COMBINED SOLAR THERMAL AND GROUND SOURCE HEAT PUMP SYSTEM

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ABSTRACT

This document presents a study for examining the viability of hybrid ground source heat pump (GSHP) systems that use solar thermal collectors as the supplemental component in heating dominated buildings. Loads for an actual house in the City of Milton near Toronto were estimated. TRNSYS, a system simulation software tool, was used to model the yearly performance of conventional GSHP as well as the proposed hybrid GSHP system.

The house was equipped with data monitoring system which was installed to read and record fluid flow, temperature and electricity consumption in different components of the system. The actual yearly data collected from the site was examined against the simulation results. In addition, a sensitivity analysis has been carried out to determine the relationship between the solar collector area and the ground loop exchanger (GHX) length. It was shown that the ratio of GHX length reduction to solar panel area of 4.7 m/m^2, results the optimum ratio which corresponds to 32m GHX length reduction with $6.81m^2$ solar collectors area.

This study demonstrates that hybrid ground source heat pump system combined with solar thermal collectors is a feasible choice for space conditioning for heating dominated houses. It was shown that the solar thermal energy storage in the ground could reduce a large amount of ground loop heat exchanger length. Combining three solar thermal collectors with total area of $6.81m^2$ to the GSHP system will reduce GHX length by 15% (from 222m to 188m). The system malfunctioning in the cooling season was also detected and options for fixing the problem were presented. Sensitivity analysis was carried on different cities of Canada and results were demonstrated that Vancouver, with mildest climate compared to other cities, was the best candidate for the proposed solar hybrid GSHP system with 7.64 m/m^2 GHX length reduction to solar collector area ratio. Overall system economic viability was also evaluated using a 20-year life-cycle cost analysis. The analysis showed that there is small economic benefit in comparing to GSHP. The net present value of the proposed hybrid system and GSHP system were estimated to be $44,834 and $41,406 respectively.

INTRODUCTION

Geothermal applications for buildings are mostly limited to full dependence on ground soil temperature for 100% of the heating and cooling energy. Although there are the advantages of low energy and maintenance costs in favour of this approach, space limitations and high initial costs may restrict a full geothermal installation. Restrictive regulations such as mandating a minimum borehole size, grouting materials, wage rates and heat exchange method, generally increase the cost of such a system. The initial cost may put the project above the budget, and in some cases, the drilling conditions may prevent the use of a large conventional closed-loop borehole field [1, 2].

In many buildings, annually, the amounts of heat extracted from and injected into the ground are not balanced. The vertical closed loop is a common type of earth coupling mostly used in buildings that have limited land areas. In designing this type of system, consideration must be made of the thermal response of the ground throughout the expected project life (i.e., 25 years). An annual imbalance in ground load will lead to lower heat pump entering fluid temperatures (EFT) in heating-dominated buildings or higher heat pump EFTs in cooling-dominated buildings, to a point where equipment capacity may be compromised if the ground loop heat exchanger is not long enough. This imbalance requires either a very large ground loop heat exchanger or some mechanism for assisting the system by supplementing deficit heat or rejecting excess heat. Because the cost of installing a very large ground loop heat exchanger may be excessive, there are a number of alternate ways to assist a GSHP. These include solar collector, which injects additional heat into the ground for heating dominated buildings, and cooling tower, which rejects excess heat into the atmosphere for cooling dominated buildings [3]. Systems that incorporate both a ground heat exchanger and an aboveground heat exchanger are commonly referred to as hybrid GSHP. In hybrid systems, the peak heat pump EFT from year-to-year should be approximately equal. In this study, the system utilizes a solar thermal collector as an above-ground heat exchanger, called a solar assisted ground source heat pump (SAGSHP).

The purpose of this study was to evaluate the performance and viability of hybrid geothermal heat pump systems with solar thermal collectors. The main objective was to perform a system simulation approach to assess the feasibility of this kind of hybrid system in heating dominated buildings. An actual residential building was modelled and the results compared to actual data collected by monitoring the related operation of equipments through specific months. It would be ideal if this study attracts the interest of researchers and contractors and provides valuable information for designing and installing this kind of hybrid system in heating dominated buildings in Canada.

HOUSE MODEL DESCRIPTION

The house selected for the proposed study is located in the City of Milton, Ontario. The house was one of two energy efficient demonstration houses built by a local builder in 2005. It is a detached two-storey building having 5,360 ft^2 (498 m^2) of heated area including the basement with the following characteristics:

Construction: Light wood frame, 50×150mm (2”×6”) exterior wall construction installed on 610mm (24”) centers.

Insulation: Spray foam insulation for walls with RSI 3.6 (R20), RSI 7 (R40) attic insulation.

Windows: Low E/Argon filled with insulated spacers, Vinyl, RSI 0.38 (R2)

Occupant: Two adults and two children for 50% of time

Basement Flooring: Concrete floor, hydronic slab under heating, RSI 2.22 (R12).

As per builder specifications, the house temperature is set at 21°C and 24°C in the heating and cooling periods respectively. Air leakage at 50 Pa. is 1.41ACH (518 l/s) with an equivalent leakage area at 10 Pa. of 697 cm^2. A continuous ventilation of 0.3ACH (110 l/s) through heat recovery ventilation system (HRV) is also considered. The sensible internal heat gain from occupants is set to be 2.4 kWh/day. The occupancy of the house is two adults and two children for 50% of the time with a hot water consumption of 225 litres/day. The base loads are considered to be 22 kWh/day including lighting, appliances, exterior use and others.

TRNBuild [4], a component of the TRNSYS simulation software, was used to generate the house load profile. TRNBuild was developed as a part of TRNSYS for simulating multi-zone building. This component models the thermal behaviour of a building divided into different thermal zones. In order to use it, a separate pre-processing program must be first executed. The TRNBuild program reads in and processes a file containing the building description and then generates two files be used by TRNSYS simulation

To get the idea of the total house load in this section, internal TRNBuild equipment component characteristics are used and later in this study separate equipment components are externally linked to the house. It uses a simulation time step that may not be equal to the time base on which the wall transfer function relationships are based. Finally, the optical and thermal window model, the way in which solar and internal radiation are distributed within each zone, the moisture balance calculations and the integrated model for thermo-active walls are considered. Thermo-active building elements (slabs or walls of a building) are used to condition buildings by integrating a fluid system into massive parts of the building itself. An example is the radiant floor heating system used in the basement floor.

The climate of Toronto, Ontario (which is about 60km east of Milton) was chosen for this study.

For the purpose of comparison and validation, the house was also modelled with HOT2000 ver10.12 software developed by Natural Resources Canada [5].

HOT2000 is a simplified residential heat loss/gain analysis program widely used in North America by builders, engineers, architects, researchers, utilities and government agencies and by a number of users in Europe and Japan [5]. Utilizing current heat loss/gain and system performance models, the program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating and the operation and performance of heating and cooling systems. HOT2000 uses a bin based method and long term monthly weather files to analyze the performance of the house. HOT2000 is a three-zone model (attic, main floors and basement) which considers utilized solar and internal gains and heat transfer between zones when calculating loads. It also accounts for on and off cycling and part load factors when determining the performance of the heating system.

In TRNbuild the house was separated in three zones: 1- Basement, 2- First floor 3- Second floor. Maximum heating and cooling demand are 11.5 kW and 9.5 kW respectively. The house load results from HOT2000 are shown in Table 1. Comparing with TRNSYS results it can be seen that there is good agreement between two models. The differences between the two simulations are most likely attributed to the difference in analysis method between TRNSYS and HOT2000. As mentioned earlier TRNSYS is an hourly simulation program using the transfer function method, and HOT2000 uses the much simpler bin method.

Table 1: House Heating and Cooling Requirements

	TRNSYS	**HOT2000**
Total Heating Load (GJ)	**95**	**92**
Total Cooling Load (GJ)	**19**	**18.5**
Maximum Heating Demand (kW)	**11.5**	**17.6**
Maximum Cooling Demand (kW)	**9.5**	**9.4**

SAGSHP MODEL DESCRTIPTION

Figure 1 shows a schematic of the solar assisted ground source heat pump (SAGSHP) system. The system is constructed from the following major components:

1- Atlas AT060 ground source heat pump (GSHP) with a desuperheater [6].
2- Enerworks solar thermal collector with three panels [7].
3- Rheem 620T hot water tank [8].
4- Power pipe grey water heat recovery [9].
5- Venmar Vane 1.3HE heat recovery ventilator (HRV) [10]

The ground loop heat exchanger (GHX) system consists of four vertical closed loop circuits, joined in parallel. Each borehole has 0.25m (10") diameter and 55m (180ft) length. They are located 3.6m (12ft) apart from each other in the backyard and merge in a 1.8m (6ft) below grade area. Figure 2 shows this arrangment.

The GHX loop is connected in parallel to the solar thermal collectors. The solar collectors receive a percentage of the total flow from the ground loop exchanger. Two circulation pumps form part of the heat pump system and they are located upstream and down-stream of the GHX flow. A solenoid valve and a control valve control the flow rate to the solar collectors.

The heat pump is selected to suit the space heating requirements of the house for both radiant floor heating and forced air heating. The same heat pump provides cooling in the summer. The heat pump has a dedicated domestic hot water generation through the desuperheater with internally mounted pump. The hot water from the desuperheater loop flows into the water tank. Both the hot water tank and heat pump are equipped with auxiliary electric heaters. Domestic cold water is directed to the grey water heat recovery equipment and then sent to the hot water tank and/or desuperheater. Basement in-floor radiant heating is directly fed from the hot water tank and a dedicated pump included in the model boosts its flow pressure.

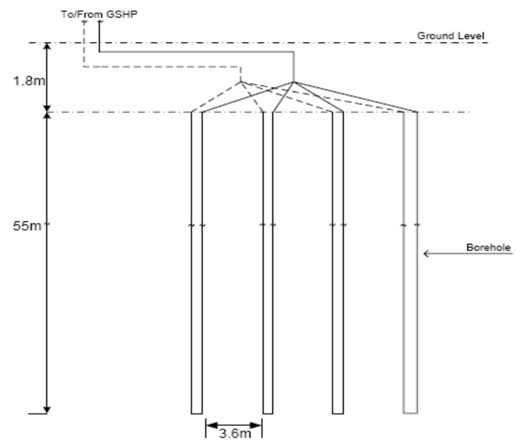

Figure 2: Ground loop borehole layout

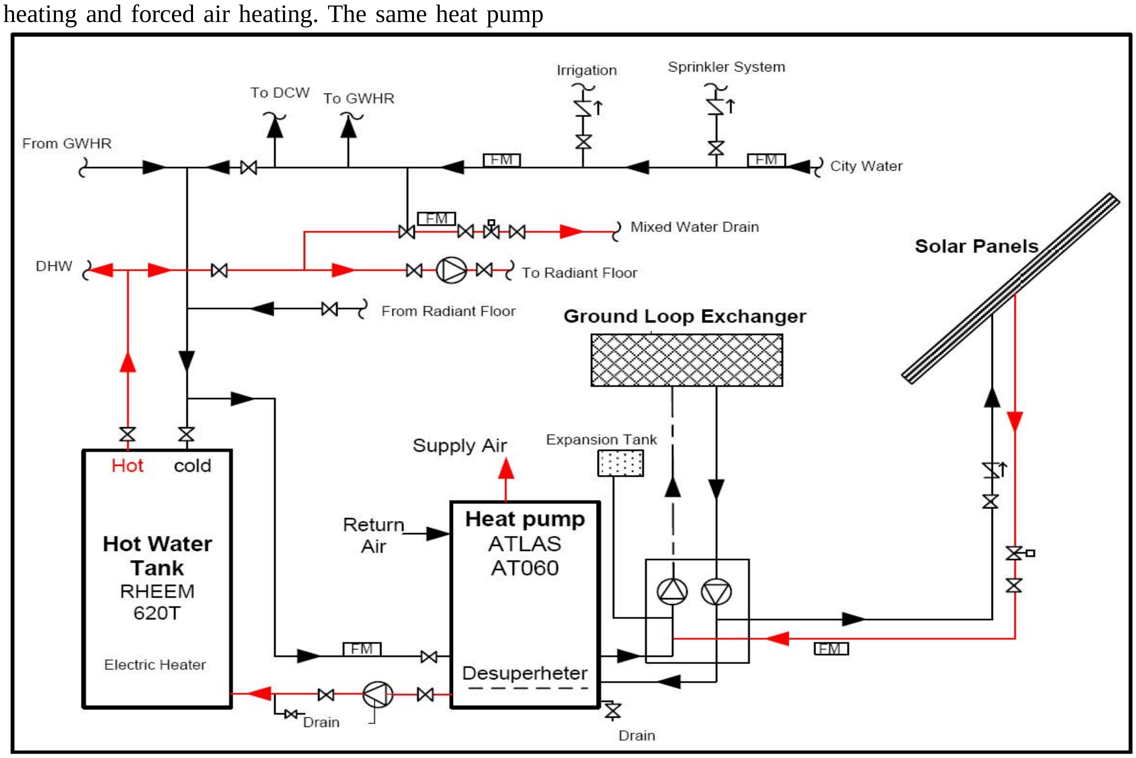

Figure 1: Schematic diagram of SAGSHP system configuration

The TRNSYS modelling environment (studio) was used to construct the system using standard and non-standard component models. The component models and their functions are each described as below:

Heat Pump Model

The selected component models a single-stage liquid source heat pump with desuperheater for hot water heating. The heat pump conditions a moist air stream by rejecting energy to (cooling mode) or absorbing energy from (heating mode) a liquid stream. The desuperheater is attached to a secondary fluid stream. In cooling mode, the desuperheater relieves the liquid stream from some of the burden of rejecting energy. However, in heating mode, the desuperheater requires the liquid stream to absorb more energy than required for space heating only. This heat pump model is intended for residential GSHP application [11]. The fluid in the GSHP exchanger loop is modelled as an aqueous solution of 50% propylene glycol [12] to avoid extreme freezing condition during winter, especially for the part that passes through the solar collectors.

Ground Loop Heat Exchanger Model

This component models the vertical GHX that interacts thermally with the ground. GSHP applications commonly use this GHX model. This subroutine models identical vertical U-tube GHX or identical vertical tube-in-tube heat exchangers. A heat carrier fluid is circulated through the GHX and either rejects heat to, or absorbs heat from the ground depending on the temperatures of the heat carrier fluid and the ground. In typical U-tube or tube-in-tube GHX applications, a vertical borehole is drilled into the ground. A U-tube or tube-in- tube heat exchanger is then pushed into the borehole. The top of the GHX is typically several feet below the surface. Finally, the borehole is filled with a fill material; either virgin soil or a grout of some type. The model assumes that the boreholes are placed uniformly within a cylindrical storage volume of ground. There is convective heat transfer within the pipes and conductive heat transfer to the storage volume. The temperature of the surrounding ground is calculated from three parts: a global temperature, a local solution, and a steady-flux solution. The global and local problems are solved with the use of an explicit finite-difference method. The steady-flux solution is obtained analytically. The resulting temperature is then calculated using superposition methods. This subroutine was written by the Department of Mathematical Physics at the University of Lund, Sweden, and is considered to be the state-of-the-art in dynamic simulation of ground heat exchangers [11, 13]. The volume of the cylindrical shaped storage region which contains the boreholes is estimated to be 2,470m^3, with the boreholes placed uniformly within the storage volume. The properties of the ground within the storage volume are considered uniform while the properties of the ground outside the storage volume may be described for several vertical layers. In this study, only one layer is considered because of insufficient ground soil information at site.

Solar Collector Model

This component models the thermal performance of a flat-plate solar collector. The solar collector array consists of three collectors connected in series. The number of modules in series and the characteristics of each module determine the thermal performance of the collector array. For this component, a second order quadratic function is used to compute the incidence angle modifier. The coefficients of the function are supplied by using the ASHRAE or equivalent test [11]. The manufacturer (Enerworks) provided the results from standard tests of collector efficiency versus a ratio of fluid temperature minus the ambient temperature to solar radiation. The fluid temperature is the average temperature of the inlet and outlet temperatures. In this component, there are five possibilities for considering the effects of off-normal solar incidence. In this instance, a second order quadratic function is used to compute the incidence angle modifier. The coefficients of the function are supplied by ASHRAE [14].

Water Tank Model

Stratified Storage Tank with variable inlets and uniform losses was selected for this component. The thermal performance of a fluid-filled sensible energy storage tank is subject to a thermal stratification that can be modelled by considering that the tank consists of N (N = 6) fully mixed equal volume segments as per manufacturer information data. Tank volume has been selected as 0.22m^3 (60 US gallons) with water density and specific heat. The specifications are correspond to equipment manufacturer; Rheem PRO620T. The heat source for the tank is a water loop from the heat pump desuperheater. The inlet location for this hot-side fluid is the node closest in temperature to that of the hot-side flow.

In-Floor Radiant Heating Model

Simple Floor Heating System/Radiant Floor is selected for the basement radiant slab heating. This component models a simple radiant slab system that operates under the assumption that the slab can be treated as a single lump of isothermal mass and the fluid to slab energy transfer can be modelled using a heat exchanger effectiveness approach. Surface heat transfer by free convection from the surface of the slab, is estimated to be 380 W/K.

Gray Water Heat Recovery Model

The grey water heat recovery system works on the principle of a gravity film exchanger, a mechanism that takes advantage of the ultra-high rates and thermal conductive properties of water film and copper. This system was installed to conduct the transfer of heat from drainage water to the incoming cold city water. The model considers scheduled hot water draw. The preheated water is then supplied to the hot water tank for further heating. Incoming cold water can get as much as 85% of the waste water (gray water) heat energy [9]. Heat exchanger with constant effectiveness is a simple choice from the TRNSYS modules to simulate grey water heat recovery component. In this module, a zero capacitance sensible heat exchanger is modelled as a constant effectiveness device which is independent of the system configuration. For the constant effectiveness mode, the maximum possible heat transfer is calculated based on the minimum capacity rate fluid and the cold side and hot side fluid inlet temperatures. In this mode the effectiveness is input as a parameter and the concept of an overall heat transfer coefficient for the heat exchanger is not used.

Ventilation Model

Air-to-air heat recovery is used for modelling ventilation to the house. In this model, the inputs are ambient temperature and relative humidity from the weather module, and indoor air temperature and relative humidity from the house. Since the system is a balanced system supply and return flow rates are the same.

Flow Control and Pump Component Model

Mixers, diverters and pumps are modelled using TRNSYS standard library component models. Controlled Flow Mixer is used in two places in the model: 1- for mixing return flows from the heat pump and solar panels and 2- for mixing grey water exchanger cold-side output flow with part of the return flow from the radiant slab. The control flow mixer is used for mixing two stream flows with different percentage of flow in each stream. Control flow diverter functions as the control flow mixer but in opposite direction. Tee piece is acting as a flow mixer without control. Single (constant) speed pump is selected for this model. It works as integral part of the heat pump for sending and receiving exchanger loop liquid to/from the ground. It is able to maintain a constant fluid outlet mass flow rate. Pump starting and stopping characteristics are not modelled, nor are pressure drop effects.

Heat Pump Equipment Control and Scheduling

Both seasonal and thermostat controls are used for the control of heat pump operation. The heating season is set from the first of October (6552 hr) to 30th of April (2880 hr) and cooling season from first of May (2881 hr) to 31st of September (6553 hr). The temperature is set back from 21°C to 19°C, in the heating mode, from 10pm to 8am. By utilizing cooling season and heating season controls plus forcing functions for heating set back, heat pump is switched from heating mode to cooling mode and vice versa when it is necessary.

DISCUSSION AND RESULTS

Optimum Flow to Solar Thermal Collectors

In the as-built system, the percentage of the ground loop flow rate divert to the solar collectors was studied using three different flow quantities. From the equipment manufacturer, the maximum acceptable flow rates to the heat pump and the three solar panels were determined to be 1173 kg/hr and 120 kg/hr, respectively. This means that the total maximum flow rate in the ground loop exchanger was the sum of the two, i.e., 1293 kg/hr. The maximum flow diversion from the ground loop was determined to be 10% of the total flow. This study showed that by increasing the fluid flow to the solar panels from zero to 10% of the heat pump flow rate, the overall system energy consumption in the heating mode decreases, whereas, in the cooling mode the system energy consumption increases. This trend is in favour of the system performance in the heating season and against in the cooling season. This indicates that for Toronto weather conditions, a residential house with a hybrid GSHP system can benefit from higher flow diversion to solar thermal collectors in the heating season; however, the reverse is true in the cooling season.

Sensitivity Analysis of the Ground Thermal Conductivity

Thermal conductivity is one of the physical properties needed for sizing GSHP. As the exact soil thermal conductivity for the site of the house was unknown, the house was modelled with different soil thermal conductivities and the effects recorded. Changing the soil thermal conductivity leads to a change in the entering fluid temperature (EFT) to the heat pump. This is a very important parameter for the efficiency of the heat pump. The heat pump of the house is designed to work between 0°C and 35°C. Analysis was carried out with four different soil types in the range of 0.85 W/mK to 2.5 W/mK. The result showed that, in the heating season, the lower thermal conductivity leads to a lower EFT to the heat pump. Soil types with a thermal conductivity lower than 2 W/mK lead to an EFT lower than 0°C and cause a malfunction of the heat pump. On the other hand, a higher soil thermal conductivity leads to higher EFT in heating season and more efficient heat pump operation. In conclusion, based on overall regional soil type, soil with 2 W/mK is a reasonable selection , and this was the value used in the rest of the studies. Having better heat transfer in the vicinity of the ground heat exchanger loop is ideal for the system whereas having lower thermal conductivity in the backfill volume would be good for overall thermal storage.

Solar Collector Area and Ground Loop Heat Exchanger Length Relation

Finding the relationship between solar collector area and ground loop length was one of the important aspects of this study. In the heating season, the results of this study showed that for this specific house located in Toronto region, three solar panels in the system helped to reduce the total ground loop heat exchanger (GLHE) length by 15% compared to the system that only has a heat pump. Increasing the number of solar panels from three to six did not double the GLHE length reduction whereas its trend would be in the range of 8% to 13% after that. An optimum relationship of three solar panels with the reduced GLHE length of 15%. Figure 3, shows percentage ground loop length reduction versus number of solar panels. In the cooling season, adding solar panels to the system would have a negative impact on the system performance and an increase in the heat pump energy consumption. Therefore in heating dominated places where the cooling season is short this incremental energy consumption for space cooling would not be significant compared to the potential savings in the heating season. Figure 4 and 5 show entering fluid temperatures (EFTs) to the heat pump in a typical cooling and heating season respectively.

System Cost Analysis

A 20-year life-cycle analysis of the system showed only small economic benefit for the hybrid system compared to the system with only a GSHP. This was due to the low borehole drilling cost of \$33/m. At the time of study the borehole drilling costs were estimated to be in the range of \$29/m to \$39/m for different ground conditions [15]. However, for the case of higher drilling costs the economic benefits would be considerable, because of the 15% reduction of GLHE length due to the three solar collectors. Table 2 shows the Net Present Value (NPV) of hybrid solar-ground source heat pump system considering borehole cost of \$33.00/m, solar collectors cost of \$125/m^2 [7], electricity cost of \$0.10/kWh [16] and interst rate of 6% [17]. During the system life cycle of 20 years, the SAGSHP system energy consumption increases slightly year over year. This effect corresponds to the reduction of a 2°C in the minimum EFT to the HP from the first to 20th year. In the case of GSHP system without solar collectors there will be higher energy consumption due to a near 4°C reduction of minimum EFT to the heat pump from the first to 20th year. This effect was not considered in this study, as it was beyond the scope of this work.

Field Study and Verification

For this study, there was limited field data available to validate the simulation results. For heat pump energy consumption, there were only 42 days of data in the heating season and no considerable data in the cooling season. However, there was almost eight months of data available for the EFT to the heat pump in 2007. The comparison of the simulation results with the field data showed a 2.7% to 6% deviation in energy consumptions. The source of this deviation was partly due to the weather data (TMY2) used in the simulation. By adjusting the simulation results with the actual weather data derived degree-days for 2007 for Toronto this deviation was reduced to 0.01 to 2.7%.

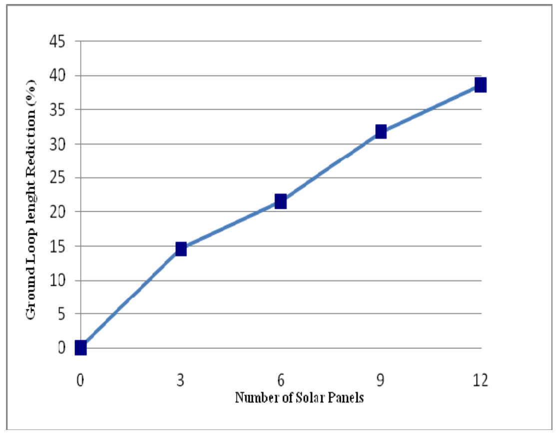

Figure 3: Ground loop length reduction percentage versus number of solar panels

Solutions to the Problem of the As-built System

The existing system had problems in functioning properly in the cooling season. The analysis results showed that the system was not properly sized for the cooling season as the EFTs to the heat pump were exceeding the allowable EFT defined by the manufacturer. This happed from June to August, almost the entire cooling season. Simulated solutions include: (a) stopping the flow to the solar panel in cooling season; (b) selecting a heat pump with a modified cooling capacity and specification; and (c) increasing the GLHE length. All three solutions are applicable with case (a) being the simplest and cost least to implement. This problem could have been preventable if the borehole lengths were increased by 35%. This solution could be justified as the system would perform better in the heating season in spite of extra borehole cost. Figure 6 shows, the existing heat pump EFT limits in system with three solar panels. It shows that in almost entire cooling season, the EFTs will fall above the heat pump capacity limit (35°C) and system stops functioning.

System Viability in Different Cities of Canada

By considering the same house characteristics, the effects of different climates in Canada were investigated. For this purpose, six Canadian cities in different regions were studied. The results are tabulated in Table 3. It is shown that in different cities, in general, as the ratio of annual heating load to annual cooling load of the house increases the reduced GLHE length to solar collector area ratio decreases. This ratio was 7.64 m/m^2 for Vancouver with an annual heating load to annual cooling load ratio of 1.54. For Edmonton with annual heating load to cooling load ratio of 3.8 resulted in reduced GLHE length to solar collector area ratio of 2.93 m/m^2. A higher reduction ratio, Vancouver, indicates better viability of the hybrid GSHP system. This would not be an absolute conclusion as other parameters such as ratio of heating degree days to cooling degree days in each city also affects the conclusion.

CONCLUSION

In this study, overall system viability was evaluated and existing system problems were detected through the dedicated modelling and simulation of the installed solar assisted GSHP system.

Viability of System

The result of this study have shown that the hybrid GSHP system combined with solar thermal collectors could be a feasible choice for space conditioning for heating-dominated houses. For the house in this study, the seasonal solar thermal energy storage in the ground in the hybrid system was sufficient to offset large amount of GLHE length that would have been required in conventional GSHP systems. The economic benefit of such system depends on climate, as well as borehole drilling cost.

System Simulation Approach

This study demonstrates the value in utilizing a system simulation approach to evaluating alternatives in complex systems. The hourly time step simulation for the implementation of complex control and operation strategies enabled the assessment of transient system responses. This study will further enhance by examining and analysing: 1) different configuration and control strategies; 2) the interaction of different components; and 3) potential benefits in broader geographical areas.

Future Research Recommendations

Some specific recommendations for further study and research arising from this study are:

a) Implementing an optimization routine into the system simulation would be useful in order to obtain the optimum values of desired parameters. In particular, minimizing system life-cycle cost by optimizing the size of GLHE versus the area of solar collectors.

b) Researching system configurations and controls in order to increase the system performance. An example could be diverting the extra energy harvested by the solar collectors during the cooling season for an independent DHW system.

c) Using more efficient solar thermal collectors in the model. In particular, using vacuum tube solar thermal collectors.

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Table 2: Net Present Value of Hybrid Solar-Ground Source Heat Pump System

Solar Collector		GLHE	Cost Analysis				
	Area	Total Length	Initial cost		Operation Cost		
No. of Panels	(m^2)	(m)	Solar Cost	GLHE and HP Cost	Annual Cost	Present Value	Net Present Value
0	0	380	$0	$19,040	$2,050	$23,514	$42,554
0	0	220	$0	$13,760	$2,330	$26,721	$40,481
3	6.81	188	$851	$12,704	$2,330	$26,723	$40,278*
6	13.62	172.8	$1,703	$12,202	$2,334	$26,776	$40,681
9	20.43	150	$2,554	$11,450	$2,337	$26,804	$40,807
12	27.24	135	$3,405	$10,955	$2,335	$26,786	$41,146

*Optimum balance between the GLHE size and solar collector size

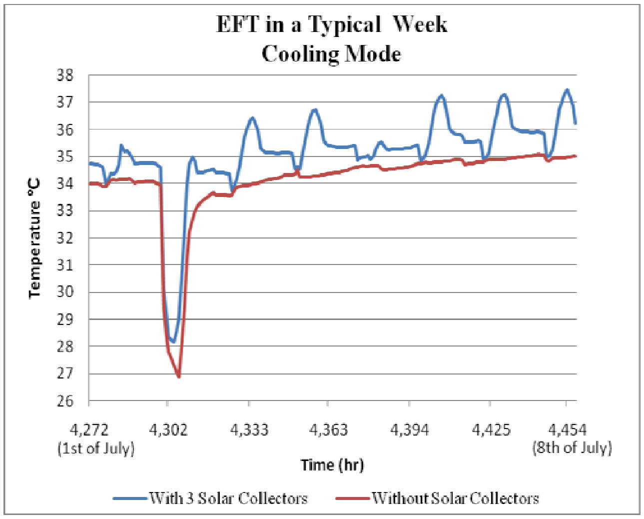

Figure 4: Heat pump EFT in a typical week of cooling season

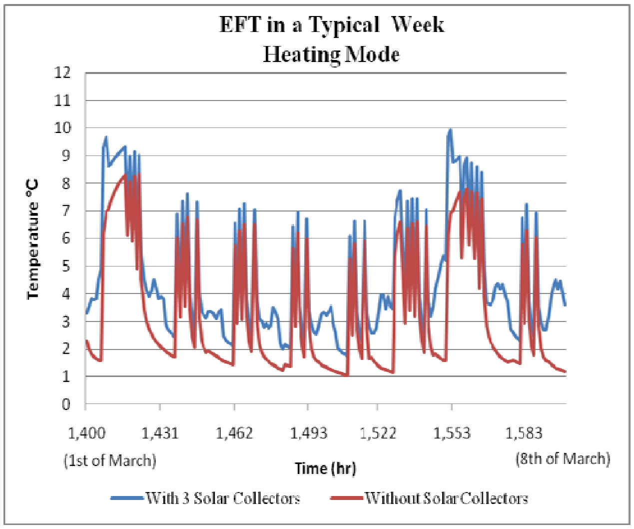

Figure 5: Heat pump EFT in a typical week of heating season

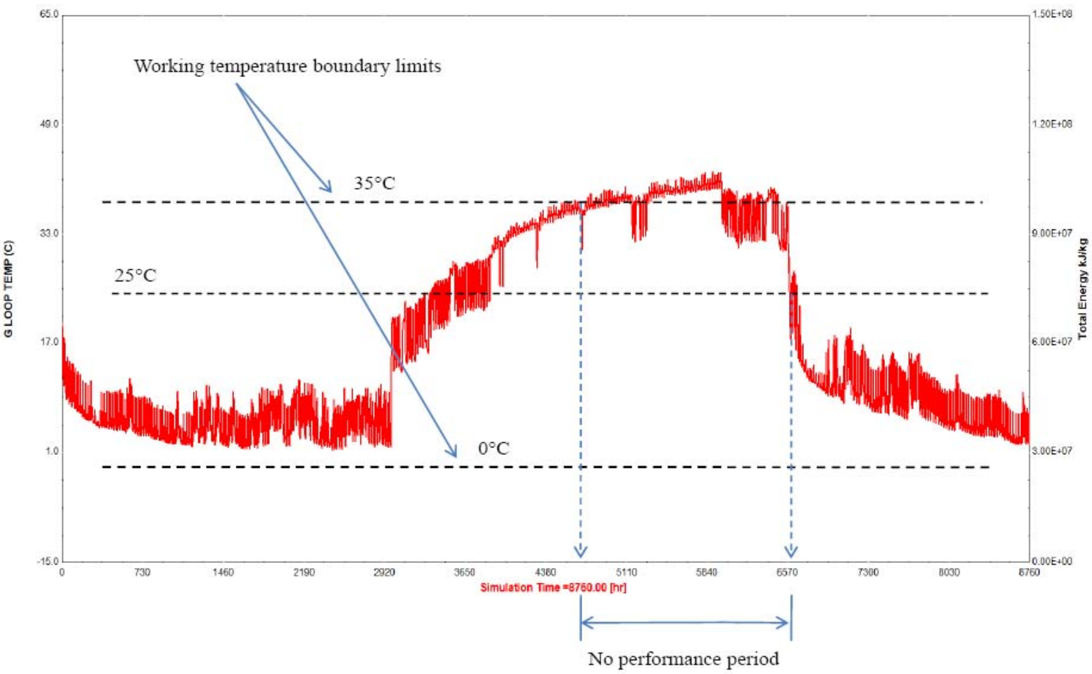

Figure 6: Existing heat pump EFT limits (System with 3 solar panels)

Table 3: SAGSHP System performance in different cities

City	Solar Collector		Ground Loop Heat Exchanger			Annual System Energy		Reduced GLHE
	No. of Panels	Area	Total Length	Borehole	Min. EFT	Space Heating and Cooling (MJ)		Length/Collector Area
		(m^2)	(m)		(°C)	Heating	Cooling	(m/m^2)
Vancouver								
	0	0	220	4×55(m)	1	46,305	5,364	(52m)
	3	6.81	168	4×42(m)	0	46,119	5,623	7.64
Toronto								
	0	0	220	4×55(m)	1	44,793	6,434	(40m)
	3	6.81	180	4×45(m)	0	44,749	6,631	5.9
Montreal								
	0	0	220	4×55(m)	0	46,766	6,989	(36m)
	3	6.81	184	4×46(m)	0	46,779	7,174	5.28
Ottawa								
	0	0	220	4×55(m)	0	46,327	6,150	(32m)
	3	6.81	188	4×47(m)	0	46,445	6,331	4.7
Halifax								
	0	0	220	4×55(m)	0	49,566	5,015	(24m)
	3	6.81	196	4×49(m)	0	49,301	5,268	3.52
Edmonton								
	0	0	220	4×55(m)	0	51,979	5,935	(20m)
	3	6.81	200	4×50(m)	0	52,052	6,076	2.93