BATIK APARTMENTS: A LOW-CARBON CENTRAL DOMESTIC HOT WATER SYSTEM

CASE STUDY

This case study describes the innovative solutions used in the central heat pump domestic hot water system of Batik Apartments, a mixed-use mid-rise residential building in Seattle, Washington. The heat pump system reduces overall energy use and helps achieve near zero operational carbon emissions.

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PREPARED BY

zebx
THE UNIVERSITY OF BRITISH COLUMBIA
CITY OF VANCOUVER
ECOTOPE

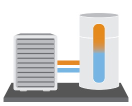
QUICK SUMMARY

BATIK APARTMENTS DOMESTIC HOT WATER SYSTEM DESIGN

Batik Apartments, a mixed-use residential building in Seattle, Washington has minimized operational energy use and greenhouse gas emissions by providing the space conditioning requirements with electric resistance baseboards and efficient heat pumps. The building also uses a central heat pump system for providing the units with domestic hot water. The innovative design and configuration of this system are expected to improve its efficiency and reduce its energy use by 55-70% compared to a typical new building using gas or electric boilers.

HEAT PUMP LOCATION

Heat pumps are installed in the underground parkade for milder and more stable temperatures to improve the heat pumps' efficiency and stabilize their functioning throughout the winter season.

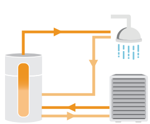


PRIMARY HEATING

Single-pass heat pumps provide the primary heating and heat the incoming cold water to 130-140˚F (54-60˚C). These heat pumps are most efficient when incoming water is the coldest, which is ensured through careful system design.

PRIMARY STORAGE TANKS

Primary storage tanks are connected in series to create significant temperature stratification, allowing the single-pass heat pumps to receive the coldest water possible while water with the highest temperature is stored in the last primary storage tank.



TEMPERATURE MAINTENANCE TANK

A separate tank stores both hot water ready for distribution and recirculated water, and maintains the water temperature at about 120˚F (49˚C). A dedicated multi-pass heat pump makes up energy losses in the piping, delivering water to all parts of the building and returning the unused water to the tank.

Credit: Runberg Architecture Group

PROJECT CONTEXT

According to Natural Resources Canada, domestic hot water systems use about 20% of the overall energy consumed by residential buildings. This case study describes the innovative and efficient design of a central heat pump DHW system used in Batik Apartments in Seattle, U.S.A.

Project Overview

Building Type	Mixed-Use Residential Building
Climate Zone	4C: Mixed Marine (ASHRAE)
Location	Yesler Terrace, Seattle, WA, U.S.A
Gross Floor Area **Site Area**	21,020 m² / 226,257 ft² 13,146 m² / 141,610 ft²
Number of Floors / Units	7 stories / 195 units
Sustainability Certifications	LEED Platinum & Salmon-safe
Project Completion	2018
Project Status	Occupied

Project Team

Developer	Vulcan Real Estate
Architect	Runberg Architecture Group
DHW System Design	Ecotope Inc.

Credit: Runberg Architecture Group

Project Context

According to Natural Resources Canada, residential buildings consume 17% of the total end-use energy in Canada. Within residential buildings, domestic hot water (DHW) is the second largest source of energy use after space heating and consumes about 20% of the total energy use of a typical residential building. Reducing DHW energy consumption can have a significant impact on reducing the overall energy demand of residential buildings. DHW in residential buildings typically refers to kitchen and bathroom lavatories, showers, washing machines and dishwashers.

This case study summarizes the key design features and learnings from the central heat pump DHW system that Ecotope designed for the Batik Apartments in Seattle, Washington as an example of a high-performance and low-carbon DHW solution for multi-unit residential buildings (MURBs). The central DHW system in Batik Apartments uses heat pumps to generate hot water for all units in the building in a unique configuration that increases overall system efficiency. With a similar climate and near-term zero emissions target for heating and hot water, Vancouver's building community can take inspiration from this successful project.

Batik Apartments is a seven-story, mixed-use building with retail and community amenities on the ground-floor and 195 residential units on the upper floors. The building was completed in 2018 in Yesler Terrace in downtown Seattle and is currently fully occupied. It uses electricity as the energy source for lighting, appliances, air conditioning, and DHW. The only exception is a gas-powered fireplace in the entry lobby.

The main design focus for the Batik Apartments project was to deliver a highly energy-efficient building with a minimal carbon footprint to respond to Washington State's goal of 70% reduction in operational energy use and GHG emissions by 2030 and the City of Seattle's goal of carbon neutrality in the operation of all new buildings by 2050. Batik Apartments has one of the lowest energy use of MURBs in Seattle. The total energy-use intensity of the building is 17 kBtu/ft² yr. (54 kWh/m² yr.), which is more than 50% lower than the current requirement in the Seattle Building Code (35 kBtu/ft² yr.).

The Batik Apartments project team minimized the energy required for space heating by using a high-performance envelope and heating system. As a result, according to the building energy model, the single largest energy consumer was DHW. Therefore, Ecotope designed an innovative and efficient DHW system to reduce this energy use.

HEAT PUMP DOMESTIC HOT WATER SYSTEM

Heat pumps are one of the most efficient heating technologies, producing two to four units of thermal energy for each unit of electrical energy used. Using heat pumps for DHW heating systems can significantly reduce energy use and the associated GHG emissions of these systems.

What is a Heat Pump?

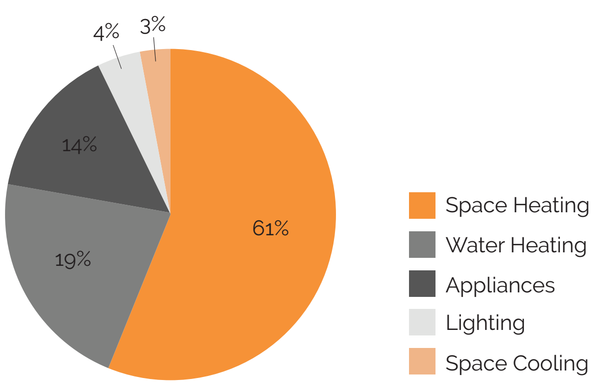
Heat pumps work like a refrigerator in reverse; they use electricity to transfer heat from one location to another, rather than generating heat by burning fossil fuels or through electric resistance. Heat pumps can transfer the heat extracted from their surroundings, e.g. from the air, water, or ground, and transfer it to air or water for space or hot water heating. Common types of heat pumps include air-to-air, air-to-water, water-to-water heat pumps.

Advantages of Heat Pump DHW Systems

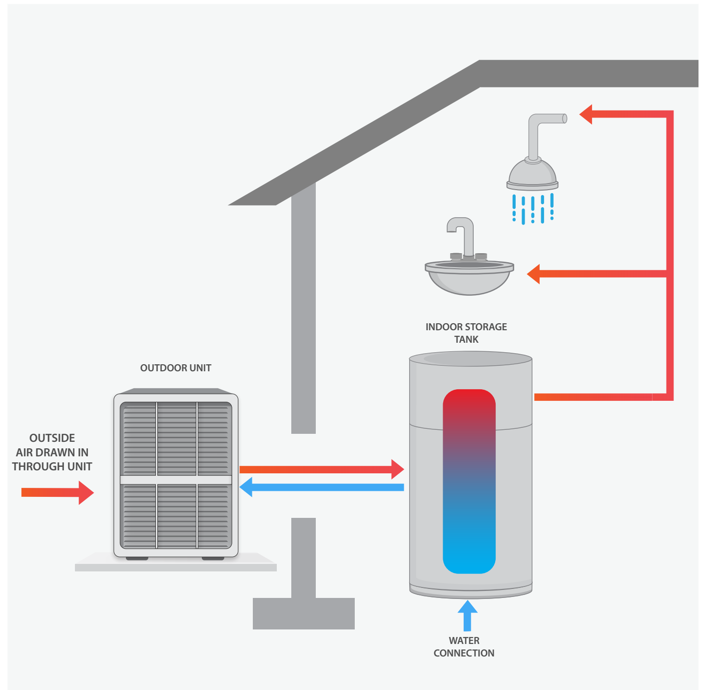
Heat pumps are one of the most energy-efficient heating technologies available on the market. They produce two to four units of thermal energy for each unit of electrical energy they use. Therefore, they can significantly reduce the energy use of DHW systems compared to conventional systems using fossil fuels or electric resistance to generate heat.

For regions like British Columbia, where close to 95% of the electricity is generated from renewable resources, heat pumps are also a low-carbon alternative to boilers and gas-fired hot water tanks that use natural gas or other fossil fuels to heat the water.

Based on the financial analysis conducted by Ecotope, the upfront cost of installing a Heat Pump Water Heater (HPWH) in a typical large MURB is more than twice the cost of a conventional gas boiler. However, projects utilizing HPWH systems may see energy cost savings throughout operations and may be eligible for incentives from the local or regional government.



DHW is the second-largest source of energy in residential buildings after space heating (Source: Distribution of residential energy use in Canada 2016, Natural Resources Canada).



A DHW heat pump has an outdoor unit and an indoor unit. Through compressing the refrigerant, the heat from outside is absorbed and is released by decompressing the refrigerant to heat the water in the indoor storage tank and supplied for domestic hot water needs.

Domestic hot water is used in the kitchen and bathroom sinks, tubs, and other appliances (Credit: Runberg Architecture Group).

COMPONENTS OF THE DHW SYSTEM

The DHW system uses an innovative design that separates primary hot water heating from temperature maintenance, allowing the different components of the system to be maximized for efficiency based on equipment selection and operating conditions.

Two Primary Single-Pass Heat Pumps

The Colmac HPWHs used in the Batik Apartments building are single-pass and regulate the flow of water with a control valve so that the incoming municipal-supplied water is heated to a set temperature between 130-140˚F (54-60˚C), regardless of the incoming water temperature. The double-walled copper heat exchanger in the heat pump transfers heat directly to the supply water. In general, the tanks are designed to meet the peak load and the heat pumps are designed to fill the tanks over a specified recovery time.

Primary Storage Tanks

The Batik Apartments building requires 2,500 gallons of primary hot water storage which is split among multiple smaller storage tanks. Smaller storage tanks were chosen because they are less expensive and easier to install than large tanks.

Aquastat Controls

To activate or deactivate the primary heat pumps, thermostat controls (aquastats) are connected to the storage tanks. The aquastats are set to turn on the heat pumps when the temperature in the middle tank drops below 115˚F (46˚C) and they stay on until the temperature in the first storage tank is raised to approximately 100˚F (38˚C).

Temperature Maintenance Tank

A separate temperature maintenance tank supplies the domestic water to the building, receiving the hottest water from the last primary storage tank. The recirculating water, which is the unused DHW returning from the building through circulation pipes is also returned to the temperature maintenance tank.

Separate Multi-Pass Heat Pump

The temperature maintenance tank is connected to a multi-pass heat pump that regulates the flow of water in a way that the temperature of the incoming water is raised by 10-20˚F (6-12˚C) maintaining the set temperature for the hot water sent to the building. Reheating the recirculated water this way prevents increasing the water temperature of the incoming water for the single-pass heat pumps which lowers their efficiency.

Electric Resistance Back-Up Tank

A back-up electric storage tank is provided alongside the primary storage tanks, which will be used to provide hot water in the event of a failure of the primary heat pumps. Similarly, a back-up electric resistance element is placed inside the temperature maintenance tank to provide heating in the event of a failure of the supplementary multi-pass heat pump or to provide additional heating for the peak loads.

Colmac heat pump located in the parkade floor (Credit: Ecotope Inc.)

WORKING OF THE DHW SYSTEM

According to the energy model, the central heat pump DHW system used in Batik Apartments contributes to about 70% reduction in the DHW energy-use compared to the baseline design that uses electric resistance boilers.

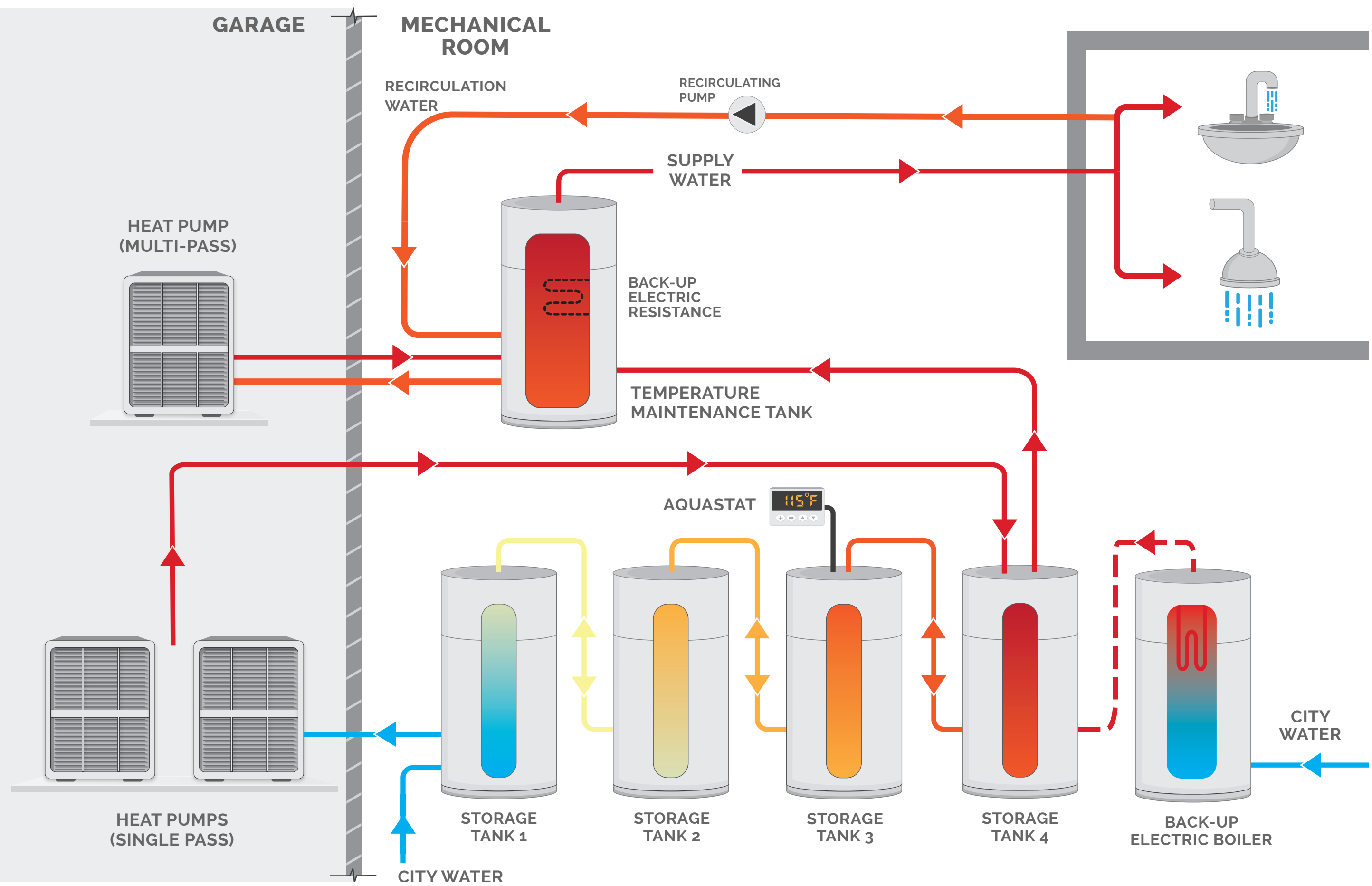
The primary Colmac heat pumps are the main source of DHW to the building. The hot water is stored in the primary storage tanks that are piped to be connected in series. The series arrangement helps to achieve temperature stratification in the tanks, allowing for a wide range of temperature difference between the first and last storage tank.

The cold water from the city water supply enters the first primary storage tank at approximately 50˚F (10˚C). This tank is connected to the primary heat pumps that heat the water to about 140˚F (60˚C). The hot water is piped to reach the fourth storage tank, which is the last of the primary storage tanks.

As water is drawn by building use, the water in each tank is replaced by water from the preceding tank, and in the case of the first tank, the city water. This ends up lowering the temperature of each tank until an aquastat in the middle tanks recognizes the drop in water temperature below 115˚F (46˚C) and trigger the heat pumps to turn on the heat.

The hot water from the last primary storage tank at 140˚F (60˚C) serves a separate temperature maintenance tank, where the building recirculated hot water also returns to. The water from the temperature maintenance tank is connected to the supply loop to provide DHW at 120˚F (~50˚C) to the building. When the water in the temperature maintenance tank is depleted, it draws more hot water from the multiple primary storage tanks.

Even when there is no call for hot water, the temperature maintenance tank can still drop in temperature due to heat losses in the DHW recirculation piping. In this scenario, no water is drawn from the primary storage tank, but rather a separate multi-pass heat pump, connected to the temperature maintenance tank, that reheats the water whenever the temperature of the water in the tank drops below 122-125˚F (~50-51˚C). If the supplementary heat pump cannot respond to demand, a back-up electric resistance element inside the tank will function to reheat the water.



Simplified schematic of the Batik Apartments' heat pump domestic hot water system designed by Ecotope (Based on Ecotope's schematic in "Batik Apartments: Case Study of Central Hot Water Plant Design")

DESIGN CONSIDERATIONS

To achieve maximum efficiency from the system, appropriate design and control measures are used in the Batik Apartments' central heat pump DHW system.

Equipment Location

HPWHs used at the Batik Apartments function best in moderate climates with outside temperatures above 40˚F (~4˚C). Winters in the Pacific Northwest region occasionally experience lower temperatures. Therefore, the heat pumps in the Batik Apartments are placed in the underground parking, which has a milder and more stable temperature than the outdoors.

Additionally, it is important to locate the aquastat controls in the right place in the tanks to trigger the activation of heat pumps at the right time. In Batik Apartments, the aquastat controls are located in the center of the stratified primary storage tanks.

Input Water Temperature

Single-pass heat pumps perform better with colder incoming water. If the incoming water is too warm, the capacity and performance of the system can drop significantly. The Batik Apartments' DHW storage tanks and controls are configured to direct the coldest possible water to the single-pass heat pumps. To do so, city supply water is sent to the bottom of the first primary storage tank, while hot water from the heat pumps is sent to the top of the last storage tanks. The tanks are piped linearly and the bottom of each tank is connected to the top of the next tank. This enables temperature stratification throughout the tanks, which keeps the hottest water and coldest water separate. This coldest water at the bottom of the first tank is then piped to supply the single-pass heat pumps.

Equipment Sizing

The heat pumps and storage tanks are sized according to ASHRAE applications for daily and peak hot water use. Unlike boilers that are usually designed with larger capacity and less storage, the heat pump hot water system is sized with an emphasis on storage and less heating capacity. This means taking the three- to five-hour peak period for storage requirement along with calculating the total daily load to derive the heat pump capacity, assuming a daily run-time of 12-16 hours.

Additionally, the fans and pumps are properly sized to support the system. The analysis conducted on the Batik Apartments' DHW system showed that these auxiliary pumps and fans must not use more than 150 Watts/ton of the heat pump's capacity to maintain the system's efficiency.

Temperature Maintenance

The Batik Apartments' DHW system efficiently maintains the temperature of heated water. The recirculation loop water is directed to a temperature maintenance tank instead of getting mixed with cold water from the municipal supply. The temperature maintenance tank is connected to a dedicated supplementary multi-pass heat pump to reheat recirculation water.

Prevent Frosting on the Air Coil

Defrost cycles should be managed to prevent frost build-up on the air coils. When the outside air is cold and moist, ice can develop on the heat exchanger coils and impede the heat transfer. If the heat pump continues to run without detecting the frost, it might get damaged. In Batik Apartments' DHW system design, the ice formation was predicted and an effective defrost cycle was included in the system.

Other Considerations

Other design considerations that contributed to the DHW system's efficiency include minimizing areas of thermal bridging in the DHW circulation loop and distribution piping and robust measurement, verification, and monitoring of the system to assist diagnosing potential issues in operation.

Indoor primary storage tanks in the mechanical room
(Credit: Ecotope Inc.)

GLOSSARY

Key terms, definitions, and abbreviations used in this case study arranged alphabetically

Aquastat
A sensor placed in a storage tank to control the operation of the water heating system.

Defrost Cycle
The defrost cycle is a working cycle of the heat pump that kicks in when the moisture in cold outside air freezes in temperatures below 30˚F (0˚C) and forms ice build up on the heat exchanger. If the exchanger is not defrosted, its efficiency will be compromised and the unit could be permanently damaged.

Electric Resistance Boiler
A DHW heater system that consists of an insulated tank with electric resistance elements that heat the water.

GHG Emissions
A measure of greenhouse gas contributions from a building and its systems.

Heat Pump
A mechanical system that transfers thermal energy in the opposite natural direction of heat transfer from a colder space to a warmer space. Heat pumps are a more energy-efficient alternative for space heating and domestic hot water compared to fossil fuel equipment and electric resistance

Heat Pump Water Heater (HPWH)
Heat Pump Water Heaters use electricity to move heat from one place to another instead of generating heat directly. Therefore, they can be two to four times more energy-efficient than conventional electric resistance water heaters.

Single-Pass HPWH
A type of heat pump technology that provides a standard output water temperature for varied incoming water temperature by appropriately controlling and regulating the flow of water to a single pass. These heat pumps provide the highest efficiency when the temperature of incoming water is cold.

Multi-Pass HPWH
It is a type of heat pump technology that provides fixed heating of 10-20˚F (6-12˚C) rise in the water temperature. In general, they function well even at higher incoming water temperature and are predominantly used in hydronic space heating applications.

Multi-Unit Residential Buildings (MURBs)
As defined in the National Building Code of Canada, Multi-unit residential building is a type of building that contains at least two residential units, like duplexes, triplexes, and low-rise residential buildings.

Leadership in Energy and Environmental Design (LEED)
One of the most widely used green building certification programs, created by the U.S. Green Building Council (USGBC). It refers to buildings that have been designed, built, and maintained using green building and energy efficiency best practices and uses a point-scoring system for certification

LEED Platinum Certification
It is the highest level of four different levels of certification achieved by projects under the LEED certification program when more 80 points from the total 120 points of the certification requirements are met.

Temperature Stratification
The natural phenomenon of warmer and less dense water rising to the top of a storage tank.

Thermal Bridging
An area or component of the equipment which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer, causing heat loss to the exterior.

NOTES

BATIK APARTMENTS :
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