Improving the Economics of Ground Source Heat Pumps through a Community Energy Utility

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ABSTRACT

Ground source heat pumps (GSHP) are an efficient, reliable, and cost-effective technology capable of achieving significant reductions in the carbon footprint of cities. However, their initial costs are viewed as prohibitively expensive by most commercial developers. In this paper we assess the value of looking beyond a single developer capitalizing on economies of scale and divergent loads. We show that these can lead to dramatically lower capital and operating costs. Furthermore, municipal governments have eminent domain over abundant public lands allowing further cost cutting through horizontal heat-exchange networks. Finally, municipal governments through their zoning regulations can encourage the colocation of complimentary loads on the network. These circumstances may call for the adoption of a development model informed by other natural resource development initiatives. This paper explores how capturing the full network benefits associated with a GSHP infrastructure lowers overall capital costs, improves system economics and can accelerate the diffusion of this technology leading to significant GHG emission reductions while improving adaptation to heat waves.

Introduction

Ground source heat pumps (GSHP) provide space heating with only 25-30% of the energy required by conventional alternatives, and offer correspondingly high reductions in GHG emissions compared to space heating by electric-baseboard systems (Hanova & Dowlatabadi 2011; IEA 2011). By using a ground loop of conductive piping to transfer thermal energy from the ground to the building and vice-versa, GSHP systems minimize the use of high-quality energy sources such as natural gas or electricity, generating significant operational savings. This can result in efficiencies between 300-500% compared to an electric baseboard system, referred to Coefficient of Performance (COP) for heating (Hanova 2007).

While GSHP systems provide lifetime environmental benefits and operational savings, their high initial capital costs have made them an unpopular choice among commercial developers. The fixed costs of GSHP systems are comprised of three main components: a) ground loop, b) heat pumps and c) distribution system within the building (Omer 2008). The heat pump operates a refrigeration cycle, using electricity to transfer energy from a low temperature medium to a higher one. The ground loop can be designed in a variety of configurations, but here the emphasis is on closed-loop vertical and horizontal configurations. In urban settings with dense development patterns, vertical loops are drilled beneath each building.

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In a more open setting, such as leisure centers and municipal parks, horizontal loops are buried in trenches at a depth of 5m over a larger surface area.

The high fixed costs of GSHP systems are not unique. They apply in many other networked systems such as energy, telecommunications, and rail. The above infrastructures had to overcome similar capital cost barriers by capturing economies of scale, capturing network benefits, or connecting divergent loads to improve overall system economics (Chandler 1990; Davies 1996, Hughes 1983, 1990). The key premise of this paper is that GSHP systems also benefit from economies of scale, network benefits, and divergent loads, and if these are exploited, their wider adoption can be accelerated. Seeking the network benefits associated with GSHP systems and expanding the system beyond a single developer may capture these economies.

The capital-cost barrier to the adoption of GSHP systems is less technical in nature than organizational, and this paper demonstrates three approaches to improve the economics. The first is to increase the size of the system to serve more than one development. There is an economy of scale in the pumps driving the GSHP system cycle that will lower unit costs. Secondly, if the GSHP system is designed for a mixed-use development or contains divergent heating and cooling loads then the waste heat can be used to decrease system size and costs. For the largest reduction in upfront costs the municipality may permit installation of horizontal ground loops beneath public land, in place of, the twice as expensive, vertical wells normally drilled beneath buildings. An immediate conclusion of the above network features is that positive engagement of municipal governments can realize greater economic returns to GSHPs than all but the largest of mixed-used private development projects.

The paper begins by introducing some of the key levers that may be pulled to improve the conditions of a community energy system and the unique advantage for municipalities in this arena. This is followed by an illustration in the reductions in capital costs available by realizing economies of scale, introducing divergent loads, and substituting horizontal ground loops in place of vertical loops. The paper concludes by briefly discussing municipal budgets, strict energy efficient standards, and proposing some alternative financing options.

Enabling a Community Energy Utility

The design and implementation of a community energy utility based on GSHP systems would be an excellent strategy for climate change mitigation and adaption. GSHP systems emit less GHG emissions compared to electric baseboard heating and even the most efficient gas-fired systems (Hanova 2007). This means emission reductions (compared to gas) are available everywhere except where coal is used to generate more than 70% of electricity (Hanova & Dowlatabadi 2007). GSHP systems also complement climate change adaptation strategies by supplying lower GHG emission air conditioning. Supplying low emission air conditioning is more resilient than passive cooling if heat waves become more frequent (Stern, 2006). However, creating a community energy utility hinges on two key powers reserved by municipalities.

The first power is access to public lands enabling horizontal heat exchange loops. The concern for private developers installing GSHP systems is that their building permit limits the land on which they can build. As a result developers drill deep wells directly beneath the building to capture geothermal energy. This is the largest upfront cost of the GSHP system. The municipality has access to relatively abundant public land compared to private developers. Horizontal shallow trenches may then be substituted for vertical wells if the space is available, at a 50% cost saving. If the municipality is willing to oversee the installation of a GSHP network this could be beneath pavements, roadways and parks. The potential for installing the GSHP ground loop in parallel with other municipal infrastructures, such as water and sewer mains, also reduce costs and increases opportunities for capturing waste heat.

The second condition is power over zoning and how this can be utilized to built complementary portfolios of heating and cooling loads. Private developers of mixed-used developments may possess divergent heating and cooling loads. However, the majority of private developers are not going to build commercial developments containing a variety of loads within close proximity. Through active permitting divergent loads may be paired allowing waste heat to be reused to lower both the systems upfront and operational costs. This could involve matching cooling loads at supermarkets, ice rinks and IT centers, with heating loads at hospitals, hotels and swimming pools. There are a large number of heating and cooling dominant loads in cities unrelated to the local climatology. The key is to seek out planned operations with divergent load profiles early on. The value in positive engagement of the municipal government is demonstrated in the following sections.

Reference System and Assumptions

The project costing exercises presented here are for illustration purposes. The costs and savings are typical for a project of this size in the Greater Vancouver Area. The mixed-used development contains 50 units occupied by both residents and businesses and each unit is approximately 100m^2. The development has commercial space available on the ground floor and residential complexes above. The annual energy intensity is 0.55 GJ/m^{2,} which is the same as the average energy intensity multi-unit buildings in British Columbia (NRCAN 2009). The energy intensity includes all energy demand including lighting and appliances of which space and water heating is a part. The mixed-use development is heating dominant with 990GJ/y required for space heating and 935GJ/y for water heating.

Table 1. Apartment and Development Energy Profile

Reference Building	**Area m^2**	**Annual Energy (GJ/y)**	**Space Heating 36% (GJ/y)**	**Water Heating 34% (GJ/y)**
1 Apartment	100	55	20	19
50 units	5,000	2,750	990	935

Benchmarked to data from NRCAN Office of Energy Efficiency 2009

The energy required by the complex is used to estimate the costs for heating and cooling with different systems and fuels, as well as the GHG emissions. Table 2 compares a GSHP system to a natural gas furnace, electric baseboard heating, and electric air conditioning. Electric baseboard heating is assumed to be 100% efficient and the natural gas furnace to be 80%. The GSHP system is able to provide heating at a COP of 4 (400%). The cost of electricity for Vancouver is assumed $78.6/MWh (Quebec Hydro 2011), and the cost of natural has is $11/GJ when including delivery charges and taxes (Fortis 2012). The GHG emissions or Carbon Dioxide Equivalents (CO_2e) are calculated using an emission factor of 50Kg CO_2e/GJ for natural gas, and 85 tCO_2e/GWh for electricity (Hanova & Dowlatabadi 2007).

Table 2. Annual Operating Costs and CO_2e Emissions for a 50 Unit Development

	Space and Water Heating		
System Type	Natural Gas	Electric	GSHP
Efficiency (%)	80%	100%	400%
Energy (GJ/y)	2,400	1,900	430
Annual Cost ($)	26,500	42,000	9,300
GHG (t CO_2e/y)	120	13	3

The fixed cost of the GSHP system for the mixed-use development includes wells, piping, and pumps. The wells are drilled vertically and represent the majority of the upfront cost. Wells and piping are approximately 75% of the upfront cost at $240,000 and the pumps cost 25% at $80,000. Maintenance costs are calculated to be 5% of the pumps capital cost at $4,000 annually. Maintenance costs for GSHP systems are typically lower than other alternatives.

The difference in operational costs between the efficient GSHP system and the electric and natural gas alternatives creates savings in costs and GHG emissions. In Table 3, both natural gas and electric space and water systems also include the cost of electric air conditioning, and the final row compares a mix of electric space heating and natural gas water heating. When calculating savings in operational costs at the end of the paper, the third row system, with both electric space heating and natural gas water heating, will be used. The operations savings accrue to eventual owners of these properties and the simple payback period for GSHP system is too long for commercial developers to install them as a default.

Table 3. Annual Savings on Costs and CO_2e Emissions

50 Units	Conventional System ($/y)	GSHP (GJ/y)	GHG Savings (t CO_2e /y)	Annual Savings ($/y)
Natural Gas	26,500	10,500	110	16,000
Electric	42,000	10,500	35	31,500
Natural Gas Water + Electric Space	34,500	10,500	70	24,000

Economies of Scale

Economies of scale result when increasing the system size results in lower per unit costs. Purchasing resources in bulk and spreading overhead costs over larger networks can lower unit costs of production. In the case of GSHP systems, a larger system can provide heating at a lower unit cost than a number of smaller ones due to the non-linear relationship between fixed costs and system size. If a system were to double in size the cost of the wells and pipes would also double, but the pumps would not. The cost of the pump would increase by smaller factor of $2^{2/3}$. This non-linear relationship is a heuristic for scaling the costs by the material needed for the size of a given pump. The associated fixed cost of pump sizes are estimated by multiplying our base cost of $80,000 by a ratio of system size. $Cost_2 = Cost_{ref} (Size_2 / Size_{ref})^{2/3}$. This also reduces the operation and maintenance costs, which are estimated to be 5% of the pumps capital expenditure.

To demonstrate, imagine two mixed-use developments constructed in close proximity to one another. The developments have the same loads, occupancy profiles, system size, and cost.

Constructed independently, the combined cost of the two systems is double one system at $640,000. Their combined operating costs would also be double a single system.

If the two systems were combined so that one GSHP system was meeting the needs of a development containing 100 units, then wells and pipes would double, but the pump would only increase to $127,000, and maintenance drop slightly. As shown in the table below, each increase in size of the reference system comes with economies of scale in pumps and operating costs. Table 4 shows the differences in upfront costs between systems with separate and combined systems, allowing economies of scale and savings. The economy of scale is the difference between two, or three systems of the same size built separately or by combing their loads. For two systems with the same GSHP system the economy of scale is $620,000 less $607,000 for a savings of 33,000.

Table 4. Economies of Scale for Pumps

	Wells & Pipes 75%	**Pumps 25%**	**Upfront Cost**	**Multiples of the Reference System**	**Economy of Scale**
50 units	240,000	80,000	320,000	320,000	0
100 units	480,000	127,000	607,000	640,000	33,000
150 units	720,000	166,000	886,000	960,000	74,000

Divergent Loads and System Size

The economics of GSHP systems improve with capacity utilizations, and a system sized to provide relatively equal heating in the winter and cooling in the summer would have better economics (CRM 2005). A system sized to provide all the heating requirements year round in a heating dominant climate would require a large and expensive ground loop that will not be utilized during most of the year. For this reason GSHP systems are sized to provide 90% of the energy needs for heating, often corresponding to about 70% of the peak load. During these periods of extreme demand, GSHP systems use electric heating designed for providing backup to make up the power needed to meet extreme demands.

Reducing the system size by shrinking the GSHP system relative to the backup system is not the only way to increase utilization and reduce fixed costs of the GSHP system. Combining heating dominant and cooling dominant loads also decreases system size requirements without reducing the size of the load met by the system.

In climates where heating is required during most of the year the majority of buildings are heating dominant, and the opposite is true for cooling dominant buildings in warmer climates. Beyond climate driven building profiles, the use of the building may determine whether it is heating or cooling dominant. Adding hot water heating to a system will make it heating dominant, but other buildings such as pools, or industrial drying facilities are heating dominant as well. Cooling dominant loads, are exemplified by electrical refrigeration units in supermarkets, industrial conditioning for IT centers and ice rinks. The ability to use the waste energy rejected in cooling by a supermarket at the same time heat is needed elsewhere improves the system economics. Expanding a network to encompass divergent loads reduces the size of the ground loop required by providing an alternative store of thermal energy other than the ground.

For simplicity, a diversity factor is estimated for the reduction in cost for the ground loop. If 25% of the heating load is met by waste heat, then the ground loop cost will reduce by 25%, while pumping costs remain the same. One could imagine a situation where two perfectly divergent heating and cooling loads, so that the waste heat could be injected at the right temperature into the other system, the ground loop could be completely removed. However, pumping would still be required to bring the temperature of the waste heat up to the desired temperature.

Consider again, two identical developments side by side using a single GSHP system. If the two buildings have identical loads, in this case they are heating dominant, the only advantage to combining the two loads is the economy of scale in pumps and maintenance costs. Now, if one of the buildings has leased its commercial space to a cooling dominant supermarket, and that the waste heat supplied enough energy to reduce the required ground loop by 10%. The cost of the ground loop drops from $480,000 to $432,000, and the cost of the pump remains at $127,000. If the cooling load increases in size and diversity factor increases to 30%, or 50% the effect on savings is even greater.

Table 5. **Divergent Loads and Reduced Capital Costs**

	Wells & Pipes 75%	**Pumps 25%**	**Upfront Cost**	**Reference System**	**System Savings***
100 units	480,000	127,000	607,000	607,000	0
10%	432,000	127,000	559,000	607,000	48,000
30%	336,000	127,000	463,000	607,000	144,000
50%	240,000	127,000	367,000	607,000	240,000

There is also a reduction in operational costs associated with divergent loads. The reduction in operating costs results from the temperature change in the overall system. If the building requires water at a temperature of 70°C, and the ground-loop temperature is 12°C, then the heat pumps much achieve a temperature increase of 58°C. If waste heat can be connected from a nearby supermarket at say 30°C, then the heat pumps need only raise that by 40°C. The average home requires 225 liters of hot water a day, so having a warmer system starting temperature saves 6 GJ over one year in a conventional system, and 1.55 GJ/y for a heat pump operating with a COP of 4.

Table 6. **Reduced Pumping Costs with Divergent Loads**

System Temp.	**Ground**	**Waste Heat**	**Heat Transfer**	**Energy Saved**	**Annual Savings**
70°C	12°C	30°C	18°C	6 GJ/y	1.55 GJ/y

Horizontal Trenching

The last reduction in capital costs is dependent on surface area available for horizontal ground loops. The majority of the upfront costs associated with GSHP systems results from the drilling of vertical boreholes (CRM 2005). This substantial cost can be effectively halved if extensive horizontal trenching is used instead of intensive vertical drilling. Drilling conditions and soil conductivity vary widely and are site dependent, usually requiring test boreholes to estimate. Utilizing horizontal ground loops, if the space is available, improves the system economics when combined with other cost reducing techniques. For simplicity, if horizontal trenching is possible then the costs for installing the ground loop are divided in half. Consider again the reference system costing $320,000. The majority of the upfront costs of drilling wells and piping may be halved to $120,000 if the space is available for horizontal trenching. This is an immediate savings of $120,000 and the largest reduction available for the system.

Table 7. Horizontal Trenching and Reduced Capital Costs

	Wells	**Pumps**	**Upfront Cost**	**Reference System**	**System Savings**
Vertical	240,000	120,000	320,000	320,000	0
Horizontal	120,000	120,000	546,000	240,000	120,000

Final Comparison of Cost Reductions

The savings in operational costs between the highly efficient GSHP system and alternatives may be treated as a revenue stream, as shown in Table 7. Here the savings are calculated as the difference between a GSHP system and another system combining electric space heating with a natural gas furnace for water and electric air conditioning (See Table 3). The savings in operating costs are used to calculate the payback period for the GSHP system, which is the length of time required for future revenues to recover the cost of initial investment, discounted here at 10%.

Table 8. Annual Savings and Payback Period

	Conventional System ($/y)	**GSHP System ($/y)**	**GHG Savings** (t CO_2e)	**Operating Savings ($/y)**	**GSHP Capital Cost ($)**	**Payback Period (Years)**
50 units	35,000	10,600	71	24,000	320,000	13.3
100 units	69,000	21,000	141	48,000	607,000	12.6
100 units with 30% Divergent Loads	69,000	17,600	142	50,000	463,000	9.0
100 units with 30% divergent Loads and Horizontal Loop	69,000	17,600	142	50,000	257,000	5.2

The first savings demonstrated is economies of scale from increasing the system size from 50 to 100 units. The economy of scale lowers unit costs and the payback period is slightly shorter for the larger system at 12.6 years.

With a 30% divergent load, the savings are realized in both capital and operational costs. The ground loop size is reduced by having cooling dominant loads contribute waste heat into the system, lowering system size requirement. The waste heat also lowers operational costs increasing the savings of GSHP systems, and reducing the payback period to 9.0 years.

Horizontal trenching remains the largest source of savings for capital costs of GSHP systems. Replacing vertical wells with horizontal trenches remains the most valuable contribution to upfront costs. With horizontal networks, the savings from the efficient GSHP system easily cover the capital cost within 5.2 years.

Municipal Finances and Strict Energy Efficiency Standards

Municipalities can create bylaws dictating a minimum energy efficiency standard for developments. Standards that set a maximum GJ/m^2 would favor efficient technologies such as GSHP systems. The energy intensity for space and water heating using the GSHP system described here is approximately 0.10 GJ/m^2, much lower than the intensity for heating using natural gas and electricity at 0.48 GJ/m^2 and 0.39 GJ/m^2, respectively. This straightforward tactic with sweeping environmental benefits is also politically unpopular.

Municipal coffers are tight. Raising public finances are difficult during a financial crisis where public indebtedness is frowned upon and municipal credit ratings are suspect. New debts are even punitive if borrowing rates for municipalities are linked, so that new debts increase the borrowing rate for the current and prior loans. In this financial climate, new developments are opportunities for economic growth, job creation, and another municipal property tax revenue stream. Municipalities are in competition with their neighbors over who will receive new businesses and stations for headquarters. Passing strict energy efficiency standards, the benefits of which are procured to the environment or perhaps utilities trying to conserve capacity, is equivalent to municipalities shooting themselves in the foot.

If a new form of utility best served with municipal powers is to succeed, it may have to look beyond municipal revenues for funding. Keeping the utility within the public arena has regulatory advantages considering the utility's potential market power, but contracting its construction, operation, and finance to the private sector in a transparent and fair regulatory regime governing its tariffs is attractive. A concession or Public-Private-Partnership (PPP) could be used to establish the utility. However, any self-sustaining utility will have to be profitable in the long run and overcome the financial risks particular to this type of infrastructure – the rate of development.

Alternative Finance and Development Rate Risk

The first financing mechanism, a closed-end investment fund, is borrowed from the wind power industry and may help side step the difficulty in raising municipal debt. Closed-end funds were first applied to wind generation in Germany, where they have grown as a vehicle for local citizen initiatives to the investment product of choice for wind power (Enzensberger, Fichtner & Rentz 2003). Using a closed-end fund as the investment vehicle for a GSHP utility, could extend the scope of the project finance from outside the municipality, developers, and bank, to other investors and maybe even future tenants.

Compared to an open-end fund that allows fund managers to reissue equity for new investors over time, closed-end funds issue equity once. Investors may sell their stakes in the project, but for the lifetime of the fund no news stakes are issued. For renewable energy projects, the equity is a claim on the future project, paid out in dividends. The utility bills paid to the GSHP utility provider by the development occupants could be treated as income for the fund. Equity investors would receive a claim on the utility bills paid by occupants and receive dividends throughout the life of the project. A GSHP utility installation might make an attractive low risk long-term investment, as heating and cooling requirements can be predicted with reasonable accuracy based on past regional demand.

While not currently employed for space and water heating, the transferability of this financial product, as well as other innovative revenue and financing solutions has merit. Closed-end funds are transparent, well understood by markets, and allow limited liability for certain investors. However, the success of closed-end funds as an appropriate low risk investment for a GSHP utility will depend on its overall returns and ability to deal with risks.

The major investment risk in a GSHP system emerges because the ground loop must be installed prior to construction and the pumps prior to any building occupancy. This means the capital-intensive investment is made before tenants are paying any bills. The municipality and any financiers are borrowing at their own cost of capital, and any delays in construction could lead to project losses. This means the rate of development, the time between the installation of the GSHP network and the buildings final occupancy, is paramount. Construction delays by private developers can range from months to years or possible cancellation if projects fail to launch. The ability to reduce these risks will be vital to finding willing municipal partners.

The utility operator might use Development Cost Charges (DCC) to pay for part of the upfront cost and thereby reduce the projects exposure to development delays. When applying for construction permits, the municipality charges for various sewer expansion and other improvements through DCC's. This could pay for the cost of the ground loop piping, typically made out of inexpensive PVC. The success of this mechanism is dependent on concurrent construction activities. Matching the ground loop installation with other construction activities could reduce the capital costs and the risk. If the development is new construction and new roads, sewers, or utility lines are being built; the then paid-for piping may then be laid to rest in horizontal loops at the same time.

The environmental benefits of a GSHP utility may warrant incentives to increase its adoption and to improve the overall returns for investors. Incentives such as feed-in tariffs or production tax credits used to subsidize renewable energy generation do not supply the right incentive for a utility designed to provide a similar service with less inputs and outputs. However, tax equity through accelerated depreciation tax credits is an attractive subsidy mechanism to help finance a GSHP utility. Accelerated depreciation tax credits are more complex than feed-in tariffs, but have been successful in growing wind, solar and geothermal energy projects in the United States.

GSHP systems like wind-power installations incur high capital costs that are depreciated over time are deducted from taxable income. Accelerating the depreciation schedule means more of the cost is depreciated sooner – sometimes up to 50% of the cost in the first year – reducing taxable income thereby increasing profits (Bloomberg 2011). Unfortunately, many renewable energy installations, or future GSHP utilities, may manage only small profits in early years while loans are paid down, meaning exposure to taxes is already minimal. These tax credits may be exchanged for investment capital to profitable companies looking to reduce their tax exposure. Without relying on subsidies based on the sale of electricity the amount of energy generation, accelerated depreciation tax credits to firms in return for investment capital would improve profitability of a GSHP utility for investors.

Conclusion

The prohibitive upfront cost of GSHP systems remains a barrier to their widespread adoption. This paper has demonstrated some key ways to reduce capital costs. Firstly, economies of scale for GSHP systems are possible due to the non-linear relationship between capital cost and system size for pumps and all things held equal larger installations would have lower unit costs. Secondly, pairing heating and cooling loads to capture waste heat into heating dominant systems can reduce fixed and capital costs. Thirdly, cooperating with the municipality to use public land for horizontal ground loops may halve the cost of the ground loop. The municipality has an unassailable economic advantage, as they are the only actor with the size able to connect divergent loads, with the power to pair divergent loads through active zoning, and access to enough public land for horizontal ground loops. While municipalities may have difficulty raising funds, there remains the potential for both Public-Private Partnerships and financial innovations through closed-end funds or tax equity. With these savings available to reduce upfront system costs, organization innovations and partnerships between municipalities and private developers to capture these economies may increase the adoption of energy efficient GSHP systems.

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