COLD CLIMATE HOUSING RESEARCH CENTER
CCHRC

Feasibility Study of a Heat Pump Integrated Heat Recovery Ventilator (HRV) in Cold Climates

Robbin Garber-Slaght, P.E.

Conor Sosebee

Bruno Grunau, P.E.

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Cold Climate Housing
Research Center

P.O. Box 82489
Fairbanks, AK 99708

Telephone: 907.457.3454
Fax: 907.457.3456

www.cchrc.org

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Feasibility Study of a Heat Pump Integrated Heat Recovery Ventilator (HRV) in Cold Climates

Introduction

The objective of this project is to assess the feasibility of integrating an air source heat pump (ASHP) with the BrHEAThe System, a combined heating and ventilation system developed by the Cold Climate Housing Research Center. This new integrated system would be capable of providing ASHP-based space heating and heat recovery ventilation through a single-duct system. The purpose of integrating the two systems is based on the concept that an ASHP could deliver heat more efficiently and at a lower cost. This report summarizes a concept-level design of the integrated heating and ventilation system that uses an ASHP for heat.

Background of the BrHEAThe System

CCHRC has developed the BrHEAThe System, an integrated system which combines space heating with heat recovery ventilation. The system utilizes one distribution network to distribute balanced fresh air and space heating for high-performance homes in cold climates. The BrHEAThe System features an oil, gas, or propane fired boiler-based space heating device integrated with a water-to-air heat exchanger, air filter assembly, and heat recovery ventilator (HRV) to supply comfortable, healthy fresh air to the building's occupants.

The BrHEAThe System was designed to overcome the discomfort experienced from cold HRV supply air (fresh air) during periods of cold outdoor ambient temperatures. Occupants tend to block the supply air ducts when supply air is uncomfortably cold, which results in an unbalanced air flow to the home. When supply air vents of HRVs are blocked, the exhaust fans within the HRV can depressurize the house and increase the risk of combustion appliance backdrafting. Limiting fresh air also lowers the quality of the indoor air. These situations raise serious health and safety concerns for the occupants.

The BrHEAThe System was developed to ensure that, even when the house thermostat is not calling for heat, the HRV continuously supplies fresh, comfortable supply air, regardless of the outdoor air temperature. When the home thermostat does call for heat the system uses the same ventilation network and an in-line fan to deliver higher speed, heated air to the home. An aquastat on the heat exchanger supply line controls the operation of the inline fan. During this time, a relief air port within the system ensures the HRV maintains balance during operation.

The duct sensor initiates what is effectively an HRV supply air post-heater without powering on the 300 CFM[1] inline fan. When this post-heater system operates, the airflow across the heat exchanger is

[1] cubic feet per minute

supplied by the HRV. The upper limit of which is approximately 150 CFM (254 m^3/h). Assuming the HRV supply air is at least 32°F (0°C) and the temperature change across the post heater is 18°F (10°C), then the heat delivered to the home is approximately 2,970 BTU/hr (0.9 kW) [2]. At this rate, the likelihood of overheating the home is minimal because at these conditions, the total heat loss from the home (heat load) is estimated to be many times greater than the heat provided by the preheater. Based on past experiences with BrHEAThe Systems installed in homes across Alaska, users have not complained about overheating being a problem. When the thermostat calls for heat based on the indoor air temperature, then the inline fan is powered and heat is delivered to the heat exchanger, thereby delivering up to approximately 25,000 BTU/hr (7.3 kW) to the home.

This system is designed to mitigate the tendency of home occupants to modify or disable components such as dampers or HRVs that they see as unnecessary or energy intensive. Figure 1 shows a schematic of the current BrHEAThe System.

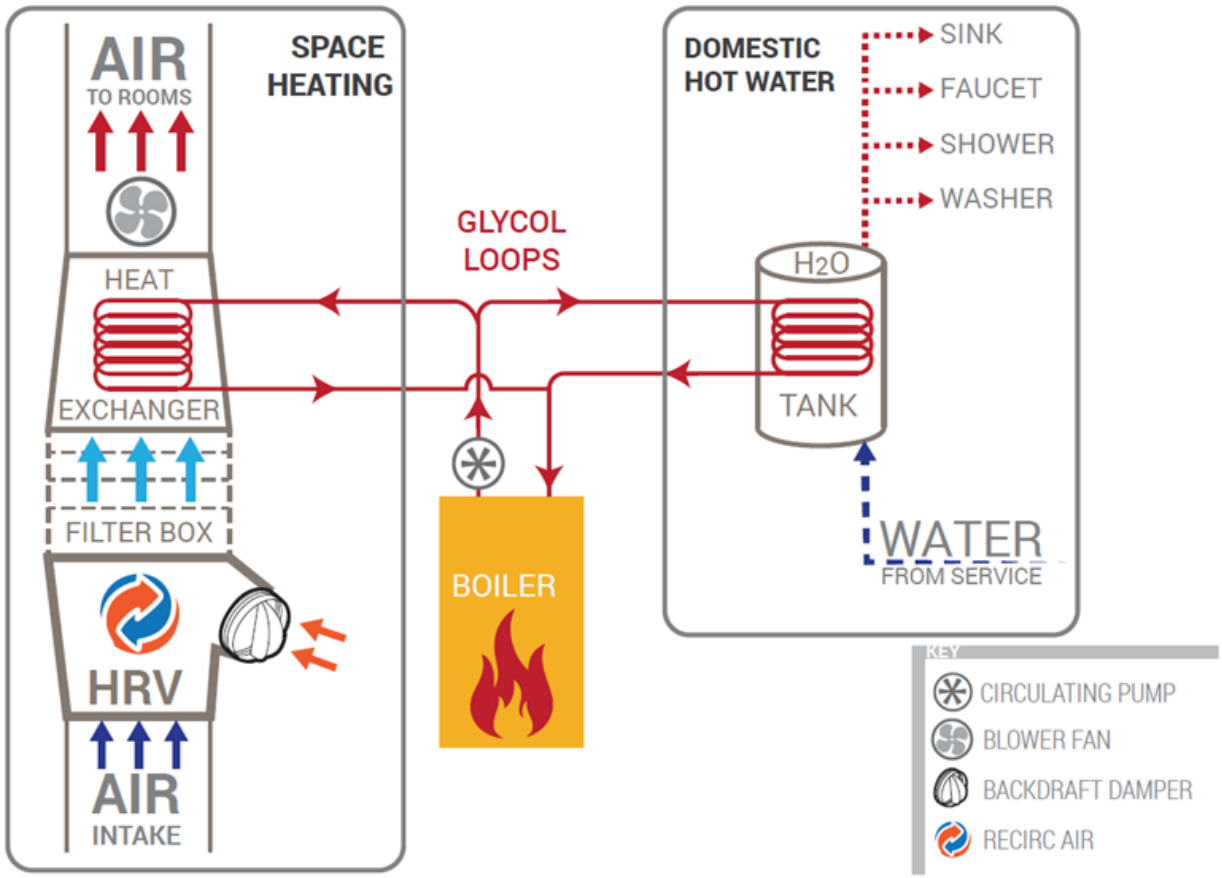

Figure 1. Existing BrHEAThe System. Adding an air source heat pump to this system will change the configuration slightly.

[2] Based on Q = 1.1 x CFM x ΔT, where Q is sensible heat delivered across a heat exchanger [BTU/hr], CFM is the airflow across the heat exchanger [cubic feet per minute], and ΔT is the air temperature increase across the heat exchanger.

Concept Development

The research team developed the concept based on criteria discussed between CCHRC and NRCan. Any system developed must meet the following criteria:

1. The system should be modular. The benefit to a modular system is that, as heat pump, HRV, and heat plant technology improves, the system can be upgraded accordingly.
2. Any ASHP used in the design must be considered to be for use in cold climates. Therefore, it must have a defrost cycle and compressor preheat to ensure the refrigerant remains in a gas state during the compression cycle during periods of cold outdoor ambient temperatures.
3. The system should use low flow heat delivery so that small ducting (i.e. no larger than 8" round duct) can be quickly and cost-effectively installed in a home.
4. The system should be able to meet a design combined heating demand of at least 25,000 BTU/hr in a cold climate.
5. Any ASHP used should be available in both Alaska and Canada. Additionally, the heat pumps selected for consideration should be commercially available and preferably have a track-record of use.
6. The system should use off-the-shelf components. Ductless heat pumps were ruled out because they would require reconfiguration of the control head to work effectively.
7. While domestic hot water heating is preferred, it is not a requirement of the system.

System Concept

For some locations in Canada and southern Alaska an ASHP by itself can meet all the demand of a high efficiency home. For very cold climates the concept integrates a boiler in the current BrHEAThe System configuration with a cold-climate ASHP that is capable for use in areas across Canada and Alaska. The integrated system is designed to provide heating, cooling, ventilation, and domestic water heating using modular components which can be upgraded as the technology improves. A buffer tank with an internal heat exchanger would be used to effectively combine the two heating components. This buffer tank supplies heat to both the BrHEAThe System water-to-air heat exchanger and the domestic hot water system. This tank is heated via the ASHP and the boiler. In this configuration, the ASHP becomes the priority heater during periods when the coefficient of performance (COP) of the ASHP is above a predetermined value. When the COP of the ASHP is below the predetermined value or when the ASHP alone cannot meet the space heating and DHW demands, the auxiliary heat to achieve the desired set point in the buffer tank is achieved by a boiler. Unlike typical boiler-only installations with small (40 gallon or less) sidearm heaters which heat water quickly, the buffer tank in this system is larger (80 gallons) to maximize the heat contribution to the tank by the ASHP.

THe ASHPs selected as options for this system feasibility study were selected based on performance and operation in cold climates, proven track records, and availability. Performance evaluations of these ASHPs such as coefficient of performance, energy use, and low-temperature cutoff, were based on available manufacturer specifications. Market-wide review cold climate heat pumps led the research and design team to three systems for consideration:

Ecologix A2W540DLI

Heating Capacity at -13°F (-25°C):	22,000 BTU/hr (6.5 kW)
Cooling Capacity at 95°F (35°C):	47,770 BTU/hr (14 kW)
Coefficient of Performance at -13°F (-25°C):	1.8
Max Water Temperature:	120
Outdoor Ambient Air Temperature Operating Range:	-13°F to 110°F (-25°C to 43°C)
Refrigerant:	R410a

Chiltrix CX-34

Heating Capacity at 17°F (-8°C):	22,237 BTU/hr (6.5 kW)
Cooling Capacity at 95°F (35°C):	29,537 BTU/hr (8.7 kW)
Coefficient of Performance at 43°F (6.1°C):	3.92
Max Water Temperature:	131°F (55°C)
Outdoor Ambient Air Temperature Operating Range:	-4°F to 110°F (-20°C to 50°C)
Refrigerant:	R744 (CO_2)

Sanden EDS-C110A

Rated Heating Capacity (temperature unspecified):	33,000 BTU/hr (9.6 kW)
Cooling Capacity:	None
Max Water Temperature:	160°F (71°C)
Outdoor Ambient Air Temperature Operating Range:	-15°F to 65°F (-26°C to 18°C)
Refrigerant:	R410a

The Broan HRV160 TE (formerly Venmar E15-ECM- HRV), the Panasonic Whisperline, the SuperStor buffer tank and the filter/heat exchanger box were selected based on CCHRC's experience using in the current BrHEAThe System. The filter/heat exchanger box is a custom built unit that is based on the drawing in Figure 2.

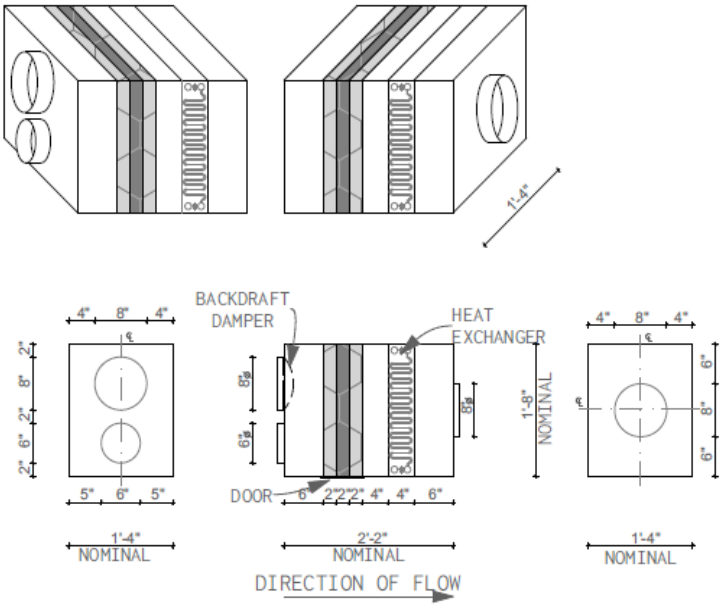

Figure 2. Filter/Heat Exchanger box specifications. This box is custom fabricated as an effective mass production box has not been found.

Some locations will need a boiler as backup heat when it is too cold for the ASHP. The addition of the boiler allows for the system to also produce domestic hot water. CCHRC has the most experience with the Toyotomi 128-HH diesel hot water heater. There are other options that could be tried; The Dunkirk VLT-050 (natural gas) looks promising as it is a low load boiler that can deliver 50,000 BTU/hr (14.6 kW) at a price comparable to conventional boilers.

A strong control system is required to make all the components function efficiently. The control needs an outdoor set point to tell the heat pump to shut down when the temperature is too cold for ASHP operation. It needs to have an in-duct sensor to tell the heat to turn on when the incoming air is too cold. It also needs to communicate with the thermostat, and the temperature in the buffer tank to know when there is a call for heat. In addition to controlling the heat pump and boiler, it will need to control the in-line fan. Table 1 lists potential control components that could meet current system requirements.

Table 1. Control System Components.

Component	Function
Tekmar Net2House Control	Maintain the temperature in the buffer tank Engage ASHP or boiler Communicate with the thermostat Engage pumps and inline fan
Tekmar 150 setpoint	Shut off ASHP at low temperature
Thermostat with slab sensor	Maintain house set point Add heat to duct when delivery temperature gets too cold
HRV Altitude Controller	Controls the HRV separate from the heat plant

Layout

Figure 3 shows a schematic of the full cold climate system with the boiler included.

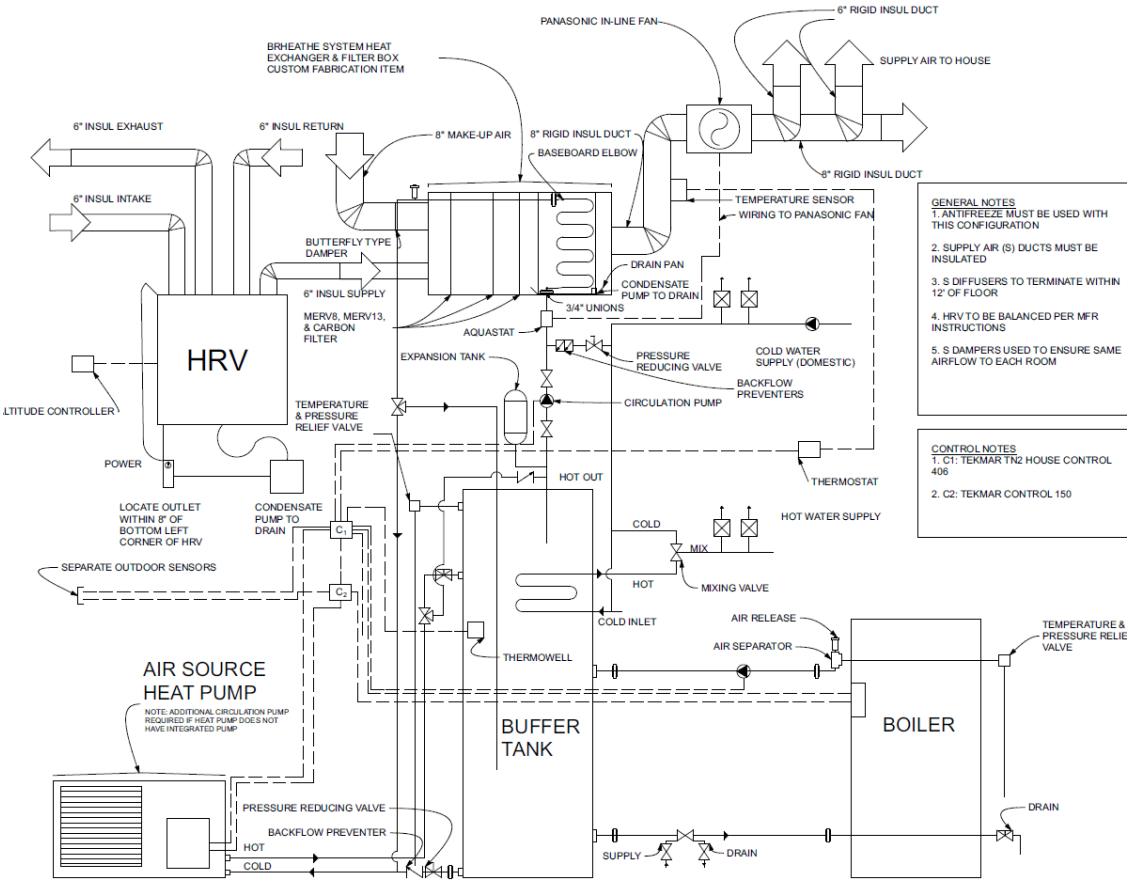

Figure 3. The new BrHEAThe System with an ASHP. The boiler may not be needed in all climates.

Components

Table 2 provides a list of components with costs and a rationale for each decision.

Table 2. Components.

	Cost (USD)	Rationale	Component	Efficiency
HRV	$1,390 $210	CCHRC has extensive experience with this model	Broan HRV160 TE (formerly Venmar E15-ECM-HRV) with Altitude controller	Apparent Sensible Effectiveness at 32°F (0°C) 80%
Boiler	$3,700		Dunkirk, Dunkirk VLT-050 (NG)	AFUE 95%

	$2,350		Toyotomi HH128 (oil)	AFUE 87.1%
Heat Pump	$3,800		Chiltrix Ecologix Sanden	dependent on outdoor temperature
Booster Fan	$185	CCHRC has extensive experience with this model	Panasonic WhisperLine (FV-30NLF1)	
Filter/Heat Exchanger Box	$1000	CCHRC has extensive experience with this model	Custom made by Holiday Parks in Fairbanks, AK	untested
Buffer Tank/Indirect Water Heater	$2,500	CCHRC has extensive experience with this model	SuperStor - SSU80	
Controls	$752 $168 $85	2-pipe, single tank, hydronic heat/cool system controller. Operates air-to-water heat pumps with a back-up heat source (boiler or electric resistance)	● TekmarNet2 House Control 406 ● Tekmar Setpoint 150 ● Thermostat	
Total Combined Cost	$12,440 to $13790			

Operational and performance impacts

Performance barriers include the temperature limitation of cold climate capable air source heat pumps. The modular nature of the system will allow for future cold climate capable heat pump systems to be implemented in the future as the technology and product proliferation improves. For instance,

Panasonic has a project in research that might fit into this system; their team is planning to modify a ductless heat pump system for hydronic delivery.

The performance of the combined system is a function of the efficiency of the components, but also how the occupants interact with the system. The idea behind the system is to integrate heating and ventilation so adequate ventilation is maintained; without ventilation there is no heat delivered. There has been a tendency in rural arctic communities to disable ventilation systems as they introduce cold air and use electricity. This combined system will meet a performance goal if ventilation systems in arctic homes are not disabled and healthy indoor air is maintained.

The performance efficiency of this system has not been tested. CCHRC is planning to test the efficiency of an older BrHEAThe install in Fairbanks this summer. As it stands the system efficiency is the sum of the efficiency of its parts. The known efficiencies are listed in Table 2. The efficiency of the ASHP models is very dependent on outdoor air temperature. In order to get accurate overall efficiencies for this system, a detailed model that accounts for hourly outdoor temperatures and ASHP efficiencies should be developed.

Marketability of System

The marketability of this system is dependent on several factors: fuel and electricity costs, ventilation codes, and home heating loads. If there is no intent to have balanced ventilation (as opposed to an exhaust system, i.e. bathroom fan) the cost of this system will seem too large for a heating system. Additionally, this system is not ideal for large homes or homes with a high heating load[3]. In order to evaluate the cost savings of the system it was evaluated within a variety of climates with different energy cost data (presented in Table 3). An energy model of a house in each location was developed and the monthly heating load was correlated with the monthly average temperature to determine a rough estimate the cost of operating a modified BrHEAThe System versus using both a 95% efficient condensing boiler and a 87% efficient boiler with a separate HRV. This rough estimate assumes that ASHP meets all of the heat load when the outdoor temperature is above the minimum operating temperature. Hence, the estimates do not take into account domestic hot water as the ASHP would not be able to meet that load and the space heating load at some temperatures.

The Fairbanks house is a 1,000 ft^2 (92 m^2) 3-bedroom home with a 16,600 Btu/hr (4.9 kW) design space heating load. Fairbanks is too harsh a climate to rely on an ASHP for heating all year, so the Fairbanks system requires a backup diesel boiler. The ASHP would almost never operate in December and January. Estimates were made on the percentage of time the heat pump would run during the month. Electricity costs $0.21/kWh and diesel heating fuel was estimated at $3/gallon ($0.79/l). Adding an ASHP to the heating systems does not save money in Fairbanks at current energy prices. Depending on the ASHP a Fairbanks homeowner would spend $100 USD to $150 USD more a year to run the ASHP.

[3] For instance, in Fairbanks, Alaska the average 1,900 ft^2 (176 m^2)home consumes 140 kBtu/ft^2/year (441 kWh/m^2/year) for it total energy use. A low-load home in Fairbanks, for which this BrHEAThe System configuration is most appropriate, consumes approximately 60 kBtu/ft^2/year (189 kWh/m^2/year).

The Canadian house is one of the test homes at the Canadian Centre for Housing Technology in Ottawa, a 2,700 ft^2 (250 m^2) 4-bedroom home. The home was used to evaluate conditions for both Ottawa and Edmonton. The ASHP would be able to run without a back-up boiler in Ottawa/Edmonton's climates. Estimates were made on the meeting all of the heating demand without the use of the auxiliary boiler. The energy costs are presented in Table 3. A summary of the costs of using a BrHEAThe System which incorporates an ASHP compared to a comparable system that does not incorporate an ASHP is shown in Table 4.

Table 3. Energy Costs

City	Oil		Electricity			Natural Gas		
	$/gallon	$/MJ	$/kwh	$/MJ	monthly base charge	$/m3	$/MJ	monthly base charge
Fairbanks (USD)	$3	$0.02	$0.21	$0.06	$17.50	---	--	---
Calgary	$3.60	$0.02	$0.10	$0.03	$13.01	$0.21	$0.01	$24.79
Edmonton	$3.41	$0.02	$0.10	$0.03	$22.57	$0.21	$0.01	$29.32
Halifax	$3.86	$0.03	$0.17	$0.05	$10.83	$0.93	$0.03	$21.87
Montreal	$4.20	$0.03	$0.08	$0.02	$12.36	$0.60	$0.02	$14.01
Ottawa	$3.94	$0.03	$0.15	$0.04	$14.07	$0.32	$0.01	$20.00
Vancouver	$4.54	$0.03	$0.10	$0.03	$5.58	$0.51	$0.01	$11.83
Winnipeg	$3.56	$0.02	$0.08	$0.02	$7.57	$0.30	$0.01	$14.00

Table 4. Annual Energy Costs of BrHEAThe Systems Based on ASHP Type and Location.

Estimated Annual Fuel Cost (CAD)						
	BrHEAThe Systems with Heat Pump			BrHEAThe Systems without Heat Pump		
City	Chiltrix	Ecologix	Sanden	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	$694.25	$691.23	$577.92	$301.50	$1,366.53	$1,394.37
Edmonton	$735.68	$711.47	$623.67	$301.50	$1,294.61	$1,394.37
Halifax	$1,088.25	$1,135.84	$882.29	$1,352.60	$1,602.14	$2,420.81
Montreal	$579.68	$574.46	$484.36	$873.93	$1,743.50	$1,156.38
Ottawa	$1,105.91	$1,091.79	$926.33	$461.93	$1,633.55	$2,190.12
Vancouver	$606.18	$660.16	$480.61	$745.96	$1,884.87	$1,484.90
Winnipeg	$719.99	$654.63	$637.05	$437.47	$1,476.48	$1,153.46

Estimated Annual Fuel Cost (USD)						
	BrHEAThe Systems with Heat Pump			BrHEAThe Systems without Heat Pump		
City	Chiltrix	Ecologix	Sanden	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	$521.99	$519.73	$434.53	$226.69	$1,027.47	$1,048.40
Edmonton	$553.14	$534.94	$468.92	$226.69	$973.39	$1,048.40
Halifax	$818.23	$854.01	$663.38	$1,016.99	$1,204.61	$1,820.16
Montreal	$435.85	$431.92	$364.18	$657.09	$1,310.90	$869.46
Ottawa	$831.51	$820.90	$696.49	$347.32	$1,228.23	$1,646.70
Vancouver	$455.78	$496.36	$361.36	$560.87	$1,417.19	$1,116.47
Winnipeg	$541.35	$492.20	$478.99	$328.93	$1,110.14	$867.26

A cost analysis was performed for each heat pump at each Canadian location. Tables 5 through 7 summarize the annual energy cost savings of using each ASHP compared to various fuel types.

Table 5. Annual Energy Savings of using BrHEAThe Systems Based with a Chiltix ASHP based on Fuel Type and Location.[4]

Estimated Annual Fuel Savings of using Chiltrix ASHP (CAD)			
	BrHEAThe Systems without Heat Pump		
City	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	($392.75)	$672.28	$700.13
Edmonton	($434.18)	$558.93	$658.70
Halifax	$264.35	$513.89	$1,332.56
Montreal	$294.25	$1,163.82	$576.70
Ottawa	($643.98)	$527.65	$1,084.21
Vancouver	$139.78	$1,278.69	$878.72
Winnipeg	($282.52)	$756.49	$433.47

Estimated Annual Fuel Savings of using Chiltrix ASHP (USD)			
	BrHEAThe Systems without Heat Pump		
City	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	($295.30)	$505.48	$526.41
Edmonton	($326.45)	$420.25	$495.26
Halifax	$198.76	$386.38	$1,001.93
Montreal	$221.24	$875.06	$433.61
Ottawa	($484.19)	$396.73	$815.20
Vancouver	$105.10	$961.42	$660.69
Winnipeg	($212.42)	$568.79	$325.92

Table 6. Annual Energy Savings of using BrHEAThe Systems Based with an Ecologix ASHP based on Fuel Type and Location.

Estimated Annual Fuel Savings of using Ecologix ASHP (CAD)			
	BrHEAThe Systems without Heat Pump		
City	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	($389.74)	$675.29	$703.14
Edmonton	($409.97)	$583.14	$682.91
Halifax	$216.76	$466.30	$1,284.97
Montreal	$299.47	$1,169.04	$581.92
Ottawa	($629.86)	$541.76	$1,098.32
Vancouver	$85.80	$1,224.71	$824.74
Winnipeg	($217.15)	$821.85	$498.84

Estimated Annual Fuel Savings of using Ecologix ASHP (USD)			
	BrHEAThe Systems without Heat Pump		
City	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	($293.03)	$507.74	$528.68
Edmonton	($308.25)	$438.45	$513.46
Halifax	$162.98	$350.60	$966.14
Montreal	$225.16	$878.98	$437.54
Ottawa	($473.58)	$407.34	$825.81
Vancouver	$64.51	$920.84	$620.11
Winnipeg	($163.27)	$617.93	$375.06

Table 7. Annual Energy Savings of using BrHEAThe Systems Based with a Sanden ASHP based on Fuel Type and Location.

Estimated Annual Fuel Savings of using Sanden ASHP (CAD)			
	BrHEAThe Systems without Heat Pump		
City	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	($276.42)	$788.61	$816.46
Edmonton	($322.17)	$670.94	$770.71
Halifax	$470.31	$719.85	$1,538.52
Montreal	$389.57	$1,259.15	$672.02
Ottawa	($464.40)	$707.22	$1,263.78
Vancouver	$265.35	$1,404.25	$1,004.29
Winnipeg	($199.58)	$839.43	$516.41

Estimated Annual Fuel Savings of using Sanden ASHP (USD)			
	BrHEAThe Systems without Heat Pump		
City	Natural Gas 95% Boiler	Oil 95% Boiler	Electric Resistance
Calgary	($207.83)	$592.94	$613.88
Edmonton	($242.23)	$504.47	$579.48
Halifax	$353.62	$541.24	$1,156.78
Montreal	$292.91	$946.73	$505.28
Ottawa	($349.18)	$531.74	$950.21
Vancouver	$199.51	$1,055.83	$755.10
Winnipeg	($150.06)	$631.15	$388.28

Conclusions

This report details the concept-level evaluation of the BrHEAThe System that includes an ASHP. At this stage of development some of the technological questions have been answered and a preliminary cost analysis has verified the concept is feasible in multiple locations; however, there are more questions to resolve before a more final design is developed.

Based on our analysis, the systems that use Sanden heat pumps consistently have the highest annual savings when compared to the Chiltrix or the Ecologix heat pumps. However, the Sanden heat pump is only capable of heating and is inappropriate for homes that have a cooling load. For regions with cooling loads, the systems that use the Ecologix and Chiltrix heat pumps provide approximately the same annual savings over systems without supplementary boiler heating systems. The cost analysis does not include domestic hot water load.

[4] CAD and USD conversions are based on the exchange rate of $1 USD = $1.33 USD as of 31 March 2017.

Due to the low cost of natural gas, none of our analyses calculated any savings in natural gas-supplied regions by incorporating an ASHP into a BrHEAThe System. However, in most regions in Canada, the ASHP produced a net savings of $450-1300/year in regions that use electric resistance heating or heating oil for heating. The savings for these units based on location are best described by Tables 5 through 7.

The technology in cold climate heat pumps is improving rapidly. It is possible that the ductless mini-spilt technology will meet the needs of this system in the next year (the current models require rewiring in the main components to work properly). It would be worthwhile to engage with cold climate ductless manufactures and keep informed of improvements in that technology, as the ductless have better cold climate performance than the current ASHPs.

In addition to watching for technology improvements, more detailed cost analysis that takes into account the hourly outdoor temperature as a function of the ASHP efficiency would be useful. NRCan has suggested creating a model of the system (using hourly data) that can be used to create a performance map of locations where it would be most cost effective. A performance map or a simpler cost calculator for different locations would be a good next step for determining the cost feasibility of the design. At the very least, CCHRC would like to expand the cost analysis beyond Fairbanks to other Alaskan communities with very different energy costs.

Efficiency analysis of the system is another important next step to further the design. CCHRC is planning efficiency testing of an older BrHEAThe System installation this coming year that could help to inform the efficiency analysis.

Appendix

The Excel tables for the cost comparisons are attached to this document