

# Reverse Cycle Chillers for Multifamily Buildings in the Pacific Northwest: Phase I Final Report

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**Final Report:** September 30, 2009

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## Table of Contents

<b>Executive Summary .....</b>	<b>iii</b>
Project Overview and Objectives .....	iii
Major Conclusions.....	iv
Summary of Energy and Demand Savings .....	v
Key Findings .....	vi
<b>Project Background.....</b>	<b>1</b>
Overview: A History of the “Problem” .....	1
Technology Overview.....	1
Available Products .....	3
Prototype Development .....	5
Past or Current Competitive Solutions .....	6
<b>Potential Barriers.....</b>	<b>7</b>
Physical Constraints .....	7
Code Barriers.....	8
Performance Limitations.....	10
Metering .....	13
Human Factors: System Designer, Installer, and/or Customer Feedback .....	13
<b>Discussion .....</b>	<b>15</b>
Incremental Costs (Materials and Installation).....	15
Savings .....	16
Useful Life .....	17
Product Evaluation.....	17
Feasibility and Market Potential .....	18
Garage Buffer Effect.....	18
Parking Garage Ventilation .....	21
Other Space Heating Applications .....	21
Design Recommendations .....	24
Improvements.....	24
<b>Conclusions.....</b>	<b>26</b>
<b>Recommendations for Future Work.....</b>	<b>27</b>

## Table of Figures

Figure 1: Basic Schematic of Reverse Cycle Chiller (Heat Pump Water Heater).....	2
Figure 2: RCC Clearances.....	7
Figure 3: RCC Performance Charts.....	10
Figure 4: Annual Heating Hours for Three Northwest Cities .....	19
Figure 5: Basic Schematic of RCC Below-grade Parking Garage Installation .....	22

## Table of Tables

Table 1: RCC Energy and Demand Savings.....	vi
Table 2: RCC Incremental Costs .....	15
Table 3: RCC Energy Savings .....	16
Table 4: Demand Savings Calculations for Large (163-unit) Prototype .....	16
Table 5: Demand Savings Calculations for Small (12-unit) Prototype .....	17

# Executive Summary

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## Project Overview and Objectives

Multifamily buildings in the Pacific Northwest have been largely developed around the use of electric resistance technologies for space heating and domestic hot water (DHW) production. For the past three decades this has been the dominant design approach as it provides the lowest initial cost to the developer.<sup>1</sup> Since electricity bills are typically paid by the tenants, the cost of energy has not been a significant factor in developers' decisions until recently. Rising electricity rates and the current focus on climate change and green building design has increased market pressure on developers to offer alternatives to the current standard designs and systems.

Over the last twenty years, considerable progress has been made in space heating energy conservation. This progress has primarily been driven by the energy code process mandating better insulation, more airtight construction, and higher efficiency equipment. These efficiency improvements have shifted the balance of energy use so that domestic hot water production is now larger than space heating in many new multifamily buildings. Analyses performed by Ecotope for regional conservation programs indicate that for multifamily buildings, production of domestic hot water accounts for approximately 25-30% of the residential energy use (Heller 2008). Reverse Cycle Chiller (RCC) technology is poised to emerge as a way to significantly reduce energy use for hot water systems in multifamily buildings. This study investigates the promise of RCCs as an Emerging Energy Efficient Technology for multifamily building applications in the Pacific Northwest.

Reverse Cycle Chillers are a form of air-to-water heat pump technology that can produce hot water at efficiencies of nearly 300% compared to electrical water heating. Although in common use in warmer climates for both cooling and hot water production, RCC technology has limitations in our climate region due to our relatively cold winter weather. This study provides analysis and a methodology to overcome these limitations in order to achieve greater energy savings in one of the largest remaining energy use categories in multifamily buildings.

This research study was developed to investigate the feasibility of a specific innovative design application of the RCC technology. Ecotope's thesis is that RCC technology can cost effectively provide for domestic water heating in multifamily buildings in the Pacific Northwest if the RCC unit is installed to use exhaust air from a below grade parking garage. The working theory is that this equipment is not currently being used in this part of the world due to its inability to function well through our relatively cold winters. RCCs perform poorly at temperatures below about 40°F. However, in a below grade parking garage the lights, vehicles, and thermal mass in contact with the ground should provide adequate buffering of the ambient low temperatures so that the RCC system could operate reliably and efficiently throughout the year.

This report was designed as Phase I of a larger Emerging Energy Efficient Technology research effort to investigate the feasibility of adapting this technology to multifamily buildings in the Pacific Northwest. Phase II will be a demonstration project where projects will be recruited to pilot this technology. Phase III will be a measurement and verification effort to validate the energy savings predictions. Phase

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<sup>1</sup> Approximately 70% of Seattle area multifamily buildings use electric water heaters. (*Leighton 1983*)

IV will be a case study report presenting lessons learned and regional market potential and development of regional marketing materials.

This report presents the findings from the Phase I feasibility study. This phase lays the groundwork for the specific engineering necessary to implement the technology in a demonstration project in Seattle. The research focused on shelf-ready RCC technologies, and included:

- ◆ A survey of equipment manufacturers and local distributors
- ◆ An analysis of potential limitations and barriers to RCC implementation in low-rise and mid-rise multifamily buildings
- ◆ Development of schematic designs for RCC systems in two multifamily prototype buildings
- ◆ Development of load profiles for both of these prototypes
- ◆ Thermal modeling to assess the interaction of an RCC system with the building and parking garage
- ◆ Cost/benefit analysis assessing construction costs and energy savings potential
- ◆ Investigation of further uses for RCC technology in multifamily buildings (corridor air tempering and space heating)

The results of this study indicate that RCC technology can indeed function well in the multifamily building market in the Pacific Northwest.

## Major Conclusions

Primary research focused on the several “Stage Gate” questions. These are listed below along with their relevant conclusions:

- ◆ **What is the range of “shelf-ready” reverse cycle chillers on the market?**

There are at least three equipment manufacturers with a complete line of “shelf ready” RCCs on the market that are easily adapted to produce domestic hot water in below grade parking garages. These companies have manufactured RCC equipment since the 1970s. The RCCs are available in an appropriate size range and offered at a price that makes this application cost effective for multifamily buildings in the region.

- ◆ **How are these technologies currently being used? Have they already been effectively implemented in the multifamily sector, and is there available research or case study data? Has this problem already been adequately solved or researched to the point where a demonstration project is not necessary?**

The RCC technology is primarily marketed for applications where cooling is needed and there is a coincidental hot water demand (commercial laundries, kitchens, and hotel resorts). It is used in multifamily applications in cooling climates with no significant cold weather (Hawaii, Texas, Guam, and parts of Asia). RCCs have not been used in colder climates for multifamily buildings and they have not been used in below grade parking garages. At least one manufacturer is currently in the process of product research aimed specifically at colder climate applications. A demonstration project is necessary to validate and publicize the ability of this equipment to function in our climate.

◆ **Are there code or physical barriers that prevent this from being an appropriate technology?**

There are no insurmountable physical, market, or code constraints to widespread use of RCC technology in the Pacific Northwest.

◆ **What is the likely cost of incorporation of this technology as proposed? Is it cost effective?**

Our research indicates that RCC technology can be incorporated cost effectively. In a large apartment prototype the incremental cost to replace electric hot water tanks with a central RCC hot water system is about \$677/unit. The savings from this alternative design are about 1,700 kWh/yr per unit with an expected measure life of 15 years. This represents a simple payback of about 4.4 years at a retail electricity cost of \$0.09/kWh.

Additional major conclusions from the study are:

1. The most effective RCC application is installation in below grade parking garages for production of domestic hot water (DHW) and tempering of corridor pressurization air. Significant savings in energy can be expected in this scenario.
2. Addition of the hydronic space heating load may be possible as well, but efficiency and cost issues arise making it not cost effective.
3. RCCs can be placed outside in ambient air for production of DHW, but only in milder West-side climates as a “hybrid” system with electric or gas back-up. This will yield high average annual energy efficiency but lower or zero peak demand benefit.
4. RCC technology can contribute significantly to garage ventilation energy use in small buildings (parking garages under 5,000 ft<sup>2</sup>), allowing for reduction or elimination of additional garage ventilation equipment. However, in larger buildings the RCC system will have minimal impact on the design of the garage ventilation system.

## Summary of Energy and Demand Savings

A sample cost benefit calculation for a mid-rise, 163-unit multifamily building is shown in **Table 1**. The results demonstrate an attractive 5-year simple payback for this DHW conservation measure. The calculation compares a base case of water heat supplied by individual electric water heaters located in the apartment units to a central water heating supply system provided by two 20-ton RCCs located in the below grade parking garage of the prototype apartment building located in Seattle. The assumed overall efficiency of the RCC system is conservatively estimated at a COP of 2.5.

Mid-Rise Prototype Multifamily Building <sup>2</sup>	
Number of Apartments	163
Area of project (ft <sup>2</sup> )	117, 500
Base Cost: Electric DHW Tanks in units (\$/unit)	\$500
Additional Central DHW Loop Cost (\$/ft <sup>2</sup> )	\$0.73
Cost of Two 20-ton RCCs	\$72,000
Installation Cost for RCCs	\$10,000
Cost of Storage Tank/Pump/Valves	\$8,000
Cost of Additional Engineering	\$16,000
Total Incremental Cost	\$110,275
Total Incremental Cost per Apartment	\$677
Baseline DHW Electric Use (kWh/unit)	2,700
HPWH Electric Use (kWh/unit)	1,000
Electric savings (kWh/unit)	1,700
Simple Payback	4.4 years
Measure life	15 years

**Table 1: RCC Energy and Demand Savings**

## Key Findings

At least three equipment manufacturers in the US produce RCC equipment that is well-suited to provide domestic hot water for multifamily buildings in the Pacific Northwest at efficiencies of approximately 250-300%. This technology has not entered the northwest market for two main reasons:

1. RCC technology has primarily been developed and marketed to fill a different market centered on cooling requirements rather than water heating.
2. Manufacturers have not marketed heavily in heating climates due to performance limitations of their equipment at wet bulb temperatures below about 40°F, and associated complications in controls for their equipment.

Rising energy costs and increasing market pressure for energy efficiency have influenced the first issue above. This has raised the importance of addressing multifamily hot water energy use to the point where the economics are more favorable. This study proposes an innovative approach to installation of RCC equipment using below grade parking garages to buffer extreme low temperatures, thus addressing the second issue noted above. By buffering the temperatures seen by the equipment, we can eliminate the extreme cold temperatures where this equipment has difficulty functioning.

<sup>2</sup> Based on building designed in Seattle. Five wood framed floors over one retail floor over two levels of below grade parking.

# Project Background

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## Overview: A History of the “Problem”

Regional energy codes have been very successful at reducing space heating energy use in multifamily buildings. New lighting technologies and programs have emerged and are having a considerable impact on lighting energy use. Technological improvements and the Energy Star program have led to reductions in energy use from major appliances. As a result, domestic hot water production remains one of the largest loads in multifamily buildings (with the exception of miscellaneous plug loads, which have increased and are extremely difficult to regulate). DHW production remains as one of the largest energy use categories primarily due to the prevalence of inexpensive electric water heaters.

Electric water heater efficiency requirements are already at over 90% efficiency, so there is not much room left to improve this equipment. The only options for significant DHW energy use reductions are:

- ◆ Reducing water use
- ◆ Waste water heat recovery
- ◆ Solar water heating
- ◆ Use of more efficient heat pump technology

This study examines the last of these four options. Heat pump technology shows great promise for significantly reducing space and water heating energy costs. Rather than creating heat by burning fossil fuels or using electric resistance, heat pumps use an electrically-driven refrigeration cycle to *move* heat from one location to another. In the case of Heat Pump Water Heaters (HPWH), the heat pump is moving heat from ambient air and putting it into the domestic hot water. These systems can function at an effective efficiency of 250-300%. Larger commercial HPWH technology has generally been referred to as Reverse Cycle Chillers since they resemble water chillers that are run in the opposite direction to produce warm water rather than chilled water. If this Emerging Energy Efficient Technology research project is successful, it could open a new market for the Reverse Cycle Chiller (RCC) products in this region.

The overall market potential for this innovation is unclear. It has the most straightforward application in new construction of mid and high rise multifamily buildings. Much of this development has stalled following the banking system collapse of 2008, however eventually we expect to see more development of this type of housing in the region. These are most common in the dense urban areas such as Portland, Tacoma, Bellevue, and Seattle, although they become more common as land use patterns change to increase density around smaller second-tier urban centers such as Burien, Everett, Salem, and Eugene. This will have the potential of developing significant energy savings in the multifamily building sector in the Pacific Northwest.

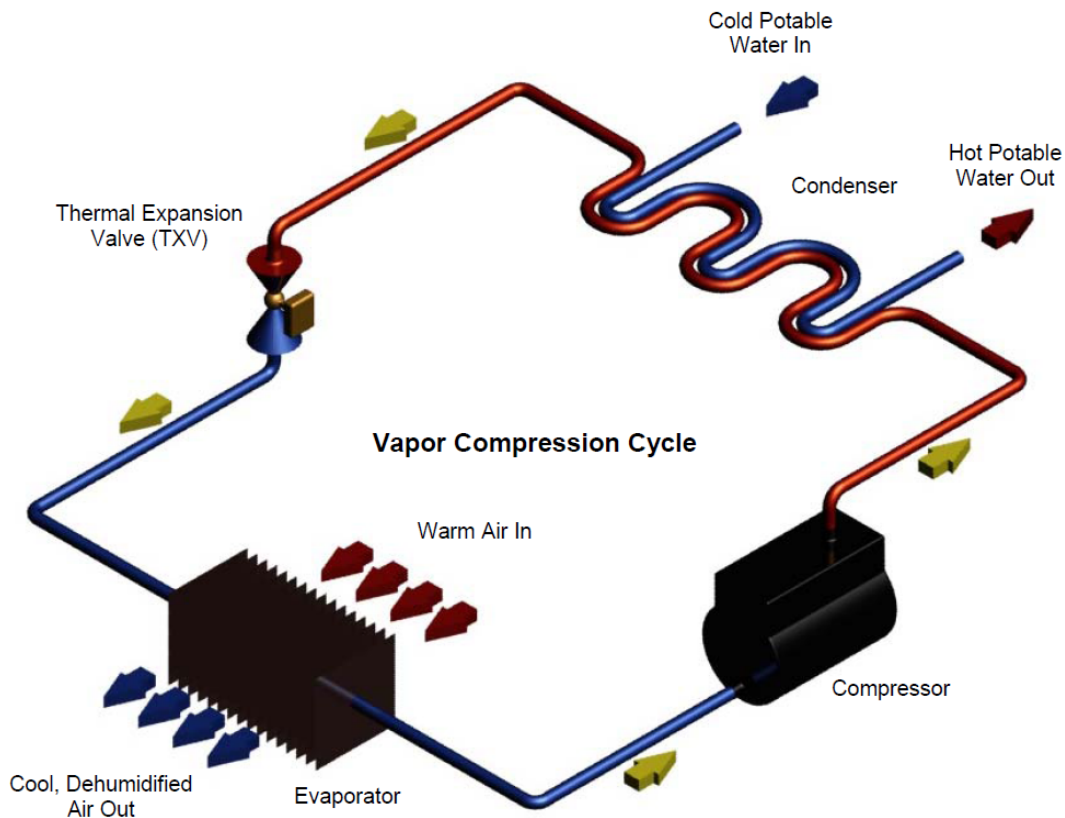
## Technology Overview

Ecotope has developed a design for the use of large central RCCs for production of domestic hot water in multifamily residential projects. This design application has the potential to save a significant amount of energy, and is particularly applicable to dense multifamily developments common in urban centers such as Seattle, Portland, Bellevue, and Tacoma. The investigation was taken further to research the possible use of this same technology to supply heat for corridor pressurization air tempering and for hydronic space heating in the apartments themselves.



The design concept involves heating water from a bank of RCCs located in a partially below grade parking garage of a multifamily building. The RCCs will use exhaust air from the parking garage as the heat source. By using the garage exhaust air, the RCCs effectively recover heat from the lights, the warm vehicles parked in the garage each evening, from the idling vehicles as they are driven into and out of the garage, and (most importantly) from ground contact. The large amount of concrete surface area in ground contact effectively buffers the extreme low temperature conditions that an RCC located outside would experience. Therefore the capacity and efficiency of the heat pumps stay in a more advantageous range. Ecotope theorizes that the buffered temperature regime seen in below grade parking garages of this type can eliminate (or nearly eliminate) the need for back-up electric resistance heating of the domestic hot water system.

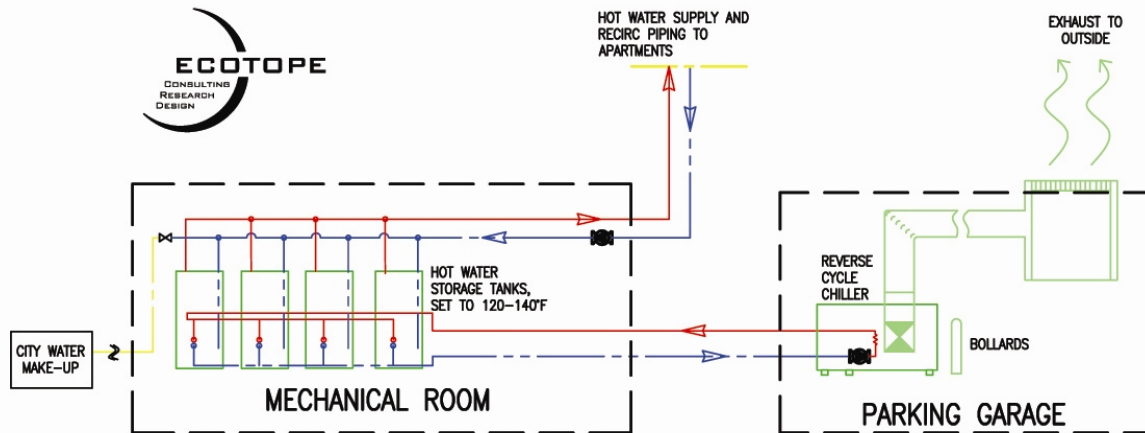
The basic configuration and operation of the equipment is shown in **Figure 1**. The RCC is a water heater which uses a refrigeration cycle with an air-side evaporator and a water-side condenser. The evaporator fan within the RCC blows tempered garage air over the refrigerant coils, this thermal energy combined with the compressor input energy boils the refrigerant. The superheated refrigerant enters the water cooled condenser where the refrigerant changes phase back to a liquid and subsequently releases thermal energy into the cold city water. This incoming water is fed into a storage tank to be used for domestic hot water and/or process heating water. All of this equipment is typically housed in a metal enclosure that is hung from the structure or (more commonly) resting on a concrete base.



**Figure 1: Basic Schematic of Reverse Cycle Chiller (Heat Pump Water Heater)**

(Source: Colmac)

In Ecotope’s design application, the RCC takes relatively warm air from the parking garage into the evaporator and exhausts cold air to the outside. The RCC will be controlled to maintain a series of domestic hot water tanks at about 120-140°F, as shown in **Figure 2**.



**Figure 2: Basic Schematic of RCC Below Grade Parking Garage Installation**

Source: Ecotope

### Available Products

Ecotope conducted a literature review, researched the internet, and surveyed HVAC equipment distributors to locate several manufacturers of reverse cycle chillers. Six manufacturers were identified with this type of equipment available for sale in the US. Following an extensive review of company product literature, telephone interviews were completed with product engineers at each RCC manufacturer identified. The manufacturers included:

- ◆ Colmac Coil
- ◆ eTech
- ◆ Heat Harvester
- ◆ MultiAqua
- ◆ MultiStack

The sixth manufacturer, Aqua Products, was taken out of consideration as their product is not capable of achieving adequate water temperatures for domestic hot water production and is not suited to installation in a parking garage. As a result of the interviews, three product lines stood out as being well-suited to a below grade parking garage application: Colmac, eTech, and Heat Harvester.

Although RCCs have been on the market for decades, there are no products currently being marketed for filling the multifamily DHW production niche in the Pacific Northwest. Mostly, RCCs have been marketed for applications where cooling is required and production of hot water is seen as an added benefit. This has mostly included industrial applications that have both a cooling load and a significant hot water load such as commercial laundries, kitchens, food processing, and hotel resorts. Currently RCCs are sold primarily in warmer climates around Asia, the Pacific Islands (including Hawaii), and the Southern United States. None of the product manufacturers identified have penetrated markets in colder climates where temperatures drop below 40°F for any significant amount of time. This is mainly

due to the added complications associated with defrost cycling. One manufacturer (eTech) noted that in the last few months they have begun to seriously look at breaking into this emerging market and are conducting research into modifications to their products that would make this easier.

All of the manufacturers identified are relatively small operations producing specialty products for small niche markets. However, AO Smith, one of the largest residential and commercial manufacturers of water heaters in the world, recently purchased eTech (April 2009). This happened shortly after both GE and Rheem announced their development of residential heat pump water heaters. It appears that this technology may finally be getting attention from industry to the point where viable products could be mass produced, marketed, and supported.

The following sections discuss the various features of the products currently on the market that affect their applicability to our Pacific Northwest target market.

### **Capacity Range Available**

RCC equipment is available in nominal 4-133 tons unit sizes. The three manufacturers of equipment most suited to this application (Colmac, e-Tech, and Heat Harvester) all offer a small unit in the range of 4-tons and a full range of standard units up to about 40-50 tons. They all also offer custom larger units if requested. The other two manufacturers have limited sizes available but are designed to stage in multiple smaller units to meet larger loads. MultiAqua has only 5-ton units and MultiStack offers any number of modules of 10-ton units but can also offer a custom 5-ton single phase unit if necessary. Standard models can be expected to have an 8-10 week lead time.

### **Electrical Requirements**

All manufacturers offer a single phase option for the smallest units (4-5-tons), however all of the larger units require 3-phase power (208 or 480 Volt). Most larger apartment buildings which would have a below grade parking garage or where central systems would be appropriate already require 3-phase power for elevators.

### **Refrigerant**

All of these products have been developed around the use of R-22 refrigerant. The Montreal Protocol mandates the phasing out of R-22 in new equipment by January 2010. Alternate refrigerants used in RCCs include R-407c, R-410a, and R-134a. R-134a is best suited to production of domestic hot water as the refrigeration systems using this refrigerant can produce water at higher temperatures than R-407c or R-410a. The three manufacturers noted above offer units with R-134a as the standard refrigerant. The other manufacturers equipment is mostly moving to the use of R-407c.

### **Fans**

Many of these RCC units are designed with axial upblast type fans for the evaporators common in air cooled HVAC equipment where the unit is designed to exhaust air into the surrounding area at very low pressure drop. However, for these units to be used effectively in a parking garage they must be capable of exhausting air ducted from the unit to the outside of the building. If the air were to be discharged into the parking garage, the surrounding air would quickly become too cold for the units to function. Colmac, eTech, and Heat Harvester RCCs all have options for higher head centrifugal fans designed to incorporate ducting. These could all incorporate fans with at least 1" of external static pressure. The MultiAqua and MultiStack units are not designed to incorporate ductwork. Multistack can offer a high

static fan, but their dual-fan design makes it difficult to prevent back drafting when only a single compressor is functioning. It should be noted that the ducting should be designed with as low pressure drop as possible since any fan energy used to move air reduces the overall efficiency of the system.

### **Performance Ratings**

There are currently no established performance rating standards for this type of equipment. ASHRAE has convened a committee to produce test procedures for a standardized rating, but this will likely take until at least 2011 to complete. The efficiency ratings reported by manufacturers are generally for the compressor system only and are at generally advantageous entering air and water temperatures. To get a true COP estimate for this equipment at any given rating point, the power of the fan and pump must be included in the overall energy use of the RCC. This auxiliary energy for fan and pumping will reduce the overall efficiency by approximately 5-10%.<sup>3</sup>

### **Potable Water Application**

The three most applicable products all include a double walled heat exchanger rated for potable water as a standard option. The other products are not designed to produce potable hot water and would require an additional heat exchanger to be installed outboard of the unit, or as a custom modification to the unit.

### **Defrost Controls**

None of the manufacturers have standard packages for defrost controls, but all offer various methods for integrating this function into the RCC unit. This is due to the fact that their primary market has been in warmer climates and that defrost controls complicate the design of the systems. All defrost control options are treated as custom features and manufacturers can offer a variety of approaches (see Performance Limitations section).

## **Prototype Development**

A prototype analysis was used to examine the applicability of RCC technology in the Seattle area. Two RCC system prototypes were evaluated based on two actual multifamily projects for which Ecotope is currently consulting.

1. A 12-unit 12,000 ft<sup>2</sup> building planned for the Magnolia neighborhood. The project consists of three stories of wood framed construction over a single level of below grade parking of about 5,000 ft<sup>2</sup>. The building includes 1 and 2-bedroom apartments surrounding a central corridor and elevator lobby on each floor. The original design included electric resistance space heating, individual electric hot water heaters located in closets in the units, and a corridor make-up air unit supplying electrically heated ventilation/pressurization air. The proposed design uses a single 12-ton RCC to exhaust the parking garage and supply DHW. Ecotope also examined the feasibility to extend the RCC system to supply apartment space heating and tempering for the corridor air.

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<sup>3</sup> Note that to get an overall efficiency rating for the hot water delivery system we must include the losses associated with the storage, distribution, and recirculation system and any auxiliary heating.

2. A 163-unit 177,500 ft<sup>2</sup> building planned for the Ballard neighborhood. The project consists of two separate above grade wood-framed towers built on a concrete slab over a ground floor level of retail and two levels of below grade parking. The building includes studio, 1, and 2-bedroom units around a central double-loaded corridor. The base design is all-electric space heat with electric water heaters in each unit. The proposed design is electric heat in the apartments and two 20-ton RCCs located in the 47,000 ft<sup>2</sup> parking garage.

## Past or Current Competitive Solutions

Heat pump technology has not made a significant entry into the multifamily hot water market in the Pacific Northwest. There are indications that the newer ductless mini-split systems may gain some of the space heating market share in the future. A few buildings currently use air-source heat pumps for their corridor pressurization air tempering. Increasingly, ground source heat pumps (GSHP) have been used in the region in custom residential projects for space heating as well as domestic hot water heating, but the cost implications of GSHP technology makes it unlikely to ever take a significant portion of the multifamily market. As a result, there are no other currently viable heat pump technology options for domestic water heating in multifamily buildings.

There has been regional interest in residential and commercial Heat Pump Water Heaters (HPWH) for years<sup>4</sup>, but no one has been able to make significant entry into this regional market. DEC was marketing the ThermaStor product in the 1990s as an exhaust air heat pump water heater and was evaluated as part of a BPA multifamily ventilation study (Heller 1992). They were conceived as combination ventilation systems and water heaters whereby the exhaust air from the apartments was used as the source air for the heat pump water heater. DEC experienced some reliability problems and the market was never large enough for them to sell a profitable product. This product is no longer marketed.

There are a few residential HPWHs at various stages of market readiness including Steibel Eltron, Geyser, eTech, Trevor-Martin, and Airstack. None of these HPWH products would be easy to adapt to the multifamily market as they are relatively noisy, require relatively large airflows, and with the exception of the DEC and Trevor-Martin units, are not set up to exhaust to the outside of the building. GE and Rheem both claim to be working on residential HPWH models, but they have yet to be released and will likely have the same limitations in regards to ducting, airflow, and noise.

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<sup>4</sup> 2003 WSU Energy Extension Service Energy Fact Sheet *Heat Pump Water Heaters – Commercial* notes that the technology had been around for over 20-years and showed promise at that time.

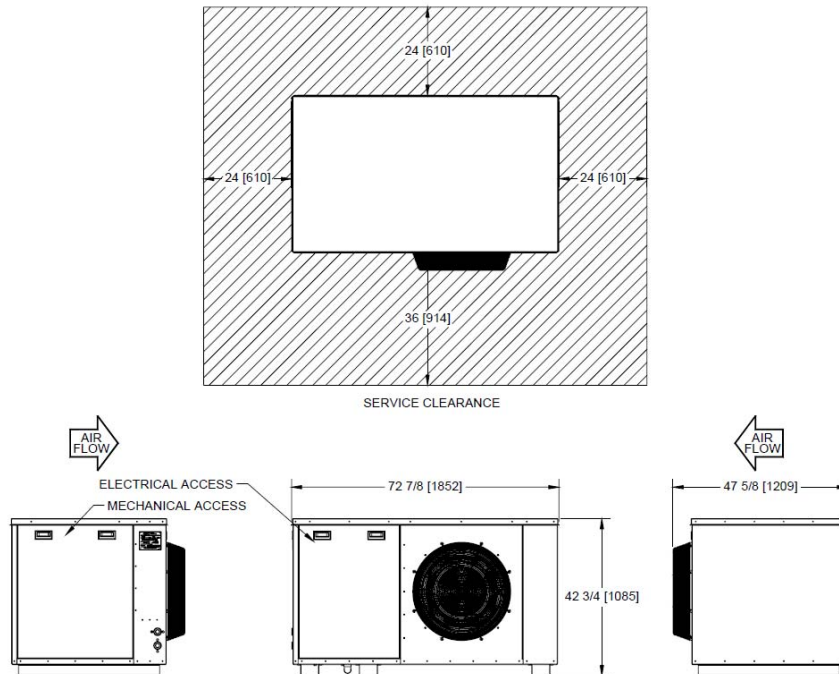
# Potential Barriers

## Physical Constraints

The installation of the RCC unit itself presents some physical design challenges including:

- ◆ Providing for adequate clearances and service access
- ◆ Ensuring adequate airflow
- ◆ Providing clean intake air
- ◆ Controlling noise
- ◆ Ensuring freeze protection
- ◆ Providing proper power supply

Incorporation of an RCC system into a project implies the location of a large new piece of equipment. This can present an architectural barrier in tight urban footprints that are already optimized for the minimum number of parking spaces and the maximum amount of leasable space. The RCC units are approximately 4’x4’x6’-8’ and are located on the floor of the parking garage. They weigh approximately 1,500 lbs each. Ideally, they will be located on the lowest level of the garage as far as possible from the garage entrance. They will have ducting connected to the fan outlet that must be routed to the outside at a location 10 feet away from any opening into the building and where it does not create a nuisance. In general it can be assumed that this system will take up approximately one parking space. If possible, it is best to integrate the equipment in the early design phases of a project. The image in **Figure 3** shows a typical RCC unit with dimensions of recommended service clearances.



**Figure 3: RCC Clearances**

Source: Colmac

If the RCC unit is installed on the roof, additional structural considerations will have to be made. If installed in a parking garage, adequate space must be allocated as mentioned above.

The RCC unit will move approximately 8,000 cfm of air when operating. This air must be filtered before entering the RCC and must be discharged to the outside of the building. If the air is not filtered, the coil will get dirty and the performance of the unit will suffer. Significant coil maintenance would need to be scheduled several times a year (otherwise filter maintenance would be required on a similar schedule). If the air is not discharged to the outside then the temperature of the space where the unit is installed (parking garage or mechanical space) will drop quickly and the unit will cease to function.<sup>5</sup>

Acoustics can be an issue if the units discharge to a sensitive area. The compressors are generally enclosed inside the sound-lined cabinet, so the loudest part of the system is the fan. If the airstream is ducted, sound lining can be designed into the ductwork to absorb noise before the air is discharged outside.

The size of the compressors needed for an apartment building generally require 3-phase power. This can be a potential problem in small projects where there is no other equipment requiring 3-phase electrical service. However any project requiring an elevator will already likely have 3-phase power available, so this may not be an issue for multifamily buildings. For projects where 3-phase power is not available, or would have a significant cost impact, most manufacturers can provide smaller single phase equipment.

Another design consideration is freeze protection. If the device is located in an area where it is possible to see any prolonged periods of freezing temperatures, then some measures must be employed to protect the piping and equipment in the event of simultaneous cold weather and power outage. This will generally be achieved through use of glycol and an additional heat exchanger between the glycol and potable water.

## Code Barriers

This section of the report examines potential barriers associated with building codes or engineering guidelines. Below is a discussion of each potential barrier along with a reference to the code or guideline discussed. All of these barriers can be overcome with proper design of these systems.

1. **Potable Water Requirements:** Heat pumps are not generally rated for potable water production. Only certain materials may come into contact with potable water and the potable water stream must be protected from non-potable water systems.

Heat Exchangers must be used to separate potable water from non-potable heat pump loops. Double wall heat exchangers can be used for this purpose or single walled heat exchangers can be used as long as the non-potable source is non-toxic and at a lower pressure than the potable water system. Most of the RCC manufacturers surveyed offer double walled heat exchangers as either standard equipment or as an option with their products.

- ◆ UPL Section 603.4.4: Single wall heat exchangers must meet requirements of Section 506.4.2
- ◆ Section 506.4.2 requires the heat transfer medium to be non-toxic and limited to 30 PSIA. Also requires a “caution” label attached with the above info.

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<sup>5</sup> An exception is if the RCC unit is located in a space with a large amount of waste heat such as a server room. It may be possible to use the RCC as a heat recovery device and provide free cooling to the server room.

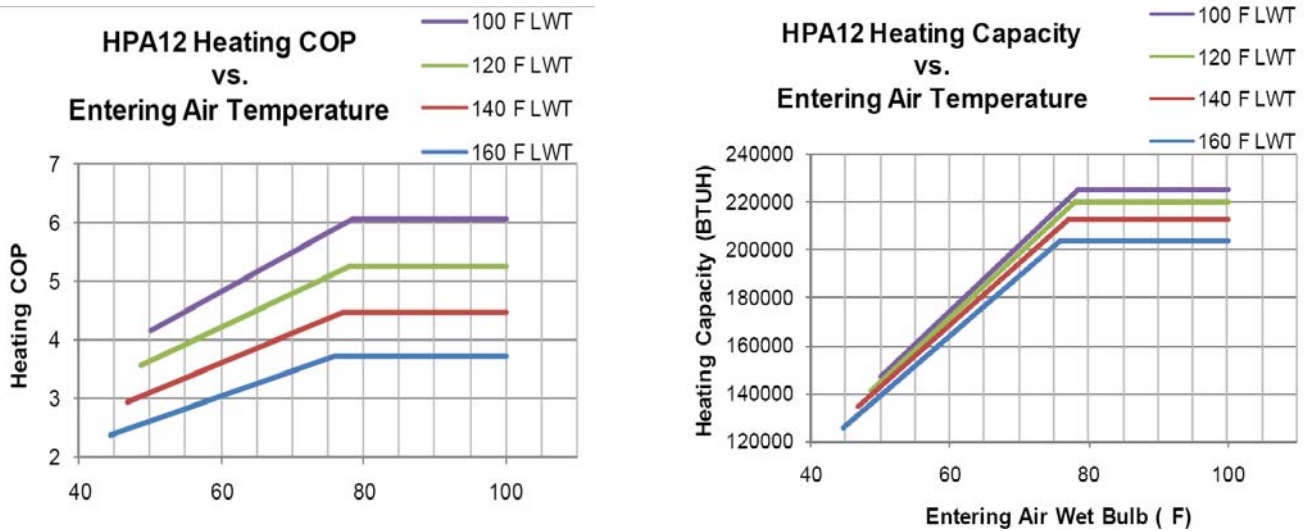
- ◆ Heat exchangers and piping that meet potable standards are readily available.
  - ◆ UPC section 604 lists materials that are acceptable for potable water in Table 6-4.
2. **Legionnaires Disease:** There are some industry concerns that warm stagnant water can harbor Legionnaires Disease. Heat pump systems are at more risk than natural gas or electric systems since they cannot produce high temperature water. Research indicates that Legionella can live in stagnant water up to 115°F. ASHRAE guidelines recommend that domestic water be heated to 140°F. However, Washington State Energy Code specifies that water heaters shall be set to maintain water at 120°F. To prevent conditions that will harbor Legionella heat pump systems can be designed to circulate water and to heat water to a minimum of 120°F. Most manufacturers' equipment can maintain water at 140°F.
- ◆ ASHRAE Applications Book Chapter 49: Legionella can colonize in stagnant water at 115°F. Recommends design of 140°F to prevent growth.
  - ◆ Washington State Energy Code Section 504.3 overrides ASHRAE; requires hot water temperature set at 120°F.
3. **Ignition Sources in Parking Garage:** Explosive gasoline fumes can be present in parking garages. Ignition sources must be elevated 18" off the floor. This requirement appears to be directed at appliances which produce open flames and does not appear to cover heat pump equipment. If ignition potential were to become an issue with code officials it might be necessary to raise the unit off the floor with a rack system. Heat pump units for space heating and cooling of ground floor commercial spaces are routinely installed in below grade parking garages.
- ◆ IMC Section 304.3 requires equipment with an ignition source to be at least 18" above the floor.
  - ◆ UPC Section 508.14 also requires an 18" separation, but only for gas water heaters.
4. **Garage Ventilation:** Parking garages must be ventilated by code. Since the RCC system acts as an exhaust fan for the garage, it could ideally reduce the need for another garage exhaust fan. Codes allow for intermittent ventilation if controlled to detect carbon monoxide (CO). Code also requires a minimum level of ventilation at all times. Most RCC manufacturers indicated that their equipment could be made to operate in fan-only mode on a call for ventilation from a CO sensor.
- ◆ IMC Section 404:
    - a. 404.1 states fans can run intermittently upon detection of vehicles or occupancy
    - b. 404.2 states garage ventilation system must be capable of 1½ cfm per ft<sup>2</sup> and cannot go below 0.05 cfm per ft<sup>2</sup> with automatic controls
    - c. Seattle Mechanical Code reduces required capacity to 1 cfm/ ft<sup>2</sup>.
5. **Exhaust Clearance:** Parking garages may not exhaust too close to lot lines or openings into buildings. Early design integration is critical to find an optimal location for exhaust. This can be the same location that would be needed with a standard garage exhaust system.
- ◆ IMC Section 401.4: Intake or exhausts minimum 10 feet from lot line or opening of building



6. **Water Tank Ratings:** Hot water storage tanks must be rated if they get too big. This issue would be encountered with any central water heating system. Multiple smaller tanks can be used to avoid required rated tanks.
  - ◆ RCW 70.79.090 (5) states that hot water tanks larger than 120 gallons must be listed by a nationally recognized testing agency and approved by the boiler inspector
  - ◆ RCW 70.79.080 (7) exempts domestic hot water tanks from the boiler and pressure vessel code
  
7. **Refrigerants:** R-22 refrigerants will be banned starting in 2010. Most heat pump products are making or have made the transition to the new refrigerants (R-407c, R-410a, or R-134a).
  - ◆ Montreal Protocol: R-22 can no longer be sold for use in new equipment starting in January 2010.

### Performance Limitations

There are two critical metrics that govern output and efficiency of RCC systems in our proposed multifamily application: leaving water temperature and incoming wet bulb air temperature. The higher the leaving water temperature, the lower the output and efficiency. The lower the incoming air wet bulb temperature, the lower the output and efficiency. **Figure 4** below shows typical performance curves of one RCC product for a range of leaving water temperatures.



**Figure 4: RCC Performance Charts**

Source: Colmac

To supply domestic hot water from a central plant in a multifamily building the system must be able to maintain a storage tank temperature of at least 120-140°F. If the water temperature drops below about 120°F in the storage tank, there will likely be complaints by occupants of insufficient hot water in their units. Therefore, the RCC must output water at least about 130°F. Some RCC products are better than others at delivering hot water at low ambient air temperatures. The refrigerant used makes a difference

as some refrigerants are better suited to higher condensing temperatures than others. R-134a for example works better than R-410a for higher water temperatures.

Flow control through the RCC also makes a difference in the temperature output of the system. Some manufacturers use a modulating valve to govern the flow of water across the condenser to achieve a constant water temperature regardless of the incoming air temperature. Other manufacturers use constant speed pumping so that the output water temperature varies depending on the incoming air temperature. Problems of low leaving water temperatures can occur at low ambient air temperatures requiring electric back-up heat. One manufacturer has indicated that they are experimenting with variable speed pumping which will give them the option to control leaving water temperature while optimizing pumping efficiency.

### **Entering Air Temperature**

RCC technology has performance limitations related to the incoming air temperature and humidity. In general, manufacturers rate their equipment based on the entering wet bulb temperature rather than dry bulb temperature. This is due to the fact that a large portion of the energy that the RCC extracts from the air is associated with condensing the available water vapor in the air. Therefore RCC equipment works better in relatively humid environments. As the outdoor air temperature drops, the ability of the air to carry moisture also decreases which affects the efficiency and output capacity of the equipment (see Figure 4 above). Wet bulb temperature is related to the amount of water carried by the airstream. For this reason RCC technology works much better in warmer and moister climates. This will favor applications on the West side of the Cascade mountains in the Pacific Northwest.

### **Defrost**

One serious limitation to the performance of RCC equipment in cold climates is related to icing of the coils. The evaporator coils can operate at temperatures below the freezing point of water, so as the incoming air temperature drops and incoming relative humidity levels go up, ice can begin to form on the coils. In the Pacific Northwest climate icing can begin to happen at ambient temperatures below about 50°F.

Frost buildup is a common problem for all types of refrigeration cycles. There are various methods used for defrosting coils. These methods can impact both the output capacity and the efficiency of the system.

1. **Fan Cycling:** One simple low energy method used to defrost the coils is to shut off the compressor and run the fan only to melt the ice off of the coils. This will only work if the incoming air is above freezing and can take a relatively long period of time to accomplish the

defrost.<sup>6</sup> During this defrost time there is no output from the RCC and back-up electric heat may be required in the hot water storage tanks to maintain hot water supply.

2. **Reversing Valve:** The heat pump cycle is reversed so that the evaporator coil becomes the hot condenser coil for a period of time long enough to melt the ice formed. This method has the advantage of being relatively quick, but it significantly affects the heating potential and efficiency of the system because for a short period of time the equipment is chilling the water and heating the air rather than the other way around.
3. **Electric Back-up:** Electric heat (or hot water) can be used to melt ice off of the coils or to prevent the ice from forming in the first place. One method that significantly simplifies controls and does not reduce the output capacity of the system is to preheat the air to the point where defrost is not necessary. This implies the use of a heater at the intake to the RCC to guarantee that the air never drops below 40°F. Output capacity does not drop, but the overall efficiency of the system goes down related to the electricity used for heating of the incoming air. Also note that this significantly impacts the peak power draw of the system.

Each of these methods further complicates the controls of the system since there must be a way to determine when defrost is necessary and how long to run in defrost mode. RCC manufacturers have typically provided only a single timed setting for defrost based on the temperature of the incoming air (e.g. 10 minutes per hour of run time if ambient temperature drops below 40°F). However, to achieve optimal performance the system should only enter defrost mode after ice has formed on the coils and is significantly affecting performance. The system should only stay in defrost mode long enough to drop the ice from the coils. To do this requires more sophisticated, expensive, and error-prone sensors and controls.

There are various methods to sense defrost conditions and all have been used by product manufacturers with varying levels of success, cost, and efficiency. The simplest method is a single air temperature measurement; when incoming air drops below a certain temperature, initiate a defrost cycle. This can be paired with a temperature sensor on the evaporator coil that can indicate the presence of ice-forming conditions. Pressure sensors across the coil have been used to indicate a coil that is restricted due to ice formation (a dirty coil can give a false positive reading). Refrigeration pressure measurements can be used with some accuracy based on condensing and evaporating pressures. A sample of defrost controls using a printed circuit board from one of the manufacturers is excerpted below:

#### ***Defrost Initiation***

*A defrost will be initiated when the three conditions below are satisfied:*

- 1) The outdoor coil temperature is below 35°F.*
- 2) The compressor has operated for at least 3 minutes with the outdoor coil temperature below 35°F.*
- 3) The measured difference between the ambient temperature and the outdoor coil temperature is greater than the calculated delta T (temperature difference).*

*Additionally, a defrost will be initiated if six hours of accumulated compressor run-time has elapsed without defrost, and the outdoor coil temperature is below 35°F.*

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<sup>6</sup> Fan only defrost can also work with relatively dry air below freezing, but it takes a longer period of time to dry the coils.

**Defrost Termination**

*Once defrost is initiated, the defrost will continue until fourteen minutes has elapsed or the coil temperature has reached the terminate temperature. The terminate temperature is factory set at 70°F although the temperature can be changed to 50°F, 60°F, 70°F, or 80°F*

**Metering**

Another potential market barrier to RCCs in some multifamily buildings is associated with metering of domestic hot water usage. One benefit of individual electric tanks in each unit is that the energy associated with hot water usage is directly metered and billed to each tenant. When individual tanks are replaced with a central water heating system, it becomes much more difficult to separately allocate all of the water heating energy based on usage. It is possible to submeter water usage in apartments through the use of water flow meters, but this adds significantly to the cost of the project.<sup>7</sup> Most apartment developers will simply estimate the cost of the water heating energy and add it to the rental fee. However, in terms of marketing, this makes their rent sound more expensive than a competitor's building, which may not include hot water. Some developers of condominiums worry that not having the ability to submeter hot water can lead to conflicts within the Home Owners Association (HOA) in that some members may accuse others of using too much hot water and not paying their share. The RCC system reduces many of these concerns since the average resulting hot water bill is relatively small (about \$5-\$10/month per apartment).

**Human Factors: System Designer, Installer, and/or Customer Feedback**

Human factors present a barrier to rapid widespread adoption of this technology in multifamily buildings. This issue primarily centers on the fact that this is a new application that few in the region are familiar with. Designers, installers, and developers are all historically reluctant to be the first to try to incorporate new technologies into their projects. One major advantage to individual electric water heaters in apartment units is that they are extremely simple and well-understood technology.

Occupants understand how individual hot water heaters work. They understand that their tank has limitations and if they use too much hot water they may run out temporarily. An insignificant level of maintenance is typically required until the tank needs to be replaced. The cost and time associated with replacement is relatively small. There is generally no need for engineering associated with the design of these systems. Each apartment is provided with a tank size based on the expected occupancy of that apartment. The tank is installed and plumbed to the fixtures by any minimally trained plumber with no specialized knowledge or skills required. There is a wide variety of different products to choose from on the market and they are all essentially interchangeable and very readily available. This is the epitome of a "Plug and Play" technology.

Currently available RCC equipment could not be considered a "Plug and Play" technology. With an RCC system the occupants will not generally understand how the system works. If they run out of hot water their only recourse is to call the apartment manager or the HOA. An RCC system will require regular service by a trained service technician with specific knowledge, tools, training, and experience with

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<sup>7</sup> The company *ISTA* (formerly *Viterra*) sells this type of submetering service for approximately \$500 per unit and will even collect data and send out bills to individual occupants for projects with more than 20 apartments. They include a billing fee of about \$3-5/month per bill.

refrigeration equipment. If there is an equipment failure there are limited parts and distribution channels for replacements and some major repairs may take several days. The system will have to be designed by a qualified mechanical engineer. It will have to be integrated into the architectural design of the building, and it will have to be installed by a trained specialist. All of this significantly increases the complexity of the hot water heating system.

### **Billing**

The principal-agent barrier can impact the success of energy efficiency efforts in multifamily projects. When the developer is not the same person that will pay the energy bills, there is a built-in incentive to keep capital costs low and to add as much load as possible onto the individual residential electric meters so that the direct energy costs are paid by the occupants. The simplest method to accomplish this is to provide electric resistance heating and hot water in the units fed from the unit's electrical panels. There is some incentive to invest more money in higher quality systems in the case of condominiums, but it is still rare for the people who end up paying the energy bills to have any input into system selection. This divide between the interests of the developer and the interests of the occupant make investment in energy efficiency in multifamily buildings difficult.

### **LEED®**

The current public focus on green buildings and energy efficiency may provide more of an opening for this type of innovative design solution. The US Green Building Council's LEED® rating system also provides some incentive to look for innovative ways to save energy in multifamily buildings. The Seattle multifamily market is so competitive that many developers see a LEED® certification as almost essential to get their project full of occupants quickly after completion. The LEED® rating system requires energy savings in relation to ASHRAE 90.1 design guidelines using Appendix G modeling baselines which assume packaged single zone heat pump systems in the base case. This means that if a project intends to use electric resistance for space heating, it is extremely difficult to show energy savings in comparison to the base case building that assumes heat pumps. Domestic hot water is one of the few significant loads that can be addressed, and an RCC system would be one relatively easy way to meet the requirements and earn points towards a certification.

# Discussion

## Incremental Costs (Materials and Installation)

The components and systems involved in installation of an RCC system are significantly more costly than the traditional electric resistance systems that can be replaced. However, in most instances it can be argued that the additional investment is cost effective from a life cycle perspective. **Table 2** below shows the design changes and associated costs for a prototype building in Seattle. The table below shows incremental cost estimates for replacing individual electric water tanks with a system based on the RCC equipment. This analysis is based on an actual 163-unit building designed for the Ballard neighborhood in Seattle. Cost data is taken from a variety of sources including a report that Ecotope produced for Puget Sound Energy, RS Means, equipment manufacturers, and engineering estimates.

Item	Value
Number of Apartments	163
Area of Project (ft <sup>2</sup> )	117,500
Cost of Electric tanks plus wiring and circuits <sup>A</sup> (per apt.)	(\$500)
Cost of Added Central Water Loop <sup>A</sup> (per ft <sup>2</sup> )	\$0.73
Cost of Two 20-ton RCCs <sup>B</sup>	\$72,000
Cost to Install RCCs <sup>C</sup>	\$10,000
Cost of Storage tank, Pump, & Valves <sup>C</sup>	\$8,000
Additional Engineering <sup>C</sup>	\$16,000
Total Incremental Cost, DHW Only	\$110,275
Total Normalized Cost (\$/Apartment)	\$677

- A. Based on RS Means cost data for prototype building (Heller 2005).
- B. Manufacturer’s budget estimate
- C. Engineering estimate - Ecotope.

**Table 2: RCC Incremental Costs**

There are a few items that have not been included in this economic analysis that may have an impact on the economics of the project. First is the elimination of the electric water heaters in the units which frees up closet space. This space is commercially valuable and potentially could be included in a cost-benefit analysis as 4 ft<sup>2</sup> of useable leasable space per apartment.

The fact that energy bills are significantly lower than a typical apartment is likely also a positive marketing point for the building that helps to offset the incremental cost of the RCC system. This may be difficult to quantify, but anecdotal evidence suggests that projects perceived to be “Green” are rented faster and for higher rental value than other similar projects (Miller 2008, Chae 1999).

The difficulty in separate metering may have a negative cost impact in some conditions. Individual electric equipment makes individual metering automatic. Once the hot water system becomes a central system it is much more difficult and costly to meter every apartment’s individual use and bill people per usage. Submetering costs have not been assumed in the above cost analysis.

## Savings

Domestic hot water usage was estimated based on submetered data from electric water heaters in manufactured homes (Roos and Baylon 1993). This data was updated based on current plumbing and appliance technology and calibrated against recent multifamily submetered data.<sup>8</sup> Usage estimates assumed an average of two people per apartment and 20% losses from an insulated recirculation loop (Goldner 1999).

Item	Value
Baseline DHW electric per apartment (kWh)	2,700
RCC electric usage (kWh)	1,000
Electric savings DHW (kWh)	1,700
Measure life	15 years
Simple Payback	4.4 years

**Table 3: RCC Energy Savings**

Demand savings will vary depending on the building size and equipment configuration. The overall connected load is significantly reduced compared to individual electric tanks, but the base case system is diversified into multiple 4.5 kW water heaters scattered throughout the building. These heaters cycle independently compared to a central system which comes on all at once. Conservatively we assume that at peak 20% of the water heaters are running simultaneously. Tables 4 and 5 detail the peak demand savings calculations for the large 163-unit prototype and the small 12-unit prototype. This analysis shows a significant reduction in peak demand for the RCC system compared to individual electric water heaters in the large building, but a negative savings in the smaller building. Note that this assumes no back-up electric heating is required in the storage tanks so the RCC units are not entering into defrost mode for any significant length of time.

Load Calculations	Electric Water Heaters	Reverse Cycle Chiller
Number of Water Heaters	163	2
System KW	4.5	21.5
Total Connected Load	734	43
Assumed diversity at Peak	20%	1
Peak Hot Water Demand (KW)	147	43
Savings		
Peak Load Savings (%)	-	71%
Peak Load Savings (KW/Unit)	-	0.6
Connected Load Reduction (%)	-	94%
Connected Load Reduction (KW/Unit)	-	4.2

**Table 4: Demand Savings Calculations for Large (163-unit) Prototype**

**Table 4** also shows a significant savings in connected load for the large prototype building. This could potentially translate into capital cost savings associated with smaller transformers and smaller distribution wiring in the building and apartments.

<sup>8</sup> Kateri Court in Bellingham, a 34-unit apartment building constructed 2007. LEED® Gold certified.

Load Calculations	Electric Water Heaters	Reverse Cycle Chiller
Number of Water Heaters	12	1
System KW	4.5	14.7
Total Connected Load	54	15
Assumed diversity at Peak	20%	1
Peak Hot Water Demand (KW)	11	15
Savings	-	-
Peak Load Savings (%)	-	-36%
Peak Load Savings (KW/Unit)	-	-0.3
Connected Load Reduction (%)	-	73%
Connected Load Reduction (KW/Unit)	-	3.3

**Table 5: Demand Savings Calculations for Small (12-unit) Prototype**

### Useful Life

Useful life for RCC equipment is difficult to assess. The manufacturers interviewed all claimed typical useful lives of at least 20 years. Some acknowledged that the compressors have a typical lifespan of about 15 years, but can be readily replaced. There are also some smaller parts that can be replaced if necessary without significant impact on the overall system. Some manufacturers noted that they had this type of equipment in service for upwards of 40 years in some cases. For the purpose of our calculations we assumed a typical measure life of 15 years.

While this could be considered added maintenance costs for the apartment owner, depending on the size of the project this could be a significant maintenance savings compared to individual water heaters in the apartments. These tanks have a relatively short design life, so in a 120-unit apartment building after about 5 years of service one could expect about one tank per month to fail for the next 10-years. When a tank fails the occupants will expect very fast replacement. Furthermore, some fraction of these tanks fail catastrophically. With 120 tanks of hot water scattered throughout the building it is likely that some fraction will fail and lead to flooding; resulting in costly material damage.

### Product Evaluation

During our product evaluation, three manufacturers were identified whose products show a great deal of promise for this application. The product lines are still relatively specialized and sold into a relatively small market. The basic products are simple and robust, using readily available parts and compressors. The products become more complicated and prone to failures as they are customized to add controls and sensors to accomplish defrost, fan controls, staging, alarms, and other added features. Therefore Ecotope recommends that where possible these additional items be avoided at this time until manufacturers offer a standardized package for options and appear prepared to stand behind their products with adequate support services.

One manufacturer, Colmac Coil is located in the Pacific Northwest and has been in business since 1971. They have a very simple product that appears robust and would be relatively easy to maintain and get back online given a failure. They have developed a method for maintaining constant water output temperatures by throttling water flow based on refrigerant head pressures. They also oversize their heat exchangers to enable higher output water temperatures.



Another manufacturer, eTech, was recently purchased by a large commercial and residential water heating company with a significant presence in China and the US (AO Smith). This indicates that they may be taking heat pump water heaters seriously and trying to expand their market share. The product development engineer interviewed indicated that they have begun a joint research effort with Copeland (makers of high efficiency scroll compressors) to develop an RCC specifically targeted for lower ambient temperatures. They expect preliminary research data back this October 2009. Having a larger company involved in the manufacture of these products may bring more resources to bear and enable faster market penetration. eTech has also been around since the 1970s making heat pump water heaters.

Also in business since the 1970s, Heat Harvester from Dallas, Texas provides a customizable product that appears very similar to the products offered by the other two companies mentioned. Interestingly, while eTech and Colmac mentioned each other as competitors in the interviews, neither of them mentioned Heat Harvester. Furthermore, when asked about competitors Heat Harvester said that they did not have any.

With three viable products available, contractors will have purchasing flexibility and more options in terms of delivery, pricing, and product support. Both Heat Harvester and Colmac are represented in the Pacific Northwest by the same equipment representative and distributor. eTech does not currently have a distributor in the region, but this may change soon due to the acquisition by AO Smith.

## Feasibility and Market Potential

Based on this research we are very optimistic in regards to the feasibility of this product in the Pacific Northwest multifamily market niche, and the potential for it to become a standard part of the market. The RCC products are available, the technology is mature and well tested, and the overall economics are impressive. The primary barrier may be convincing the developers that their investment in higher efficiency equipment will pay back in terms of quicker rental or sales rates or higher rents or prices.

Multifamily development has slowed considerably in the last year following the banking crisis. Many projects have been put on hold or are searching for financing. However, population and density pressures continue to rise and eventually market forces will once again drive more multifamily building construction. With adequate marketing and incentives, RCC systems could be in a position to be incorporated into the next wave of multifamily construction.

This is a more difficult system to retrofit into buildings unless the building already has a central gas or electric water heating system. Many of the Seattle Housing Authority buildings use electric central water heating systems that date from the early 70s. Although it would be relatively easy to switch to an RCC system, these buildings often do not have parking garages.<sup>9</sup>

## Garage Buffer Effect

RCC systems are much more prevalent in southern climates where the ambient air rarely drops below 40°F. They can be used outdoors without management of defrost cycles. In the Pacific Northwest, ambient winter temperatures are frequently in the range requiring defrost, so one of the methods noted earlier would have to be employed with a consequent impact on system capital cost, reliability,

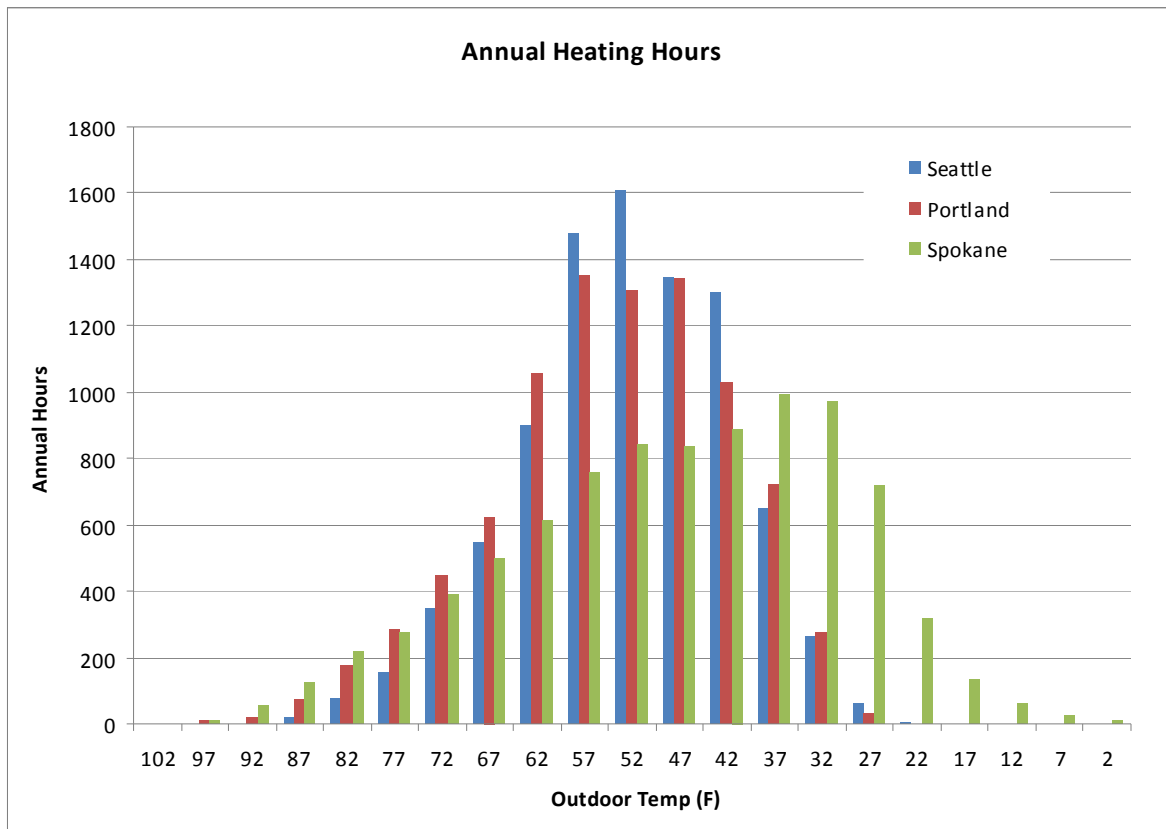
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<sup>9</sup> For example Beacon Tower and Olive Ridge projects in Seattle owned by the Seattle Housing Authority.

and performance. A question investigated by this research is whether it is feasible to operate an RCC system in the Pacific Northwest cost effectively given the colder temperatures experienced here. One possibility is that an RCC system installed in ambient air in the Pacific Northwest could be considered a hybrid system in conjunction with electric resistance or gas back-up. This concept is similar to a hybrid automobile in that during most of the year it operates on the RCC system with extremely high efficiencies, but for part of the year it relies on electric resistance or gas heat to back-up the system. The following sections examine the pros and cons for such an approach.

**RCCs in Ambient Conditions**

Below is a chart that shows the ambient temperature profile for three northwest cities: Seattle, Portland, and Spokane. As Figure 5 shows, for cities on the west side of the Cascade Mountains such as Portland and Seattle, there are relatively few hours each year where temperatures fall below freezing.



**Figure 5:** Annual Heating Hours for Three Northwest Cities

Performance data was evaluated for the Colmac RCC model HPA12. The output from this device producing 140°F water with 40°F Wet Bulb air is about 120,000 Btu/hr at a compressor system COP of about 2.4. With penalties taking into account the fan and pump energy, the system COP is approximately 2.1. It is assumed that this heat output remains relatively constant when electric heat is used to maintain a 40°F entering airstream during cold conditions. To get an estimate of performance during defrost we therefore add the energy input for the electric heaters to the energy input for the RCC to determine a total effective system COP for the RCC/electric hybrid system. We then take a weighted average of the COP in the various temperature bins to determine an effective annual COP.

The effective COP during freezing weather is low and even drops below 1.0 at temperatures below 27°F. However, as long as the annual number of hours in these low temperature bins is small, there is a small impact on the overall annual weighted average COP. For Seattle and Portland the average COP remains at about 2.7 when the poor operating conditions at lower temperatures are factored in. The electric heat operation starts to have a much more significant impact in colder climates such as Spokane where the average annual COP drops to about 2.3. Other defrost methods such as reverse cycle operation or fan-only operation will have a similar impact on overall annual average COP.

While using the RCC technology in ambient conditions in the Pacific Northwest provides significant energy savings in comparison to electric resistance heating, it has the drawback of not having a significant impact on peak electrical demand. For this region, the peak electric loads tend to occur during the coldest weather, which is the same time that this system begins to rely on electric resistance heating. Therefore, from the utility perspective widespread use of this technology in ambient conditions will not have as significant of an impact on the required peak load energy production. To significantly reduce both energy usage and connected load using this technology it is necessary to avoid operations at temperatures where electric backup for defrost becomes necessary. The best way of doing this is to install the RCC in a buffered environment that rarely (if ever) falls below 40°F.

### **RCC in Buffered Conditions**

Anecdotal evidence suggests that below grade parking garages can provide an ideal location for such an installation.<sup>10</sup> To test this theory a finite element thermal analysis model (SUNCODE) was used to predict the interior temperatures in a below grade parking garage in Seattle with exhaust rates driven by a RCC. For the garage model we used an actual building design in Seattle that includes 12 apartment units over a 5,000 ft<sup>2</sup> below grade parking garage. The design was based on the use of a Colmac RCC model HPA12 exhausting the garage at 5,000 cfm while operating. This project was used for the model because it represents a real life example that will be on the more conservative side in terms of garage temperature (a relatively small garage with a relatively large RCC). The apartments were evaluated to predict typical hot water demand to calculate required run-time of the equipment. From this runtime, an average exhaust rate was modeled for the parking garage. This model takes into account the interaction with the lighting energy use in the garage and the vehicle impact by setting a rate of internal heat generation in the garage equivalent to those sources. The model also predicts the impact of the large amount of thermal mass and the ground effect of the below grade slab and walls.<sup>11</sup>

Running the RCC to provide only domestic hot water for this building of 12 apartment units with low flow plumbing fixtures results in an average ventilation rate for the garage of about 0.6 air changes per hour (ACH). At this ventilation rate the lowest temperature in the garage is 42°F occurring on February 19<sup>th</sup>. This is offset from the peak low temperature outside because of the impact of the ground buffering and the thermal cycle of deep ground temperature. The average efficiency of the Colmac RCC under these conditions is predicted to be a COP of about 2.2. This modeling indicates that below grade parking garages in multifamily projects can indeed provide adequate temperature buffering to run RCC systems without significant defrost in the Pacific Northwest.

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<sup>10</sup> Ecotope's office is in a 7-story multifamily building with a 2-level below grade parking garage. Temperatures were monitored during the winter of 2008-2009 with garage temperatures never recorded below 41°F, even while outdoor temperatures were below 25°F. This includes the impact of our space heating heat pump which is installed in the garage and the garage ventilation system.

<sup>11</sup> While both garage lights and vehicles add heat to below grade parking garages, the primary buffering effect comes from the large amount of surface area exposed to deep ground temperatures.

## Parking Garage Ventilation

An RCC system installed in a parking garage acts as an exhaust system. The timing of hot water demand, and thus the operation of the RCC, is generally well-matched to the need for garage exhaust. In the morning the showering peak coincides with morning commuters leaving the garage, and evening cooking hot water use peak coincides with vehicles returning.

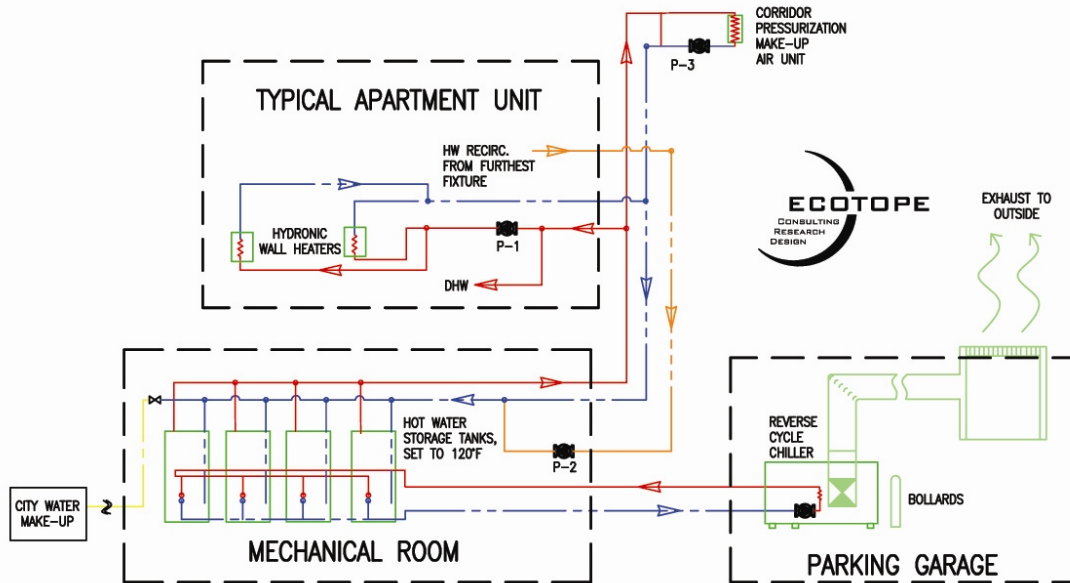
This study examined whether an RCC system installed in the parking garage could eliminate or reduce the size of the code-required garage ventilation system, and if it might provide additional energy savings by reducing or eliminating the run-time of the garage ventilation system.

The hours of operation for the RCC system depend on the demand for hot water. These systems are set up such that the fan and heat pump are turned on by an aquastat located in a hot water storage tank. In order to estimate the number of hours of operation implied by the hot water load, it is necessary to compare this load to the output of the heat pump. Two prototype projects were evaluated; the 12-unit and 163-unit projects mentioned earlier. Water usage was estimated based on sub-metered residential water consumption updated with current water conserving fixtures (Roos and Baylon 1993). Assuming standard new fixtures and an average of two people per apartment the average annual ventilation rate for the garage is predicted to be 0.6-0.9 ACH.

While this results in a relatively high average ventilation rate for the parking garage, our analysis indicates that it does not lead to significant energy savings through offsetting garage exhaust fan operation. If we assume 75% of the time the RCC is running it is offsetting garage exhaust fan operation, it offsets only about 140 kWh/year of electricity in the small prototype, and 1,200 kWh/year in the large prototype. This translates to a savings of only 7-12 kWh/yr per apartment in exhaust fan energy.

## Other Space Heating Applications

The ability to heat water to 120-140°F with an RCC system suggests that in addition to supplying domestic hot water, the system could be used for hydronic space heating. There are two primary components to space heating in multifamily buildings; space heating in the apartments and tempering of corridor pressurization air in buildings with central enclosed circulation space. These two loads are examined separately. **Figure 6** below presents a basic schematic of how an RCC domestic hot water system could be extended to provide for space heating and tempering of corridor air.



**Figure 6: Basic Schematic of RCC Below-grade Parking Garage Installation**

Source: Ecotope

**Corridor Pressurization**

Mid-rise and high-rise multifamily buildings typically include an elevator core connected to enclosed circulation corridors. By code these corridors must be supplied with ventilation air. Fire codes and traditional mechanical engineering design practices call for pressurizing these corridors in relation to the apartment units as a means of controlling smoke and odors. The typical design pressurizes corridors continuously with 100% outside air tempered to 65-70°F. For electrically heated buildings, this has most commonly been accomplished with an electric resistance rooftop make-up air unit. Up to this point the regional energy codes have mostly ignored corridor pressurization systems. There are no guidelines on sizing, controls, or limitations on the use of electric resistance heating. Heating in many of these systems is controlled from a duct thermostat so that heat comes on any time the outdoor air is lower than the setpoint; including at night and during the summer. Heating energy used in these corridor systems can be greater than the entire annual heating energy for all of the apartments combined (Knowles 2008).

Given a central RCC hot water system with tank temperatures of 120-140°F, it would be relatively straightforward to supply heating for corridor pressurization air from this same source with minimal increase to the capacity of the water heating system. A hydronic fan coil rooftop make-up air unit could replace the electric furnace. Supply and return piping would be run from the storage tank to the coil. If a copper coil is used with copper or rated piping, then potable water can be used directly in the coil with no need for an intermediate heat exchanger.

A prototype corridor pressurization system was designed for the large 163-unit prototype building using rule-of-thumb engineering guidelines<sup>12</sup>. This building requires approximately 4,500 cfm of pressurization air. At peak, this requires 59 kW of electric resistance heat. This could be replaced with 17-tons of heating by the RCC system. The RCC design for this building includes 40-tons of capacity for the domestic hot water load. The corridor pressurization air load could be accommodated by increasing the storage volume and adding back-up electric elements to the storage tanks designed to come on if peak heating

<sup>12</sup> Flow needed to obtain adequate pressurization of the corridors assumed to be 20 cfm per doorway plus 100 cfm per elevator door.

and peak hot water demand draw down the stored hot water to the point where the RCC system cannot maintain setpoint. This represents a small increase in the cost of the total RCC system of approximately \$5,000.

If the RCC system is serving the corridor pressurization load in addition to the DHW load, then the RCC system will run more frequently during the winter. This increases the ventilation rate in the garage during the cold part of the year. The thermal modeling of the garage was evaluated for the increased ventilation associated with the corridor pressurization load.

If we assume the RCC will provide hot water for tempering corridor pressurization air in addition to the domestic hot water, then the average ventilation rate of the garage increases from 0.6 ACH to about 1.2 ACH during the winter months. This has a surprisingly small effect on the garage ambient temperature. The lowest temperature predicted for the garage drops from 42°F to 40°F during these times. The average annual COP of the system remains constant at about 2.8.<sup>13</sup>

Savings for adding the corridor pressurization air tempering onto the RCC system are significant. Assuming 4,500 cfm of air continuously tempered to 65°F in the Seattle climate requires 152,000 kWh/yr of electric resistance heating. At a COP of 2.8 for the RCC system, this results in a savings of 98,000 kWh/yr. Normalizing cost and savings per apartment results in a savings of about 600 kWh/yr/apartment at a cost of \$31/apartment.

Based on this analysis, Ecotope recommends including tempering of corridor pressurization air along with production of DHW for RCC systems. While there are minor additional costs and performance implications, the large energy savings potential make inclusion worthwhile.

It should be noted that the buffering effect of the parking garage is much more critical to the performance of the overall system when the corridor pressurization is included. Domestic hot water demand is spread relatively evenly over the year, so the few hours of cold conditions do not significantly affect the annual efficiency of the DHW system. However for corridor heating, the coldest times of the year require the greatest operation of the system. Maintaining high efficiency during this time is critical.

### **Space Heating**

Space heating in the apartments can also be accomplished with a central hot water source, but this is much more involved than adding corridor pressurization air tempering.

Hot water produced by the RCC system is relatively low temperature for most space heating systems. Radiators and fan coils are generally designed around the use water temperatures of 160°F or greater. Low temperature water (120-140°F) leads to low air delivery temperatures which can cause comfort complaints, or oversized radiators which significantly increase cost. Integration of hydronic heat delivery into the building's architecture can be difficult. This requires dropped ceiling spaces for ductwork or large wall areas for radiators or wall heaters.

Including apartment space heating into the load requires the RCC system to run much more frequently during the winter. However, the parking garage still successfully buffers the ambient air temperatures. Winter average ventilation rates for the parking garage increase from about 0.6 ACH for DHW-only to about 2.4 ACH for DHW, corridor, and space heating. Thermal modeling of a parking garage with this level of ventilation results in a low temperature of 37°F. As a result, the system's average annual COP drops to 2.5.

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<sup>13</sup> Not including losses associated with storage, distribution, and recirculation.

Heat loss calculations for the large prototype building result in a Design Heat Loss Rate of about 375 kW. This accounts for an additional 107-tons of RCC capacity, compared to the 40-ton DHW system. This represents a significant added cost of about \$2,600/unit for a very simple wall-heater type system. Energy savings from adding this measure are predicted to be approximately 1,500 kWh/yr/unit.

Based on this analysis, Ecotope does not recommend trying to extend an RCC system to capture space heating load. This introduces too many comfort, architectural, cost, performance, and reliability issues.

## Design Recommendations

During the course of this research study, Ecotope developed the following design recommendations:

- ◆ The best and most effective use of an RCC system is installation in a below grade parking garage for DHW and corridor heating only.
- ◆ Ensure that the RCC system exhausts parking garage to the exterior.
- ◆ For small parking garages, investigate whether there is benefit to replacing part or all of the garage ventilation system.
- ◆ Use more than one RCC if possible to provide redundancy.
- ◆ Install back-up electric coils in hot water storage tanks for safety, redundancy, and for servicing of the RCC unit.
- ◆ Provide sound lining in exhaust ducts to reduce noise impacts and complaints.
- ◆ Provide pre-filtration of garage air to keep coils clean.
- ◆ Keep duct pressures low to keep fan energy down
- ◆ Set up equipment for fan only defrost based on pressure sensors across coil and ambient temperature.

## Improvements

Improvements to the RCC equipment would make it more effective for use in cold climates. These improvements are geared specifically to production of domestic hot water, more energy efficient, and more “Plug and Play” system installation. The current products are mostly customized and based on a reverse cycle chiller designed to provide air conditioning to a space with excess heat, producing hot water as a byproduct. None of the manufacturers have specifically developed a product optimized for production of domestic hot water in colder climates. At least one manufacturer has embarked on internal research and development aimed at achieving some of these goals. The following is a list of specific areas of research that could improve RCC products for application in multifamily buildings in the Pacific Northwest:

- ◆ Improve and standardize defrost controls for reliable and robust methods of determining when defrost is needed and when to terminate the defrost cycle. Offer this as a standard feature on a product line aimed at domestic hot water production.
- ◆ Provide all controls on a standardized packaged circuit board that could be quickly swapped out in the event of a control failure.
- ◆ Base product lines on readily available parts and compressors to simplify maintenance and availability issues.

- ◆ Install variable speed pumps to allow control of outgoing water temperature and minimize pump energy.
- ◆ Install variable speed fans to reduce fan energy.
- ◆ Costs could be reduced by eliminating reversing valves and running as a heater only with fan-based or electric defrost.



# Conclusions

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The Bonneville Power Administration has developed a list of criteria for evaluating promising “Emerging Energy Efficient Technologies”. The application of RCC systems proposed in this report match well with these criteria:

## ***Innovative***

- ◆ The proposed approach is a new application for an existing developed technology.
- ◆ Heat Pump Water Heaters or Reverse Cycle Chillers are not in common use for domestic hot water production in colder climates, but this research indicates that they hold significant promise.

## ***Attractive***

- ◆ This is appealing to consumers as it provides a way to reduce the energy use of hot water production by nearly a factor of three. There is no other affordable technology on the market that can offer this level of energy reductions for DHW.
- ◆ Energy benefits are significant, both in total energy use and in peak demand for large multifamily buildings. Non-energy benefits include increased useful space in the apartments and the ability to regularly service and maintain the water heating system.
- ◆ Widespread adoption of this technology would lead to significant business potential for suppliers, installers, and manufacturers in the region.

## ***Available***

- ◆ These products are currently commercially available “Shelf-Ready.”
- ◆ With some minor product improvements, publicity, and contractor and designer training, widespread availability could be achieved in 1-3 years. RCC products could be well-positioned for regional acceptance.

## ***Reliable***

- ◆ The energy savings of RCC systems designed as proposed are quantifiable, specifiable, and cost effective.
- ◆ RCC products are reliable and have been on the market for over 30-years.

## ***Relevant***

- The application of the proposed RCC system design meets a Bonneville/utility target or need since the 6th Power Plan has specific targets for reduction of energy use associated with domestic hot water. This technology could be the means by which those targets are met.

## ***Scalable***

- ◆ There is significant regional market penetration potential for RCC systems. This is primarily in new multifamily development in urban areas, but there is also some retrofit opportunity in buildings with existing central hot water distribution systems.

# Recommendations for Future Work

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This research study was developed as Phase I of a potentially longer study. Given the highly promising potential of the RCC technology in this application we recommend implementation of the following phases:

**Phase II - Market Demonstration Projects:** The next phase is to identify and recruit one or two multifamily developments as demonstration projects for this technology. The developer should be expected to pay for incremental design and construction costs, but BPA and local utility conservation programs could provide support in the way of energy efficiency incentives. BPA could also offer technical support for additional follow-up that may be necessary to ensure a high quality installation given the innovative nature of the design. This would include funding of a full commissioning and documentation process for the demonstration projects.

**Phase III – Measurement and Verification (M&V):** After the demonstration projects are built, a full M&V process should be carried out. The M&V phase of the project involves design and installation of a monitoring system, data collection, analysis, and reporting. Ecotope anticipates important variables to measure include: ambient temperature and inlet air temperature into the RCC unit in the parking garage, Btu metering of the domestic hot water production (incoming and outgoing water temperatures and flow), hours of operation of the parking garage exhaust fans, and electricity usage of the RCC unit. This metering take place for at least one year, and perhaps longer depending on the vacancy rates in the building during the initial leasing ramp-up. The building operator would be asked to supply occupancy records to assess the number of occupants associated with the metered hot water use. This could later be compared to secondary data associated with DHW use in other regional multifamily units. Analysis would determine actual annual COP of hot water production, quantify any seasonal variation, estimate any additional energy savings associated with reduction in operation of garage exhaust fans, and verify manufacturer’s performance claims.

**Phase IV – Case Study Lessons Learned, Regional Potential and Marketing Materials:** The final phase for this study will provide some of the materials needed to assist with market penetration for this innovative technology. This will include a write-up of the demonstration project(s) and results, as well as lessons learned. The report would also detail appropriate applications and estimated savings potential for a range of building types and configurations. This could be used by utilities in conservation program development and marketed to leading developers and designers. Ecotope would provide the content for this product, but it is anticipated that BPA would provide editing and graphics resources to assist with production of the final marketing materials.

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