# Centralized Plants with Decentralized Solutions

## Using Uponor's AquaPort™ Substations for Enabling Energy and Exergy Efficiency, Conservation of Energy and Mass, and Promoting Safety and Hygiene in Multistory Potable-water Systems


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## About the Author

Robert Bean is an ASHRAE Fellow, Distinguished Lecturer, and recipient of the Distinguished Service Award. He is a retired practitioner who specialized in the design of indoor environments and high-performance building and energy systems. He has authored many papers, articles, and course curriculums. He serves on numerous technical committees related to indoor environmental quality, building, and energy systems.

His motto is, Design For People, Good Buildings Follow.™

## Description

AquaPorts are engineered, factory-assembled, tested, and certified appliances for generation of domestic hot water when supplied with fluids from a central heating plant. They are commonly referred to in community-based systems (i.e., district energy) as substations, heat-transfer stations, or heat-interface units (used interchangeably in this paper).

This paper describes the benefits and features of integrating these devices into mechanical engineering practices within the property development industry.

## Introduction

In building architecture, the design and installation of mechanical and plumbing systems in North America have remained relatively unchanged since the 19th century. HVAC and plumbing systems remain mostly site assembled and unique to each project. Most other industries have advanced away from customization and towards standardization facilitated with professional engineering and factory assemblies.

The consequences of bespoke mechanical systems are circumstantial and relative. Generally, on-site assemblies can lead to lengthy and costlier installs, often with unnecessary waste and commissioning complexity.

Building owners and mechanical technicians have long experienced the frustrations of maintaining custom systems as original installers are replaced with new personnel unfamiliar with the assemblies and operations. Arriving on site with unknown skills and frequently with experimental ideas can create operational friction between the original design intent and subsequent modifications when implemented. Over time, the repeated changes of service staff, components, and subsystems, especially when underfunded, can leave the building and electromechanical systems in a state of dysfunction in energy conservation, efficiencies, hygiene, and performances.

In contrast, consider the design, assembly, and launch of NASA's Space Shuttle Program, where standardization of what is essentially a "truck" enabled quick turnaround times for several launches over many decades. Similarly, reliable automobiles can be assembled in three to five days for a Tesla or under 24 hours for a Toyota Corolla. Commercial airliners, such as a Boeing 737, are completed in less than three months. Most practitioners recognize that a 30-story condominium (i.e., 270,000 $ft^2$) assembly is almost the same as constructing a large, custom, single-family home (i.e., 15,000 $ft^2$). Each is having about two-year construction timelines. As did the Royal Caribbean's cruise liner, Symphony of the Seas. But with a capacity of over 6,000 guests and 2,000 crew, the ship is far more complex and sophisticated in all its thermal, mechanical, and plumbing systems compared to the high-rise building or custom home. It is not possible to assemble such systems so efficiently without the prefabrication of standardized subsystems. Other significant industries' streamlined processes should make property development teams and their contractors evaluate building engineering and fabrication practices. This includes the “engine and transmission systems of the building”, defined by the HVAC and plumbing assemblies.

## Centralized Plants with Decentralized Solutions

The successful principles behind centralized plants with decentralized, standardized solutions can be found throughout the world in district energy systems. Standardized, factory-assembled, heat-interface units for domestic hot water generation and thermal energy distribution for space heating and cooling are the norms rather than the abnormal (Figure 1). These systems are characteristic of one or more substations in each building serviced by a horizontal municipal distribution system connected to a centralized plant. However, this characteristic can be turned vertically with substations located in, for example, each suite or tenant space on each floor of multistory buildings (Figure 1)[i].

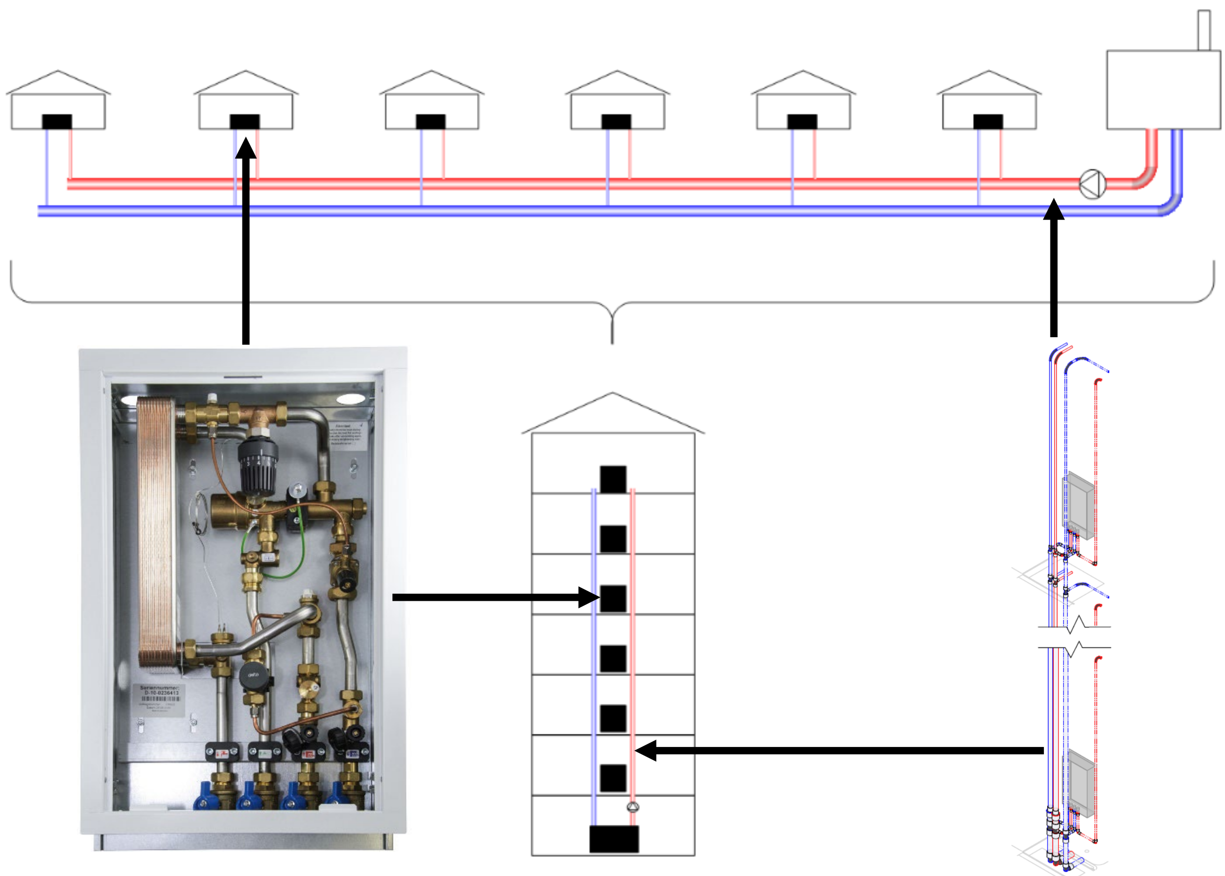


Figure 1: Typical district energy characteristics with heat-transfer stations (top illustration) rearranged into a vertical format (bottom illustration)

**Substations (Heat-transfer Stations)**

Substations (Figure 2) are the transmission between heat production (boilers, heat pumps, solar thermal, electric, etc.) and consumption [heat terminal units (HTUs), domestic-water heating]. They are engineered to manage the transient nature of flow, pressure, and temperature under dynamic demands. They provide safe, hygienic, reliable flow to fixtures while promoting energy and mass conservation to enable energy and exergy efficiency in systems.

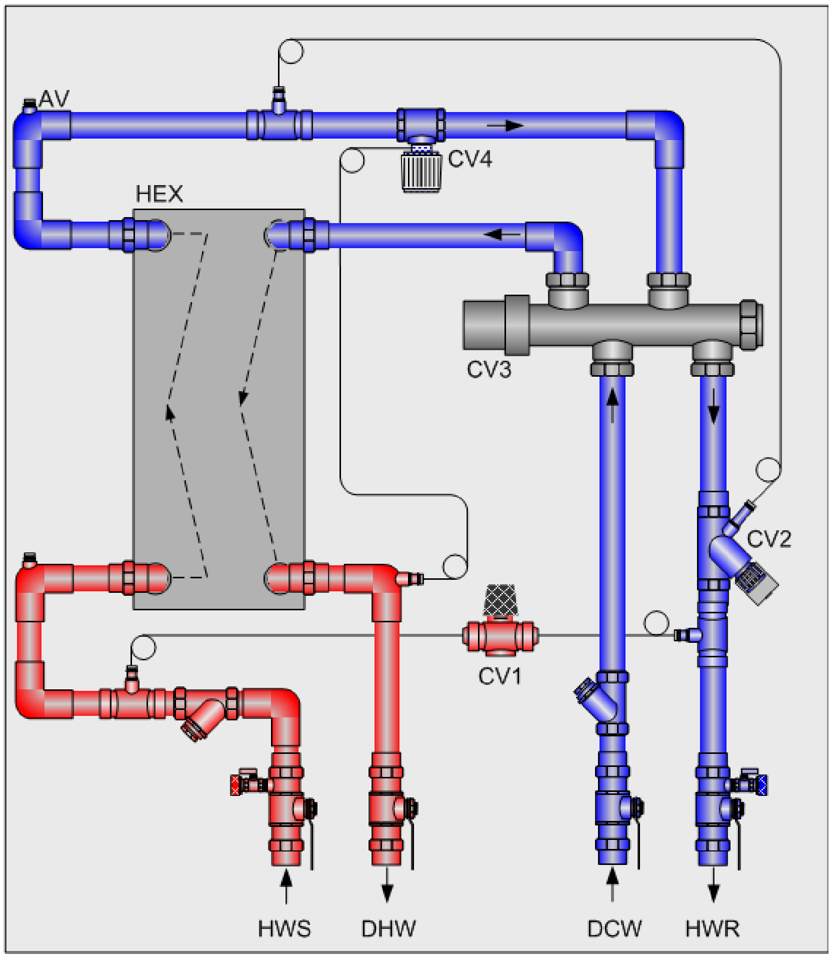



Figure 2: Standardized, factory-assembled substations for domestic hot water generation

Table 1: Sub-station Equipment List, Descriptions, and Function/Purpose for Figure 2

| Tag | Description | Function/Purpose |
|---|---|---|
| CV1 | Thermal bypass control valve | Maintains a microflow at HEX for reducing standby delays |
| CV2 | Pressure/flow control valve | Regulates available pressure (HWR flow) through CV3 |
| CV3 | Proportional flow control valve | Regulates HWS flow based on DCW inlet flow |
| CV4 | DHW temperature control valve | Limits the outlet temperature to the fixtures |
| AV | Manual air vents | For bleeding air from HWS |
| HEX | Heat exchanger | Double-wall brazed exchanger for heating DCW |
| HWS | Heating (hot) water supply | From the space heating supply riser for heating DCW |
| HWR | Heating water return | To the return riser back to the heating plant |
| DCW | Domestic cold water | From the cold water riser for domestic purposes |
| DHW | Domestic hot water | Heated domestic water supply to fixtures |

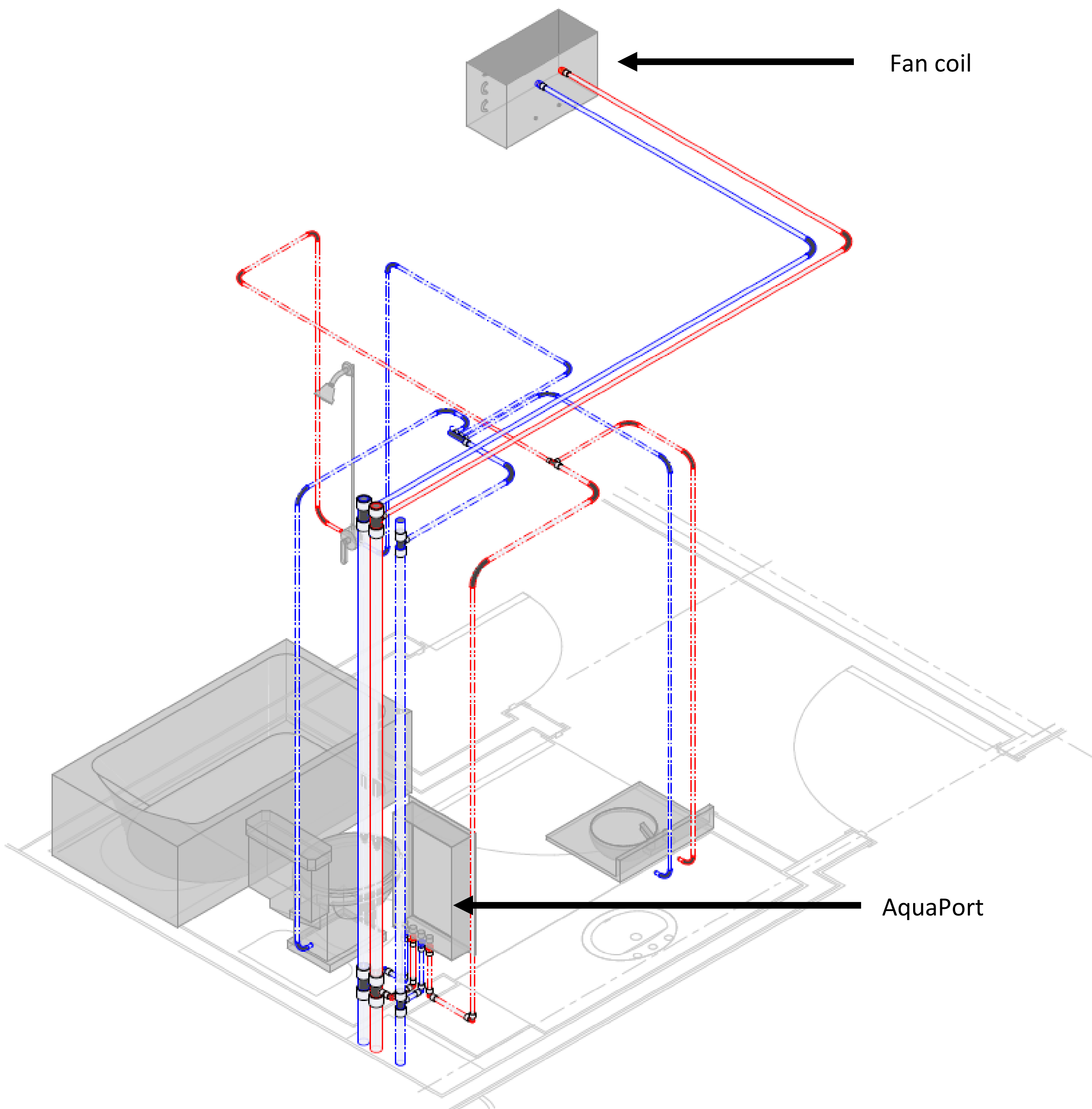



Figure 3: Typical application of an AquaPort sub-station serving the potable requirements of a typical suite. Also shown is the space-heating fan coil (by others).

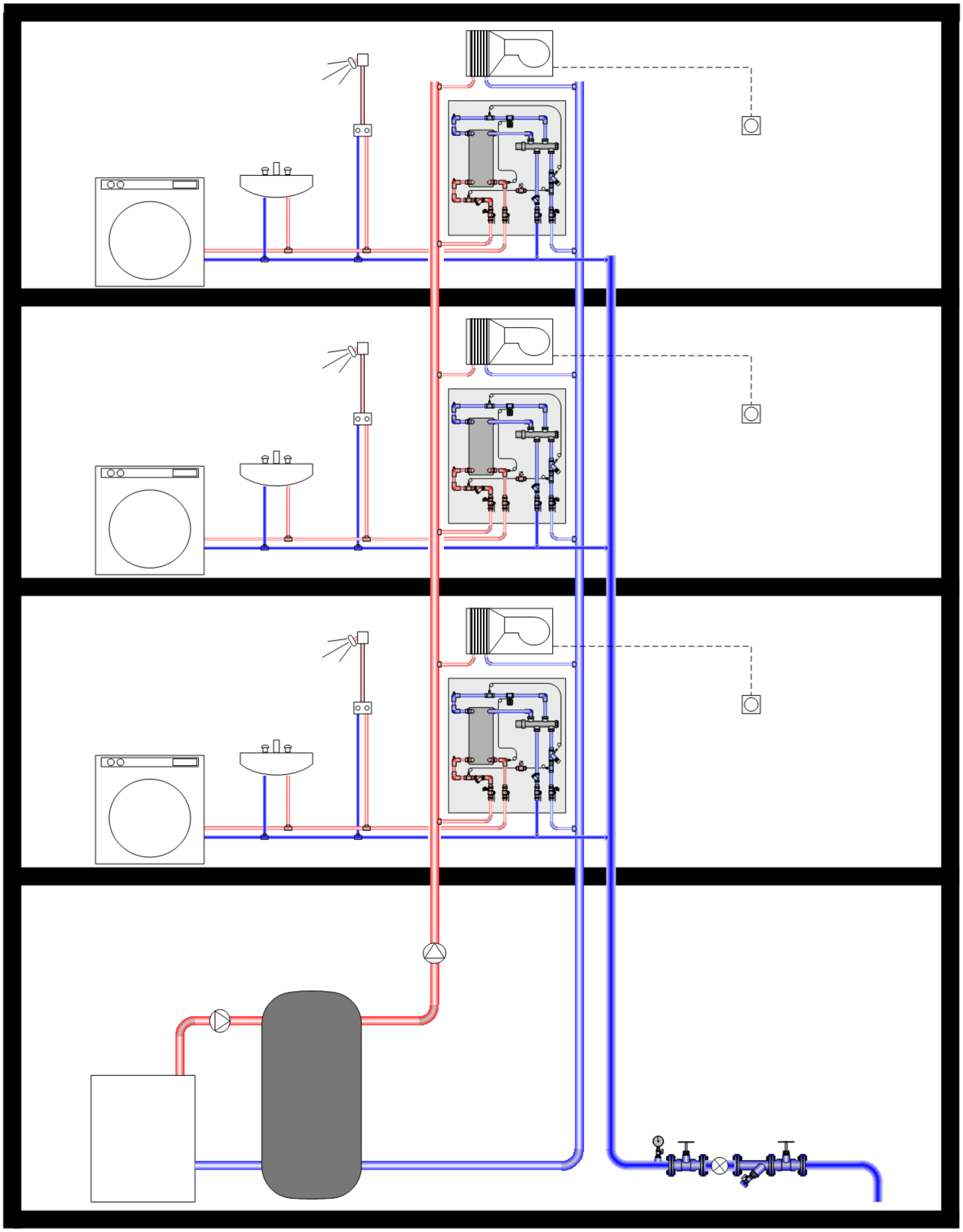


Figure 4: Application illustration for AquaPort substations in vertical-based district systems

## Benefits of Vertical-based District Systems with Domestic-water Substations

In modern engineering practice, energy and exergy efficiency, conservation of energy, and system hygiene are of utmost importance. These can be achieved by the streamlined design, specification, and installation practices using standardized substations, such as Uponor's AquaPorts offering.

**Lifecycle cost improvement: elimination of domestic hot-water riser, recirculation lines, and water heaters**

A vertical-based system's key features using substations are eliminating the domestic hot-water risers and recirculation lines, water heaters/domestic storage tanks, and correlated water volume itself (Figure 5). Coupled with these is removing sleeving/coring, fire stops, piping

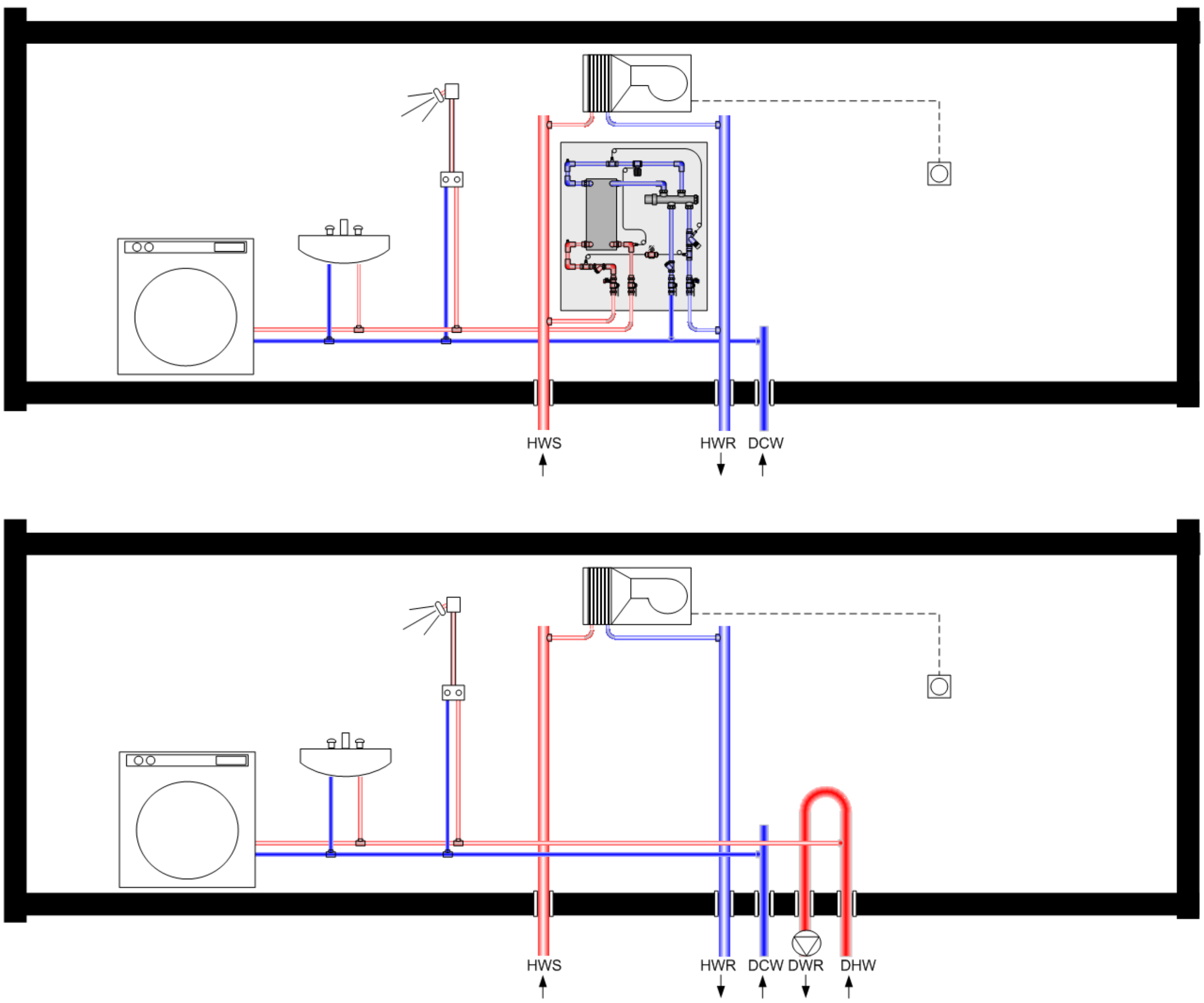
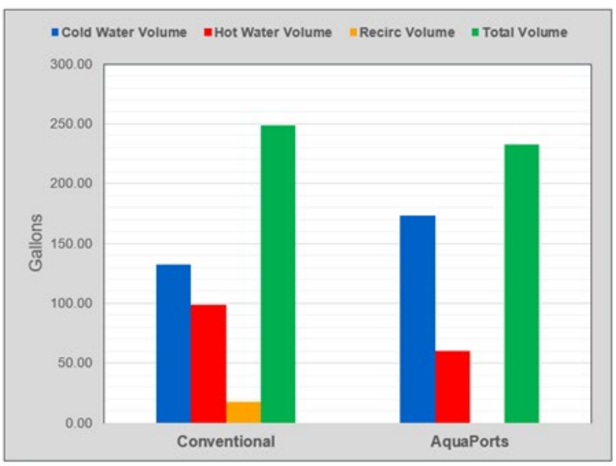



Figure 5: Comparison of sub-stations in a vertical-based district system (top) versus traditional riser piping assemblies (bottom).

supports, expansion joints, pipe insulation, labor, and materials. The additional benefit is the reduction in the size of piping chases. This strategy also mitigates piping and fitting failures commonly associated with traditional recirculated potable systems. This would include anything related to velocity, velocity-related surges/shock, and water characteristics (i.e., chemistry). All electrical and thermal energy use associated with circulating heated domestic-water flow is also removed. This includes the elimination of parasitic transfer from space heating lines to recirculation lines. Since the total potable-water volume is conveyed in a single riser, it reduces the water-volume-to-pipe-surface area. This is beneficial in lowering bacteria risk and transmission losses.

**Energy and Water Conservation in Domestic Systems**

By relocating domestic water heating from a large reservoir in the mechanical room into small, on-location/on-demand stations, it reduces standby and transmission losses. This is due to the reduction and elimination of stored, heated potable water, recirculation lines, and associated issues with maintaining thermally charged domestic-water distribution networks. As illustrated from one case study (Figure 6), there is a significant reduction in heated-water transportation. Compared to a traditional system, there was a 30% reduction in cold domestic volume, 39% reduction in hot domestic supply volumes, and total elimination of recirculated domestic volumes for a total combined reduction of 6% over a conventional system. Correlated with those reductions are fewer transmission losses, less mass to move, lower pumping energy, fewer materials and labor, and fewer potential piping failures associated with recirculation lines (i.e. oxygenated-chlorinated water at high velocity and high temperatures to kill legionella).




| System Volume Delta | | |
|---|---|---|
| **Domestic CW Delta** | | |
| -40.58 | Gallons | 31% |
| -338.02 | lbs | 31% |
| -93.34 | sq.ft. | 8% |
| **Domestic HW Delta** | | |
| 56.41 | Gallons | -49% |
| 469.86 | lbs | -49% |
| 289.87 | sq.ft. | -30% |
| **Total System Volume Delta** | | |
| 15.83 | Gallons | -6% |
| 131.84 | lbs | -6% |
| 196.53 | sq.ft. | -9% |

Figure 6: Water volume comparison between a traditional system and an AquaPort system

The on-location/on-demand features of the AquaPort offering reduce water consumption, relative to some domestic systems, which can have inherently long wait times resulting in lukewarm tap water being drained without any benefit.

## Efficiency and Conservation of Energy

Equipment and systems designed around AquaPorts enable aggressive Delta Ts across the heat exchangers serving each space/suite/load. These lower Log Mean Temperature Differences (LMTD) require a one-time increase in the exchanger surface area. The benefit is a lifetime of low return temperatures (i.e., 75°F/24°C), which extracts the maximum efficiency from the condensing boilers or heat pumps serving the systems (Figure 7 and Figure 8). The same is true for low-entropy renewable systems, which support increases in exergy efficiencies (see exergy description below). Of equal interest is the return temperature profiles under part load, representing the most significant number of hours in most applications.

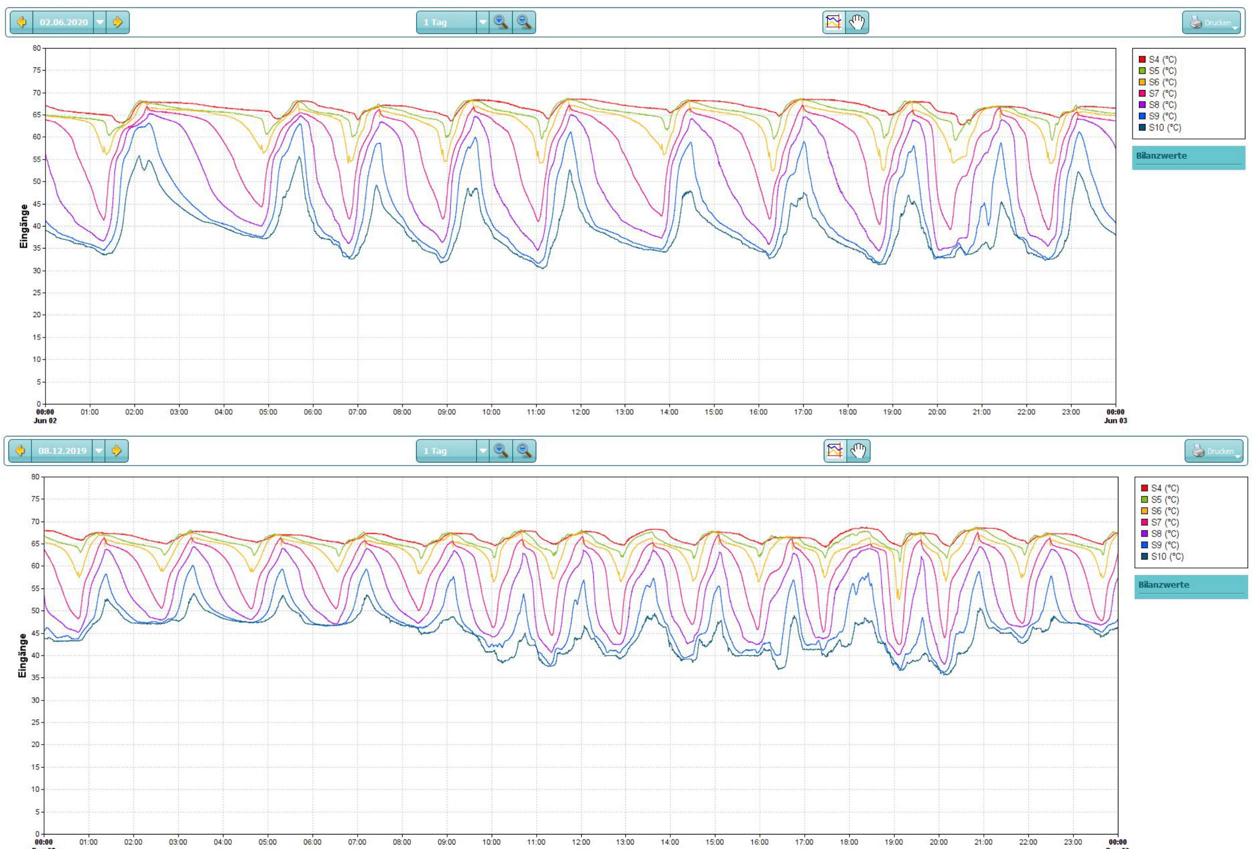



Figure 7: Actual field data from summer (top) and winter (bottom) occupant-based demand cycles. The uppermost data line in each graph represents supply temperatures from buffer tanks, with the lowest representing return temperatures. Make a note of the deep Delta Ts in the summer (domestic water only) weekday (Tuesday, June 2, 2020), with maximum extraction occurring under peak loads in the early morning and late evening (a nominal 154°F/68°C to 88°F/31°C). Make a note in the winter period (space heating and domestic water heating) weekend (Sunday, December 8, 2019) how the operation of the AquaPort drew down the daily return temperature an additional 18°F/10°C. In all operational cases, the reduced return temperatures enable the heating plant to achieve higher-rated efficiency. It also conserves energy due to the reduction of as parasitic line losses in return lines.

These engineering fundamentals should always be considered when comparing against equipment rated under such labels as Energy Star® or CGA, which don't capture exergy analysis realities nor variable and dynamic load profiles. Good practice suggests the simplified systems described within this paper should be considered when looking at other options involving individual gas heaters per unit or multiple gas heaters per building. These combustion-based solutions introduce numerous points of failure risks in gas piping, combustion, exchangers, venting, and controls. These add to the systems' lifecycle costs and unnecessarily expose occupants to life-safety hazards.

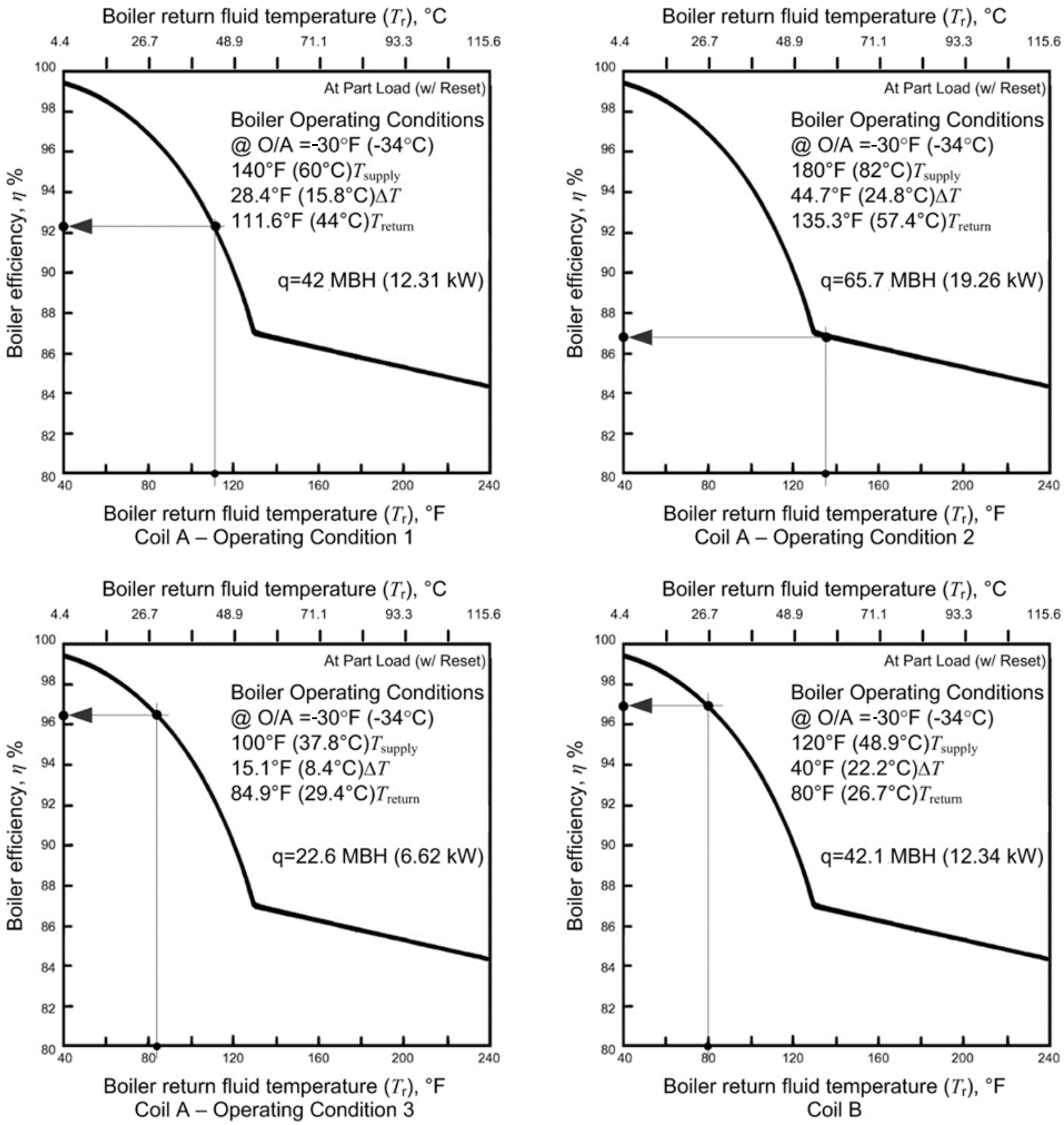



Figure 8: The effects of return water temperatures (x-axis) from heat exchanger selection on boiler efficiency (y-axis).

**The effects of return water temperatures from heat exchanger selection on boiler efficiency (Figure 8).** Coil A under three operating conditions — note the wide range of performances. Note the benefit of coil B on efficiency and performance. Coil B has a slightly larger face area (2.92 $ft^2$ vs. 2.25 $ft^2$), two more rows (4 vs. 2), corrugated fin pattern vs. sine-wave fin pattern and built with smaller-diameter tubes (½" vs. ⅝"). This extra capital cost is a one-time expense having a lifetime of efficiency benefits. Combined with the lower LMTD from domestic water generation using the AquaPort, the two systems enable heating plants to operate near peak performance under minimum and maximum loads.

**Exergy-efficiency Potential**

Since the lower LMTD defines the required demand from the source energy, any reduction in differences between source and demand temperatures reduces the system's entropy. By decreasing this entropy, it improves the systems' exergy efficiency. A perfect marriage for this scenario would be solar thermal space heating systems or heat pumps served by hydro, wind, or photovoltaic (PV) power or multistage hybrid systems using, for example, waste heat from industrial processes or in conjunction with CHCP plants.[ii] The AquaPort supports IEA Annex 49 in reducing exergy demands leading to reductions in CO2 emissions afforded by sustainable renewable energy systems.[iii]

**Exergy Efficiency**

"The energy performance of HVAC systems is usually evaluated based on the first law of thermodynamics. The energy analysis alone is not adequate to gain a full understanding of all the important aspects of energy utilization processes, if the quality of available energy is not considered. Sometimes it misses the important aspects for improvement (Schmidt 2003). Exergy, an important thermodynamic concept, is defined as the maximum possible useful work that a system can deliver when it undergoes a reversible process from the initial state to the state of its environment, the dead state. Exergy measures the quality and quantity of energy. In a process or system, the total amount of exergy is not conserved but is destroyed due to internal irreversibilities and heat transfer crossing the system boundaries. The exergy destruction is proportional to the entropy created due to irreversibilities associated with the process (Cegel and Boles 2002)."

Source: Yu Wu, X., Zmeureanu, R. (2011) Exergy Analysis of Residential Heating Systems: Performance of Whole System Vs Performance of Major Equipment. Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November

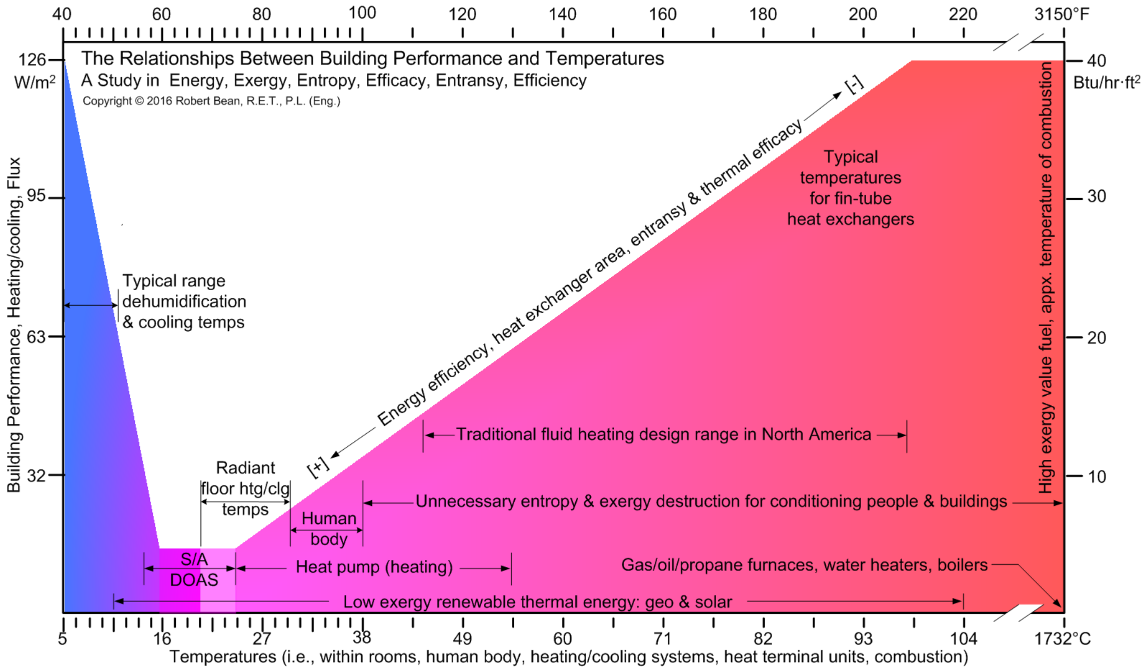



Figure 9: The relationship between building performance (y-axis), heat-exchanger sizing, and temperatures (x-axis). In essence, the larger the heat exchanger surface area to serve lower-flux results in a lower-temperature requirement more aligned with renewable systems, a fundamental principle in sustainability.

**Combustion to Electrification**

Traditional building and HVAC design show large fluxes from low-performance enclosures, > 10 Btu/hr/ft$^2$ (32 W/m$^2$), and small-surface-area heat exchangers (fin-tube types). They demand higher LMTD to transfer the necessary thermal energy to the building (Figure 9)[iv]. When connected to combustion-based sources, these systems inherently have high entropy losses, destruction of exergy, and poor system efficiency. They have high infiltration with inadequate mean radiant temperatures (see ASHRAE Standard 55). The combination promotes stratification, radiant asymmetry, downdrafts, and cold floors. As a result, they also tend to have poor thermal efficacy leading to non-compliance with thermal comfort standards and comfort complaints. The consequence is low conservation of energy and less-than-optimum efficiency.

The combination of poor architecture, high loads, and small heat exchangers also destroys any opportunity for sustainable low entropy, high exergy-efficient renewable systems using PV, wind, or hydropower, enabling high COP from heat pumps. The latter made possible with higher-performance enclosures and larger-surface-area heat exchangers. Therefore, all designs should prepare for electrification using renewable energy sources for engineering low-entropy, high-energy-and-exergy-efficient systems.

The AquaPort heat exchanger and assembly have been selected to offer a wide range of performances, including use with low-temperature supplies (120°F/50°C) from heat pumps.

**Hygiene and Safety**
As part of a layered bacteria control strategy, the AquaPort substations with associated Uponor AquaPEX® and Uponor PP-RCT pipe distribution systems reduce health and safety risks to the users. Since there is no potable storage nor recirculation network, the water volume in the domestic piping systems is decreased significantly, lowering the chances of contamination due to stagnation. Water velocity is optimized through analysis of available water pressures and selections of pipe diameter. These higher-engineered velocities in the AquaPort and Uponor piping systems minimize bacteria growth while reducing wait times and tap-water consumption. There is no greater risk of bacteria in an AquaPort DHW system than what one might find in a standard cold-water piping system.

Also, the AquaPorts are furnished with atmospherically vented double-wall plate heat exchangers. This feature prevents cross-contamination from the heating plant to the potable water in the unlikely event of exchanger plate failure.

Components for the AquaPort are listed under ASSE LEC Proportional Flow Control Devices, with Protection from Cross-Contamination via Hydronic Water, for use in Drinking Water Installations (see also ICC-ES PMG-1543).

**Reduced Consequences of Shutdowns**
With the relocation of heat transfer within each suite, servicing an AquaPort does not affect the entire building. The maintenance becomes micro-based rather than macro-based. If needed, the appliance can be replaced in its entirety. It is simply a matter of closing the isolation valves, relieving any latent pressure via drains, and removing and inserting the replacement. Furthermore, all major components are non-customized standard devices typically available from Uponor or industry supply houses.

## Overview of Standardized AquaPorts vs. Customized On-site Assemblies

Engineers are already familiar with the concepts of standardization. Consider the selection and specifications for boilers, chillers, heat pumps, heat exchangers, and circulators, etc.

Manufacturers use engineering principles for creating catalogs of finished goods with specific performances that the design practitioners specify once the loads are known. These components are building blocks for assembling subsystems and complete systems. They are designed around safety, performance, and flexibility. These are the same principles employed when designing and constructing planes, cars, and ships. The strategy enables long-term accessibility to a vault of engineering and service support, documentation, and parts. It is with these principles that the AquaPort product is offered to the engineered-systems community.

**Integrated Design**
The AquaPort solution consolidates thermal loads by integrating the space heating and domestic-water heating demands through risers to each substation. This enables a single-point understanding of energy demands, facilitating optimization of energy and exergy efficiency.

**Faster Installs and Commissioning**
It is unnecessary from the AquaPorts' perspective for the building to be fully completed before commissioning. Once the heating plant is operational and risers are available, the AquaPort can be quickly connected for generating domestic hot water and space heating. This means

performance verifications and operations can begin during construction rather than having to wait for final completion. In buildings with hundreds of loads, this has a significant advantage over stick-built/site-assembled systems.

**Certification and Quality**

The AquaPort has been certified to ICC-ES PMG-1543 and is an engineered, factory-assembled product under ISO certifications (9001, 14001, and 50001). The AquaPort follows a structured design, component procurement, assembly, and testing sequence. This is similar to what is found in industry catalogs. Specifically, each assembly is saturated with a leak indicator and observed under 73 psig (5 bar) air pressure to ensure water tightness.

**Limited Warranty**

The AquaPort falls under the category of appliances coming with a manufacturer's limited warranty.

**Immune to Labor Shortages and Installer Changeover**

As with other major components, such as boilers, fan coils, etc., the AquaPort is a finished product not requiring further field modifications at any time over its life expectancy. Its installation, operation, and maintenance are explained in Uponor's documentation. The standardization eliminates the post-commissioning guesswork associated with custom installations by technicians who may no longer be employed with the company.

**Immune to Lost Documentation**

As an appliance, each substation is furnished with a permanent electronic record of parts and assembly.

**Enables Lower Cost of Installations**

Each appliance's shipping weight is light enough for one or two people to transport the device to the installed location without mechanical assistance. Additionally, the complexity and skill level required have been optimized for installations by apprentices supervised by journeypersons (pre-commission inspections/start-ups).

**Improves Cash Flow**

As with any delivered appliance, the AquaPorts are finished goods. For the businesspeople managing the mechanical contracting company's accounts receivable, this enables responsible management of the company's finances. Unlike custom on-site assemblies, AquaPorts do not need to reach completion stages for requesting progressive payments. They can be invoiced once delivered to the site. This enables better cash flow for the business rather than cash from operations to finance parts and labor procurement over the project's life.

**Reduces Multiple Gas Line and Venting Installations**

The AquaPort promotes reductions in installations of fuel lines, gas meters, and venting associated with designs using a fuel-fired appliance in each suite. The benefit is safety for occupants and conservation of energy with higher efficiencies.

**Avoids Obsolescence**

The AquaPort avoids obsolescence by using proven and available off-the-shelf components. Because it is a fluid-based appliance, it is fuel neutral. There will be no modifications required in the event of electrification and transition to renewables. Its function will remain timeless for the life of the building.

**Integrated with Metering**
Where domestic and heat metering is required, the AquaPort can be installed in between the meters and the loads.

**Testing and Technical Support**
The AquaPort substation is tested and performance is demonstrated in Uponor's North American headquarters and technical support center.

Figure 10: Uponor North American test laboratory and demonstration lab for AquaPorts

## Applications

The AquaPort product has utility whenever there are needs for domestic water heating and hydronic space heating in low-rise or high-rise buildings. The applications are numerous; consider the following:

- Accommodations, including condos/apartments/dormitories/hotels/motels
- Commercial projects, including offices/retail/athletic facilities/universities/colleges
- Institutional projects, including hospitals/research facilities/care facilities/prisons
- Industrial projects, including manufacturing/processing

## Fundamentals

According to good engineering practice, load assessment for each AquaPort specified is based on fixture units and HTU demands. This includes the demand flow, available inlet pressures and temperature, and desired outlet pressure and domestic-load temperature. Also required is assessing the pressure surges when tapping water valves are opened and closed and water quality requirements (contact Uponor Construction Services for support).

**Typical Flows and Temperature Demands**

**Table 2: Typical design flows and temperature demands (ref.: DIN VDI 6003)**

| Load | Performance Class, Flow, l/min (U.S. gpm) | | | Temperatures C (F) |
|---|---|---|---|---|
| | Level 1 | Level 2 | Level 3 | |
| Sink | 3 (0.80) | 5 (1.32) | 6 (1.59) | 40 (104) |
| Shower | 7 (1.85) | 9 (2.38) | 9 (2.38) | 42 (108) |
| Bathtub | 7 (1.85) | 10 (2.64) | 13 (3.43) | 45 (113) |
| Kitchen sink | 3 (0.80) | 5 (1.32) | 6 (1.59) | 50 (122) |
| Bidet | | 3 (0.80) | 3 (0.80) | 40 (104) |
| Large bathtub | | 13 (3.43) | 13 (3.43) | 50 (122) |

## Performance Curves for HX = B16DW 20

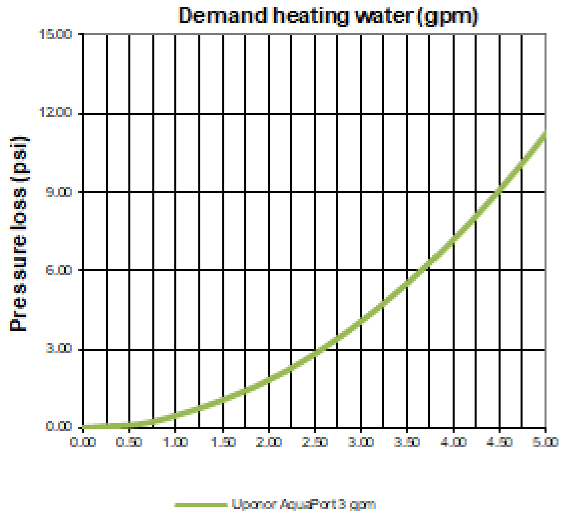



Figure 11: Pressure drop through HX = B16DW 20, on hydronic side (primary) for 3 U.S. gpm (680 L/h) warm water tapping

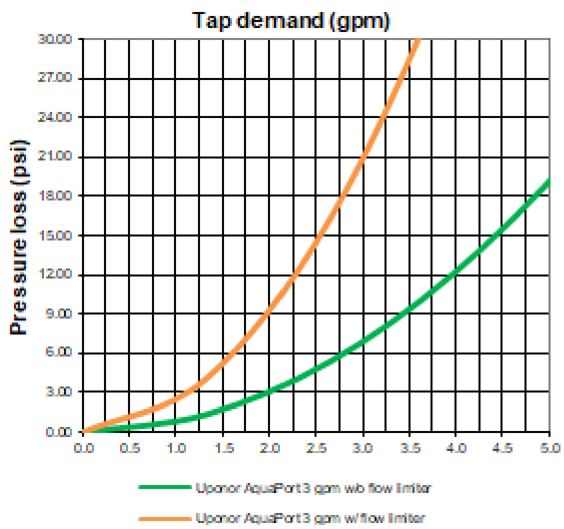



Figure 12: Pressure drop through HX = B16DW 20, on tap water side (secondary) for 3 U.S. gpm (11.4 L/min) warm water tapping

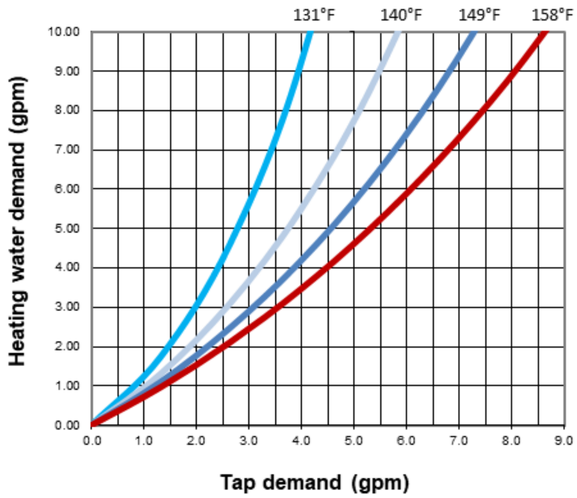



Figure 13: Supply temperatures and flow rates required for HX = B16DW 20 when heating domestic water from 50°F (10°C) to 120°F (49°C)

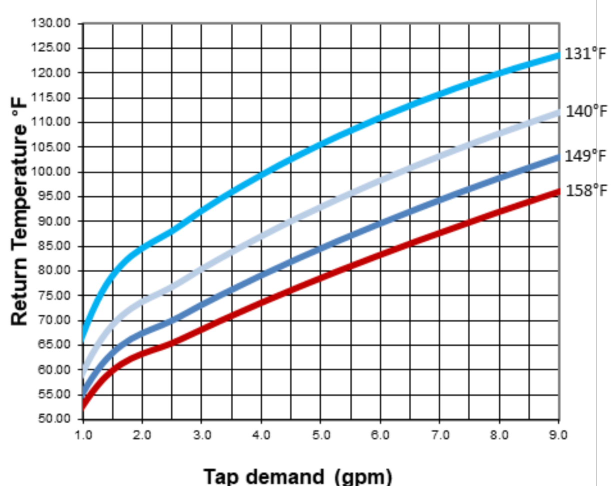



Figure 14: Hydronic return temperatures for HX = B16DW 20 when heating domestic water from 50°F (10°C) to 120°F (49°C)

## Performance Curves for HX = B16DW 40

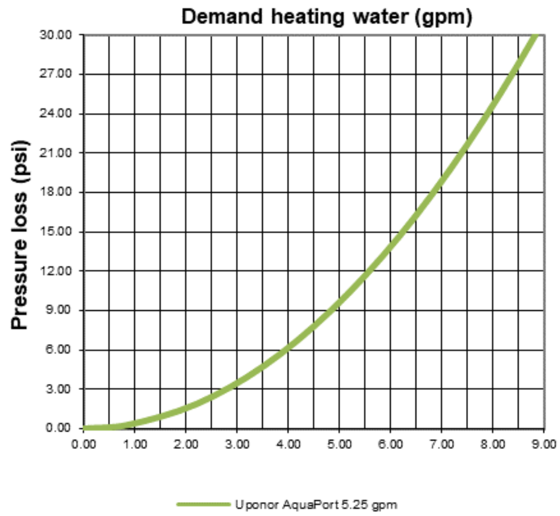



Figure 15: Pressure drop through HX = B16DW 40, on hydronic side (primary) for 5.25 U.S. gpm (1136 L/h) warm-water tapping

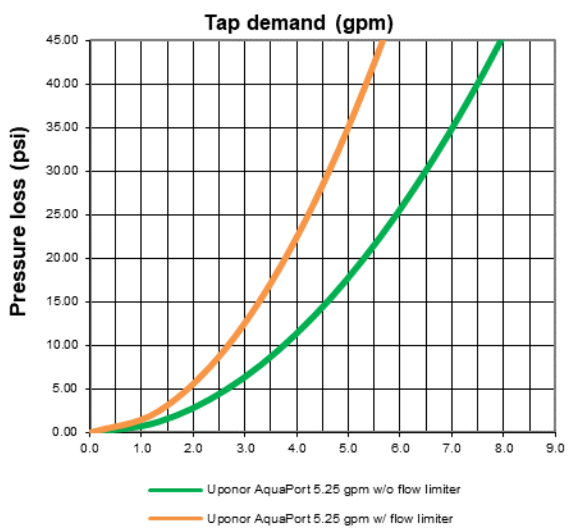



Figure 16: Pressure drop through HX = B16DW 40, on tap water side (secondary) for 5.25 U.S. gpm (19 L/min) warm-water tapping

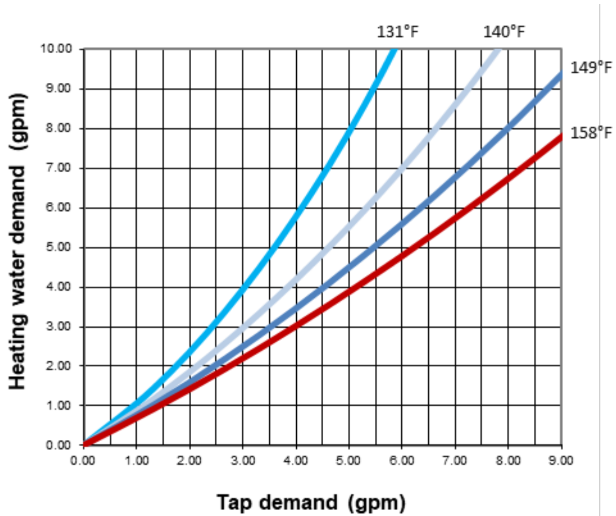



Figure 17: Supply temperatures and flow rates required for HX = B16DW 40 when heating domestic water from 50°F (10°C) to 120°F (49°C)

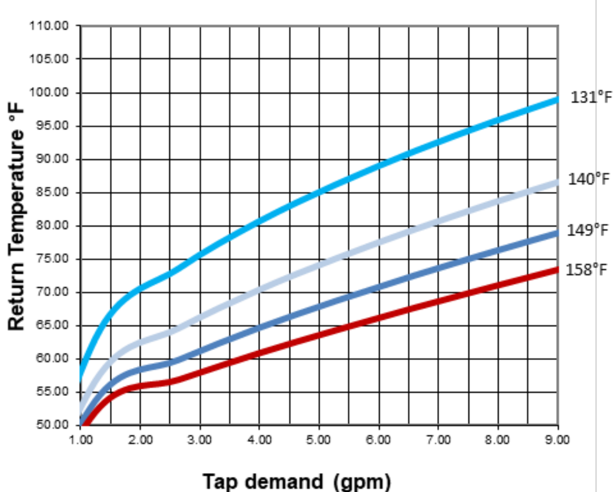



Figure 18: Hydronic return temperatures for HX = B16DW 40 when heating domestic water from 50°F (10°C) to 120°F (49°C)

**Simultaneity/load diversity**
Simultaneity is governed by the fact that no more than the two points of withdrawal of hot water with the highest required output is opened simultaneously (e.g., kitchen and shower). For further information about this topic, please make a request to Uponor Technical Services at technical.services@uponor.com or 888.594.7726 for the technical information on Combi Port and AquaPort 1094902.

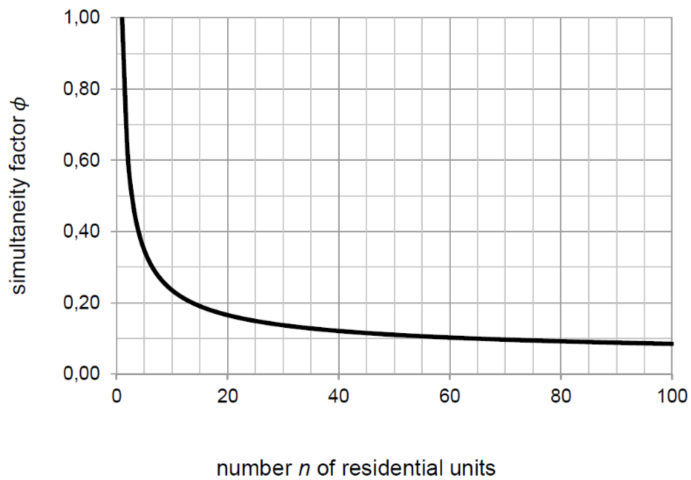



Figure 19: Simultaneity curve representing likelihood of 100% demand on the heating source for domestic purposes based on the number of installed units. See AquaPort sizing example on the following page using the fixture unit method as is standard practice in North America.

## Piping Layout for a Four-story, Three-riser System using AquaPorts

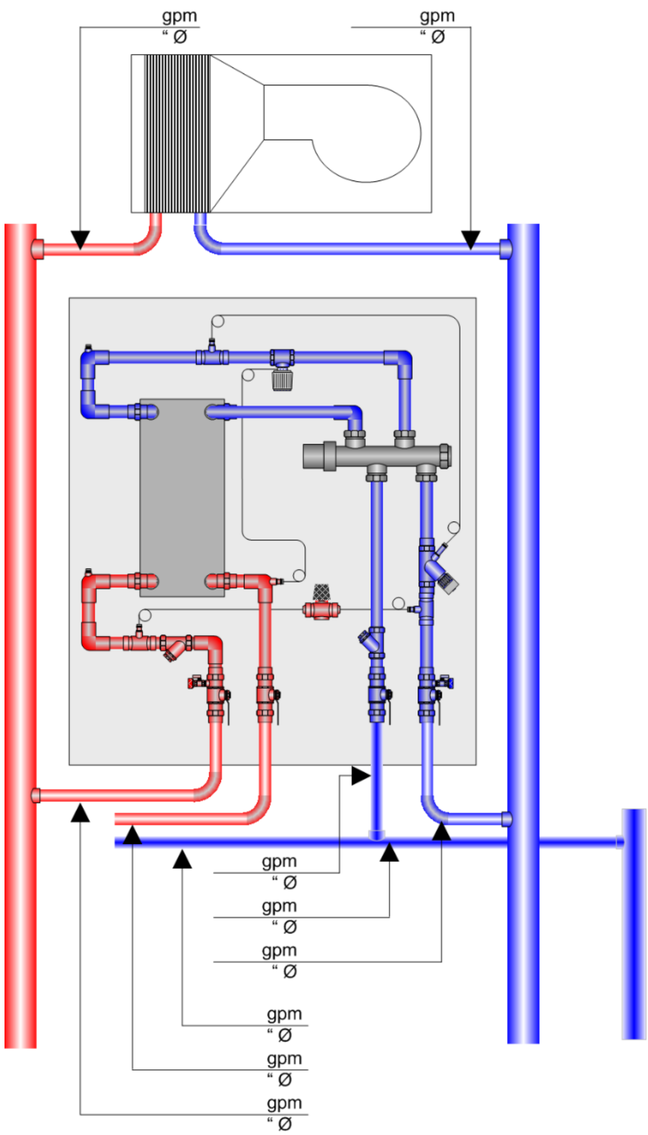



Figure 20: Dimensioning requirements for an AquaPort substation and HTU; includes flow, diameter, velocity, and differential pressure requirements

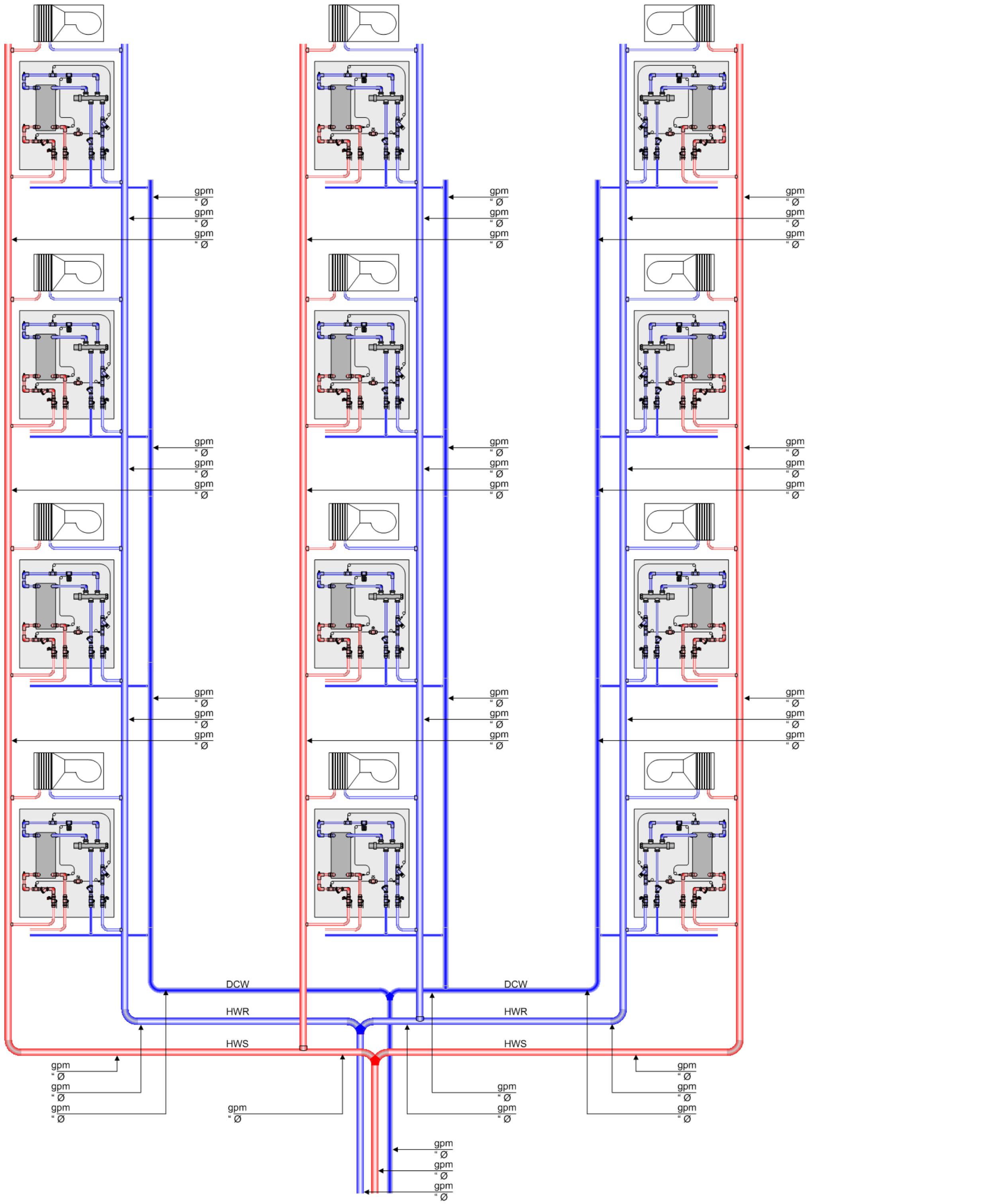



Figure 21: Example of a riser piping layout and dimensioning requirements for an AquaPort system. Note: It is advised that HTUs (i.e., fan coils, radiant floors, radiators, etc.) have return-temperature limiters to prevent unnecessary temperature increases through the heating plant.

## Typical System Schematics (fill assemblies and air separation omitted for clarity)

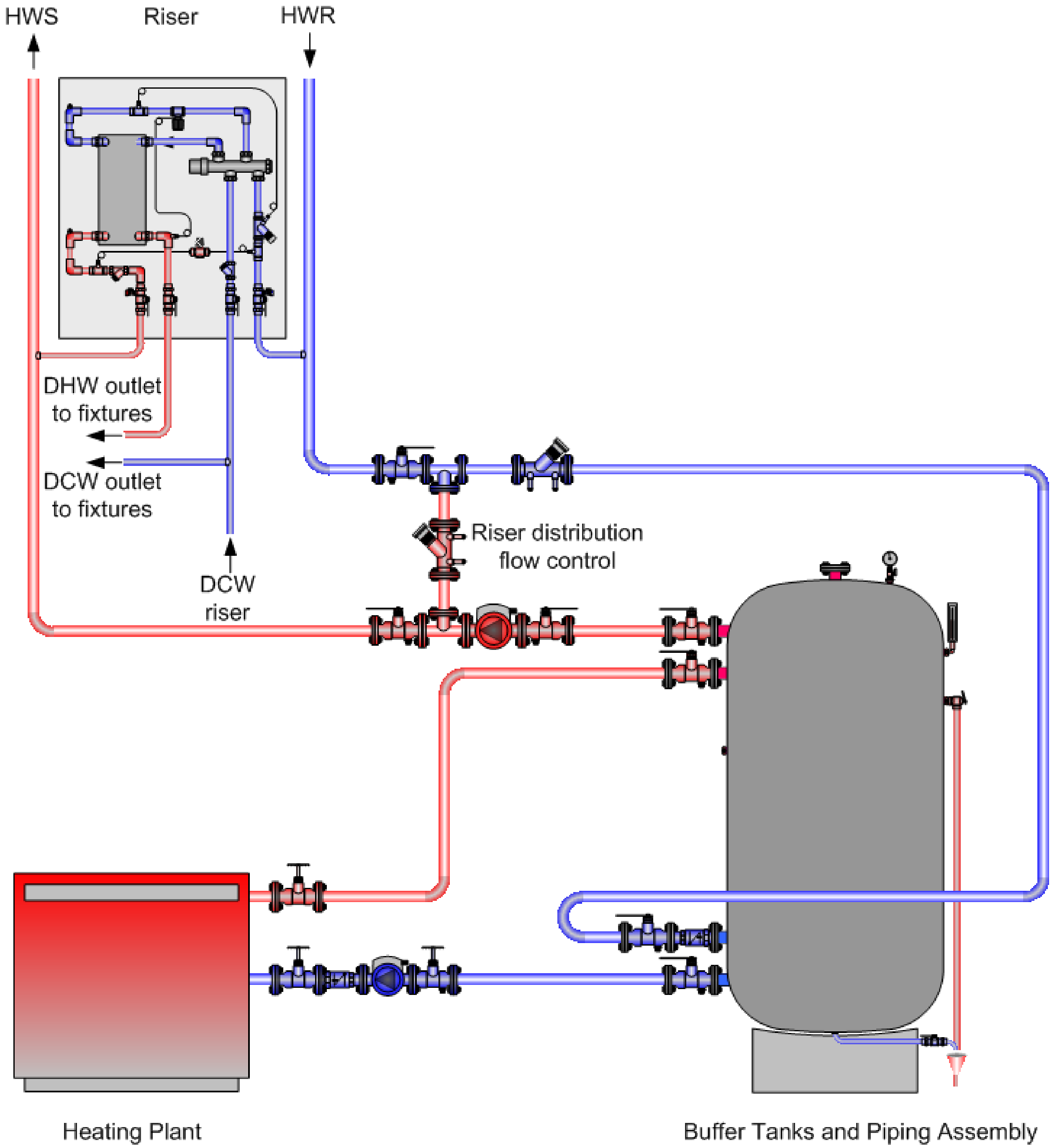



Figure 22: Single-source heating plant with a buffer tank feeding distribution network to system risers.

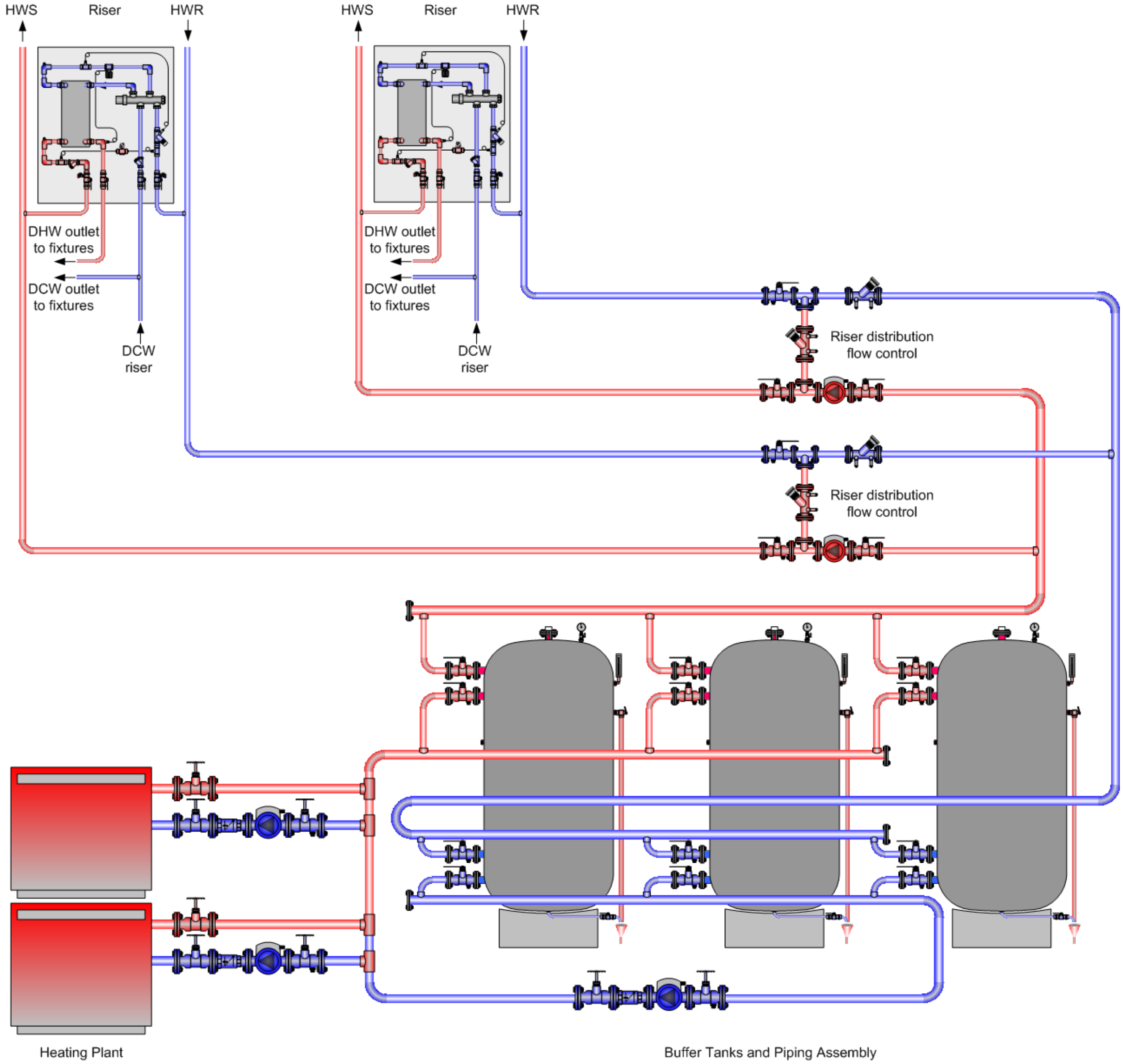



Figure 23: Multisource heating plant using a primary/secondary strategy serving multiple buffer tanks piped in reverse-return, feeding distribution networks to system risers. Generally, parallel buffer tanks are used with systems having more than 200 AquaPort units.

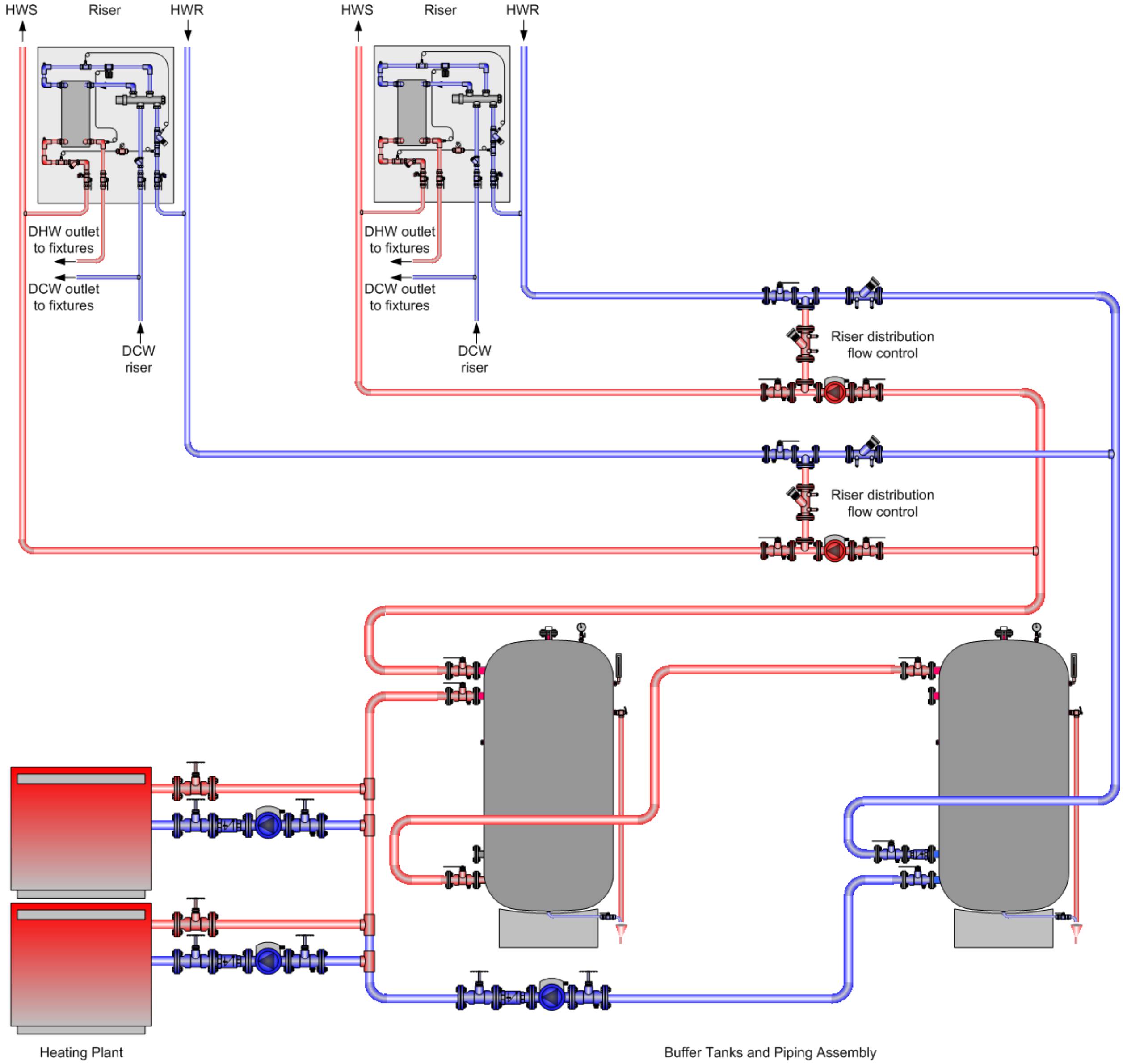



Figure 24: Multisource heating plant using a primary/secondary strategy serving multiple buffer tanks piped in series, feeding distribution networks to system risers. Generally, in-series buffer tanks are used with systems having less than 200 AquaPort units.

## Buffer Tanks and Their Role in System Design

An essential element of designing for the efficient and stable operation of a heating source and variable demand system is to a) operate with the lowest return temperature possible, b) reduce the cycling time of the plant, and c) have necessary power immediately available to meet the demand. The lowest return steady-state condition must be the result for maximum thermal extraction and equipment durability (less stress). This strategy cannot be ignored with lower-mass, highly zoned systems with intermittent source energy. Consider the application with low-mass fan coils with low-mass air-to-water or water-to-water heat pumps or boilers or the diurnal swings with solar thermal systems. Then, consider these conditions with the variable and transient nature of space heating and domestic-water heating loads. Quickly, the benefits of using buffer tanks rather than mixing valves become apparent, especially when considering their utility in separating air and dirt and neutralizing pressure differential effects from multiple circulator systems.

Additionally, when ground source systems are employed, it is often beneficial to operate the heat pumps during off-peak hours and store the energy when rates are higher[v]. It is essential to ensure that the storage tank is fully stratified to maximize its exergy efficiency. Tanks without baffles promote mixing and lower the LMTD available to the system and lead to persistent underperformance.

While the use of buffer tanks in practice is beneficial to the AquaPort system performance, the designer is advised to consult with the specified boiler manufacturers for possible alternatives in supplying the necessary power to each AquaPort.

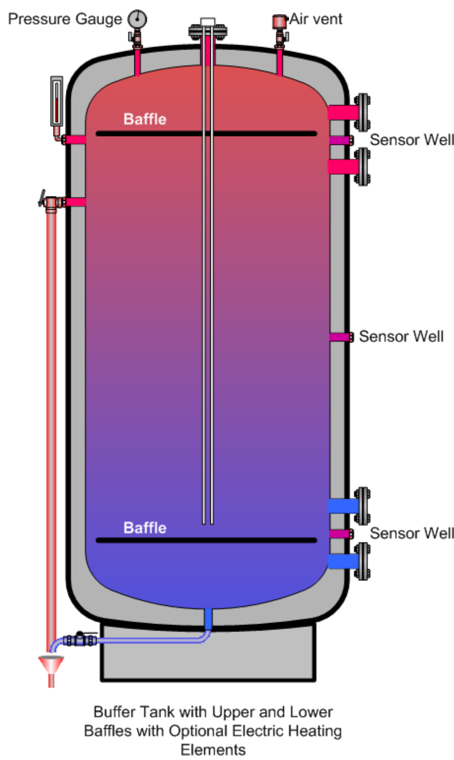



Figure 25: Highly insulated multiport buffer tank with baffles for promoting stratification

## Control Objectives with AquaPort

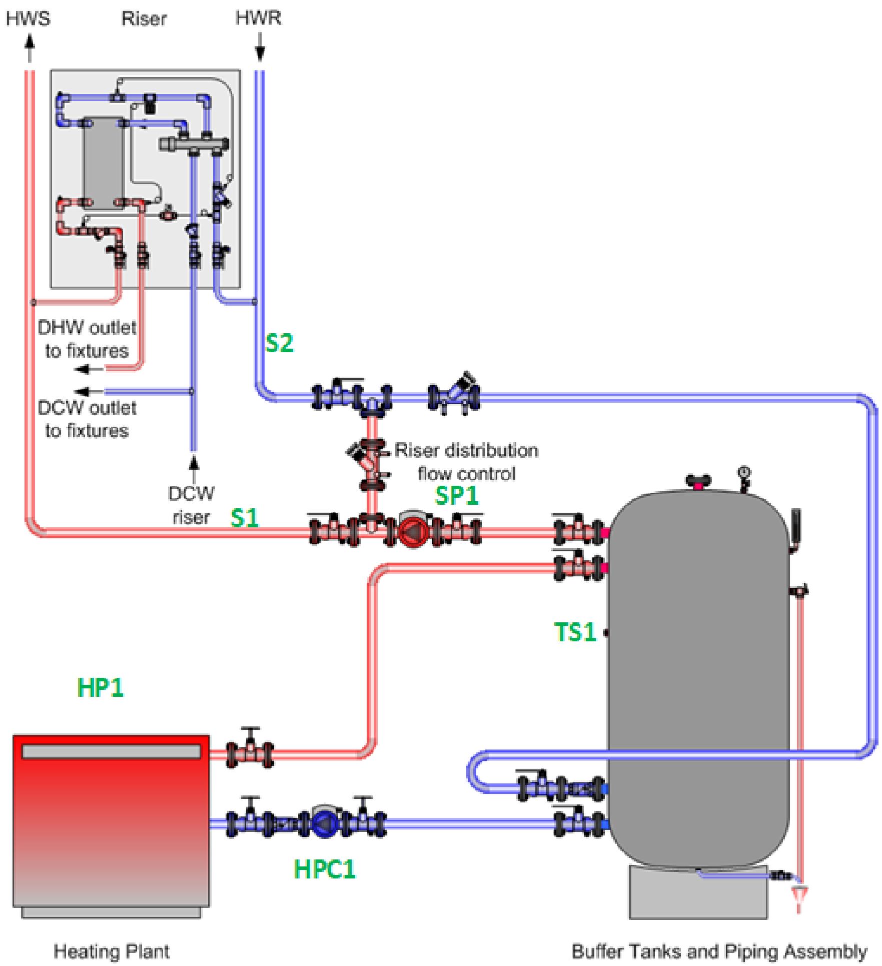



**Figure 26: Typical control points for AquaPorts using buffer tanks**

**Controlling Temperatures in Buffer Tanks**
Generally, the setpoint temperature for the buffer tank (TS1) should be approximately 18°F (10K) above the domestic-water tapping temperature. For example, for domestic hot-water supplies to fixtures of 120°F (50°C), the mid-tank sensor should be controlled to 140°F (60°C). Summer and winter sensors located in the lower part of the tank should shut the heating plant off as the lower-tank temperatures approach the mid-tank temperature. This strategy reduces the potential for overcharging the tanks.

**Controlling Pressure and Temperature and Differentials in System Distribution Lines**
Generally, the onboard controls built into the circulator (SP1) should be selected for constant pressure (cp). The constant-pressure curve might also need to be proportionally offset to reflect the seasonal differences in pressures (Δp). The control signal input to the circulator should be 0-10vDC or 4-20mA. For summer, where heating loads are off, differential pressures would be lower (i.e., 10 ft./3m Δp). For winter, where heating loads (i.e., fan coils) are on, differential pressures would be higher (i.e., 20 ft./6m Δp). These load differences will be reflected by the variations in differential temperatures (ΔT). It is helpful to have the external control logic influence the differential pressure offset (Figure 27) should the differential temperature increase beyond normal calculated values. For example, suppose steady-state differential temperatures are expected to be 49°F (27K) to 54°F (30K) but increase due to a spike in demand. In that case, the constant-pressure curve should be shifted proportionately upward to compensate for the increased demand. Likewise, as the loads decrease, it would be helpful to also lower the constant pressure curve. This will ensure all units continue to receive their demand flow, pressure, and temperature at all times. It is advised that HTUs (i.e., fan coils, radiant floors, radiators, etc.) have return-temperature limiters to prevent unnecessary temperature increases through the heating plant.

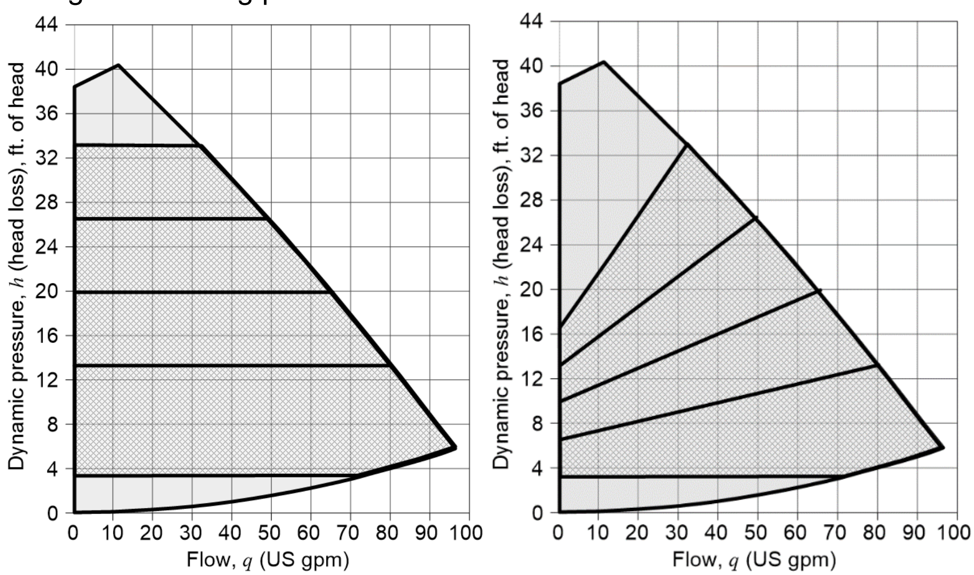



**Figure 27: Constant pressure control (L) vs. proportional pressure control (R). It may be necessary, in some cases, to have an external input to the circulator from the system controller to offset (shift) the curves to accommodate peak and seasonal demands through the AquaPorts and HTUs.**

**Reducing the Potential for Flow Noise**
Piping networks serving suites should be designed for quiet operation. Good practice suggests less than 3.3 ft/s (1 m/s) for piping velocities and control valve Cv's selected for 30% to 50% authority with less than 2.3 psi (160 mbar) Δp.

**Controlling the Heating Plant**
If the system design incorporates multiple boilers, follow the equipment manufacturer's guidelines regarding staging and rotation. Boiler(s) will activate based on the tank's sensor(s) temperature falling below the buffer tank setpoint minus the differential (adj.). The heating cycle will end once the tank temperature sensor(s) reach the setpoint target.

**Heating Equipment Circulator (HPC1)**
Heat plant circulator should be integral to the operation of the heating equipment. A call for heating based on tank temperature(s) should activate the heat plant and circulator. If multiple heating devices are used, control logic should include the operation of this circulator when any or all heating devices are in operation.

**Supply and Return Sensors (S1 and S2)**
Install sensors in immersion wells to be used as points of monitoring system operation. If the system pump is capable of reading supply (or return based on installation) temperature and can be shared with the BMS, one sensor can be eliminated.

**Outdoor Sensor (OAS)**
Not required for AquaPort(s) installation. Install as needed for heating equipment manufacturer.

## Port Sizing Example

Step 1: Select the port size for the application (AquaPort 3 U.S. gpm or 5.25 U.S. gpm) by determining the "tap demand" (the amount of hot water needed). For this example, as shown in Figure 28, a unit containing a lavatory, sink, shower/tub, water closet, and HTU.

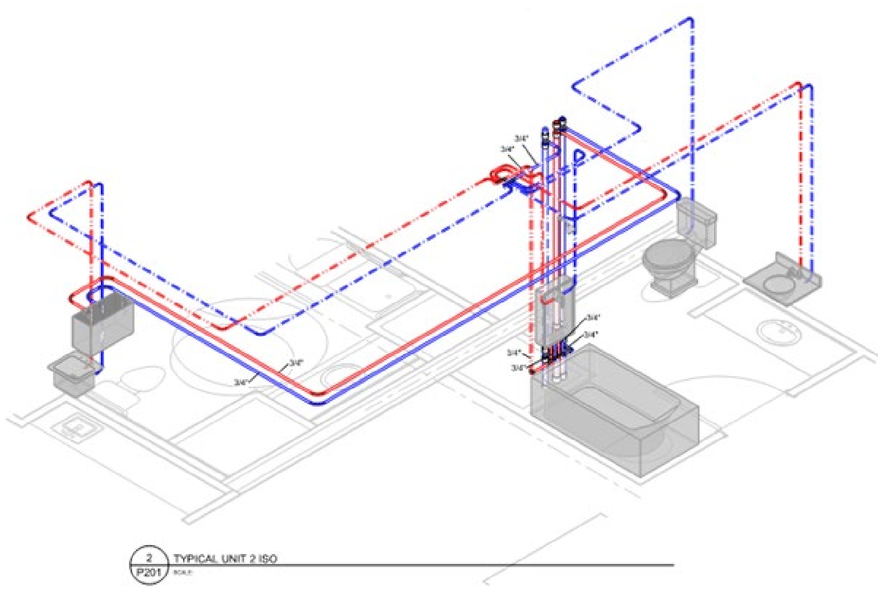



**Figure 28: Typical AquaPort application for lavatory, sink, shower/tub, water closet, and HTU.**

Table 3: Sample of fixture flow rates

| Load | Performance Class, Flow (U.S. gpm) | | | |
|---|---|---|---|---|
| | WaterSense | WaterSense (70% HW factor) | EPAct 1992 | EPAct 1992 (70% HW factor) |
| Lavatory/Sink | 1.5 | 1.05 | 2.2 | 1.54 |
| Shower/Tub | 2 | 1.4 | 2.5 | 1.75 |

**Note:** There are no U.S. gpm limits for other fixtures such as icemakers, dishwashers, and laundry machines. Please reference the fixture manufacturers' data for detailed U.S. gpm demand requirements or the design documentation for hot-water demand assumptions.

### Hot-water Tap Demand

Using the EPACT 1992 with a 70% HW Factor, the tap demand for this unit is calculated to be:

Lavatory (1.54 U.S. gpm) + sink (1.54 U.S. gpm) + shower/tub (1.75 U.S. gpm) = 4.83 U.S. gpm

Therefore, the tap demand for the unit is 4.83 U.S. gpm (18.3 L/min); select the AquaPort 5.25 U.S. gpm model.

Full flow at every fixture is used in this example to identify the cumulative gallons per minute (gpm) requirements. In situations where there may be more fixture groupings per AquaPort, proper evaluation of simultaneous hot-water usage will be required.

### Total Cold Water for Suite

Lavatory (2.2 U.S. gpm) + sink (2.2 U.S. gpm) + shower/tub (2.5 U.S. gpm) + toilet (4 U.S. gpm) = 10.9 U.S. gpm (41.3 l/min)

### Hydronic Distribution Riser Sizing

To determine what temperature is needed to heat up 4.83 U.S. gpm (18.3 L/min) of drinking water from 50°F (10°C) to 122°F (50°C), the performance curves for the AquaPort 5.25 U.S. gpm are needed as shown on Figure 29. (Draw a vertical line on the x-axis of the tap demand and then a horizontal line to the y-axis at the intersection point of the water temperature curve.)

As shown, with a water temperature of 140 °F (60°C), the hydronic U.S. gpm required for the AquaPort will be 5.1 U.S. gpm (1158 L/h). This value of 5.1 U.S. gpm (1158 L/h) will be needed for each suite to calculate the hydronic distribution pipe size for the riser.

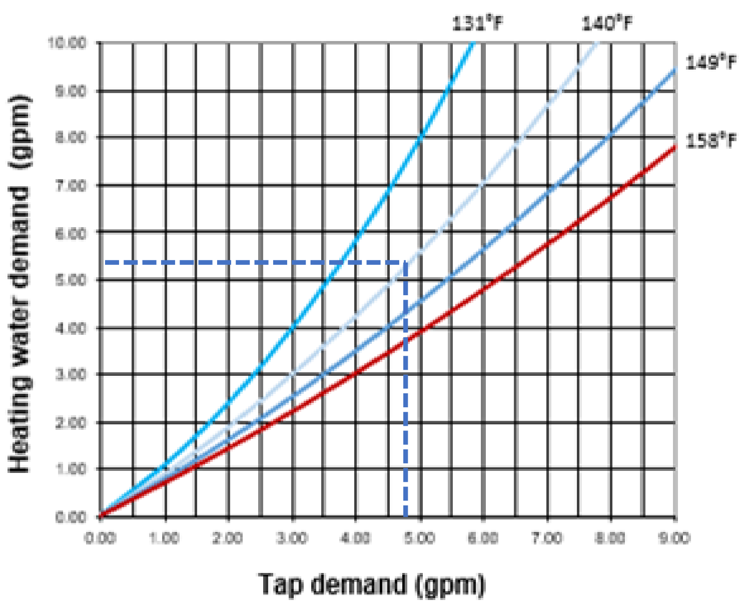



**Figure 29: Performance curve for AquaPort 5.25 U.S. gpm**

## Pressure Loss through the AquaPort

Water flowing through the AquaPort on the demand heating side and tap demand side will experience a pressure loss. This loss will have to be factored in to determine the correct pipe size for the riser. For the hydronic distribution riser, the demand heating water pressure loss through the AquaPort must be calculated. Using the value of 5.1 U.S. gpm (1158 L/h) the pressure loss through the demand side of the AquaPort is shown on Figure 30.

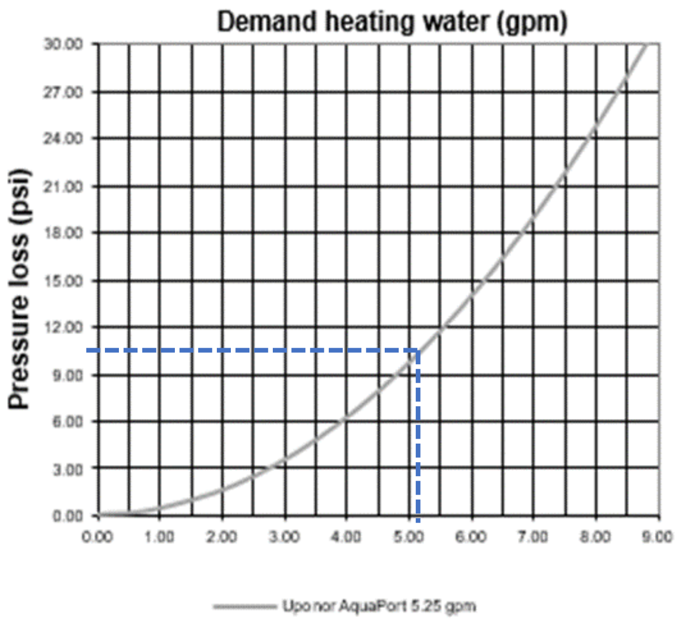



**Figure 30: Demand heating water pressure loss curve for AquaPort 5.25 U.S. gpm**

As shown on Figure 30, the approximate pressure loss is 10.5 psi (72 kPa). This value will be used to determine the hydronic riser size.

## Heating System

As shown in Figure 20, the apartment unit contains a fan-coil system for space heating. The U.S. gpm value of 1.2 U.S. gpm (273 L/h) was calculated (not shown) to satisfy the heat loss of this unit. The calculated U.S. gpm and pressure drop through the heat pump will also be used to calculate the size of the hydronic riser.

## Cold-water Riser Sizing

For cold water, riser sizing based on fixture unit values (for specific codes) will be used. Pressure losses from fittings and appliances (such as AquaPorts) will be required. The codes listed below provide the necessary values of fixture units for accurately sizing the cold-water riser.

## Plumbing Code Variances

### IPC Plumbing Code

**Table 4: Examples of water supply fixture units for private (occupant) use**

| Fixture Type | WSFU (water supply fixture units) |
|---|---|
| Lavatory | 0.7 |
| Shower | 1.4 |
| Water Closet | 2.2 (1.2*) |
| *One fixture unit can be subtracted per bathroom if a lavatory, shower, and water closet are in the same bathroom. | |

**Table 3: Fixture unit to pipe size table (all sizes at maximum velocity, 10 ft/s)**

| Pipe Size | WSFU Range | Max U.S. gpm |
|---|---|---|
| ¾" | 0-6 | 11 |
| 1" | 7-16 | 18 |
| 1¼" | 17-43 | 27 |
| 1½" | 44-79 | 38 |
| 2" | 80-199 | 65 |
| 2½" | 200-369 | 99 |
| 3" | 370-588 | 141 |

### UPC Plumbing Code

**Table 6: Examples of water supply fixture units for private (occupant) use**

| Fixture Type | WSFU (water supply fixture units) |
|---|---|
| Lavatory | 1 |
| Shower | 1.5 |
| Water Closet | 2.5 |

**Table 7: Fixture unit to pipe size table (all sizes at maximum velocity, 10 ft/s)**

| Pipe Size | WSFU Range | Maximum U.S. gpm |
|---|---|---|
| ¾" | 7-15 | 11 |
| 1" | 16-26 | 18 |
| 1¼" | 27-46 | 27 |
| 1½" | 47-77 | 38 |
| 2" | 78-199 | 65 |
| 2½" | 200-375 | 99 |
| 3" | 376-589 | 141 |

Once a plumbing code is selected and the fixture units are accounted for, the pressure loss experienced through the tap demand side must be calculated. Using Figure 31 and the tap demand (already determined from Figure 29), the pressure loss can easily be obtained.

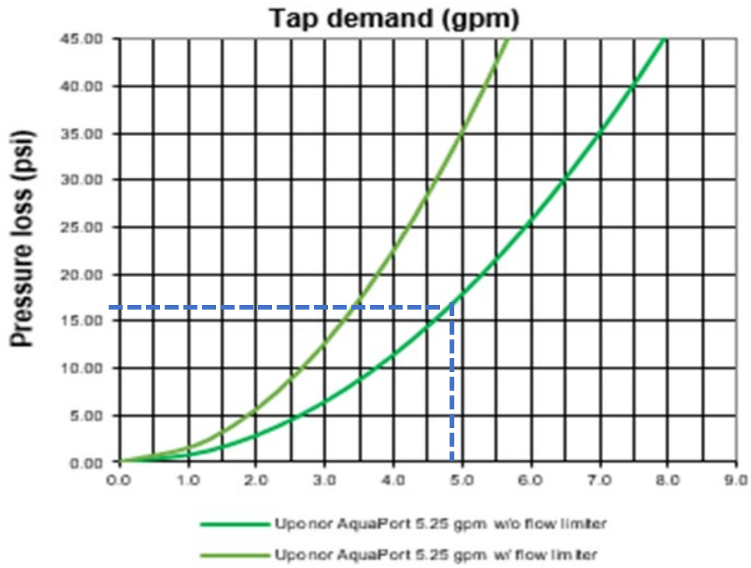



**Figure 31: Tap demand pressure loss curve for AquaPort 5.25 U.S. gpm**

Using the 5.25 U.S. gpm Uponor AquaPort without a flow limiter gives us a pressure loss of 16 psi (110 kPa). This value will be incorporated and used to calculate the cold-water riser.

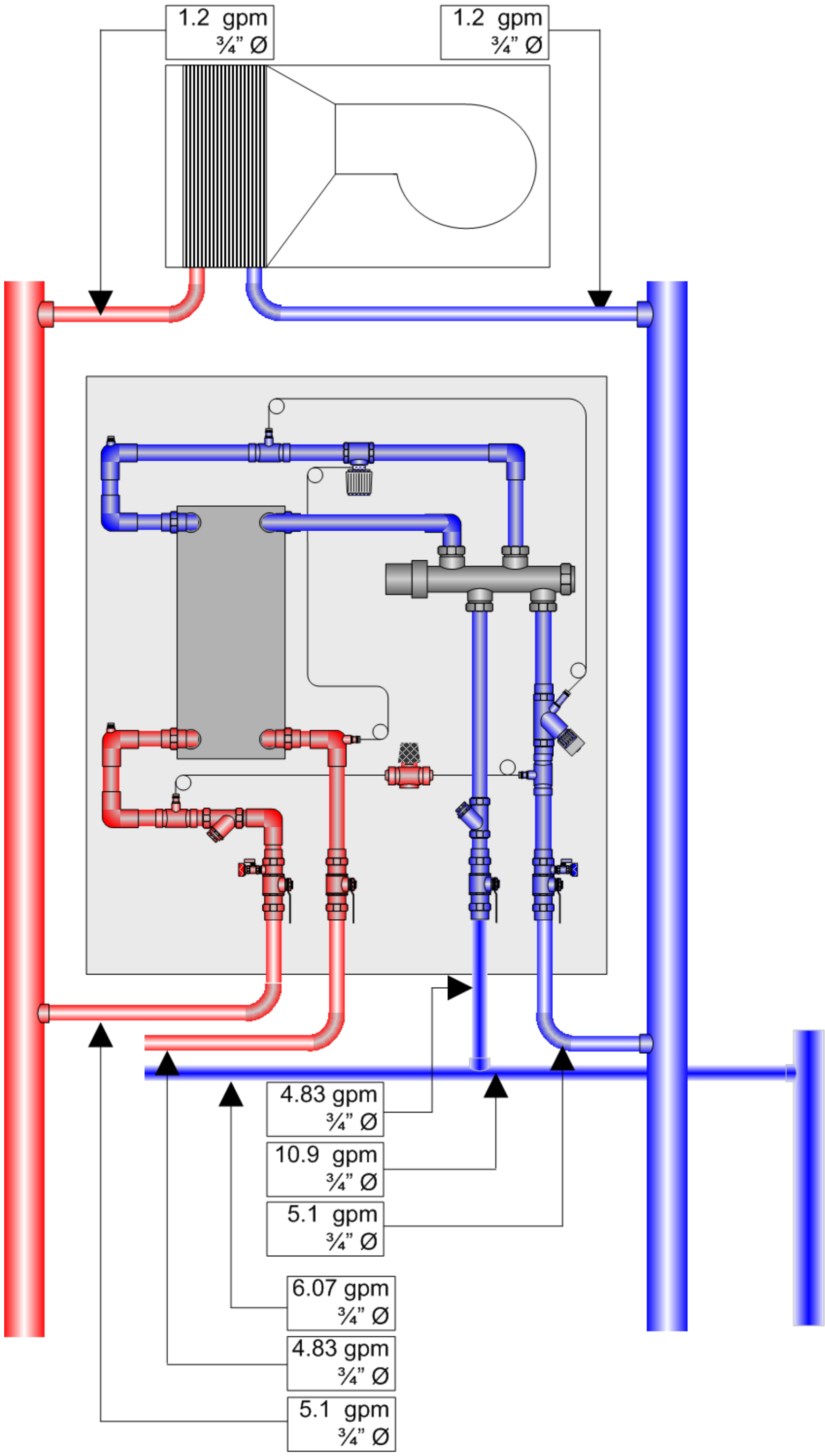
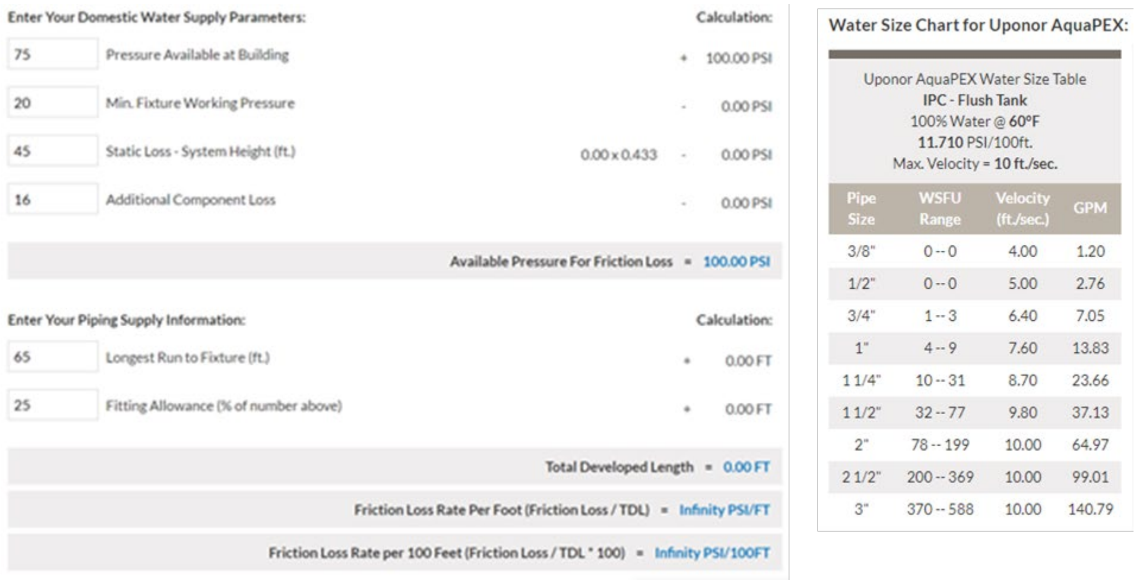



Figure 26: Dimensioning the design flows for the AquaPort

## Plumbing Riser Sizing Calculation

To size the domestic cold-water riser, first access the Uponor pipe sizing calculator located at https://tools.uponorpro.com/calculator/. Complete the fields, select the desired code, and click the calculate button at the bottom of the page. The 16 psi (110 kPa) loss through the AquaPort is included in the additional component loss field. After clicking the calculate button, the sizing tables are generated. For the AquaPort domestic riser only, the cold water table on the left is needed.



Enter Your Domestic Water Supply Parameters: — Calculation:

75 Pressure Available at Building + 100.00 PSI

20 Min. Fixture Working Pressure - 0.00 PSI

45 Static Loss - System Height (ft.) 0.00 x 0.433 - 0.00 PSI

16 Additional Component Loss - 0.00 PSI

Available Pressure For Friction Loss = 100.00 PSI

Enter Your Piping Supply Information: — Calculation:

65 Longest Run to Fixture (ft.) + 0.00 FT

25 Fitting Allowance (% of number above) + 0.00 FT

Total Developed Length = 0.00 FT

Friction Loss Rate Per Foot (Friction Loss / TDL) = Infinity PSI/FT

Friction Loss Rate per 100 Feet (Friction Loss / TDL * 100) = Infinity PSI/100FT

Water Size Chart for Uponor AquaPEX:

Uponor AquaPEX Water Size Table
**IPC - Flush Tank**
100% Water @ **60°F**
**11.710** PSI/100ft.
Max. Velocity = **10 ft./sec.**

| Pipe Size | WSFU Range | Velocity (ft./sec.) | GPM |
|---|---|---|---|
| 3/8" | 0 -- 0 | 4.00 | 1.20 |
| 1/2" | 0 -- 0 | 5.00 | 2.76 |
| 3/4" | 1 -- 3 | 6.40 | 7.05 |
| 1" | 4 -- 9 | 7.60 | 13.83 |
| 1 1/4" | 10 -- 31 | 8.70 | 23.66 |
| 1 1/2" | 32 -- 77 | 9.80 | 37.13 |
| 2" | 78 -- 199 | 10.00 | 64.97 |
| 2 1/2" | 200 -- 369 | 10.00 | 99.01 |
| 3" | 370 -- 588 | 10.00 | 140.79 |

Figure 27: Uponor online pipe sizing calculator

Add up the fixture units of the fixtures supplied by each segment of pipe and refer to the WSFU range column of table generated by the pipe sizing calculator to select pipe diameter. For example, a value of 35 fixture units would require a 1½" diameter pipe based on the table above.

### Hydronic Riser Sizing

To size the hydronic risers, first access the Uponor pipe sizing calculator located at https://tools.uponorpro.com/calculator/. Fill it out with the desired water temperature, maximum velocity and maximum head loss per 100 ft. of pipe. Click the calculate button. This will generate a table to size the riser off of. This will need to be done for the supply and return side (two separate charts). See Figure 34 for charts used to size the example.

| Water Temp 1 | | | |
|---|---|---|---|
| PEX - ASTM F876 Sizing Table<br>100% Water @ 140°F<br>4 Ft of Head Loss / 100 ft.<br>Min. Velocity = 1.5 ft./sec.<br>Max. Velocity = 8 ft./sec. | | | |
| Pipe Size | GPM Range | Velocity (ft./sec.) | Feet of Head per 100-Ft. of Pipe |
| 5/16" | Out of Range | Out of Range | Out of Range |
| 3/8" | 0.45 -- 0.48 | 1.50 -- 1.60 | 3.87 -- 4.00 |
| 1/2" | 0.83 -- 1.10 | 1.50 -- 2.00 | 2.63 -- 4.00 |
| 5/8" | 1.21 -- 1.77 | 1.50 -- 2.20 | 2.07 -- 4.00 |
| 3/4" | 1.65 -- 2.76 | 1.50 -- 2.50 | 1.70 -- 4.00 |
| 1" | 2.73 -- 5.46 | 1.50 -- 3.00 | 1.25 -- 4.00 |
| 1 1/4" | 4.08 -- 9.25 | 1.50 -- 3.40 | 0.97 -- 4.00 |
| 1 1/2" | 5.68 -- 14.40 | 1.50 -- 3.80 | 0.79 -- 4.00 |
| 2" | 9.75 -- 29.24 | 1.50 -- 4.50 | 0.57 -- 4.00 |
| 2 1/2" | 14.85 -- 51.49 | 1.50 -- 5.20 | 0.44 -- 4.00 |
| 3" | 21.12 -- 81.66 | 1.50 -- 5.80 | 0.35 -- 4.00 |
| 3 1/2" | 28.46 -- 121.45 | 1.50 -- 6.40 | 0.29 -- 4.00 |
| 4" | 36.88 -- 172.11 | 1.50 -- 7.00 | 0.25 -- 4.00 |

| Water Temp 2 | | | |
|---|---|---|---|
| PEX - ASTM F876 Sizing Table<br>100% Water @ 120°F<br>4 Ft of Head Loss / 100 ft.<br>Min. Velocity = 1.5 ft./sec.<br>Max. Velocity = 8 ft./sec. | | | |
| Pipe Size | GPM Range | Velocity (ft./sec.) | Feet of Head per 100-Ft. of Pipe |
| 5/16" | Out of Range | Out of Range | Out of Range |
| 3/8" | Out of Range | Out of Range | Out of Range |
| 1/2" | 0.83 -- 1.05 | 1.50 -- 1.90 | 2.75 -- 4.00 |
| 5/8" | 1.21 -- 1.77 | 1.50 -- 2.20 | 2.16 -- 4.00 |
| 3/4" | 1.65 -- 2.65 | 1.50 -- 2.40 | 1.78 -- 4.00 |
| 1" | 2.73 -- 5.28 | 1.50 -- 2.90 | 1.30 -- 4.00 |
| 1 1/4" | 4.08 -- 8.98 | 1.50 -- 3.30 | 1.01 -- 4.00 |
| 1 1/2" | 5.68 -- 14.02 | 1.50 -- 3.70 | 0.82 -- 4.00 |
| 2" | 9.75 -- 28.59 | 1.50 -- 4.40 | 0.59 -- 4.00 |
| 2 1/2" | 14.85 -- 50.50 | 1.50 -- 5.10 | 0.46 -- 4.00 |
| 3" | 21.12 -- 80.25 | 1.50 -- 5.70 | 0.37 -- 4.00 |
| 3 1/2" | 28.46 -- 119.55 | 1.50 -- 6.30 | 0.31 -- 4.00 |
| 4" | 36.88 -- 169.65 | 1.50 -- 6.90 | 0.26 -- 4.00 |

Figure 28: PEX flow characteristics from the Uponor online calculator for 100% water at 140°F (60°C) and 120°F (49°C)

### Hydronic Riser Critical Path

To calculate the critical path (path with the most head loss), U.S. gpm, pipe size, and fittings will have to be taken into account. Using the hydronic pipe sizing calculator, input each section of pipe (U.S. gpm and size) and its fittings into the calculator.

In this example, the critical unit is the top right or top left unit, assuming they are the same distance from the heat source. The total head loss that the pump will have to overcome is 31.3 ft. (94 kPa) of head.

Supply and return head loss = 7.05 ft. of head (21 kPa)

Head loss through AquaPort = 24.25 ft. of head (73 kPa)

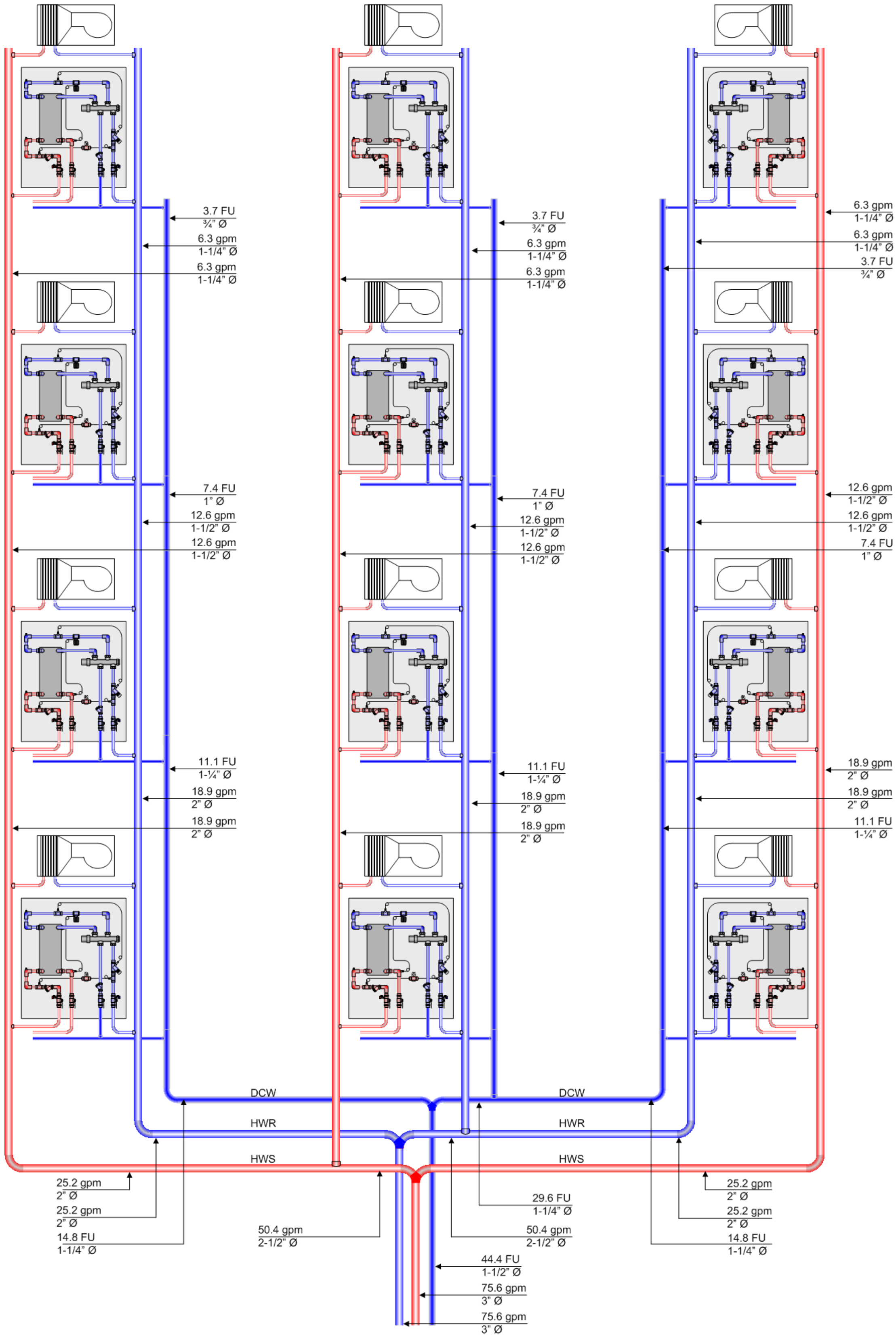



Figure 29: Riser diagram and dimensioning for the example given

## Case Study

Galileo Business Hotel Marriott Courtyard, Garching bei Muenchen, Germany

256 rooms and 159 apartments, potable demand for hygienic, fast reaction times (5 to 8 seconds), riser supply temperature of 131°F (55°C), high simultaneity of 5 U.S. gpm (19 l/min).

## Case Study

Leonardo Hotel, Dortmund, Germany

181 rooms, potable demand for hygienic, fast reaction times (4 to 6 seconds), riser supply temperature of 140°F (60°C), high simultaneity of 3 U.S. gpm (12 l/min).

## Summary

AquaPorts are engineered, factory-assembled, tested, and certified appliances for generation of domestic hot water when supplied with fluids from a hydronic heating system. Systems could be based on boilers, heat pumps, district energy system, or any renewable source, such as solar thermal.

They offer the following benefits:

1. No energy storage in the tap water
2. Low total heat losses with fewer risers
3. Small hot-water networks
4. Hot-water generation on demand
5. Individual comfort
6. Optimal system in combination with renewable energy for exergy efficiency
7. Cold return temperatures for enabling plant efficiency
8. Elimination of recirculation and thus potential for reduction in pumping energy
9. Smaller riser shafts offer space and reduce costs

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[i] Bean, R., Doran, T., Olesen, B, Simmonds, P. (2005) Vertically Integrated Systems in Stand-Alone Multistory Buildings. ASHRAE Journal, Vol 47, No. 6 <https://www.healthyheating.com/downloads/ASHRAE_Journal.pdf > 2020.11.16

[ii] LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles. EBC Annex 64 Final Report, September 2019 < http://www.iea-ebc.org/Data/publications/EBC_Annex_64_Final_Report_September_2019.pdf> 2020.11.16

[iii] Torio, H., Schmid, D. (Ed.) (2011) International Energy Agency. EBC ANNEX 49 Lo w Exergy Systems for High Performance Buildings and Communities. Summary Report < https://iea-ebc.org/projects/project?AnnexID=49>

[iv] Bean, R. (2013) The Interaction and Connection between Buildings, HVAC System, and Indoor Environmental Quality. ASHRAE IAQ 2013. Environmental Health in Low Energy Buildings. October 15 - 18, 2013. Vancouver, British Columbia, Canada

[v] Siegenthaler, J. (2017) Heating with Renewable Energy, Cengage Learning