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Feasibility of using ground source heat pumps in heating and cooling of residential buildings

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Abstract

In many building types, heating and cooling demands are often unbalanced and using a single ground source heat pump (GSHP) to meet both heating and cooling demands introduces various options to designers in sizing the ground heat exchangers coupled to the heat pumps. Due such unbalanced heating and cooling demands, use of ground source heat pumps may not be feasible, or not financially feasible if coupled with a supplementary system. In this study, the impact of heating and cooling demands typical of a residential building on the feasibility of use of ground source heat pumps is studied. A typical residential building block in Ontario, Canada is modeled in eQuest 3.65. Simulation results of the models for space heating and cooling demand are used in RETScreen to arrive at a combination of technologies that may be able to provide heating and cooling to the buildings. Comparison of the approximate cost estimations for the various design options show the importance of employing customized coupling strategies in order to take maximum advantage of ground source heat pump systems and promoting their financial feasibility.

Keywords: Ground-source heat pumps; Heating and cooling; Balanced; residential; eQuest; RETScreen;

1. Introduction

As governments place more stringent requirements on energy performance of buildings and provide financial incentives for construction of sustainable buildings, use of more efficient heating and cooling energy systems in building designs is becoming more popular compared to a decade ago. For example, City of Toronto has mandated employment of renewable energy technologies in city properties [1]. Ground source heat pumps (GSHPs) seem to be suitable options to promote sustainable building designs and their financial and technical feasibility is assessed with varying levels of detail in several studies [2][3][4]. For example, in order for their use to be financially feasible over the system life cycle, the variation in heating and cooling load of the building need to be reviewed. Accurate estimation of building energy performance is possible with computer programs that are able to perform hourly building energy simulations, such as eQuest 3.65 and Hourly Analysis Program (HAP) [4]. eQuest 3.65 is a computer program based on a solver engine developed for the US Department of Energy and performs hourly building energy simulations [5]. While it has been used in a number of scholarly articles to show building energy performance and/or to calculate building heating and cooling loads [3,6-7], it has not been used in combination with other software to show financial feasibility of GSHPs. RETScreen [8] provides a tool to perform technical and financial feasibility analyses of various energy system types and has been used in several scholarly studies [4,9-12]. This software is used for many feasibility analyses in early stages of the design when various heating and cooling options are explored. Another software used for analysis of the systems when system details are available is TRNSYS; however, this software is often used by scholars aiming to evaluate existing designs or systems [3]. Except a few studies on economic analysis of GSHPs [13], their financial feasibility has not been widely studied and not compared for various design options as the current study has.

In the preliminary stage of building design, i.e., design development stage, a preliminary feasibility assessment is sometimes performed to estimate the financial feasibility of use of geothermal heat pumps. The

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outcome of this feasibility study is important since it would consequently impact the decision whether to select geothermal heat pumps as the optimum candidate for a given building type or not. The objective of the current article is to show how sensitive such preliminary analysis outcome is to the selection of parameters such as building loads, design strategy studied for a given building load, and system component costs. Some details are intentionally not included in the study to ensure that the conclusions are based on what is indeed the limited inputs in the ground source heat pump feasibility analyses. If geothermal heat pumps are shown to be financially feasible, further detailed analysis needs to be performed. However, in some cases, the preliminary feasibility analysis may not show satisfactory financial feasibility for incorrect reasons. It may be concluded that some parameters need to be the subject of more focus to ensure the preliminary feasibility analysis shows results that are accurate enough. In this study, the impact of heating and cooling demands typical of a residential building in Ontario, Canada, selected design strategy, and system component costs on the financial feasibility of use of ground source heat pumps is studied.

2. Method

The method used in this study consists of two parts: estimation of heating and cooling energy requirements and feasibility of providing such energy, fully or partially, through ground-source heat pump(s).

2.1.Building energy consumption

In this section, information regarding the characteristics of typical newly-built residential buildings in Ontario, Canada, such as floor area and HVAC systems used are included. In addition, the general method used in estimating the heating and cooling energy consumptions of the building block is provided.

The information used in the models includes the total residential building area (total and square footage), building envelope characteristics, building use characteristics and number of residential units. A summary is provided in Table 1. Note that while much detail is included in the model to generate hourly heating and cooling demands of the building, only main ones are included in this section. Further details on the building are deemed unnecessary for the purpose of discussions in this article and the level of accuracy aimed.

Table 1: Building general characteristics

Building Specification	Value
Site location	Toronto, Ontario[1]
Total building area	3135 m^2
Building footprint	784 m^2
Percentage of building residential area	90%
Number of houses	32
Floor height	3.0 m

[1] weather file for Toronto in 2016 is used in the eQuest model.

Using the information in Table 1, the heating and cooling demands of the building block is calculated in eQuest 3.65. The eQuest model inputs are categorized in three section and are selected from building standards currently used in Ontario, Canada (see Table 2). They are building envelope characteristics, internal gains, outdoor air requirements and air distribution systems.

Table 2: Building envelope and use characteristics

Building characteristic	
Weather file	Toronto, Ontario
Envelope	NECB[1] 2015 standards
Internal gains	NECB 2015 standards
Window-to-wall ratio	20%

[1] National Energy Code of Canada [14]

2.2.Heating and cooling provision using ground source heat pumps

Once the space heating and cooling loads are estimated for the building block, the model is further developed in RETScreen to include the heating and cooling systems. A base case and four cases with various ground source heat pump strategies are investigated (see Table 3). Note that the information listed in the table are based on RETScreen database that is supported by available heat pump models. However, performance details of such heat pumps are not included in the analysis as in [15][16]. For example, an average COP for heating is used for calculation of the electricity requirements of the heat pump in the heating mode and seasonal load variations and their impacts on the performance of the heat pump is not accounted for. As a result, much of the details of a heat pump system such as refrigerant type and compressor type are not included in the current article. Such technical detail on various heat pump models can be found on the heat pump manufacturer websites such as the one used in the current article [17], but is not included in preliminary feasibility models. It is only after a feasibility analysis shows positive results of feasibility of use of ground source heat pumps that inclusion of details of heat pump performance are included in the model. The systems used as the base case, are heating and cooling systems typical of those used in conventional townhomes built in Canada. The strategies are selected based on individualized versus centralized systems. Individual systems refer to heating and cooling systems that that are installed in each townhome and only meet the needs of that individual townhome. Central systems refer to one system for heating and/or cooling all townhomes. The strategies are also based on how heating and cooling energy demand is covered. In many locations such as in Toronto, Ontario, annual heating and cooling demands of residential buildings cannot be covered using a single ground source heat pump with heating and cooling capacities equal to the demand. In such cases, GSHP systems can either be sized for cooling demand or the heating demand. In Toronto, Ontario, residential buildings have larger heating demands than cooling ones. However, when using a heat pump to provide heating and cooling to the building, the amount of heat that is exchanged with the ground is larger during cooling than during heating. This is due to the fact that the energy that is transferred to the ground via a heat pump in the cooling season includes the compressor energy as well as the energy extracted from the space which increases the energy transfer to the ground. Similarly, the energy that is delivered to the space in the heating season includes the compressor energy as well which reduces the amount of energy needed from the ground. In order to keep the heat exchange between the building and the ground balanced, two strategies arise in sizing the GSHP: sizing for heating demand and for cooling demand. When the systems are sized for cooling demand, theoretically all the heat removed from the space is transferred to the ground and only some of that is used to meet the heating demand in the heating season while the rest is rejected to the outside air when not needed. This is to avoid temperature rise in the ground as the cycle repeats seasonally. In this case, the energy transferred to the ground in the cooling season is first calculated as

$$Q_{g,inj} = Q_{sp,c} + \frac{Q_{spc,c}}{COP_C} \tag{1}$$

where $Q_{g,inj}$, $Q_{sp,c}$, and COP_C are heat to be transferred to the ground (heat injection), space cooling needs, and coefficient of performance of the heat pump in cooling mode, respectively.

In this case, the heat available for heating is more than needed in the space and is calculated as:

$$Q_{g,ext} = Q_{g,inj}\left(\frac{COP_H}{COP_H - 1}\right) \tag{2}$$

where $Q_{g,ext}$ and COP_H are heat to be extracted from the ground and coefficient of performance of the heat pump in heating mode, respectively.

Table 3: Building envelope and use characteristics

		Heating system	Cooling system	Peak cooling system
Case 0		Furnace	AC [3]	
Base system	Ind.[1]	80% efficiency	COP 3	
Energy source		Gas	Electricity	
Case 1		GSHP [4]	GSHP	
	Ind.	COP_H 3.2	COP_C 4.5	
Energy source		Electricity	Electricity	
Case 2		GSHP	GSHP	AC

	Ind.	COP_H 3.2	COP_C 4.5	COP 3
Energy source		Electricity	Electricity	Electricity
Case 3		GSHP	GSHP	
	Cen.[2]	COP_H 3.2	COP_C 4.5	
Energy source		Electricity	Electricity	
Case 4		GSHP	GSHP	AC
	Cen.	COP_H 3.2	COP_C 4.5	COP 3
Energy source		Electricity	Electricity	Electricity

[1] Ind. Individual system for each dwelling
[2] Cen. Central system for all dwellings
[3] AC Vapor compression air conditioner
[4] GSHP Ground source heat pump

The additional heat that need to be rejected to the outside air is calculated as

$$Q_{additional\ heating} = Q_{g,ext} - Q_{spc,h} \tag{3}$$

where $Q_{spc,h}$ is the space heating need.

Alternatively, when the systems are sized for heating demand, only part of the heat removed from the space in the cooling season is transferred to the ground via a GSHP. The amount of heat corresponds to the heating energy demand during the heating season. The rest of the space heat in the cooling season could be removed via a vapor compression air conditioning unit. In this case, the energy transferred from the ground in the heating season is first calculated as

$$Q_{g,ext} = Q_{sp,h} + \frac{Q_{spc,h}}{COP_H} \tag{4}$$

In this case, the heat allowed to be rejected to the ground, in order to maintain balanced ground temperature over one heating and cooling cycle, ($Q_{spc,c,al}$) is less than space cooling demand as and is calculated as:

$$Q_{spc,c,al} = Q_{g,ext}\left(\frac{COP_C}{COP_C + 1}\right) \tag{5}$$

where COP_C is the coefficient of performance of the heat pump in cooling mode. The additional heat that needs to be provided via a cooling system other than the ground source heat pump (e.g., and air conditional unit) is calculated as

$$Q_{cooling\ deficit} = Q_{spc,c} - Q_{spc,c,al} \tag{6}$$

Note in Table 3 that the values used for efficiency of systems, are those typically found in many manufactured systems available in Canada. In addition, it must be noted that that the use of seasonal COPs in the current feasibility analysis is only acceptable for analysis done in design development stage where no detailed design information is available. Once detailed designs are available, a more thorough analysis must be performed to validate the COPs used for the ground source heat pump that vary based on ground temperature variation as heat is stored and collected from the ground.

In cases 2-4, a ground heat exchanger component is modeled in RETScreen which uses the heating and cooling demand calculated in the previous section and approximates the size of heat exchangers needed to exchange the required heat with the ground. Such analysis could become very complex and required use of specialized numerical methods and tools to estimate the size of the heat exchanger. Such accurate analysis is often encouraged for detailed design of ground source heat pump systems, but is often not used for preliminary feasibility analyses preceding the design stage. For this reason, the simplified method used to approximately estimate the heat exchanger length in RETScreen is considered satisfactory for this study. In the current study, boreholes, i.e., vertical ground heat exchangers (shown in Figure 1), are used in the model due to their small land area requirements compared to horizontal ground heat exchangers. While horizontal heat exchangers offer better financial benefits, their use in buildings with small outdoor land area (e.g., backyard) may not be technically feasible. Ground properties for clay rich soil are used in the model as they are closest to the type of soil observed in north Toronto area when reviewing cross-section of geological conditions in Toronto [21]. The soil properties used in the model are listed in Table 5. Assumptions made in the heat exchanger model as well as estimated calculated length for the boreholes are included in Table 6.

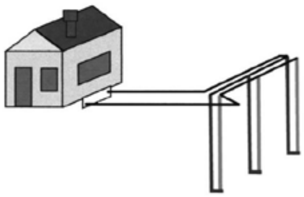

Figure 1: Schematic of vertical ground heat exchangers [22]

2.3.Other system assumptions

The pumping head is calculated based on the length of the boreholes and 15 m of head is added to the pumping head to account for the pressure losses in piping. The mean ground temperature is assumed to vary from 7.5°C by an altitude of 21.4°C on the ground surface with variations decreasing to zero at depths more than 15 m. The temperature of the water flowing into the heat pump is assumed as 0°C and 25°C for heating and cooling modes, respectively. The variation in the ground temperature as heat is injected and extracted from the ground is not accounted for in RETScreen. Such detailed analysis would not be performed at the early stages of design and is therefore neglected in the current study.

2.4.System cost estimation

Once technical specifications regarding the heating and cooling systems are included, capital and operating costs are included in the RETScreen model to analyse the impact of various system selection strategies on financial feasibility of the systems. A summary of the cost information used to compare the various selection strategies is provided in Table 4.

Table 4: Capital and operating costs used in the model [8, 18-20]

Item	Cost
Electricity	$0.13 /kWh
Natural gas	$0.30 /m^3
Fuel cost escalation rate	4.5%
Natural gas furnace	$88 /kW Heating
Heat pump	$350 /kW heating[1]
Vapor compression air conditioner	$350 /kW cooling[1]
Ground heat exchanger loop - pipe	$4 /m
Ground heat exchanger loop – drilling and grouting	$21 /m
Ground heat exchanger pump	$800/kW
Townhouse unit sub-meter	$400 /house
Central heating/cooling plant (sub-meter and piping)	$6000
Operation and maintenance cost	$2-3/ m^2 [2]
Inflation rate	2%
Discount rate	3.5%
Debt ratio	30%
Debt interest rate	3%
Debt term	20 years

[1] 10% reduction in capital costs are assumed for central systems

[2] space unit area

In the next section, a summary of preliminary findings of the RETScreen model (e.g., as system size information) are provided.

3. Results and Discussions

The method described in the previous section is used for a base case and four cases with various ground source heat pump design strategies to compare their financial performance.

Table 5: Thermal properties of soil

Characteristic	Value	
Conductivity	1.3	W/m°C
Diffusivity	6.45 x 10^{-7}	m^2/s
Density	2100	kg/m^3
Heat capacity	0.96	kJ/kg°C

Table 6 Ground heat exchanger characteristics

Characteristic	Value
Borehole diameter	150 mm
Borehole total length	920-1420 m[1]
Borehole distance	12 m

[1] Estimated in RETScreen

Conventional furnace heating and compression cooling were assumed as a baseline for the townhouses. As shown in Table 3, the baseline energy systems use natural gas and electricity to operate.

Simulation results of heating and cooling loads in eQuest are shown in Figure 2. As expected in Ontario, Canada, the heating and cooling maximum space demand for the building in the occurs in months of January and July and are approximately 73 kW and 77 kW, respectively. This is typical of residential systems in Ontario, Canada, weather where the cooling loads are larger than the heating loads. Such effect is often magnified in other building use types such as office buildings where there is much internal heat gains to be removed by the cooling systems.

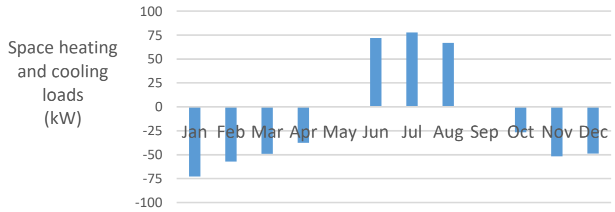

Figure 2: Simulation results of heating and cooling loads for the residential building block

As explained in the previous section, in order to keep the heat exchange between the building and the ground balanced, either the heat pump needs to be sized for cooling and be oversized for heating, or the system must be sized for heating and a supplementary air conditioning unit be used for cooling. In this study, both options are investigated since the first has reduced the capital and operating costs due toavoidance of a secondary cooling system in addition to the ground source heat pump, but has larger ground heat exchangers which generally contribute to about 80% of capital costs. The latter case, i.e., sizing for heating and using a supplementary cooling system, results in a smaller size ground heat pump, and therefore, fewer boreholes that would need to be installed for the smaller heat pump. The distribution of cooling design capacities are shown in Figure 3 for Cases 1 and 2, respectively. It is seen that compared to sizing the GSHP for cooling (Figure 3a), when the system is sized for heating, only a portion of cooling demand can be met by the GSHP and an additional cooling system, in this case a vapor compression air conditioner, is needed to cover the remaining cooling demand (Figure 3b). If heating and cooling loads were each 10% lower and higher than the case modeled in the current study, respectively, the size of the supplementary cooling system would become more pronounced. It is shown in Figure 3c that the additional 3% cooling demand covered by a supplementary system in Figure 3b would increase to 23% in such case. This would affect the cost and financial feasibility of the hybrid system design where the cooling loads are met by GSHP and a supplementary cooling system.

It should be noted that the distribution of cooling loads for the 10% lower and higher heating and cooling demands would resemble that of Figure 3a for Case a where GSHP is sized for cooling demand. Such case, however, would result in a much more oversized system for heating.

Figure 4 shows the amount of heat available in the ground to meet the building heating needs. The additional heat available must be removed from the ground to ensure balanced ground temperatures over the annual operation of GSHPs. In cases where there is no use for this additional heat, it can be transferred to the outside air. Comparing Case 1 and Case 2 with cooling distributions in Figs. 4a and 4b shows how a perfect balance of heat exchange with the ground may never be achieved when using a GSHP. As expected, Figure 3c and the 10% cases in Figure 4 show that the larger the imbalance between space heating and cooling demands, the larger the supplementary system capacity is when sizing the GSHP for heating, or the larger the amount of heat that needs to be removed from the ground when it is not needed when sizing the GSHP for cooling.

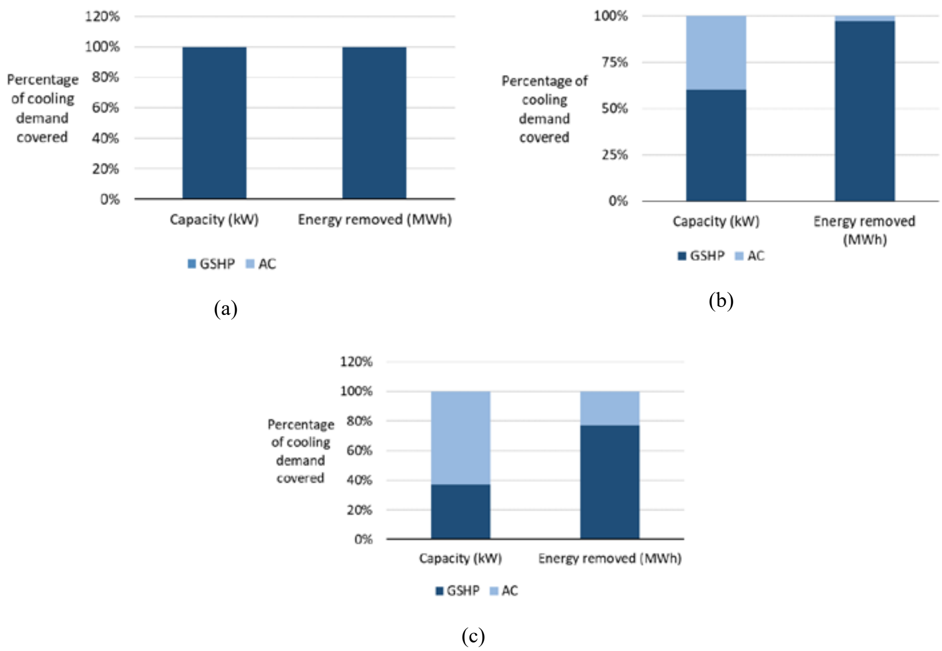

Figure 3: Distribution of cooling design capacities for (a) Case 1, GSHP sized based on cooling demand, (b) Case 2, GSHP sized based on heating demand, (c) Case 2, Case 2 for 10% more cooling demand and 10% less heating demand.

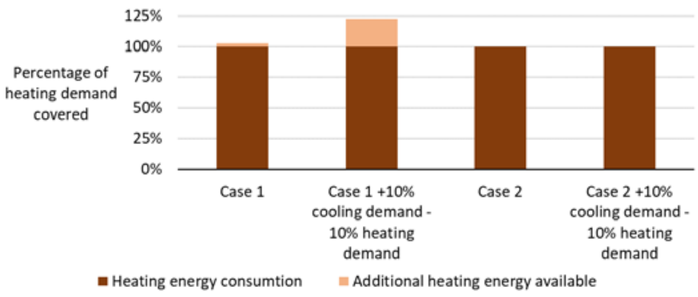

Figure 4: Distribution of heating energy available from the GSHP in four cases

To understand how these various design options contribute to the cost of the system and to its financial feasibility, Figure 5 shows the cumulative cash flow diagram for Case 1, when GSHP is used for heating and cooling with no supplementary cooling system. It is shown that the payback period for this case is about 7 years which could lead to the conclusion that the GSHP alone with no supplementary cooling system and oversized for heating would be profitable. Similar analysis on Cases 2-4 were made and the results for estimated payback periods are shown in Figure 6. It is seen in Figure 6 that although sizing for cooling demand and use of a supplementary cooling system (Case 2) is expected to result in lower capital costs due to smaller ground heat exchangers (estimated 18% lower size of the ground heat exchangers), it would still result in higher costs for the case in the current study. This is due to the higher costs associated with maintenance of air conditioners compared to GSHPs as well as the larger capital costs associated with two cooling systems as opposed to one GSHP (Case 1).

To examine how such conclusions would vary if a central system was used for Cases 1-2, Cases 3-4 were analyzed which included 10% reduced capital costs for the GSHP and supplementary systems. Such assumption was made due to lower design oversizing factors needed for systems serving more than one residential units. However, the costs of metering each residential unit within the block were estimated to be higher than that of individual systems. This led to the overall capital cost of the central systems for Cases 3 and 4 to be larger than their individual system equivalents (Cases 1 and 2, respectively), as seen in Figure 6. Lower metering costs and a larger block size may contribute to their improved financial performance. Such detailed focus is part of ongoing research and is outside of the scope of the current analysis. Another parameter that could greatly impact the comparisons made between the various cases is the coefficient of performance (COP) of the GSHP in heating and cooling modes and that of the supplementary cooling system. In the current study standard values were selected (see Table 4), but it is suggested that the results of the current study be used in cases with comparable heat pump and air conditioner COPs.

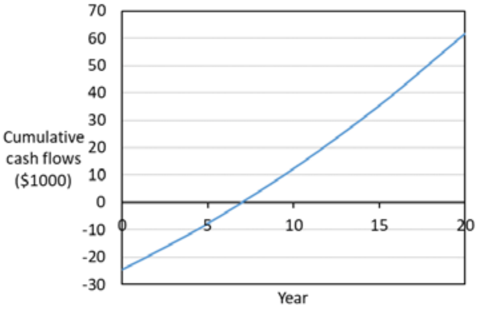

Figure 5: Cumulative cash flow for Case 1, GSHP used for heating and cooling with no supplementary cooling system

Lastly, the four cases described in Table 3 were compared against four cases with an increased unbalance between heating and cooling demands, i.e., 10% lower heating demand and 10% higher cooling demand compared to the demands simulated in eQuest 3.65 in the current study. It was found that although more unbalanced demands may result in more unbalances in system design and heating and cooling system sizing (see Figure 3c and Figure 4), their impact on system financial performance and payback period would remain relatively the same. More unbalanced systems with larger cooling demands and smaller heating demands may results in slightly lower payback periods for Cases 1 and 3 where the amount of heating demand directly affects the cooling via the GSHP and the ground heat exchanger. A lower heating demand, in the case of sizing the GSHP on heating demands, will result in lower amount of heat transferred to the ground in the cooling season. As a result, the GSHP and the ground heat exchanger sizes are reduced compared to the case of the current study. The cooling load would have to be covered using a larger supplementary system, but the decrease in capital costs due to smaller GSHP and smaller ground heat exchanger sizes would dominate the impacts and would result in slightly lower payback periods. However, the variation in payback periods observed in this case is considered negligible (less than 5%) and it is concluded that the results of Figure 6 could represent such unbalanced cases as well. From a more general perspective, this could refer the importance of coupling loads of various building types in order to maximize financial advantage of using ground source heat pump systems.

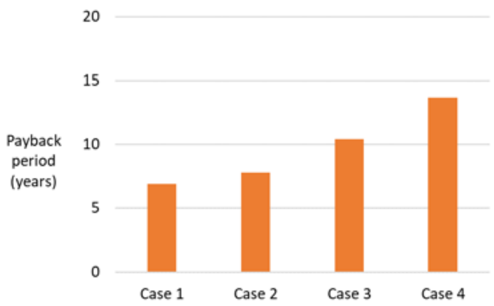

Figure 6: Payback periods estimated for various GSHP cases (refer to Table 3 for details of each design case)

For example, central geothermal heat pumps designed for a number of buildings of more than one type with various load profile characteristics could result in an overall heating and cooling load whose distribution is closer to one corresponding to an optimum geothermal heat pump design. Such optimum load profile could avoid use of supplementary cooling devices or oversized geothermal heat pumps which negatively impact financial feasibility of geothermal heat pump use.

4. Sensitivity Analysis

Here, the calculated payback period for the four cases (shown in Figure 6) are analyzed using a sensitivity analysis to verify the impact of a number of system cost components on the overall feasibility of using geothermal heat pumps for heating and cooling residential building use in the current study.

In the current analysis, it is assumed that heat pumps and chillers will have the same cost and that the additional cost of a geothermal heat pump systems is related to the ground heat exchanger costs. However, in some countries, higher costs are involved with heat pumps. In order to examine how the variation in cost affects the results of the analysis, a sensitivity analysis is performed to examine the variation in results of Figure 6 when the cost of heat pumps are 20% higher than the cost of chillers. It is found that a 20% increase in the cost of the heat pump compared to a chiller results in approximately 9-17% increase in the payback period, i.e., 8-15 years. The effect of variations in cost of geothermal heat pump compared to the cost of a vapor compression air conditioner is considered relatively small on the overall outcome of the feasibility analysis. With more advances in heat pump technologies and their increased use, it is estimated that the payback period would not exceed their current-day values and that geothermal heat pumps will become more favorable in the future.

In addition to varying the cost related to the heat pumps and chillers, the cost of electricity and gasoline is also expected to greatly impact the results of the analysis. Since Ontario has one of the higher electricity rates in Canada, a sensitivity analysis is performed by decreasing the cost of electricity up to 20%. It is seen that, compared to the capital costs associated with the geothermal heat pump and the air conditioner, the cost of electricity has a much higher impact (approximately 40-60% increase) on the payback period in the current case calculated for use of geothermal heat pump and consequently on the decision whether to use geothermal heat pumps or not. This is due to the fact that the large capital costs of geothermal systems are often compared to the annual operating costs of the base system, in this case the furnace and the vapor compression air conditioner that operates using electricity. A lower electricity price would result in a longer payback periods making geothermal heat pumps less favorable and in some cases financially infeasible (Case 4 in the current study). Similarly, it is expected that higher costs of gas in regions where gas heating is typical will result in lower payback periods for use of geothermal heat pumps (approximately 15-45% decrease for 20% increase in gas price in the current case). This is result is important as the cost of electricity and gas in various regions around the world vary and could make the feasibility of use of geothermal heat pumps for residential heating and cooling vary greatly in addition to the design strategy discussed earlier in this section.

The largest component contributing to the cost of geothermal heat pump systems is the cost of grouting and filling for installation of ground heat exchangers. A sensitivity analysis is performed to estimate the impact of 20% reduction in costs of filling and grouting on the financial feasibility of the system. It is seen that up to 17% reduction in payback period for Case 1, i.e., less than 6 years payback period, is resulted for the building under study.

5. Conclusions

A preliminary feasibility assessment is performed to estimate the importance of parameters used in such analysis on the financial feasibility of use of geothermal heat pumps. Such feasibility study is often performed at the early stages of design and its outcome would consequently impact the decision whether to select geothermal heat pumps as the optimum design for a given building type or not. The impact of parameters such as building loads, design strategy studied for a given building load, and system component costs on the outcome of such feasibility analysis is examined in the current study. Financial feasibility of geothermal heat pumps is decided using payback periods calculated when using geothermal heat pumps as opposed to a typical heating and cooling system used in Ontario, Canada, over the life of the system. It is concluded that some parameters such as the price of gasoline and electricity over the life cycle of the technology need to be the subject of more focus to ensure the preliminary feasibility analysis shows results that are accurate enough. Knowledge of such information could guide designers, developers, and energy modelers in equipment recommendation, infrastructure and operational requirements, constraints, estimated costs and off-site opportunities. They are listed as follows:

5.1. Building loads

A few GSHP design strategies are examined in the current study. They are mainly sizing the GSHP and its coupling ground heat exchanger

- solely based on building heating demands, or
- based on building cooling demands while including in the design a peaking cooling system to be used with the GSHP.

Based on industry standard design assumptions and cost estimates for the capital and operating costs of the systems in Ontario, Canada, it is found in this study that using ground source heat pump systems for residential building blocks in Ontario, Canada, are feasible with a payback period of about 7 to 14 years. It is concluded that the range of payback periods varies depending on the specific heating and cooling demand characteristics of the building. In a broader perspective, this emphasizes the importance of employing smart building coupling strategies in order to maximize financial advantage of using ground source heat pump systems. Strategies could consist of designing geothermal heat pumps to serve buildings of more than one type with various load profiles in order to avoid use of supplementary cooling devices or oversized geothermal heat pumps which negatively impact financial feasibility of geothermal heat pump use.

5.2. Design strategies

Comparison of various GSHP design options in the current study shows that the range of payback periods varies significantly depending on the strategies that are employed in designing GSHPs to meet building heating and/or cooling demands. This emphasizes the importance of employing various design strategies in order to maximize financial advantage of using ground source heat pump systems.

5.3. Component costs

A sensitivity analysis of operating costs and capital costs show that cost of fuel used for heating and cooling in the base case (i.e., electricity and gas in the current case) may have the largest impact on financial feasibility of using geothermal heat pumps. Other costs such as cost of geothermal heat pump or cost of grouting and filling of the ground heat exchanger, while still impactful, may have lower impact on the outcome of the feasibility analysis performed at this level.

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