Multifamily Case Study: Geo-Exchange vs. VRF Space and Water Heating

Final Report

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Executive Summary

The Puyallup Tribal Housing Authority set out to build 20 highly energy efficient low income housing units, a project called The Place of Hidden Waters. The multifamily units were built in two separate phases with two nearly identical buildings. Phase 1 uses a Geo-Exchange or Ground Source Heat Pump (GSHP) system in a central heating plant to provide space and domestic water heating for the apartments. Phase 2 uses a central Variable Refrigerant Flow (VRF) system to provide heating and hot water.

This study evaluated the overall energy use performance of the GSHP and VRF systems at The Place of Hidden Waters through use of billing analysis and on-site audits. Also presented in this report are lessons learned and best practices for designers of VRF and GSHP systems as well as for those tasked with measurement and verification of these custom projects.

Overall the project achieved an energy savings of about 20-30% compared to typical new multifamily construction. This was less than anticipated by the design team. The water use and miscellaneous energy uses (lights, plugs, appliances) appear to be very close to typical for regional multifamily populations so it is unlikely that the shortfall in predicted energy savings is due primarily to occupant behavior.

The water heating energy use was much higher than expected with an overall savings of approximately 30% compared to a typical non-heat pump water heating system in a multifamily building. The project anticipated approximately double this level of savings. The shortfall appears to be primarily due to overly conservative heat pump controls with very low target temperature setpoints. This in combination with the hot water circulation design was causing the electric back-up tanks to provide all of the circulation losses and the majority of the water heating energy during low load periods; with the heat pumps only active during high water use periods. This has been adjusted in the case of the Phase 1 geothermal system and we anticipate significantly improved performance in the future. We recommend the elimination of circulation loops in systems using VRF water heating.

The Phase 1 geothermal space heating system appears to be delivering significant savings close to initial predictions, but the Phase 2 project is using significantly more heating energy than anticipated. Without more detailed end use metering it is not possible to determine the exact cause of the high heating energy use in the Phase 2 building. The VRF equipment appears to be operating correctly. It is most likely that the increased heating energy is attributable to unanticipated electric resistance heating (“freeze protection”) in the mechanical rooms.

One important finding is that without detailed Measurement and Verification (M&V) data it is very hard to pinpoint or troubleshoot where excessive energy is being used. M&V systems are a crucial piece to understanding how any new technology works and especially useful for optimization of new technology applications. M&V plans should be developed early in the design process and included with any emerging technology project as billing analysis alone does not provide detailed end-use breakdowns.

Another important lesson learned is that pilot or demonstration projects for emerging technologies must be screened to ensure that the technology is appropriate for the project. Projects incorporating new technologies must have a well-trained champion within the owner or operations group who is capable of understanding the functioning of the technology and monitoring ongoing controls, operations, and maintenance. Without trained staff in a position to monitor the system, new technologies will have a much lower chance of success.

Introduction

This study examines two high performance (10-unit) multifamily buildings located in Puyallup, WA. The project, called The Place of Hidden Waters, was developed by the Puyallup Tribal Housing Authority in two phases that are nearly identical in programming, design, exposure, insulation, ventilation and end-use clientele. The two phases differ by floor construction (slab vs. crawlspace), mechanical heat plants, and use of onsite renewable energy.

The goal of this study is to evaluate and compare these two multifamily projects, specifically; to understand the energy usage between these two phases, to understand the specific differences between mechanical approaches, to document lessons learned and to establish best practices for future building designers and builders who wish to apply these low energy solutions to other projects.

This report will refer to two phases for the project.

- Phase 1 is the Ground Source Heat Pump (GSHP) based system
- Phase 2 is a Variable Refrigeration Flow (VRF) based heat pump system

Both of these projects employ high efficiency R-410a refrigerant heat pumps for central space heating and central domestic water heating (DHW). Phase 1 uses water source heat pumps to heat water for hydronic radiant floor heating systems and for DHW. Phase 2 uses air source heat pumps to make hot water for DHW and zonal wall-hung ductless heat pumps for each main living space.

The housing units were developed by the Puyallup Tribal Housing Authority. Phase 1 was completed in 2010 and Phase 2 was completed in 2012. Housing units are intended for low-income tribal occupants who qualify for housing assistance. This development was intended to develop affordable and durable housing for the Puyallup Tribal Housing Authority with a focus on low operating costs for tenants and low maintenance costs for the Housing Authority. Phase 1 was constructed at a cost of $200/sf. Phase 2 was constructed at a budget of $175/sf.

The program called for two phases of 10 unit housing units that incorporate traditional tribal housing styles with current best practices for sustainability and low-maintenance. The housing units are arranged as 5 single story units on one side and 5 double story units arranged with a common south sloping roofline with a shared courtyard between the 2 rows of housing. This arrangement represents a traditional Salish Lodge style of architecture, illustrated in Figure 1.

Figure 1: Architectural Configuration.

Envelope and Systems Characteristics

Envelope

Key to any low energy and low maintenance development are the envelope and control of outside air for space conditioning. The envelope is constructed from Structural Insulated Panels (SIP's) and Triple Glazing with the following characteristics values:

- Walls: R-30
- Roof: R-50
- Slab on Grade: Fully Insulated R-15, with R-10 perimeter (Phase 1 only)
- Floor Over Crawl: R-30 Batts in Floor Joists (Phase 2 only)
- Glazing: Triple Glazed (U-0.19, SHGC-0.23)
- Opaque Doors: U-0.23

Table 1: Glazing Characteristics

Unit	Heated Floor Area (sf)	South Glass (sf)	North Glass (sf)	Total Glass (sf)	Glazing %
1 bed (5x)	2,860	250	260	510	18%
2 bed (5x)	4,600	615	500	1115	24%

Table 2: UA Characteristics

Unit	Heated Floor Area (sf)	Total HFA (sf)	Envelope UA	Ventilation/ Infiltration UA	Total UA	Avg. UA/unit	Unit Design Heat Load (Btu/hr)
1 bed (5x)	572	2,860	440	177	617	123	5,781
2 bed (5x)	920	4,600	635	284	919	184	8,648

Ventilation Systems

All phases of the project use continuous exhaust fans and slot vents in windows to meet the requirements of ASHRAE 62.2. The primary bathrooms in both 1 and 2 bedroom units are equipped with exhaust fans set to run continuously at low volume exhaust and ramp up on occupancy sensors for 20 minutes. Ventilation systems were tested and are functioning per design. Continuous exhaust fan rates are as follows:

- 1 bedroom units: 30 CFM
- 2 bedroom units: 45 CFM

Lighting

Interior lights are installed at approximately 0.6 W/sf with manual switching. Exterior lights are installed at approximately 950 Watts per Phase and are controlled from daylight sensors.

Appliances

All Appliances meet *Tier 2 Energy Star* ratings and are electric based. There are no natural gas appliances installed in either phase of this project.

Space Heating Systems

Phase 1

A central Ground Source Heat Pump (GSHP) system is provided for Space Heating and Domestic Hot Water (DHW) for the 10 apartment units. A vertical bore closed loop ground coupled heat exchanger is located in the courtyard between the 1 bedroom and 2 bedroom row houses and connected to three water to water extended range geothermal heat pumps. All three heat pumps have dedicated pumping systems that run with each respective heat pump.

The ground coupled heat exchanger is made up of ten 300-foot vertical U-tube loops. Loops are spaced on 25 foot centers and piped in reverse return configuration to ensure balanced flows between all heat exchanger loops.

Space heating for all 10 units is provided by two 5-Ton extended range water source heat pumps setup to maintain a hot water storage tank for radiant floor distribution systems. A central load side variable speed pump is used to distribute hot water from the buffer tank to all radiant floor zones. Each residential unit includes a radiant floor manifold with a constant pressure flow control valve for balancing and 2-way zone valve controlled by a programmable thermostat.

The primary heating circulator is a single variable speed pump maintaining constant pressure in the hydronic system. As more unit radiant zones open up, system pressure drops and the pump speeds up to maintain constant pressure.

Figure 2 shows the Phase 1 heat and hot water plant. DHW is provided by a single 3-Ton water to water heat pump shown in the center of the photo. It is setup to heat 350 gallons of storage to 120°F (tanks on right side of photo). A final back-up electric hot water heater (far right in the photo) is provided in cases where the heat pump requires service or the demand outpaces the storage and recovery. Hot water is delivered as a separate hot water supply circuit for each row of housing. A circulation hot water loop is provided for each 5-unit supply leg. The circulation pump cycles on an aquastat. The two 5-ton heat pumps stacked on the left side of the photo heat water for the space heat buffer tank shown at far left.

Total cost for the geothermal system was approximately $25/sf of heated floor space. The 10 bore geothermal heat exchanger system was installed for a cost of $11,000/bore which is significantly higher than regional averages ($7,000/bore was budgeted during the feasibility phase). The drilling conditions on the site combined with the contractor and sub-contractor markups contributed to this higher cost.

The geothermal DHW system in Phase 1 was originally setup with a setpoint of 120°F per the design documents. However, after project completion the installing contractor reduced the setpoint to 103°F. This change was likely due to a previous experience with another project where high head pressure lockouts were experienced and this was the attempt to mitigate any call-backs. Since this geothermal loop was designed for a peak low temperature of 35°F, there is plenty of lift available to make 120°F water on the load side. This set-point change had a major impact on the total DHW system efficiency as final trimming and circulation reheating to 120°F was accomplished with electric resistance. This setpoint change was discovered after analysis of the high water heating energy bills and the system is currently functioning per design.

This geothermal preheat set-point change also impacted the availability of hot water to the tenants. The final electric trim tank was intentionally not designed to provide 100% back-up so that the occupants would know if something was wrong with the geothermal heating system. As the smaller final delivery trim tank ran out of (120°F) hot water, what was left was 103°F water to the rest of the tenants. Additionally, the mixing valves installed on the project were not balanced properly and caused a severe pressure drop on the hot water side. Tenants were complaining to maintenance staff who apparently did not investigate the cause of complaints because of their fear of the “LEED Police”. Maintenance staff thought the issues with temperature and pressure were a result of the LEED Platinum rating where performance compromises were part of the package. Both of these issues have been corrected and the maintenance staff was reassured that the LEED rating would not be affected. The tenants are now satisfied with the hot water availability and water pressure.

Figure 2: Phase 1 Geothermal Heat Plant Mechanical Room

Phase 2

A central Variable Refrigerant Flow (VRF) heat pump system is used for primary space heating and DHW preheating. Two VRF systems are installed and used for each cluster of five units. The VRF unit for the 1-bedroom apartments is a 6-ton outdoor unit connected to five 3/4-ton indoor heat pump wall cassettes and a 3-ton Hydronic Heat Pump unit. The VRF unit for the 2-bedroom apartments is an 8-ton outdoor unit connected to three 3/4-ton and two 1-ton indoor heat pump wall cassettes and a 3-Ton Hydronic Heat Pump unit.

Space heating and cooling is provided to all 10 apartments with a ductless wall hung heat pump located in each main living space. All bedrooms are provided with zonal electric resistance cove heaters for additional heating control in the bedrooms, even though the heat pump units are sized to handle all of the space heating loads. This phase differs from Phase 1 in that space cooling, though rarely used, is also available to tenants.

A photo of one of the Phase 2 mechanical rooms is shown in Figure 3. The VRF refrigerant to water heat exchanger is the box to the left side of the photo. It is set up to preheat water in the storage tank in the middle. The tank to the far right is the electric finishing tank.

Figure 3: Phase 2 VRF Water Heating Plant Mechanical Room A

Domestic Hot Water heating is provided by the VRF hydronic heat pumps. Hydronic heat pumps use a water-to-refrigerant heat exchanger which condenses the hot gas refrigerant and transfer this energy to water. This is similar to ductless heat pumps that condense the hot gas refrigerant energy using room air. VRF Hydronic heat pumps in this setup preheat a large volume of water (240 gallons) from ~50°F to ~108°F for each VRF system. A final 9 kW, 80-gallon electric trim tank is used for final heat trimming setup to deliver 120°F water to tenants. A small circulation pump is setup on an aquastat timer and cycles to keep the lines primed.

Upon start-up, the hydronic heat pump for the DHW preheating kept tripping out on fault. This caused the plumber to become upset and make claims that the system design was at fault. It was later discovered that the plumber failed to read the installation instructions and wired the close contact for a heating call into the safety input designed to protect the heat pump when no flow is present. Once this was discovered and corrected, the water heating system has been working as intended.

Another interesting finding was the installation of electric heaters in the below grade crawlspace. The space heaters were installed after the fire marshal inspected the project and felt that the wet sprinkler piping in this below grade buffered space required freeze protection. These heaters have very poor built-in controls and we found them cranked all the way up to high output at the end of the construction period. We have made recommendations to add better controls on these heaters but this has not yet occurred.

Billing Analysis

The project uses electricity only as an energy source. Each phase includes electric meters for each residential apartment as well as a single "Common" house meter. The common meter provides electricity for the central heating plant as well as exterior lighting and any other miscellaneous use outside of the apartments. Resident bills cover apartment lighting, fans, appliances, and miscellaneous plug loads. Residents pay their own electric bill directly and the Puyallup Housing Authority pays the common bill.

Billing releases were obtained from all residents to enable us to collect electric bills for all apartments as well as the Common meter. We evaluated the most recent 1-year of billing history available for each phase[1]. The electrical usage for the two phases is shown in Figure 4, separated between the common bill and the sum of all the apartments. Note that both the Phase 1 and Phase 2 apartments have a small increase in energy usage during the winter months corresponding to supplementary electric heat and longer lighting energy hours. Note also that both projects have a more prominent seasonal shift in energy use apparent in the common bill due to the fact that the heat pumps are working harder in the winter. This seasonal heating energy use is much higher for the VRF system than for the GSHP system.

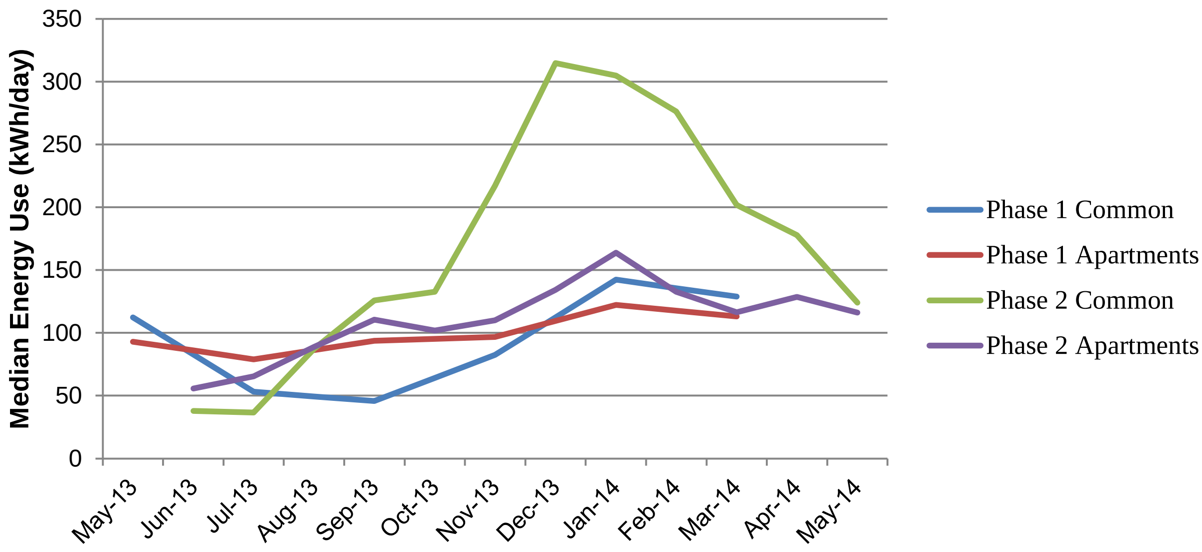

Figure 4: Electric Bills

In order to compare these buildings to others in the region a normalization technique was used to look at energy use per square foot or per occupant. To account for vacancies and unusually high energy users we performed our analyses using the Median monthly bill for apartments in each phase. We used a change point analysis using the summer base usage to indicate the water heating energy with adjustments to account for warmer incoming water during the summer

[1] Phase 1 bills were available for every 2-month period. Phase 2 bills were available for 1-month periods.

months. In this way we were able to divide the bills into the primary end uses; water heating, space heating, common space lighting, and apartment electrical use (lights, appliances, miscellaneous). Totals for these end uses are shown below in Tables 3 and 4 normalized by area and number of occupants. For comparison Table 3 also includes the average usage at new (2004-2008) mid-rise electrically heated apartments in Seattle, WA[2].

Table 3: Energy Use Comparisons by Area (kWh/sf-yr)

End Use	Phase 1 (GSHP)	Phase 2 (VRF)	New Seattle Average
Water Heating	2.0	2.2	2.8
Space Heating	1.3	4.1	2.7
Common Lights[3]	0.4	0.4	2.1
Apartment Electric	3.9	3.6	3.6
Total	**7.6**	**10.2**	**11.1**

Table 4: Energy Use Comparisons by Occupants (kWh/person-yr)

End Use	Phase 1 (GSHP)	Phase 2 (VRF)	New Seattle Average
Water Heating	1,136	1,059	1,580
Space Heating	751	1,983	1,496
Common Lights	260	219	1,226
Apartment Electric	2,273	1,742	2,014
Total	**4,420**	**5,003**	**6,316**

There are a number of considerations which should be pointed out in this data:

Water Heating

Water heating per person appears to be only about 30% better than more traditional tank or boiler systems. This is surprising as we expected a larger reduction based on the COP of the heat pumps. In practice both systems are using a relatively large amount of electric resistance heating. The VRF system can only heat water to about 108°F, and the GSHP system was mistakenly set to heat the preheat tanks to only 103°F; with the electric resistance tank heating the water up to 120°F. This was discovered in April 2014 and changed, but the effect of this change has not yet been seen in the bills.

[2] *J. Heller, K. Geraghty, and S. Oram. Multifamily Billing Analysis: New Mid-Rise Buildings in Seattle. 2009. Prepared for the Seattle Department of Planning and Development.* Electrically heated mid-rise apartments built between 2004-2008.

[3] The common lighting bills for the Seattle mid-rise buildings are not directly comparable since these buildings have corridors with constant lighting and this bill also includes other miscellaneous common space electricity such as elevators, fans, leasing office, and parking garage lights.

One possibility explored was that the residents use more hot water than average since they do not pay water or water heating bills directly. However, the water bills for this project suggest that the occupants use an average of about 38 gallons per person per day. This is very close to the typical amount seen in newer multifamily buildings with low flow plumbing fixtures.

It appears that the hot water circulation systems in both phases of construction are driving a large amount of heat loss and causing the electric finishing tanks to do all of the water heating except during times of high water usage. The hot water circulation is plumbed to come back into the heat pump preheat tanks at a higher temperature than the heat pump setpoint. During periods of low water use this will heat up the preheat tanks to the temperature of the hot water circulation loop (~110°F) and keep the heat pumps from firing. This means that during periods of low water use the electric finishing tanks were doing all of the water heating and standby losses.

The setpoint of the preheat tank for the Phase 1 geothermal system has been raised to 120°F which will allow the heat pump system in that phase to make-up the standby losses in the circulation system. However, the VRF system is not able to make water hotter than about 108°F, so the circulation losses in Phase 2 will continue to be made up by the electric resistance heater.

Apartment Miscellaneous Electric Use

The apartment electric bills include power used for lighting, appliances, fans, space heaters, and miscellaneous plug uses (TV, computer, clocks, etc…). The energy usage for these apartments is very typical; matching up quite well with the average usage seen in the Seattle mid-rise sample. Both phases of construction show a relatively small seasonal variation in the apartment electrical usage. This indicates the likely use of some electrical space heaters, more lighting hours, and for the VRF project more indoor heat pump unit fan energy. The interesting conclusion here is that the electric heaters provided for the bedrooms in the VRF phase do not appear to be used for a significant amount of time and are not significantly impacting the apartment energy use.

Space Heating

The ground source heat pump system at Phase 1 appears to be functioning quite well delivering space heating for less than half the energy use of a typical new electrically heated apartment in Seattle. The envelope is better insulated than typical, but the envelope to floor area ratio is also much higher in the Puyallup project in comparison with the typical double loaded corridor apartment building.

The phase 2 project is performing much worse than expected for space heating energy. The summer time base load is relatively low; indicating no significant energy use for space cooling. However, the winter energy is quite high in comparison with Phase 1 and even in comparison to the typical new mid-rise electrically heated apartment. This is contrary to other experience that we have had with this same type of VRF heat pump equipment in commercial buildings where we have seen extremely low space heating energy usage.[4]

One likely explanation is the presence of the electric resistance heaters in the mechanical room and crawlspace. As mentioned above, the below grade crawlspace areas in Phase 2 include sprinkler piping. When the project was nearly complete the fire marshal required the electrical contractor to add electric heaters for "freeze protection" in the crawlspace; even though this violated the energy code requirements for heaters in uninsulated spaces. The baseboard electric heaters installed include poorly calibrated integral thermostats. During the first winter these thermostats were turned up to a relatively high level. This was discovered and the thermostats were turned down, but it is not clear if someone has since turned them back up again.

After discovery of the high heating energy usage, a representative from the heat pump manufacturer visited the site to survey the equipment and verify correct operations. He found normal operations and normal refrigerant charge. He did find extremely dirty coils on the outdoor units and instructed the maintenance staff in cleaning procedures. He also found that the units were cycling frequently at very low load (20-30Hz) due to low demand from the water heating system. He reset the controls to disallow operations below 30Hz. While these issues may have slightly increased energy usage during the heating season they do not explain the large heating signature shown in the common area electric bill.

Lessons Learned

The mechanical systems in the two phases of this project are not typical residential mechanical systems. These systems were new to the building owners, occupants, and the contractors. The hydronic portion of the VRF system in Phase 2 was the first of its kind in WA State, so the designers and equipment distributor were also new to the equipment. As with any new technique or equipment, mistakes were made and lessons were learned in the process.

1. <u>Hot water circulation</u>: Hot water circulation systems can be a very large component of DHW heating energy. With low flow water fixtures reducing hot water usage in new apartments, the standby losses can represent a very large fraction of the total hot water heating energy for central water heating systems. Hot water distribution and circulation piping needs to be well insulated to keep these losses as low as possible. When heat pump water heating systems have "finishing tanks" or back-up heating, care must be taken in the handling of the circulation loop as it interacts with the water heating equipment. If the piping design is not handled properly, this can eliminate much of the savings potential of a heat pump water heating system. If the circulation water is brought back to the finishing tank downstream of the heat pump storage tank, then all of the circulation losses will be made up by the back-up heating system. If the circulation water

[4] Shawn Oram and Carmen Cejudo. *Designing For Off*. ASHRAE High Performance Buildings Magazine. Summer 2013 Edition. http://www.hpbmagazine.org/case-studies/office-institutional/rice-fergus-miller-office-and-studio-bremerton-wa

is brought back to the heat pump storage tank and it comes back too warm, it will keep the heat pump from firing and cause the back-up heater to provide the majority of the heat to the system. If possible use heat trace cable and eliminate circulating water loops in heat pump water heating systems. If a circulation loop is used, we recommend using balancing valves, controlling the circulation pump with an aquastat, or a variable speed pumping system to control the return water to return as cool as possible (about 105°F) and to plumb this back to the heat pump preheat storage tank. Furthermore, the heat pumps must be set up with a setpoint higher than the circulation return water temperature (see Figure 5 below).

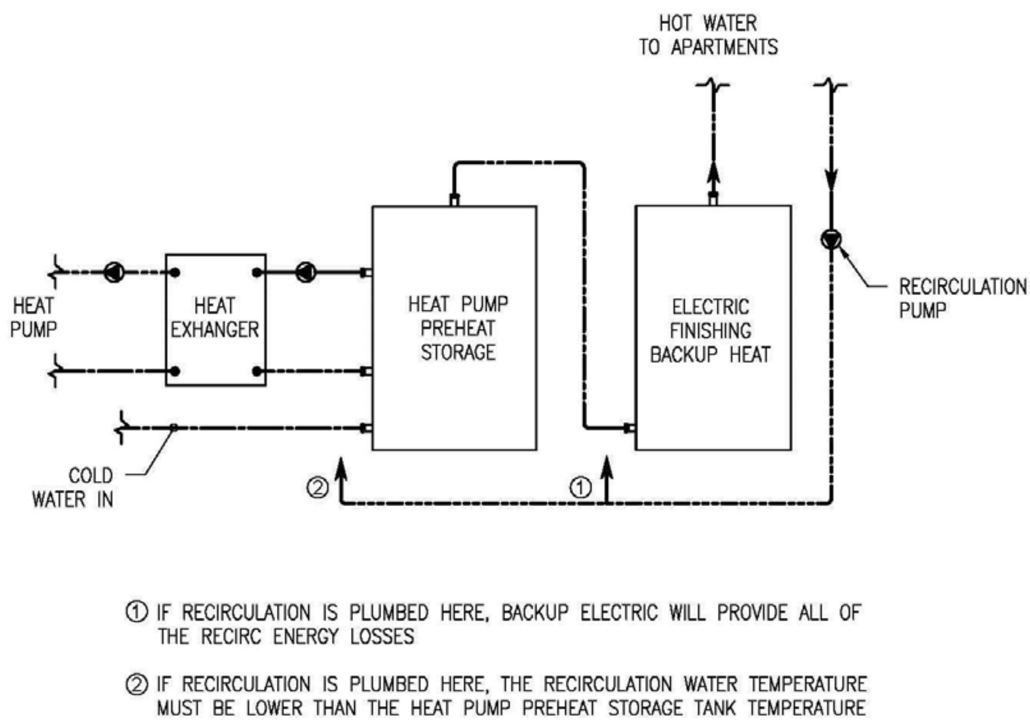

Figure 5: Circulation Piping Schematic

2. <u>Hot Water Setpoint</u>: The efficiency of a heat pump water heater drops significantly with higher target temperatures. R410a systems are not capable of producing water hotter than about 120-125°F. Code requirements for double walled heat exchangers further reduce the temperatures achievable in the potable water tank. Therefore these systems will typically require finishing or back-up heaters in the Pacific Northwest climate. The back-up heaters should be set to as low of a setpoint as possible to allow the heat pump water heater to provide the majority of the water heating energy. For example, if the heat pump

system heats the water to 110°F and the back-up heater is set to maintain 140°F, then the heat pump system will at best provide only about 2/3 of the heating energy.[5]

3. Legionella: Concerns about controlling for the growth of legionella bacteria can have a significant impact on the potential for R410a heat pump water heaters. Guidelines for facilities housing at-risk populations with compromised immune systems recommend storing water at 140°F and circulating water at 124°F.[6] These temperatures are not attainable with R410a systems. It is therefore not recommended to use R410a heat pump water heating systems for assisted living or other similar facilities where occupants with compromised immune systems are expected.

4. Tempering Valves: Tempering valves are provided on multifamily central hot water distribution systems to prevent possible scalding water delivered to the apartments. These valves are typically designed assuming 130°F or hotter supply water and 120°F delivery water. These valves are also typically significantly oversized based on old assumptions for water use with high flow fixtures. Lower supply water temperature and oversized valves leads to extremely poor control. We recommend either using a digital mixing valve or undersizing the tempering valve by one nominal size smaller than the calculated peak flow to provide better control over delivered water temperature.

5. Freeze Protection: Beware of the electric heater installed for "freeze protection". Poorly controlled space heaters anticipated to be used only for emergency purposes can use an inordinate amount of energy, especially as other building loads are optimized. If there is any heating or freeze protection in a space, it is imperative to include insulation and dedicated controls with thermostats capable of freeze protection setpoints (35-45°F). Most electric wall heaters don't have controls with the ability to maintain a space at only 35°F and will significantly overheat for the purpose of freeze protection.

6. Back-up Water Heaters: Ground source heat pump systems are capable of producing domestic water hot enough for delivery to the apartments without additional electric resistance heating. However, it may still be desirable to include an electric tank as emergency back-up in the event of a heat pump failure. However, if back-up electric is provided care must be taken to ensure that there is some way for the operators to know if it is operating and when the primary heat pump system has failed. Installing a backup resistance heating system that can only meet part of the DHW load and not the full load will ensure that problems with the primary high efficiency heat plant don't go unnoticed.

7. Commissioning and Signage: Slightly altered setpoints can cause heat pump water heating systems with electric backup to become electric water heating systems with heat pump backup. HVAC and Geothermal contractors are typically conservative with systems and will often setup systems trading off efficiency for reduced call-backs. With readily accessible controls it is imperative that signage be included on setpoints so that

[5] The heat pump will raise the water about 60°F (from 50°F to 110°F) and the electric finishing heater will provide an additional 30°F (from 110°F to 140°F).

[6] ASHRAE Guideline 12-2000.

changes that impact performance are not made after commissioning. Ideally projects should include a line item in the commissioning budget for the commissioning agent to come back after 3-6 months of operation to verify that the setpoints are still in the correct range.

8. Thermostats: Thermostats for ductless heat pumps need to include a separate heating and cooling setpoint and include a 5 degree deadband between setpoints. The unit shall be shut off when temperatures are between the setpoints. This is nominally required by the Washington State Energy Code, however it has been interpreted differently by the heat pump manufacturers. The original control strategy for this equipment was developed in Japan and South Korea and has focused on comfort over energy savings. Unless specified the controls will often allow for only a single setpoint with the units cycling between heating and cooling in order to maintain that setpoint.
9. Radiant Floors: Radiant floors in highly insulated homes will not feel warm to the touch except in very cold weather. This can lead to complaints as tenants may sense that the floors are cool, therefore believing that the system is not working.
10. Innovative Systems: Various design, installation, commissioning, and O&M difficulties that were experienced with these systems highlight the challenges associated with integrating emerging technology into projects. One lesson learned here is that care should be taken when selecting projects to pilot new technologies. Ideally there would be a sophisticated, well-established, and well-trained champion for the new technology as part of a permanent O&M staff who will be responsible for tracking performance and maintaining the equipment. When this person is not available it is easy for small control changes or installation irregularities to happen that can significantly impact the performance.
11. Division of Labor Between the Trades: Care must be taken with innovative new technologies where any two trades overlap. With heat pumps used for space and water heating this overlap occurs between the plumber and the HVAC contractor (and to a lesser extent the electrician). Where installation or controls problems emerge it is easy for each contractor to point to the other as bearing responsibility. Ideally construction documents should be written in a way that clearly defines the roles and responsibilities of each subcontractor.

Case Study Best Practices

The central heat plants in Phases 1 and 2 offer key advantages for owners, tenants and maintenance personnel. With central heat plants owners and maintenance personnel have immediate access to all heating equipment without the need for tenant notifications and disruptions. Central plants free up valuable rentable floor space inside living units. Central heat pump systems are significantly less expensive than individual heat pump systems in each apartment.

Program implementers and project verifiers have a hard job with custom energy conservation projects determining if systems are designed in a manner to deliver the expected savings. This section points out some key "Best Practice" design considerations for these systems and potential pitfalls to avoid.

1. Redundancy and Back-up: Heating systems should be provided with redundant heat pumps and backup heaters to ensure tenants are not without heat or hot water in cases where heating equipment is down for service or maintenance activities. In the Phase 1 GSHP units, the heating system is supplied by two 5-Ton (nominal, 3.5 Ton at design) water source heat pumps for radiant floor heating in lieu of a single 10 ton unit of which the building loads require. This redundancy and staging allows for partial back-up in the event that one of the heat pumps fails.

2. Self-Balancing Variable Flow Hydronic System: The hydronic system in Phase 1 provides low temperature radiant floor heating to all 10 units. A single variable speed pump with inclusive pressure sensor and feedback controls built into the pump provides variable flow for all 10 units. This smart variable speed pump is coupled with 2-way zone valves and pressure independent constant flow control valves at every apartment which makes it so the hydronic system requires no balancing and provides all necessary flows for each radiant zone. This is justified based on first cost as the component upgrades are typically less than the labor associated with balancing the typical primary/secondary systems. This variable speed component saves energy by not over-pumping.

3. Sizing Heat Pump Systems: Heat pump capacity is relatively expensive, therefore they should not be oversized to maximize heat pump cost effectiveness. For space conditioning heat pump capacity should be sized between 100-130% of the Design Heating or Cooling Load. For water heating systems recovery capacity can be traded for storage volume to some extent. ASHRAE sizing guidelines should be followed per the ASHRAE Handbook of HVAC Applications Chapter 50: Service Water Heating (see Figure 6). This tends to yield a smaller heat and storage system than comparable calculations from water heater manufacturers. Note that the ASHRAE calculations were developed before the widespread use of low flow plumbing fixtures, so they will tend to be conservative anyway.

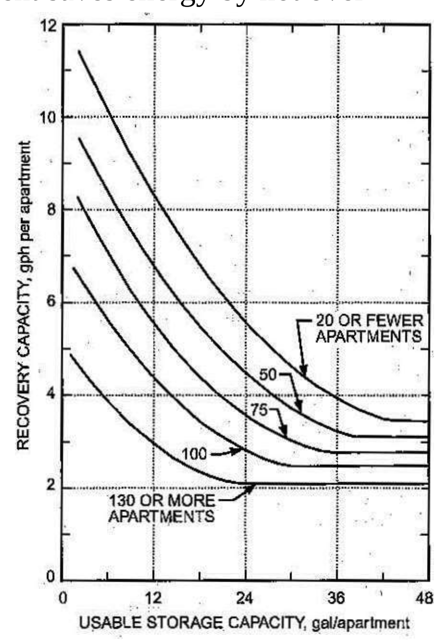

Figure 6: ASHRAE Service Water Heating Sizing

4. Ground Coupled Heat Exchangers[7]:

    a. Loops should be designed for a 30°F Entering Water Temperature and designed by a certified IGSHPA ground loop designer. Vertical bores should be sized at 225' bore length/nominal ton minimum and spaced at 20' centers minimum. Horizontal loops should be sized at 800' of pipe/ton minimum and 1200 sf of horizontal land area per nominal ton.

    b. Ground loop circulation pumps should cycle on a call for heat/cool and not be setup to run continuous.

    c. Ground loop pumping flow centers should not exceed 180Watts/nominal ton of heat pump capacity.

5. Variable Refrigerant Flow Systems:

    a. Variable Refrigerant Flow systems should include manufacturer approved design verification which comes with most VRF manufacturer's software design packages

    b. VRF systems should be setup to cycle heat pumps only on a call for space heating or cooling as opposed to running fans continuously during occupied hours.

    c. VRF cassettes should be controlled from zone mounted thermostats vs sensing at the return air plenum of the cassette.

    d. Thermostatic controls should have a separate heating and cooling setpoint separated by at least a 5°F deadband where the equipment is shut off.

    e. VRF heat pump controls shall also be setup to sense at the thermostat and allow a 2-3 degree drift from setpoint prior to firing to meet setpoint.

6. Central Heat Pump Fired Domestic Hot Water Systems:

    a. To maximize efficiency heat pumps should be set up to produce water as close as possible to the final water delivery temperature. If the heat pump target temperature is too low then the back-up heat will provide a large fraction of the water heating. If the heat pump target temperature is too high the efficiency of the heat pump is significantly reduced.

    b. Hot water should be stored as cool as possible while still meeting the needs of the project. Higher storage temperatures will result in higher standby losses, more back-up heating energy, and lower heat pump efficiency.

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[7] Where possible, installation and design should follow specifications adopted by the Regional Technical Forum: Residential Ground Source Heat Pump System Installation Standards. October 4, 2011. http://rtf.nwcouncil.org/subcommittees/gshp/meetings.asp. Note that specific site conditions may override these general specifications.

   c. Additional thermal insulation jackets installed around hot water storage tanks should be used in any project.

7. Hot Water Circulation:

   a. If possible, eliminate the use of a circulation loop with heat pump water heating systems.

   b. Insulation of hot water distribution piping and circulation piping is very important and often not enforced by plans examiners and building inspectors. Ensure all parts of the distribution system are insulated at least to levels prescribed in the latest edition of the Energy Code.

   c. If electric or gas trimming is used to raise the temperature of the final storage tank to a higher temperature than produced by the heat pump, then care must be taken in the design of the circulation loop. The circulated water should come back as cool as possible (105-110°F). ***The circulated water must come back at a lower temperature than the heat pump preheat storage tanks.***

   d. Install the smallest size hot water circulation pump possible. Use timers or aquastats on circulation piping to guarantee that circulated water comes back as cool as possible.

   e. In large multifamily projects the circulation loop (or "ring main") can be maintained with a separate small heat pump system. This eliminates the complications of bringing hot circulation water back to the storage system.