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Assessment of a solar assisted air source and a solar assisted water source heat pump system in a Canadian household

Martin Kegel[a]*, Justin Tamasauskas[a], Roberto Sunye[a], Antoine Langlois[a]

[a]NRCan-CanmetENERGY-Varennes, 1615 Lionel Boulet, Varennes, QC, Canada

Abstract

This paper presents an assessment of two solar assisted heat pump systems integrated into an air distribution system in three different 210 m² single detached residential houses in Montreal, Canada. The housing types considered are a 1980's house, an energy efficient house and a "net zero ready" house. The advanced heat pump systems considered in the analysis focused on coupling solar energy on the evaporator side of an air source and water source heat pumps to improve performance compared to a standard air source heat pump and provide an alternative to a costly ground source heat pump system. The annual energy consumption and utility cost of the solar assisted heat pump systems were compared to a market available air source heat pump, a ground source heat pump system as well as the typical reference housing heating and cooling system. The results predicted that a solar assisted air source heat pump has a comparable capital cost to a ground source heat pump system in all housing types and the highest energy savings for a "net zero ready" house of 34% compared to the base case. The solar assisted water source heat pump did not yield interesting results, as the solar assisted air source heat pump demonstrated improved energy savings and lower capital costs in all housing types considered. Comparing the 20 year life cycle costs of the solar assisted heat pump systems to the base case, only in the 1980's housing archetype did the solar assisted air source heat pump system demonstrate a lower life cycle cost than the base case. A standard air source heat pump yielded the lowest life cycle cost in the 1980's and energy efficient house considered and the reference base case system had the lowest life cycle cost in the net zero ready house considered.

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Keywords: Solar assisted heat pump; cold climate; air source heat pump, water source heat pump; annual building simulation

* Martin Kegel. Tel.: +1-450-652-5187; fax: +1-450-652-5177.
E-mail address: mkegel@nrcan.gc.ca.

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1. Introduction

In Canada, the residential sector accounts for 16% of the secondary energy consumption of which 83% can be attributed to space heating, space cooling and DHW production [1]. Heat pumps are widely used to upgrade free heat from renewable energy sources and can provide a dramatic reduction in energy consumption and ultimately on homeowner utility costs. The use of solar thermal energy in combination with a heat pump system is becoming increasingly popular with over 95 different commercial systems available on the European market [2]. However, many of the proposed systems use water based distribution systems, a method not widely used in the North American market.

Integrating solar assisted heat pump (SAHP) systems into air based distribution systems has been studied in the past. White et al. [3] presented an analysis of two solar assisted systems where the solar thermal energy assisted the heat pump by directly serving the heating load. Bernier et al. [4] have evaluated systems using solar thermal energy indirectly to meet the heating load, by assisting the evaporator side of a ground source heat pump (GSHP) system. In cases where GSHPs may not be feasible, little has been presented in coupling solar thermal collectors with the evaporator side of an air source heat pump (ASHP) or a water source heat pump (WSHP). Furthermore, limited analysis has been performed of SAHP systems on annual building load simulations. The purpose of this paper is to present, evaluate, compare and perform a life cycle cost assessment of two SAHP systems using solar energy on the evaporator side of the heat pump in an annual residential building energy model.

To perform the assessment, an energy model of a detached single family home located in Montreal, Canada was developed using the TRNSYS v. 17 simulation tool. Montreal was selected because of its cold winters, warm summers and use of electricity as a primary heating energy. TRNSYS was selected as the simulation tool because of its strength in modeling non-standard HVAC systems such as solar assisted heat pumps. To determine the impact of different building heating loads on a solar assisted heat pump system, three housing types were assessed making changes to the building envelope and HVAC system of the selected housing type. Changes were done to reflect a typical 1980's house, a newly designed energy efficient house and a home considered to be "net zero ready" (NZR).

2. Energy model development and validation

The housing models developed for this analysis were based on the Canadian Centre for Housing Technology (CCHT) twin research houses constructed in Ottawa, Ontario [5]. Characteristics and features of these test houses can be found in a research report by Swinton et al. [6]. The CCHT research houses were selected as the archetype because of the available detailed construction information and measured performance data for the energy model validation.

The validation housing model was modeled in TRNSYS v. 17 using the multizone building component (Type 56a). Heating, cooling and ventilation were controlled and modeled in the simulation studio using standard TRNSYS components. The energy model was validated by comparing the predicted energy consumption, temperature and relative humidity to the recorded 2003 data set of the CCHT house. The model results were typically within 10% of the measured data. Further information on the energy model validation can be found in a paper by Kegel et al. [7].

3. Definition of the base case housing models

Three housing construction types were considered in this analysis - a typical 1980's house, a newly constructed energy efficient house and a house considered to be "net zero ready".

To have an accurate representation of a typical Montreal single detached 1980's house, the Canadian Single-Detached and Double/Row Housing Database [8] was consulted. The database was filtered for single detached houses in the Montreal, Quebec region constructed between 1980 and 1989 in which 100% of the houses used electricity as the primary heating energy.

Characteristics of the newly designed energy efficient house were selected based upon meeting the minimum requirements to achieve an EnerGuide Rating System [9] (ERS) of 80 with a typical electrical baseboard heating system.

A NZR home is defined as a house which has an infrastructure and building envelope in which the addition of renewables becomes cost effective to achieve "Net Zero Energy" (a house which produces as much energy as it consumes annually). For this analysis a NZR house is considered to meet a rating of 86 on the ERS scale [10].

Table 1 summarizes the key characteristics of each housing type.

Table 1. Key Characteristics of the defined base case housing models

Property/Characteristic	1980's house	ERS-80 house	ERS-86 house
Roof RSI value	4.81 (m²·°C)/W	6.76 (m²·°C)/W	8.93 (m²·°C)/W
Wall RSI value	2.80 (m²·°C)/W	3.41 (m²·°C)/W	5.46 (m²·°C)/W
Basement wall RSI value	1.83 (m²·°C)/W	3.50 (m²·°C)/W	4.95 (m²·°C)/W
Basement slab	Uninsulated	Uninsulated	2.58 (m²·°C)/W
Overall window u-value	2.92 W/(m²·°C)	1.99 W/ (m²·°C)	1.29 W/(m²·°C)
Heating system	Electric Baseboard	Electric Baseboard	Electric Baseboard
Cooling system	Split System Rated COP = 2.93	Split System Rated COP = 3.45	Split System Rated COP = 3.45
DHW	Electric	Electric	Electric
Ventilation	None	Heat Recovery Ventilator 0.84 effectiveness 31 L/s (65 cfm)	Heat Recovery Ventilator 0.84 effectiveness 31 L/s (65 cfm)
Air leakage	5.9 ACH @ 50Pa	1.5 ACH @ 50Pa	0.75 ACH @ 50 Pa

Major appliances were assumed to consume the average 1990 EnerGuide energy consumption values (14 kWh/day) [11] in the 1980's house, while the energy efficient and NZR houses were assumed to have EnergyStar appliances installed (6.6 kWh/day). The major appliance schedules were modeled having the same operating schedule simulated in the CCHT test houses. Receptacle loads (small appliances) were assumed to consume and operate according to the EnerGuide Rating System levels (3.0 kWh/day) in all housing types and lighting was assumed to draw 0.7 kWh/day assuming compact fluorescent light fixtures and the same CCHT simulated operating schedule. A daily hot water draw schedule of 233 L was also maintained from the CCHT house. Heating and cooling systems were sized and controlled to meet a 21°C and 23°C set point temperatures, respectively.

4. Base case energy consumption and utility costs

To perform a life cycle cost, the electricity rates for the Montreal region, which are one of the lowest across Canada, were taken from Hydro Quebec [12]. The electricity rates are 5.39 cents/kWh for the first 30 kWh/day and 7.51 cents/kWh thereafter. The daily charge of 40.64 cents was not included in the analysis, since this is a constant cost across all measures considered.

The predicted energy consumption and utility costs of the three reference housing models evaluated is summarized in Table 2. The TRNSYS simulation was run with the Montreal TMY2 weather file and a simulation timestep of 5 or 15 minutes depending on the system.

Table 2. Predicted energy consumption and utility costs for the three reference housing models

Annual energy use	1980's house	ERS-80 house	ERS-86 house
Lighting, appliances & receptacles (kWh)	7,203	4,476	4,476
HRV fans (kWh)	0	964	964
Space cooling (kWh)	1,038	806	1,302
DHW heating (kWh)	4,928	4,728	4,729
Space heating (kWh)	26,814	15,413	7,915
Annual energy consumption (kWh)	39,982	26,387	19,385
Annual utility cost ($, CDN)	$2,778.85	$1,758.08	$1,229.69

5. Base case air source heat pump and ground source heat pump systems

To compare how the proposed solar assisted heat pump systems compare to traditional heat pump systems the base case housing energy models were retrofitted with an ASHP and a GSHP system. An ASHP utilizes the energy available in the outdoor air, upgrading low grade heat for heating through an outdoor unit serving the refrigerant-air coil located indoors. In cooling mode, the ASHP operates in reverse, transferring the low grade heat from indoors to the outdoors. The GSHP operates under the same principle, however uses the available energy stored in the ground to meet the heating demand. Similarly, the ground is used as a sink during the summer, when low grade heat is rejected back to the ground.

5.1. Air source heat pump (ASHP)

The 1980's house model was retrofitted with a multi-split ASHP system. The multi-split ASHP was selected to reduce installation costs, since the 1980's house has no ductwork. The proposed system has two indoor units (one for each floor level) for heating and cooling and one outdoor unit. Electric baseboard heaters are used to meet the heating load when the ASHP is unable to maintain comfort conditions. Simulating various discrete heat pump sizes in the energy model, it was found a 2-ton air source heat pump would provide the lowest life cycle cost.

For the ERS-80 and ERS-86 energy models, the existing ductwork for the HRV was enlarged and a central heating and cooling system was incorporated with an ASHP system. The ductwork was enlarged because of the increased airflow in the central distribution system. A back-up electric duct heater is also installed to ensure comfort conditions are maintained when the ASHP is unable to meet the heating load. Similar to the 1980's house, the 20 year utility cost was estimated for various discrete heat pump sizes, and a 1.5 ton system was determined to have the lowest life cycle cost.

5.2. Ground source heat pump (GSHP)

The GSHP systems were retrofitted into a central system in each of the housing archetypes. The HRV ducting was increased in size to accommodate the central distribution system, and new ducting was installed in the 1980's house. The GSHP size and borehole lengths summarized in Table 3 were estimated to meet the required heating loads of each house.

Table 3. GSHP size and borehole length for each housing archetype

GSHP details	1980's house	ERS-80 house	ERS-86 house
GSHP size (ton)	4	2.5	1.5
Total borehole length (m)	180	101	58
No. of ground heat exchangers	2	1	1

5.3. ASHP and GSHP energy consumption and utility cost results and discussion

Using the developed TRNSYS energy models with the ASHP and GSHP system incorporated, the annual energy consumption and utility costs were predicted. Table 4 summarizes the results.

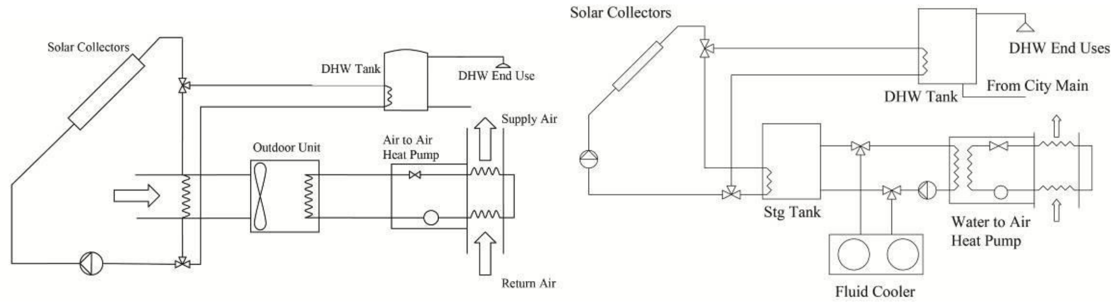
Table 4. Predicted energy consumption and utility costs for the reference ASHP and GSHP systems

Reference Case	Annual energy consumption and percent savings over base case		Annual utility cost ($, CDN) and percent savings over base case	
1980's – ASHP (2 ton)	28,150 kWh	(29.5%)	$1,889.84	(32.0%)
ERS-80 – ASHP (1.5 ton)	20,643 kWh	(21.8%)	$1,325.60	(24.6%)
ERS-86 – ASHP (1.5 ton)	15,869 kWh	(18.1%)	$966.41	(21.4%)
1980's – GSHP (4 ton)	19,609 kWh	(51.0%)	$1,246.69	(55.1%)
ERS-80 – GSHP (2.5 ton)	16,903 kWh	(35.9%)	$1,042.67	(40.7%)
ERS-86 – GSHP (1.5 ton)	14,079 kWh	(27.4%)	$831.55	(32.4%)

As anticipated, substantial energy consumption and utility cost savings are achieved by replacing the baseboard heaters with heat pump systems. The most promising results are seen in the 1980's house where by installing a 4 ton GSHP system, energy savings over 50% can be attained with 55% energy cost savings. Less energy and utility cost savings are found with high efficient housing designs where results predict a 1.5 ton GSHP system has just over 27% annual energy savings and over 32% energy cost savings. This is expected as the heat pump systems address the heating load, which declines as the building heating load decreases. The ASHP systems demonstrate a similar trend; however without the same level of percentage energy savings.

6. Solar assisted air source heat pump and solar assisted water source heat pump concepts

Standard ASHP systems demonstrate a significant drop in their coefficient of performance (COP) and/or capacity when ambient temperatures drop below 5°C. As such, ASHPs are often not a suitable option in the colder Canadian climate; however being a mature technology ASHPs do not exhibit a substantially high incremental cost, compared to the base case. Using earth energy, GSHP systems maintain their capacity and COP throughout the cold season, resulting in improved performance compared to an ASHP system. However, GSHP systems require a ground heat exchanger, which can be expensive and potentially not feasible. To overcome the degradation in ASHP performance and associated cost and size of a GSHP system, two advanced heat pump systems are evaluated, where solar energy is coupled to the evaporator side of an air source and water source heat pump incorporated into an air distribution system common in North America. A schematic of each system is shown below (Fig. 1).



(a) (b)

Fig. 1. (a) Solar assisted air source heat pump layout (b) Solar assisted water source heat pump layout

6.1. Solar assisted air source heat pump (SA ASHP) concept

The objective of this concept (Fig. 1a) is to reduce the temperature difference across the evaporator and condenser of an air to air heat pump through the use of solar energy, thereby improving the system performance and heating capacity at lower ambient temperatures. Solar collectors mounted on the south facing roof heat the circulating fluid, preheating the ambient air through the outdoor unit during heating mode. The circulating pump is controlled to operate when heat gain from the solar collector is available. In the event the ASHP is not in operation, the circulating fluid is diverted to the DHW storage tank used to preheat the DHW for the household. An electric heater ensures DHW is maintained at adequate temperatures. When the ASHP is unable to meet the heat demand of the house, the electric baseboard heaters are controlled to meet comfort conditions in the 1980's house (2 ton multi-split ASHP system) and electric duct heaters in the ERS-80 and ERS-86 house (1.5 ton central heating and cooling ASHP).

6.2. Solar assisted water source heat pump (SA WSHP) concept

The objective of this concept (Fig. 1b) is to investigate the feasibility of using solar energy to drive a water to air heat pump instead of using a ground heat exchanger which can be expensive or a traditional ASHP system which is inefficient in cold climates. Similar to the SA ASHP, solar collectors mounted on the south facing roof inject heat into a storage tank located on the evaporator side of the heat pump. The solar collector circulation pump is controlled to operate when heat gain from the solar collector is available and there is a storage capacity for heat. The 1,000 liter (L) storage tank on the evaporator side of the heat pump is maintained up to 45°C, with any additional solar heating used to offset the DHW load. In the event the evaporator side storage tank falls below 5°C and there is a demand for heat, the heat pump is stopped and an electric duct heater is activated to maintain comfort conditions. In cooling mode, heat is rejected through a fluid cooler and any solar heating is used to meet the DHW load. The DHW tank has an electric heater to ensure adequate DHW temperatures are attained.

6.3. Solar assisted heat pump energy consumption and utility cost results and discussion

Using the developed TRNSYS models, the annual energy consumption and utility costs were estimated. To assess the impact on solar collector sizing, parametric runs were conducted for each household, setting the solar collector equal to the entire south facing roof area (8 panels at 3.44 m² each) (Table 5) and half the south facing roof area (4 panels at 3.44 m² each) (Table 6).

Table 5. Predicted energy consumption and utility costs for the SA HP systems with 8 solar collector panels and 1,000 L tank

Scenario with 8 solar collector panels and 1,000 L tank	Annual energy consumption and percent savings over base case		Annual utility cost ($, CDN) and percent savings over base case	
1980's – SA ASHP (2.0 ton)	25,387 kWh	(36.5%)	$1690.09	(39.2%)
ERS-80 – SA ASHP (1.5 ton)	17,281 kWh	(34.5%)	$1,099.29	(37.5%)
ERS-86 – SA ASHP (1.5 ton)	12,149 kWh	(37.3%)	$718.37	(41.6%)
1980's – SA WSHP (4.0 ton)	28,181 kWh	(29.5%)	$1,887.92	(32.1%)
ERS-80 – SA WSHP (2.5 ton)	19,127 kWh	(27.5%)	$1,214.37	(30.9%)
ERS-86 – SA WSHP (1.5 ton)	12,884 kWh	(33.5%)	$765.77	(37.7%)

Table 6. Predicted energy consumption and utility costs for the SA HP systems with 4 solar collector panels and 1,000 L tank

Scenario with 4 Solar Collector Panels and 1,000 L Tank	Annual energy consumption and percent savings over base case		Annual utility cost ($, CDN) and percent savings over base case	
1980's – SA ASHP (2.0 ton)	25,878 kWh	(35.3%)	$1,726.21	(37.9%)
ERS-80 – SA ASHP (1.5 ton)	17,874 kWh	(32.3%)	$1,142.20	(35.0%)
ERS-86 – SA ASHP (1.5 ton)	12,731 kWh	(34.3%)	$759.21	(38.3%)
1980's – SA WSHP (4.0 ton)	32,623 kWh	(18.4%)	$2,221.55	(20.0%)
ERS-80 – SA WSHP (2.5 ton)	21,798 kWh	(17.4%)	$1,405.99	(20.0%)
ERS-86 – SA WSHP (1.5 ton)	14,636 kWh	(24.5%)	$891.23	(27.5%)

The amount of solar collectors had a minimal impact on the SA ASHP system as there is a minimal improvement in energy savings when compared to the reference case. The solar collector coverage had a much greater impact on the SA WSHP system, where an improvement of up to 11% energy savings is predicted with a fully covered roof compared to the base case.

Comparing the percent energy savings over the base case, the SAHP systems do not display the same trend as the standard ASHP and GSHP systems assessed. The ASHP and GSHP systems have a declining percentage energy savings as the building heating load decreases, since the heat pumps are addressing the space heating needs. For the SAHP systems, a similar trend is observed in the reduced percentage savings with the heating load; however the overall percentage energy savings does not decline as steeply and increases for the ERS-86 house, which is attributed to the fact that the solar collectors meet a portion of the DHW load. As a result, the SA ASHP displayed the highest energy savings for the ERS-86 house of all systems assessed.

The SA WSHP system did not demonstrate the same potential in energy savings as the SA ASHP. This occurred since the SA WSHP system is stopped when the storage tank temperature falls below 5°C and the back-up heating system is used to meet the heating load. With the SA ASHP system, the heat pump operates until it is no longer beneficial to operate the unit (COP < 1.0) and thus operates much more frequently than the WSHP. To increase the operating period of the SA WSHP system, an analysis was also performed on using an antifreeze circulating fluid by allowing the tank temperature to fall to -20°C. It was found however that the additional energy savings allowing the heat pump to operate at a lower evaporator temperature was unable to overcome the capital cost of the circulating fluid. A parametric run was also conducted on increasing the evaporator side storage tank volume to increase the operating period the SA WSHP system. The results are summarized in Table 7.

Table 7. Predicted energy consumption and utility costs for the SA WSHP systems with 8 panels and 10,000 L tank

Scenario with 8 solar collector panels and a 10,000 L tank	Annual energy consumption and percent savings over base case		Annual utility cost ($, CDN) and percent savings over base case	
1980's – SA WSHP (4.0 ton)	31,707 kWh	(20.7%)	$2,152.70	(22.5%)
ERS-80 – SA WSHP (2.5 ton)	19,853 kWh	(24.8%)	$1,267.95	(27.9%)
ERS-86 – SA WSHP (1.5 ton)	12,925 kWh	(33.3%)	$770.18	(37.4%)

The results of increasing the storage tank volume did not predict any improvement in energy savings as anticipated. In fact an increase in energy consumption occurred as the WSHP operated less. It was found that through the control strategy, the WSHP stops when the tank temperature falls below 5°C and only restarts when the tank goes above 7.2°C. As a result, with an increased tank volume, it takes the 10,000 L tank longer to go above 7.2°C than the 1,000 L tank and as a result the WSHP operates less. In order to improve the system performance an increased number of solar panels would be required. An analysis using antifreeze in the 10,000 L tank was not performed.

7. Life cycle cost analysis

All of the heat pump systems assessed have demonstrated energy savings and utility cost savings compared to the modeled reference base case housing results. To determine, whether these systems are economically viable, a life cycle cost (LCC) analysis is performed comparing the system capital costs and utility costs over a 20 year period. An assumed inflation rate of 3%, discount rate of 6% and an electricity escalation rate of 0.4% is assumed [13]. For the 1980's house, it is assumed all equipment is due for replacement and the ERS-80 and ERS-86 houses are newly constructed.

7.1. Capital costs

Capital costs were obtained for each system on a component basis, and included both equipment and installation costs. Pricing for each system included all necessary ductwork and piping modifications based on data obtained from RS Means [14]. The cost of all required controllers was also included using data from manufacturer representatives [15] and RS Means. The capital cost of the base case included the baseboard heaters and air conditioner. The final price of each component was obtained using data from RS Means. The capital costs for the ground source system included the borehole drilling costs, WSHP, and circulation pumps. Drilling costs were estimated at $60/m for boreholes longer than 60 m, and $100/m for boreholes less than 60 m [16]. Costing for the heat pump and circulation pumps was based on data obtained from RS Means and component manufacturers [17]. Pricing for each of the two solar systems included the cost of the heat pumps, circulation pumps, fluid cooler, storage tanks and solar collectors. The price of each ASHP was based on a survey of HVAC contractors, while the cost of the WSHPs was obtained from RS Means. The pricing for the circulation pumps [17], solar collectors and storage tanks [18] were obtained from manufacturer representatives, while the price of the fluid cooler was obtained from RS Means.

7.2. Life cycle cost analysis results and discussion

The following table (Table 8) summarizes the associated capital cost, 20 year utility costs and 20 year life cycle costs for the various layouts presented. For the discrete ASHP sizes evaluated, only the heat pump with the lowest determined life cycle cost is presented. The results of the fully covered solar collector roof for the SA ASHP and 10,000 L storage tank SA WSHP are not shown because no significant savings were identified between a less costly system with the same operating strategy.

Table 8. Life cycle cost analysis of all systems assessed in the 1980's, ERS-80 and ERS-86 housing archetypes

1980's Archetype Costs	Base Case	ASHP	GSHP	SA ASHP (4 solar coll.)	SA WSHP (8 solar coll.)	SA WSHP (4 solar coll.)
Capital cost ($,CDN)	$9,305	$12,662	$28,579	$20,590	$37,197	$31,748
20 year utility cost ($, CDN)	$32,330	$21,987	$14,504	$20,083	$21,965	$25,846
20 year life cycle cost ($, CDN)	$41,636	$34,649	$43,084	$40,673	$59,162	$57,594

ERS-80 Archetype Costs	Base Case	ASHP	GSHP	SA ASHP (4 solar coll.)	SA WSHP (8 solar coll.)	SA WSHP (4 solar coll.)
Capital cost ($,CDN)	$8,858	$11,659	$18,315	$19,587	$30,873	$25,424
20 year utility cost ($, CDN)	$20,454	$15,423	$12,131	$13,289	$14,128	$16,358
20 year life cycle cost ($, CDN)	$29,312	$27,082	$30,446	$32,876	$45,002	$41,782

ERS-86 Archetype Costs	Base Case	ASHP	GSHP	SA ASHP (4 solar coll.)	SA WSHP (8 solar coll.)	SA WSHP (4 solar coll.)
Capital cost ($,CDN)	$7,505	$10,803	$15,177	$18,731	$27,629	$22,180
20 year utility cost ($, CDN)	$14,307	$11,244	$9,675	$8,833	$8,909	$10,369
20 year life cycle cost ($, CDN)	$21,811	$22,046	$24,851	$27,564	$36,538	$32,549

Comparing the life cycle costs of both SA HP systems, the SA ASHP had the lowest life cycle cost in all housing types considered. This is expected, since the SA WSHP system has a higher capital cost because of the added storage tank and fluid cooler and higher 20 year utility cost since the WSHP does not operate when the tank temperature falls below 5°C.

Comparing the SA ASHP system to a GSHP system, the SA ASHP has a lower 20 year life cycle cost in 1980's house. The 20 year utility cost savings of the GSHP system are unable to overcome the higher capital cost of the longer borehole length required to meet the housing heating load. As the heating load decreases, the GSHP system demonstrates a better 20 year life cycle cost than the SA ASHP because of the reduced capital cost (smaller borehole length) and lower 20 year utility costs. For the ERS-86 housing archetype, the SA ASHP added energy savings by reducing the DHW heating load was unable to overcome the system higher capital cost associated with the solar collectors.

Comparing the SA ASHP to the standard ASHP system, the lower 20 year utility costs are unable to overcome the higher capital cost of the solar collectors in all housing types. As a result, the standard ASHP system is found to be the most economically viable option of all heat pump systems assessed in all three housing types. Comparing the standard ASHP system to the base case heating and cooling systems, the standard ASHP had a lower 20 year life cycle cost in 1980's and ERS-80 house; however its 20 year life cycle cost in the ERS-86 house was slightly above the base case as the ASHP has less of an impact on a reduced heating load. Although the heat pump systems analyzed presented significant energy savings compared to the base case, due to the low electricity rates, it was not enough to overcome their higher capital cost.

8. Conclusion

An assessment was performed on two SA HP systems, where solar energy was coupled to the evaporator side to improve system performance during the heating season. A SA ASHP pump was evaluated as well as a SA WSHP to compare which system would be best suited for the Montreal region. Using TRNSYS, annual simulations of the SA HP systems were run in three building archetypes – a typical 1980's house, an energy efficient house (ERS-80) and a "net zero ready" house (ERS-86). The annual energy and utility costs were compared to the reference case as well as a standard ASHP and GSHP system. The SA ASHP system exhibited the lowest annual energy consumption compared to the SA WSHP in all three housing types assessed. However, the SA ASHP system was only the most energy efficient for the ERS-86 housing type when compared with a GSHP system. Performing a life cycle cost analysis on the systems, the benefit of coupling solar energy to improve the heat pump performance was unable to overcome the high capital cost associated with these systems. The assessment concluded that the standard ASHP system had the lowest life cycle cost for the 1980's and ERS-80 house, and the base case for the ERS-86 house. Due to the low electricity rates in Quebec, the superior energy savings of the heat pump systems over the base case had difficulty to overcome the added capital costs associated with these systems. Different conclusions may result evaluating these systems in other Canadian provinces.

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