# Reverse Cycle Chiller (RCC) Best Practices Design Guidelines

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# Executive Summary

This report provides best practices recommendations for design of heat pump water heating systems in multifamily buildings in Seattle using Reverse Cycle Chiller (RCC) technology. RCCs are commercial air-cooled chillers setup with reversing valves to function as heat pumps to create hot water as opposed to chilled water.

Recommendations in this design guide have been developed based on experience gathered during a pilot project of this technology funded by the Bonneville Power Administration's Emerging Energy Efficient Technologies (E3T) program. This project funded design assistance, commissioning, and Measurement and Verification (M&V) studies of two RCC installations in multifamily buildings in Seattle. Lessons learned from those projects have been incorporated here to propose a design approach that delivers high efficiency, reliability, redundancy, low cost, and does not require non-heat pump back-up equipment. Some of the key design features needed to ensure a high level of consistent performance include the following:

1. Install RCCs to pull supply air from a below grade parking garage to provide warm air year-round to the RCCs.
2. Set up RCCs to function in "single pass" mode; varying water flow through the heat exchanger to deliver a fixed outlet water temperature to the hot water storage tanks (120F minimum).
3. Provide temperature stratified hot water storage; most easily accomplished with multiple storage tanks in series.
4. Use latest ASHRAE sizing methodology outlined in the 2015 ASHRAE Handbook: HVAC Applications, Chapter 50, page 50.16 to size total storage and heat pump capacity.
5. Provide multiple stages of water heating equipment arranged in parallel and stage them in a lead/lag configuration. Provide controls to prevent short-cycling of compressors.
6. Provide full insulation on all distribution and recirculation piping to limit heat loss from the piping system. Eliminate thermal bridging at piping supports. Provide insulated water tank jackets for storage tanks.
7. Consider inclusion of a separate small heat pump water heater to maintain the temperature of the recirculation loop. Do not use electric resistance or gas fired equipment for hot water circulation reheating.
8. If back-up (gas or electric resistance) equipment is used, configure for emergency-only operations.
9. Optimize the performance of all of the components of the RCC system such as compressors, heat exchangers, pumps, and fans. Select a combination of fans and pumps using no more than 150 Watts per nominal ton of RCC capacity.
10. Include basic alarm notifications and measurement and verification equipment to allow for monitoring and troubleshooting of system performance over time.

In apartment buildings heated with electric resistance space heating a typical RCC installation following these general guidelines can be expected to reduce the required energy use of the hot water system by approximately a factor of 2.6.

## Introduction

In 2009 Ecotope completed a feasibility study for the Bonneville Power Administration (BPA) Emerging Energy Efficient Technology (E3T) program.[1] The study examined the use of Reverse Cycle Chillers (RCC) to produce domestic hot water for multifamily buildings in the Pacific Northwest. An RCC is essentially commercial chiller technology set up to operate in reverse as a heat pump water heater and equipped with a double-walled copper heat exchanger so that it can process potable water directly. The RCCs used in the study contain R-134a refrigerant which does not function well at supply air temperatures below about 40F. The innovation in this study was to take advantage of the thermal buffering effects of below grade parking garages to allow the use of R-134a heat pump technology year-round at relatively high efficiency for the production of domestic hot water in the Pacific Northwest climate.

Following the feasibility study two multifamily building projects in Seattle were recruited for pilot projects. In addition to support for the pre-design work carried out in the feasibility study, BPA provided funding for system commissioning, and a Measurement and Verification (M&V) study. Seattle City Light provided energy conservation incentive money for both projects. The M&V data allowed for a number of issues to be identified and corrected in the pilot projects and led to changes to improve the design and overall performance. Lessons learned from the pilot projects has contributed to the recommendations included in this Design Guide.

**Figure 1: Stream Uptown Apartments – The first RCC Pilot project to be completed in Seattle**

Based on the performance of the first two RCC pilot projects it is clear that RCCs can be used effectively in the Seattle climate to produce domestic hot water in multifamily buildings at a COP of around 2.6

[1] Reverse Cycle Chillers for Multifamily Buildings in the Pacific Northwest: Phase I Final Report. Jonathan Heller and Carmen Cejudo, Ecotope Inc. September 2009. Produced for the Bonneville Power Administration.

without the need for back-up electric resistance or gas heat. However, there are a large number of potential design pitfalls that will reduce reliability and/or energy efficiency of an RCC system. The intent of this Design Guide is to present some of the critical issues to be addressed by RCC designs in the Seattle climate to ensure a highly efficient and effective water heating system. It also presents recommendations for design features that should be included in all RCC designs to be provided with Seattle City Light energy conservation rebate money and expected savings from these systems.

## Available Air-to-Water Heat Pump Equipment

Air-to-water heat pump technology is available in a wide range of configurations; some of which are appropriate for heating domestic hot water in multifamily buildings in the Pacific Northwest. The various classes of available Air to Water Heat Pumps are shown in the photos below and described in Table 1.

Integrated Units

Small CO2

Split System R410a


Multi-Pass RCC

Single Pass RCC (CO2)


Single Pass RCC 134a

**Figure 2: Range of Available Heat Pump Water Heating Equipment**

**Table 1: Classification of Various Commercially Available Air-to-Water Heat Pump Equipment**

<table>
<tr><th>Make/Model</th><th>Description</th><th>Refrigerant</th><th>Equipment Capacity</th><th>Single or Multi-Pass</th><th>COP Range</th></tr>
<tr><td>GE, Rheem, AO Smith, Steibel Eltron, etc.</td><td>Integrated Units (heat pump and tank)</td><td>R-134a</td><td>4,500-8,700 Btu/hr +<br>4500 W Electric</td><td>Multi</td><td>1.6 (Recirc reheat)<br>2.4 (city cold water)</td></tr>
<tr><td colspan="6">Notes: This equipment was designed for the single family market. Banking a few of these to serve as a central water heating system for a small multi-family (MF) building is feasible. These are also useful for dedicated recirculation water reheating. These units work in heat pump mode down to ~37F entering air so ideally these are located in an area with some amount of earth buffering or waste heat.</td></tr>
<tr><td>Sanden Eco ($CO_2$)</td><td>Packaged Units with storage tanks</td><td>R-744 ($CO_2$)</td><td>15,000 Btu/hr</td><td>Single</td><td>3.2 (city cold water)</td></tr>
<tr><td colspan="6">Notes: Useful for small to medium size MF buildings as a single pass primary heat plant, the peak hot water flows limit design options as each tank has only a 3/4" connection, piping these in parallel is a solution to larger incoming water flows, requires additional storage downstream. Outputs 149 F water at low flow rate. Not suitable for any other use beside primary cold water heating in a single pass (need separate system for reheating of circulation loop).</td></tr>
<tr><td>Daikin Altherma</td><td>Split or Monoblok<br>No Tank</td><td>R-410a</td><td>24,000-54,000 Btu/hr +<br>6kW Electric</td><td>Multi</td><td>2.0-3.0</td></tr>
<tr><td colspan="6">Notes: Useful for small to medium size MF buildings. Low temp, multi-pass. Not rated for potable water - requires heat exchanger for double wall potable protection. Works as heat pump down to -5F entering air so it can be installed outdoors. These units may require back-up gas or electric trim tank for final heating.</td></tr>
<tr><td>Heat Harvester, AO Smith, MultiStack, Aermec, Colmac</td><td>Multi pass commercial units</td><td>R-410a</td><td>100,000-420,000 Btu/hr +<br>6kW Electric</td><td>Multi</td><td>2.0-2.5</td></tr>
<tr><td colspan="6">Notes: Potentially useful for medium to large size MF buildings. Low temp, multi pass. Not rated for potable water - requires heat exchanger for double wall potable protection. Works as heat pump down to -5F entering air so it can be installed outdoors. These units may require back-up gas or electric trim tank for final heating.</td></tr>
<tr><td>Colmac, Single Pass</td><td>Single Pass Commercial Units</td><td>R-134a</td><td>48,000-180,000 Btu/hr</td><td>Single</td><td>2.8-3.2 (city cold)<br>1.8-2.0 (hot water circulation)</td></tr>
<tr><td colspan="6">Notes: Single Pass, output 130-160F, can take up to 120F entering water. Works down to 40F entering air – ideal for below grade parking garage.</td></tr>
<tr><td>Mayekawa</td><td>Large single pass Commercial Units. (0 GWP)</td><td>R-744 ($CO_2$)</td><td>200,000 Btu/hr</td><td>Single</td><td>3.0-4.0 (city cold)<br>1.8-2.0 (hot water circulation)</td></tr>
<tr><td colspan="6">Notes: Single Pass, output 149F or 194F water, needs high lift (100 degrees above entering water temperature). Peak entering water 95F. Works down to -5F entering air, not recommended for hot water circulation – include separate unit for reheating circulation loop.</td></tr>
</table>

The BPA pilot project was focused on larger commercial fixed-capacity chiller technology with R134a refrigerant setup in a single pass arrangement. This is equipment is well-suited to the problem of multifamily water heating as it is capable of producing water up to about 160F from relatively cold air.


Figure 3: Colmac Industries RCC Equipment

The Single Pass setup is ideal for primary water heating as it does not require the use of a gas or electric resistance back-up “finishing” tank. Due to poorer low temperature performance of this equipment it is most appropriate where it can be buffered from ambient winter conditions such as locating it in below grade parking garages. This type of equipment and installation will be the primary focus of this design guide.

## Recommended Measures

The following is a list of measures recommended for inclusion in an RCC design in the Pacific Northwest climate based on 134a equipment installed in below grade parking garages.

### 1. Locate RCCs in below grade parking garage. Vent air to the outside.

There is a wide range of performance characteristics in RCC technology. The performance varies based on the equipment manufacturer and model as well as based on the energy content of the source air and the temperature of the inlet and outlet water. Figure 4 shows the theoretical heating performance of a typical 134a RCC compared to source air wetbulb temperature.

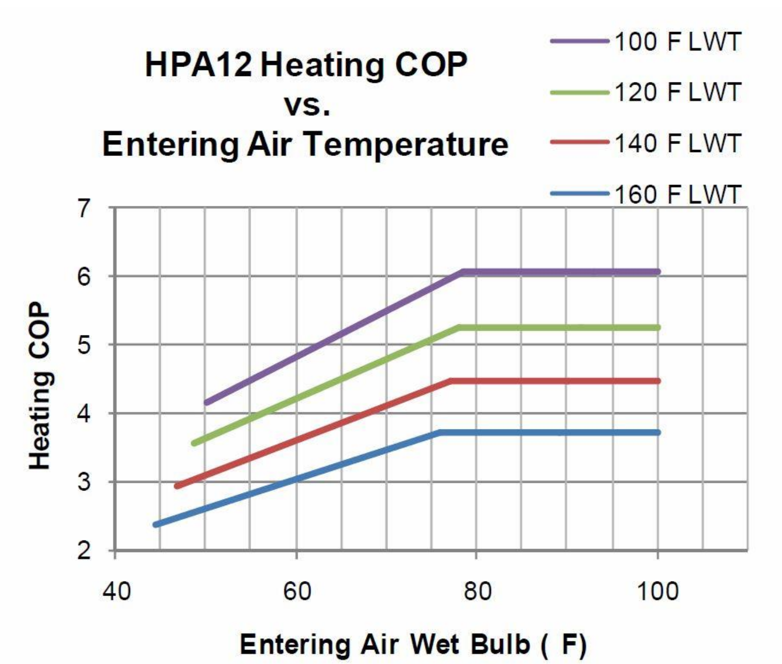


**Figure 4: Manufacturer’s performance curves for RCC (70F entering water temp)**

The warmer the source air, the higher the efficiency of the RCC. Note also that no data is shown below about 40-50F. This is due to the fact that the 134a refrigerant type RCCs will likely spend a lot of time in defrost mode when temperatures drop that low. This indicates that outdoor air is not a good source for this type of equipment in the Pacific Northwest for a year-round load such as domestic hot water since during much of the winter we experience temperatures below about 40-50F.

However, data from the pilot projects indicates that below grade parking garages in this region will remain above 50F year-round. The garages in the pilot projects were close to "worst case scenarios" for this type of application since they are both relatively small, not fully below grade, one includes a large number of space heating heat pumps which are extracting heat from the space, and the other is located below a large exterior courtyard rather than a heated building. Even in these locations the lowest average daily temperature did not drop below about 50F at any time during the year.

The figure below shows the average daily temperatures in the parking garages of the two pilot projects compared to the dotted line showing outdoor temperature. Note that it is warmer in the parking garage than outside for all but a small number of very hot summer days. This indicates that there is a significant COP benefit to locating the RCCs in the garages (~0.5 COP points). Note that the exhaust air from the RCC should be vented to the outside of the garage so as not to further cool the garage. This can serve the dual purpose of ventilating the parking garage.

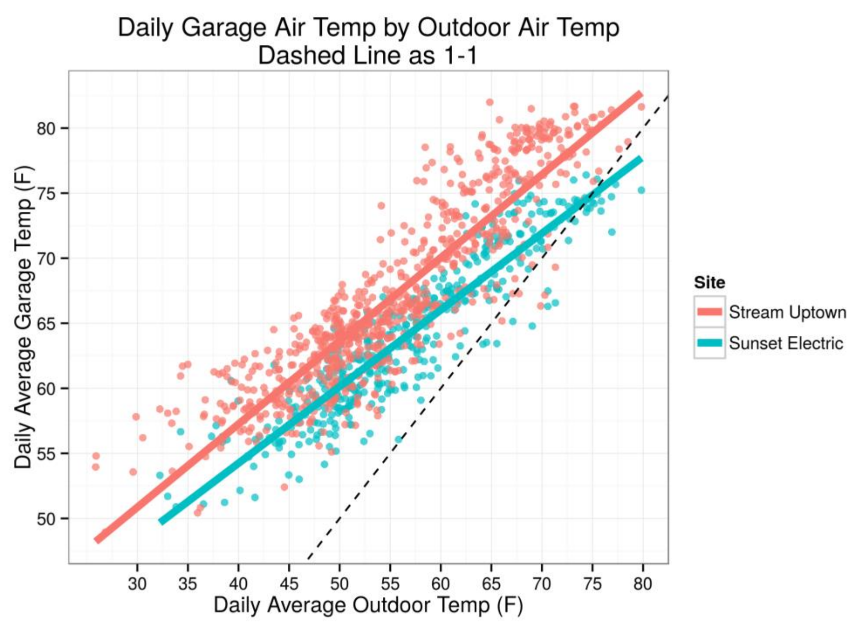


**Figure 5: Measured Temperature in Below Grade Parking Garages in 2 RCC Pilot Projects**

The next figure shows that the temperature in the garage is remarkably constant throughout the day. It tends to vary only 2-3F from a low point in the morning to a high point in the evening.

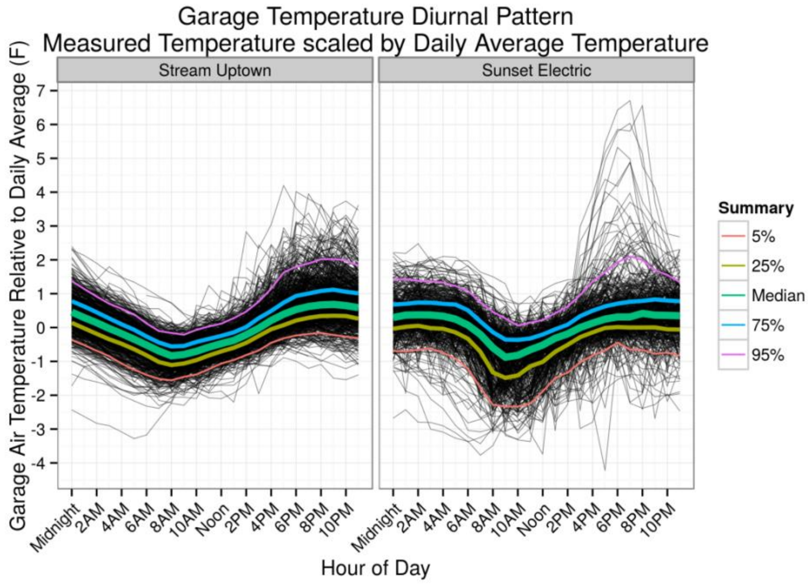


**Figure 6: Daily Swing in Temperature in Below Grade Parking Garages in 2 RCC Pilot Projects**

## 2. Single Pass

The design should be based around a "Single Pass" water pumping strategy as opposed to the typical "Multi Pass" strategy employed in most hydronic heating applications. This means that the flow of potable water through the RCC is regulated by a control valve or variable speed pump to maintain a target output temperature of 120-140F. This results in a variable flow rate and variable temperature rise across the heat pump as opposed to the typical fixed flow rate and fixed 10-20F temperature rise on the water. The heat pump can therefore output water hot enough for direct delivery to the building with incoming water temperatures to the heat pump ranging from 40-110F. The advantage of the Single Pass arrangement is that a usable water temperature is always delivered to the top of the storage reservoir. If a Multi Pass logic is used it is likely that another non-heat pump system such as electric resistance or gas water heater will have to be used in a "finishing tank" configuration to ensure that hot enough water is always available to the building. Not all RCC manufacturers offer a Single Pass configuration option.

## 3. Multiple Storage Tanks

The design should be based around the use of multiple storage tanks plumbed in series. The series plumbing arrangement enables a high degree of temperature stratification throughout the system with the hottest water at the end of the storage system from where water is sent to the apartments. It also allows the use of smaller cheaper tanks that are easier to install. Tanks should be sized to provide approximately half of the daily hot water demand (see sizing discussion below).

**Figure 7: Domestic Hot Water Storage Tanks in Parking Garage**

## 4. Hot Water Storage and Heat Pump Sizing Calculations

When sizing storage volume and water heater output capacity for a domestic water heating system there is a trade-off between storage volume and heat pump capacity. With minimal storage volume the heaters must be sized to handle the peak expected instantaneous demand (e.g. on-demand water heaters). With high enough storage volume (over half of the daily demand) the heat output capacity could be as low as the average hourly demand. Somewhere between these extremes is the optimal combination of storage and capacity.

ASHRAE provides methodologies for sizing multifamily hot water systems based on the number of apartments which enables a trade-off of storage volume and heat output capacity. The older simplified methodology that is commonly used was developed at a time with much higher average fixture and appliance flow rates, higher average apartment occupancy, and potentially very different lifestyles compared to the current typical apartment tenant in Seattle. The systems for the pilot projects were sized based on this methodology and in practice are oversized by approximately a factor of 2. In addition to higher equipment cost and more space required, this leads to short cycle times on the heat pumps, which is hard on compressor equipment.

The 2015 ASHRAE Handbook: HVAC Applications provides an updated sizing methodology that is much more appropriate for modern multifamily systems. The methodology is detailed on pages 50.14-50.16 and provides *Low, Medium, and High* use curves for different demographic groups. The M&V data collected at the two pilot projects indicates that these apartments are using an average of 13-19 gallons of 120F water per person per day. Peak usage data shows that they are very close to the *Low* usage curves from the ASHRAE data.[2] Table 1 below shows the *Low* and *Medium* usage data from Chapter 50 of the 2015 ASHRAE Application Handbook referenced above. We recommend sizing calculations target sizing based on the *Low* no greater than the *Medium* flow guidelines for new Seattle buildings.

**Table 2: Peak Gallons of Hot Water per Person at Various Time Intervals for Use Sizing RCC Systems per Methodology in 2015 ASHRAE Applications Handbook, Chapter 50**

| | Peak Minutes | | | | | | Maximum | Average |
|---|---|---|---|---|---|---|---|---|
| Guideline | 5 | 15 | 30 | 60 | 120 | 180 | Daily | Daily |
| Low | 0.4 | 1 | 1.7 | 2.8 | 4.5 | 6.1 | 20 | 14 |
| Medium | 0.7 | 1.7 | 2.9 | 4.8 | 8 | 11 | 49 | 30 |

Note that data from the Seattle pilot projects also indicates that standard design assumptions for sizing plumbing and hot water systems appear to be very conservative for modern apartments in Seattle. The highest average flowrate of hot water over the course of a year with a 10-minute data logging interval was about 10GPM at a building with 92 apartment units. This is an order of magnitude less than the peak hot water flow rate assumed by the calculation methodology of Appendix A of the 2012 Uniform Plumbing Code. The peak flow assumed by the plumbing code for the purpose of sizing the plumbing is over 200GPM of hot water. More realistic assumptions about hot water demand could potentially

[2] Both pilot projects included water conserving low flow plumbing fixtures.

significantly reduce the capital cost of apartment plumbing systems, but any changes to the plumbing sizes would have to be negotiated with the Authority Having Jurisdiction over the plumbing systems.

## 5. Multiple smaller heat pump stages

The expected lifespan of compressors such as those used in RCC equipment are typically more closely tied to number and frequency of start/stop cycles than they are to years of operation. Therefore to extend the useful life of a heat pump system it is best to limit the number of cycles per day. One way to accomplish this is to provide multiple smaller pieces of equipment that can be staged in with increasing load as opposed to one larger unit that will meet the load more quickly and cycle more frequently. This also provides a mechanism for providing for some redundancy in equipment. For example see the schematic in Figure 9. In the case of a 20-ton load during the peak period of water consumption, the system could be provided with two 10-ton heat pumps and an emergency back-up electric boiler. These can be staged in as needed with a single heat pump unit running most of the time and a second heat pump brought in only to meet peak loads. The back-up is then available when one of the first units is down for maintenance.

Another methodology to prevent short cycling is to implement a time lag between a call for heating and the initiation of the heat pump. A 30-minute time delay allows for more cold water to enter the system before starting the heat pump, thus providing for a longer run-time.

## 6. Manage hot water circulation loop

Well-functioning hot water circulation loops are an essential component of a central hot water heating system in a multifamily building. Hot water must be maintained at all times in the primary hot water supply pipe so occupants can get hot water at their fixtures within a reasonable time lag after turning on the water. Inadequate circulation systems lead to high water usage and high levels of occupant complaints. However, high flows of relatively warm water (105-115F) returning to the storage system can have negative effects on a heat pump water heating system. Heat pump efficiency is directly tied to incoming water temperature. Heating COP for the heat pump decreases with warmer incoming water temperatures.

Furthermore, if the temperature of the water entering the heat pump is too high the heat pump will not be able to reject all of the heat produced and the refrigerant head pressure will rise and cause the unit to fail on a high pressure alarm. The design of the storage and circulation must be managed to avoid high temperature water from entering the heat pumps directly.

One recommended effective method for reducing these problems is to provide a separate dedicated heat pump to maintain the circulation loop directly. This eliminates the interaction of the circulation loop with the primary water storage; ensuring that the primary heat pump system will always operate at peak efficiency with lower incoming water temperatures. The heat pumps treating the circulation loop can be optimized for the constant load and higher water temperatures associated with the circulation loop. See Figure 10 below.

## 7. Limit Distribution and Circulation Losses

A very large amount of heat is lost in the storage, distribution, and circulation of hot water from a central water heating system. With low water usage associated with low flow fixtures and less water-intensive lifestyles these distribution losses can account for a very high fraction of the total water heat energy. In the RCC pilot projects the distribution losses were 30% of the total heat energy created by the RCCs at one site and 45% at the second site. This amounts to approximately 55-75 Watts of continuous heat loss per apartment. This compares very closely to an average heat loss of about 60 Watts for a typical electric water heater tank.

An important conservation measure is to reduce these losses and increase heat pump water heater efficiency by paying close attention to the insulation of the water distribution and circulation piping. Every portion of pipe with circulating water must be insulated. The insulation should be continuous through the supporting clamps with technology similar to that shown in Figure 8. Current code requires R-4 or 1” insulation on hot water piping. [3]

**Figure 8: Recommended Configuration for Full Pipe Insulation**

Note that some fraction of the distribution losses heat up the building and offset heating that would otherwise have been accomplished by the building heating systems. Depending on the space heating system and distribution of heat loss, this may negate the importance of these losses. When the building is heated with electric resistance heaters the losses from the distribution system during the wintertime likely *decrease* the overall energy use of the building since the heat in the loop was created at a COP of about 2.6 and the heating offset would have been created by an electric resistance heater with a COP of 1. With this accounting of total building energy, if 38% of the heat lost from the distribution loop goes to offset electric resistance space heating equipment the overall energy impact to the building of the distribution losses is zero.

## 8. Configure Back-up Heat as Emergency Only

A back-up heat source may be provided for additional redundancy in case of compressor or other equipment failures. However, care must be taken in the controls set-up to guarantee that the back-up heating source does not operate unless there is a failure in the heat pump system. Improperly set-up back-up heating systems can lead to continuous energy usage which will draw down the overall water heating system efficiency. Ideally the controls set-up for the back-up are designed as a fool-proof manual switch-over to avoid inadvertent controls changes that could lead to the back-up system taking over the water heating without the building operator’s understanding.

[3] Unfortunately plumbing insulation is currently a portion of code that does not receive adequate enforcement. Insulation is not reviewed by the plumbing inspector, nor is it reviewed during inspection of the envelope insulation.

## 9. Optimize Performance of RCC Components

Not all RCCs are created equal. The performance of RCC equipment varies based on manufacturer and varies within a manufacturer across the range of their equipment offerings. Below is a table listing the rated performance of various sizes of the same series of equipment from a single manufacturer.

**Table 3: Sample of RCC Equipment Performance Data**

| Model | Heating Capacity (BTUH) | Cooling Capacity (BTUH) | Heating COP | Cooling COP |
|---|---|---|---|---|
| **HPA4** | 66,141 | 52,573 | 4.87 | 3.87 |
| **HPA7 (Axial)** | 110,681 | 86,049 | 4.49 | 3.49 |
| **HPA7 (Centrifugal)** | 110,681 | 80,959 | 3.72 | 2.72 |
| **HPA9 (Axial)** | 130,056 | 100,943 | 4.47 | 3.47 |
| **HPA9 (Centrifugal)** | 130,056 | 95,853 | 3.8 | 2.8 |
| **HPA11 (Axial)** | 169,439 | 133,333 | 4.69 | 3.69 |
| **HPA11 (Centrifugal)** | 169,439 | 128,243 | 4.11 | 3.11 |
| **HPA12 (Axial)** | 207,107 | 164,806 | 4.9 | 3.9 |
| **HPA12 (Centrifugal)** | 207,107 | 159,716 | 4.37 | 3.37 |
| **HPA30 (Axial)** | 468,030 | 347,353 | 3.88 | 2.88 |
| **HPA30 (Centrifugal)** | 468,030 | 339,718 | 3.65 | 2.65 |

The heating COP varies by 33% across this range of equipment sizes. Note that, these COP ratings do not take into account the energy use of all potential variations of the peripheral uses of pumps and fans. The sizing and efficiency of these items is also critical to the overall performance of the equipment. The fans and pumps should be selected for energy efficiency and should be sized only as large as necessary or should include variable speed drives (VSD) if possible. Total energy for the fans and pumps associated with the RCC system should add up to no more than about 150 Watts per nominal ton of capacity. Also note that the manufacturer's efficiency numbers are typically published for optimal water and air temperature conditions.

## 10. Monitoring, Alarms, M&V

A certain amount of measurement, monitoring, and alarm capability is essential with this type of system to ensure proper operation. With any emerging technology it takes time for the designers, contractors, maintenance providers, building operators, and owners to fully understand that technology; what is required to set it up properly and keep it functioning. Performance data is critical to understand what is actually happening with any such system. At a minimum the system should send automatic alarms to maintenance personnel when there is a failure so that repairs can be completed as soon as possible. Total energy use of the system must also be available to allow for tenant billing of water heat energy. Tracking of this energy use periodically will allow for analysis of ongoing system performance. Increasing energy use could be associated with refrigerant leakage or equipment failures. The ability to record temperatures at the outgoing water line, the circulation system return, and throughout the storage system is important to understanding the severity and potential source of occupant water temperature complaints.

## Sample Schematic Configuration

Recommended example system schematics for an RCC system are shown below. Key features that incorporate the recommendations from above include:

- The storage is arranged in multiple tanks in series to maintain maximum temperature stratification.
- Multiple smaller heat pumps are arranged in parallel so that they can be staged in as needed and controlled for longer run times.
- Electric back-up heat is provided as a separate stage that can be brought on only in the case of emergency if the RCCs cannot satisfy the load.
- The heat pumps draw cold water from the first storage tank and deliver hot water to the top of the final tank in a "single pass" arrangement so that hot water is always available.
- Temperature sensors in each storage tank allow for optimization of controls and staging and diagnosis of any potential problems.
- Recommended sequence is to start first stage heat pump when temperature in the second storage tank drops below set point and to run until temperature in the first tank is up to setpoint. Control second stage heat pump on when temperature in third tank drops below setpoint and run until temperature in second tank reaches setpoint, and so on.

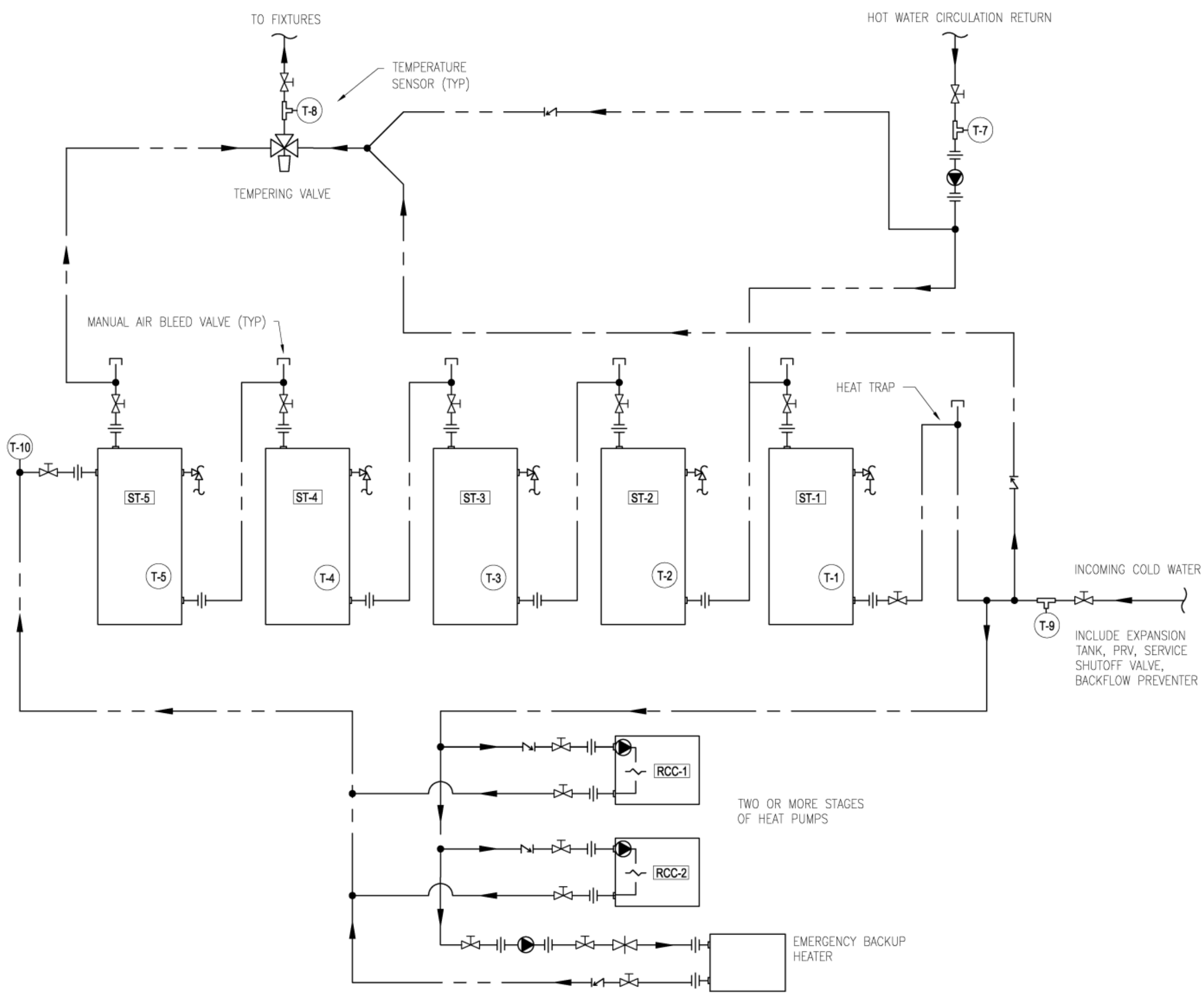


**Figure 9: Sample RCC Schematic**

An alternate schematic is also included which shows the hot water recirculation loop being treated with a separate heat pump. This configuration adds equipment and complexity to the system, but it avoids some of the problems and inefficiencies associated with bringing hot circulated water back into the heat pump system. An electric heater can be used as an emergency back-up for the circulation loop heat pump to maintain the loop during maintenance events.

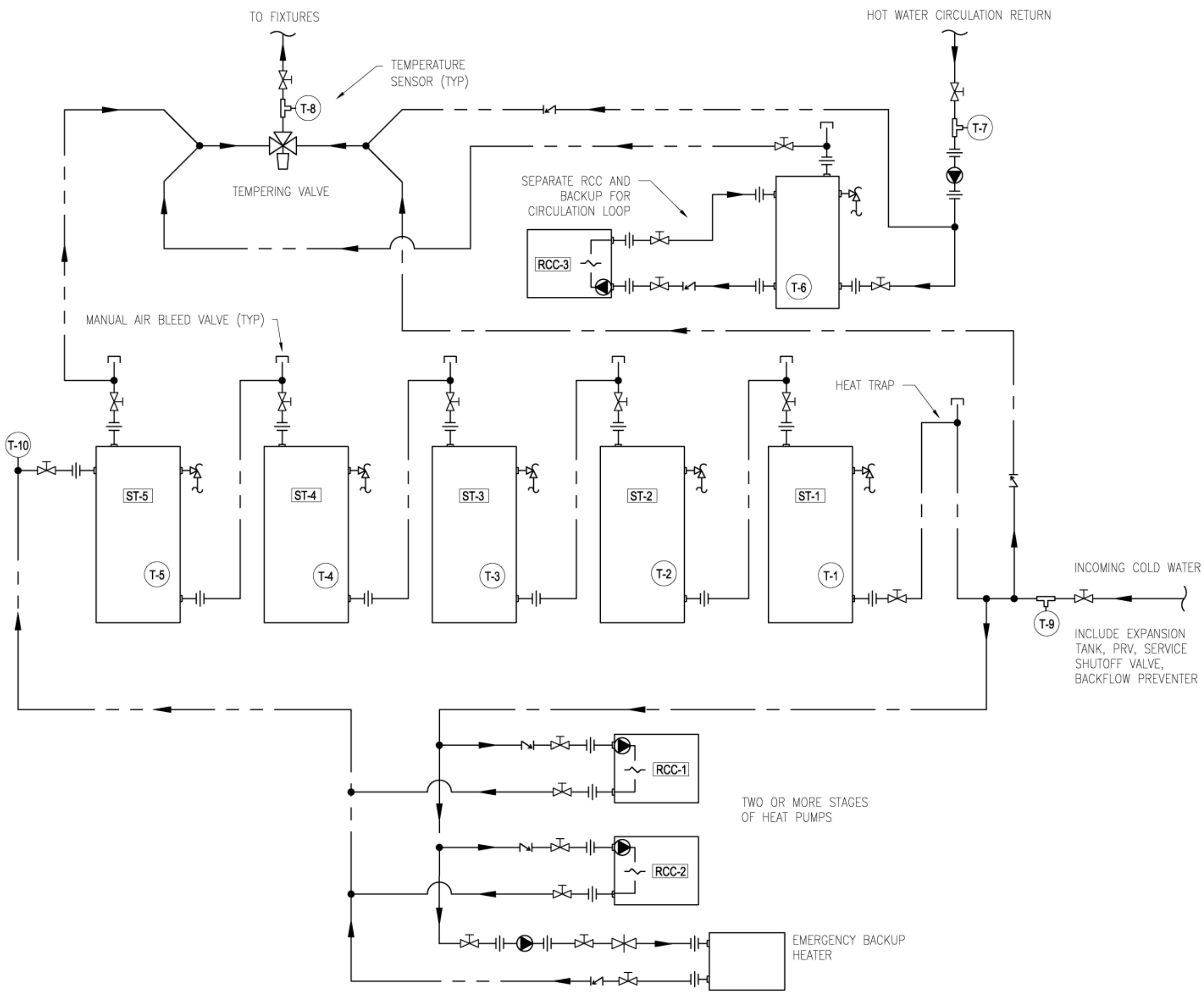


**Figure 10: Sample RCC Schematic w/ Dedicated Circulation Loop Heat Pump**

## Summary of Key Recommendations and Expected Performance

If the basic recommendations of this design guide are followed then performance similar to that measured in the BPA-funded pilot projects can be expected. Heating COPs of greater than this are possible if additional care is taken to optimize the various performance factors discussed above. The key design features needed to ensure a high level of consistent performance include the following:

1. Install RCCs to pull supply air from a below grade parking garage to provide warm air year-round to the RCCs. Vent cold exhaust air to the outside.

2. Set up RCCs to function in “single pass” mode; varying flow through the heat exchanger to deliver a fixed outlet water temperature.
3. Provide multiple storage tanks in series to provide temperature stratified hot water storage.
4. Use ASHRAE sizing methodology outlined in the 2015 ASHRAE Handbook: HVAC Applications, Chapter 50 to size total storage and heat pump capacity.
5. Provide multiple stages of water heating equipment arranged in parallel and stage them in a lead/lag configuration. Provide controls to prevent short-cycling of compressors.
6. Provide full insulation on all distribution and recirculation piping to limit heat loss from the piping system. Eliminate all thermal bridging at piping supports. Provide insulated water tank jackets for storage tanks.
7. Consider inclusion of a separate small heat pump water heater to maintain the temperature of the recirculation loop. Do not use electric resistance or gas fired equipment for hot water circulation reheating.
8. If back-up (gas or electric resistance) equipment is used, configure for emergency only operations.
9. Optimize the performance of all of the components of the RCC system such as compressors, heat exchangers, pumps, and fans. Select a combination of fans and pumps using no more than 150 Watts per nominal ton of RCC capacity.
10. Include basic alarm notifications and measurement and verification equipment to allow for monitoring and troubleshooting of system performance.

In apartment buildings heated with electric resistance space heating a typical RCC installation following these general guidelines can be expected to reduce the required energy use of the hot water system by approximately a factor of 2.6.