-fault protection are not built into the unit, and are typically provided in the local disconnect or as part of the panel serving the device. Best practice is to install overcurrent, short circuit, and/or ground-fault protection in the local disconnect within the line of sight (see NEC 440). The installation manual states that each unit must be wired individually through a local fused disconnect with at least 3 mm of contact separation and the current leakage breaker or fuse. Both fused disconnect and the current leakage breaker/fuse should be 63A, per the documentation. The time-delay fuse allows a large power draw for a short period of time to start the compressor, but does not allow sustained power spikes that could harm the equipment.

As Mitsubishi develops product documentation for the U.S., it is recommended that it include minimum circuit ampacity, or MCA, and maximum overcurrent protections, or MOP, because U.S. engineers need those values to specify wire gauge and fuse/breaker ampacity. The current documentation only states the minimum wire size and breaker ampacity of 63A. However, since a 63A breaker size is uncommon in the U.S. and 70A breaker will be suitable.

In addition to equipment requirements and electrical connections auxiliary equipment, heat trace, pumps, electronic mixing valves, etc. are required. For a packaged system, a

single point of connection is recommended for each heat pump to simplify the electrical design.

Plumbing engineers typically select water heating equipment. However, the QAHV is a much more complex piece of equipment than the typical gas or electric water heater. Maximizing the potential of the QAHV requires a system with thermal-storage tanks for primary hot-water storage and a temperature-maintenance tank (swing tank), to manage recirculated water.

Typically, plumbing engineers do not have the time or funds to research the details to design a complex custom system such as the QAHV. As a result, the QAHV may be designed improperly and waste energy or not be used at all because the plumbing engineer will be unable to easily support the design. Therefore, it is critical that the QAHV is developed as a fully packaged integrated system.

## CONNECTIONS

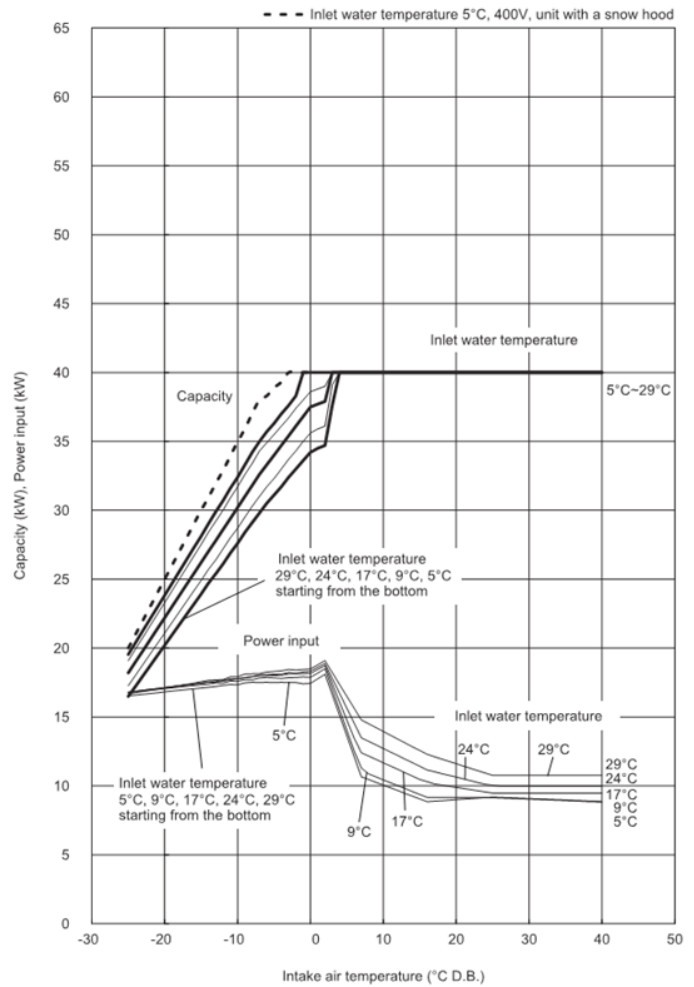
The QAHV has two ¾" piping connections to take in cold water and supply hot water. In a typical packaged system suitable for the U.S., these connections would be in the Unit Heating Circuit described early in the System Component Assessment. Additionally, a connection to city water will enter the secondary side circuit at the bottom of the storage tank. The hot-water supply and hot-water recirculation return connections provide the hot water to the building from the hot-water supply circuit.

*The QAHV can provide up to 60kW of heat in maximum-capacity operating mode and 40kW (136,480 Btu/hr) in the default energy-saver mode*

### CAPACITY

The QAHV can provide up to 60kW of heat in maximum-capacity operating mode and 40kW (136,480 Btu/hr) in the default energy-saver mode. When combined with thermal storage, it can provide heating for a hot-water load with a much higher peak demand. Unlike electric resistance heaters, the amount of heat that can be provided using a HPWH changes with outdoor air temperature. Figure 9 is a graphical representation of capacity as function of outdoor air temperature. Capacity and power input are plotted for a variety of inlet water temperatures from 5°C (41°F) to 29°C (84°F) for an outlet water temperature of 60°C (140°F). Note that the QAHV has a rapid drop-off in capacity when the unit is operating below freezing temperatures. Also, the unit was only tested to an incoming water temperature of 84°F.

*Sizing tool development is critical to appropriately size capacity and storage for different water-draw patterns and climates.*



**Figure 9. Capacity in Relation to Outdoor Air Temperature**

Because capacity is de-rated in colder climates, the number of units and people that can be served will vary. A correctly designed QAHV system for Seattle should be able to serve 100 to 150 apartments with 1,500 to 2,500 gallons of storage. As HPWHs enter the market, sizing tools are required to appropriately size capacity and storage for various-draw patterns and climates.

### FREEZE PROTECTION

Even in below freezing temperatures, the QAHV can operate at a COP greater than 1. However, propylene glycol cannot be used because it damages the internal pump. An anti-freezing operation is used to prevent pipes from freezing in sub-freezing temperatures. During anti-freezing operation, the unit will provide heat when outdoor air temperature and incoming water temperature drops to near freezing (34°F OAT, 38°F IWT).

The unit must be kept on for anti-freezing operation. If the unit cannot be kept in operation, Mitsubishi recommends draining the pipes of water and refilling with propylene glycol during the period where the unit is not operating. Before the unit is restarted, the propylene glycol must be drained and replaced with water. Heat trace is recommended on all pipe connections to the QAHV in a sub-freezing climate.

## DEFROST

If HPWH evaporator coils freeze, a defrost cycle initiates. The QAHV controls for defrost with three defrost start conditions and four defrost end conditions.

Defrost start conditions (all conditions must be met to enter defrost):

1. Refrigerant temperature at the air-heat exchanger inlet is at or below the value determined in relation to the outdoor air temperature shown in Figure 9.
2. Cumulative compressor-operation time has reached 35 minutes since the completion of the last defrost operation.
3. Cumulative compressor-operation time has reached 35 minutes since the operation-ON signal was sent or the outdoor temperature is  $-15^{\circ}\text{C}$  or below the specified temperature.

Defrost end conditions (one condition must be met to exit defrost):

1. The refrigerant temperature at the air-heat exchanger inlet is at or below the value determined in relation to the outdoor air temperature show in Figure 10.
2. Cumulative compressor-operation time has reached 35 minutes since completion of the last defrost operation.
3. Cumulative compressor-operation time has reached 35 minutes since the operation-ON signal was sent. Or, the outdoor temperature is  $-15^{\circ}\text{C}$  or below the specified temperature.
4. High pressure has reached 12.0 MPa or above at the frequency of 30 Hz.

The QAHV can operate at low temperatures; However, below freezing temperatures and need for defrost reduce the equipment performance and capacity. An equipment defrost cycle will be observed as part of the applications test.

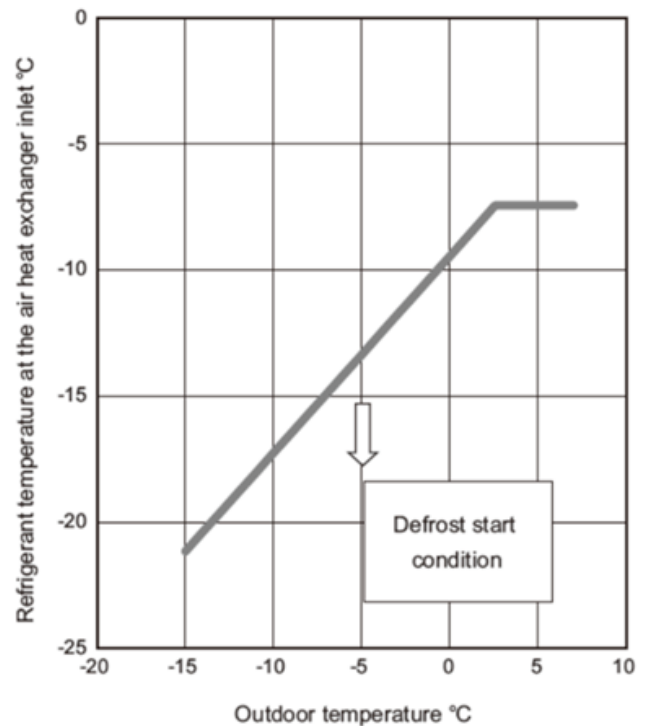


Figure 10. Refrigerant Temperature

*The QAHV can operate at freezing however, below freezing the defrost cycle reduces equipment performance and capacity*

## Owners

Owners want a product that can reliably deliver hot water. Energy efficiency and load-shifting capability are additional benefits but not primary drivers. When designed properly, the QAHV should be able to provide long-term quality performance. If a system is not designed properly, there is potential

for poor performance and repeated failure of expensive components. A fully packaged integrated system is key to ensuring consistency and reliability using the QAHV.

For building owners interested in controlling for load shifting, the QAHV has the ability to handle a utility signal for load shifting. Packaged systems will be designed with increased thermal storage to operate with load shifting and have the ability to be controlled, per Joint Appendix 13 (JA13) requirements.

## End Users

End-users are concerned with consistent delivery of hot water. The key to consistent delivery in a HPWH system is appropriate sizing of the thermal storage. Calculation tools must be developed using hot-water usage profiles and equipment capacity to size thermal storage appropriately and consistently.

The QAHV has an output for control of auxiliary equipment such as an electric resistance backup water heater. The backup water heater could be the same heater used for temperature maintenance. However, some buildings in cold climates may choose to add an inexpensive, electric resistance back-up heat in case the QAHV malfunctions or outdoor units cannot meet demand on extremely cold days.

## Cost and Constructability Assessment

The Cost and Construction Assessment confirms additional costs associated with acquiring and installing the product. It also assesses cost associated with initial market entry and potential for cost reductions as the product becomes more widely available.

## Availability

This section discusses the capacity of the manufacturer to provide products for the

growing Northwest market and lead times associated with the product in a fast-paced construction economy.

## Supporting Infrastructure

Buildings are a community of interacting architectural, structural, mechanical, electrical, plumbing and Ethernet systems. Every component in a building is installed to support another component or provide a service to the occupants.

The packaged QAHV system will require a supporting structure, electrical connections, condensate drain and plumbing connections to operate. The unit can operate with 208/230V and 460/480V 60Hz power, and will require an electrical system designed, per the NEC. Airflow is required so the system has access to fresh air for heat exchange. If the unit is installed outdoors, the IOM has instructions for unit placement. If the unit is installed in a garage, fans and louvers are required to insure airflow through the room. A mechanical engineer will be responsible for designing fans and louvers. A small condensate connection to drain any condensate created in defrost mode is included toward the bottom of the unit. Condensate can be routed to a nearby floor drain by the plumbing contractor.

When provided as part of a packaged system, less supporting infrastructure will be required for plumbing. The only required connections are a connection to city water on the inlet and a connection to the building hot-water loop with a hot-water recirculation pump on the outlet side. However, if the QAHV is provided alone, significant supporting infrastructure must be provided. If the supporting infrastructure is not designed and installed properly, the unit will not perform. When provided separately, the supporting infrastructure includes a multi-pass heat pump or electric resistance water heater, thermal storage, heat exchangers, pumps, expansions tanks, valves, instrumentation and other auxiliary piping hardware.

Items		Higher mid-range temperature water system Water Temp. > 60°C	Make-up water criteria (with secondary side control enabled) Water Temp. > 60°C	Tendency	
		Recirculating water	Recirculating water	Corrosive	Scale-forming
Standard items	pH (25°C)	6.5 ~ 8.0	6.5 ~ 8.0	O	O
	Electric conductivity (mS/m) (25°C)	30 or less	30 or less	O	O
	(µs/cm) (25°C)	[300 or less]	[300 or less]		
	Chloride ion (mg Cl <sup>-</sup> /l)	30 or less	30 or less	O	
	Sulfate ion (mg SO <sub>4</sub> <sup>2-</sup> /l)	30 or less	30 or less	O	
	Acid consumption (pH4.8) (mg CaCO <sub>3</sub> /l)	50 or less	50 or less		O
	Calcium hardness (mg CaCO <sub>3</sub> /l)	6.5 ≤ pH ≤ 7.5: 90 or less 7.5 ≤ pH ≤ 8.0: 50 or less	250 or less		O
Ionic silica (mg SiO <sub>2</sub> /l)	30 or less	30 or less		O	
Reference items	Iron (mg Fe/l)	0.3 or less	0.3 or less	O	O
	Copper (mg Cu/l)	0.1 or less	0.1 or less	O	
	Sulfide ion (mg S <sup>2-</sup> /l)	Not to be detected	Not to be detected	O	
	Ammonium ion (mg NH <sub>4</sub> <sup>+</sup> /l)	0.1 or less	0.1 or less	O	
	Residual chlorine (mg Cl/l)	0.1 or less	0.1 or less	O	
	Free carbon dioxide (mg CO <sub>2</sub> /l)	10.0 or less	10.0 or less	O	

Reference: Guideline of Water Quality for Refrigeration and Air Conditioning Equipment. (JRA GL02E-1994)

**Table 2. Water Quality Standards**

## Construction Schedule

When provided as part of a fully package system there will be little impact to a construction schedule. Similar to VRF systems, a packaged HPWH system should be straightforward and easy for contractors to install on schedule and within budget. Multifamily buildings do not typically have complicated HVAC and plumbing systems. When the QAHV is used for hot water in a residential building, it will likely be the most complicated piece of equipment installed. If the QAHV is not offered as a fully packaged system, there is potential for incorrect designs. If not properly designed, mistakes found during commissioning may significantly delay the construction schedule.

## Installation Cost Impacts

Cost for the product is to be determined. Ecotope estimates a fully packaged skid will cost approximately \$50,000. When integrated into a well-designed hot water system and controlled correctly, the QAHV has potential to provide significant annual utility bill savings. As this product moves forward in the TIM, more about the payback of installing a system will be quantified.

## Retrofit Feasibility

HPWHs are good retrofit candidates for replacing central water-heating systems that are electric resistance or gas. The Mitsubishi system could be an option for retrofitting large buildings with limited mechanical room space because it can be placed outside. Barriers to retrofit include finding a space to install and increasing thermal storage capacity.

## Maintenance Assessment

Maintenance assessment is broken into two sections: Maintenance and Customer Service. Customer Service assesses the ability of the manufacturer to aid Northwest customers. Maintenance addresses maintenance requirements performed by the owner to insure product longevity.

## Customer Service

Mitsubishi is in the process of determining how they will provide customer service to the Northwest and the overall U.S. Currently, Mitsubishi plans to provide customer service similar to the way customer service is provided for their VRF systems. A local

distributor will support the contractor; Mitsubishi's service department and customer care center will support the local distributor. Additionally, Mitsubishi will provide installation and service training to contractors.

Warranty for the QAHV is to be determined. For their VRF systems, Mitsubishi provides to all purchases one year on parts and seven years on the compressor. If the contractor provides specific data and an as-built design, Mitsubishi will offer 10 years on parts and the compressor. The Mitsubishi Commercial Product Management Director has suggested a warranty for the QAHV will be structured similarly.

## Maintenance

The only component that requires regular maintenance is the heat exchanger between the QAHV and secondary loop. The heat exchanger should be cleaned based on the level of scale buildup. The degree of scale buildup depends on the water quality and filtration system.

Table 2 shows the recommended water-quality standards for interaction with heat exchangers. (Japan Refrigeration and Air Conditioning Guideline for Water Quality for Refrigeration and Air Conditioning Equipment) For each item, the chart shows whether there is a corrosion or scaling concern. For example, pH can cause corrosion and scaling depending on its value. A high pH will cause increase fouling; a low pH will cause corrosion. Figure 11 illustrates the rates of corrosion and fouling to pH (Augustin,

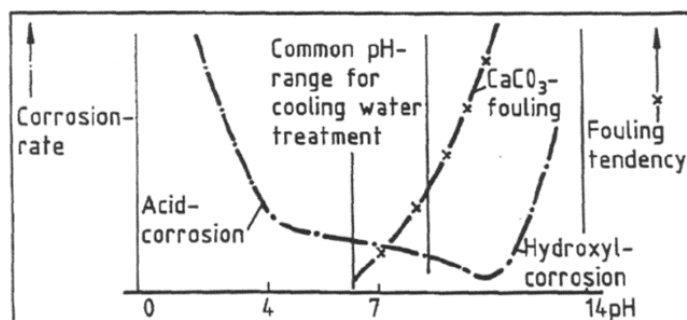


Figure 11. Rates of Corrosion

1994). Water-quality reports for major cities in the Northwest and California show municipal water does not meet the water-quality requirement in QAHV documentation. For instance, Seattle municipal water typically has a pH above 8, which would cause an unacceptable amount of scaling.

To improve reliability and decrease maintenance requirements, a secondary loop with controlled water quality should be provided with the QAHV. If further testing is done to show the QAHV can accommodate a wider range of water qualities, or if the heat exchanger is redesigned to accept domestic Figure 10 water, no secondary loop will be required. However, it is possible that the large amounts of scaling associated with high temperatures will prevent Mitsubishi from designing an internal heat exchanger that will work for municipal water, and that the best solution would be a secondary heat-exchanger loop.

## Conclusions and Recommendations

### Conclusions

The Mitsubishi QAHV CO<sub>2</sub> HPWH is a promising product. Its ability to operate in low temperatures and provide high-lift for incoming city water offers advantages for use in hot-water systems in the Northwest. However, before the QAHV can be introduced to the market and provide consistent energy savings, Mitsubishi must provide a robust fully packaged system.

One of the most pressing challenges for the QAHV is the secondary heat-exchanger loop. Few municipal-water supplies are compatible with Mitsubishi's internal heat exchanger water-quality standard. Additionally, the heat exchanger does not comply with the SWDA through NSF 372. Therefore, a secondary heat-exchanger loop is required. It is imperative that Mitsubishi provide a standard secondary loop-heat exchanger, pump and

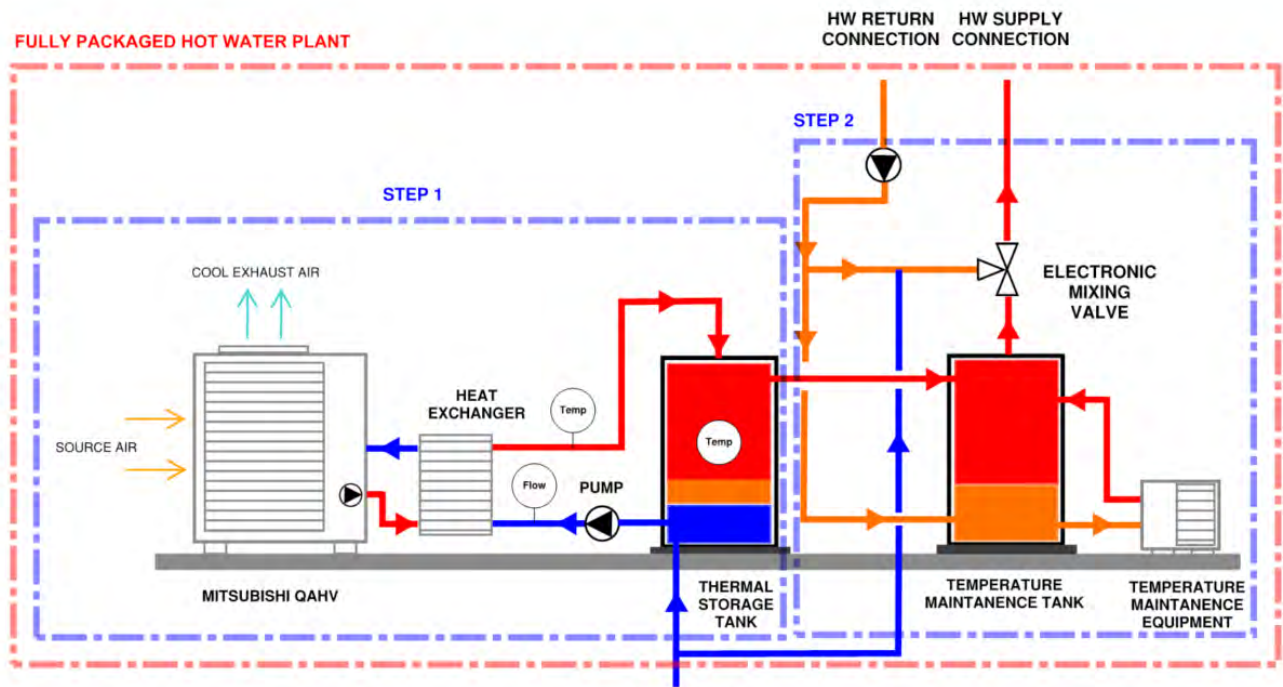


Figure 12. Schematic of Envisioned Packaged QAHV System

controls packet for this circuit. Figure 12 shows the major components required for a fully packaged Mitsubishi QAHV HPWH system. Step 1 includes the most pressing challenge — the secondary heat-exchanger loop with thermal storage. This should be addressed before a demonstration project is initiated to assess the robustness of maintenance required on the QAHV water loop and the secondary heat exchanger. Step 2 includes supplying temperature-maintenance equipment and other auxiliary equipment such as a tempering valve and expansion tank.

## Manufacturer Recommendations

Ecotope and BPA have recommended Mitsubishi use the process outlined in the TIM to introduce the product to market. Mitsubishi has agreed, and will work to develop a packaged system and move the QAHV through the TIM.

## Utility Recommendations

The QAHV has enormous potential to provide energy savings and load shifting when included as part of a well-designed fully packaged system. It is recommended the product move forward in the TIM process to Application Testing. This next step will provide design information required to determine if the product is ready for a demonstration project. During this process, the team will work closely with Mitsubishi to assist in providing a resilient package design with all necessary sizing tools, design guidelines and documentation so the product can be introduced to the market in a way that ensures electricity savings and load-shift capability. A preliminary list of research questions to be addressed during Applications Testing is below. Applications Testing should begin in fall 2020.

## Applications Testing Topics for Investigation:

- Determine equipment performance with secondary heat exchanger loop.
- Evaluate controls of internal QAHV pump when operating with a secondary heat-exchanger loop.
- Evaluate controls of the external load-side pump when operating with secondary heat-exchanger loop.
- Observe defrost cycle and assess effectiveness.
- Assess the ability to control temperature-maintenance secondary equipment.
- Monitor error codes provided by equipment through central control.
- Ability of the equipment to log data. Whether the equipment can provide accurate internal data logging to be accessed during demonstration testing.
- Capability and effectiveness of the equipment to load shift through a CTA-2045 port.



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