Analysis of District Heating Potential in Toronto Using Geographical Information Systems

by

Yan Lung Lu

A thesis submitted in conformity with the requirements for the degree of Masters of Applied Science and Engineering

Civil Engineering
University of Toronto

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Abstract

New district heating systems in Toronto have the potential for significant financial and environmental gains. Through the use of Geographical Information Systems (GIS) and the data required to estimate heating loads, heat maps were generated on a building-by-building basis for over 4400 buildings at nine different intersections in Toronto. School locations and planned construction maps were used to enhance the data and demonstrate the benefit of considering factors beyond finance and the environment. Out of the intersections studied, Yonge and Eglinton; Yonge and Sheppard; and Yonge and Empress held the largest heating loads. Individual building data allowed for plant locations to be suggested based on their proportional distance to the highest loads. GIS allowed for the visualization of the vast quantity of data. The opportunities for improvement include increasing the availability of location-based data and the application of the methodology to other areas of infrastructure planning and decision making.
Acknowledgments

Thank you, Professor Bryan Karney and Enwave Energy Corporation for all your support and guidance.

Contact

The research in this document is based on computer software and digital data which I’d be glad to share. If you have interest in obtaining the data or have any questions please feel free to e-mail me at y.lu@utoronto.ca.
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Chapter 1
Perspectives, Objectives and Overview

How do we determine what the ‘best’ solution is in practice? In any situation there are numerous opinions pulling from various directions and it is of this author’s opinion that ‘the best solution’ is always subjective in practice. This immediately brings up the divisive question of who it is best for. These questions and the theme of a subjective ‘best’ are the underlying drivers for the following research. The aim is to practically determine a better way to develop solutions that take into account different groups of opinions and considerations. This aim is pursued here through the real-world issue of district energy.

In this chapter the fundamental drivers and the specific objectives of the research are explained. A brief technical background on district heating and geographical information systems (GIS) provides the reader with a general understanding of the two main concepts in this thesis. This chapter concludes with the structure of the remainder of the thesis.

1.1 Preference Utilitarianism and Perspectives on Good

Utilitarianism is the concept of the best choice being the one that produces the most good for the most people. However, ‘good’ is subjective and each person’s definition varies. Therefore, it could be said that the most utilitarian solution is the one that considers each perspective of ‘good’ and fulfills upon each perspective the most. Hare identifies this as preference utilitarianism (Hare, 1981). Taking this approach complicates the once eloquent concept and often creates a challenging mesh of issues including directly opposing views of ‘good’.

These challenges can be illustrated in business, government, environmental decision making and practically any other facet of the world. Corporations are often under the pressures of generating value for stakeholders, meeting government regulations, creating attractive products/services for consumers, marketing their product/service/brand and avoiding bad press. Governments battle between pressure groups; local and regional issues; and balancing budgets between demands. Sustainability solutions can be approached from an economic and/or awareness standpoint. Some people prefer a precautionary approach to sustainability, while others, prefer explicitly
considering and weighing risks. Regardless of the situation, this complex set of opinions and perspectives is not only a challenge but also an opportunity for solutions.

Daniel Khaneman, a psychologist and behavioural economist, explains how human choices can be irrational in *Thinking, Fast and Slow*. Khaneman describes how our brains can (misleadingly) simplify when burdened by complex choices (Kahneman, *Thinking, Fast and Slow*, 2011). These findings further reinforce the need for more systematic approaches to decision making which combat the downfalls of our heuristics and biases.

Applying preference utilitarianism to engineering decision making challenges us to improve the process beyond weighted-decision matrices and cost-benefit analyses. Engineers not only find solutions to design problems but also improve upon the decision making process itself. As such, it is important to understand choices can be made based on logic, ratios, needs, and how the problem is identified (Kahneman & Tversky, 2000).

In pursuit of methods to understand and reconcile multiple perspectives, both the gathering of information and its organization is vital. Within reason, the information gathered should be relevant, trustworthy, compatible, and comparable. The organization of the information must enhance - and not hinder - understanding and decision making. Specifically, this means the presentation of the information must be clear, bring about insight and facilitate analysis.

The inspiration for this thesis is to discover methods which aid in the gathering, understanding and analysis of various perspectives in order to improve decision making and thus the solutions implemented. This approach is applied to areas within sustainability, with the main focus of this dissertation being the use of GIS in organizing perspectives related to developing district heating networks.

### 1.2 Perspectives on Sustainability

The topic of sustainability attracts numerous perspectives and is riddled with various questions, opinions and proposed solutions. Two such perspectives relevant to district heating are long-term investments and the internalization of impacts. These perspectives would be difficult to plot geographically but can be supported by improving the implementation of district heating systems through the use of GIS.
Sustainability strategies tend to involve higher capital costs with lower operational costs (and, over a project’s lifetime, lower overall costs and environmental impacts). This can be exemplified by buildings where investing in more insulation, higher efficiency furnaces and weather-stripping will result in a more costly and valuable facility with lower heating bills. However, when purchasing a building (or making any costly decision) humans often exhibit temporal discounting and value the immediate (capital) costs disproportionally to the long-term (operating) costs (Green, Myerson, & McFadden, 1997).

On the aspect of internalization, numerous external costs have been overlooked for centuries but would be imprudent to ignore now due to their increased magnitude. There are externalities which are still unaccounted for today. One particular reason could be because they are difficult to quantify. An example is the system wide impact of consuming a natural resource. It is indeed a challenge to understand how almost any individual action will affect the atmosphere, climate, economy, social well-being and wildlife, but certainly if everyone took the same action it would have a profound impact.

Overcoming these two challenges requires a deep understanding and critical approach. Shifting towards a paradigm of long-term investments and internalized costs has great potential to improve the sustainability of human behaviour. Despite the challenges, Table 1 below illustrates clear examples of progress on these fronts in the past. These examples demonstrate how humans have gone and are continuing to go down a more sustainable path.

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**Table 1 – Examples of Progress in Long-Term Investments and Internalization**

One technology which is influenced by progress on both fronts is district energy. Compared to individual furnaces and boilers, district energy systems have higher capital costs but also higher efficiency. Further, the higher efficiency and cost savings are only partially realized as the costs
associated with conventional furnaces/boilers and the benefits of district energy systems are not fully internalized. With Canada being one of the highest per capital consumers of energy, investigating these issues with regards to district energy bodes significant potential for reducing environmental impacts (The World Bank, 2009).

The challenges to district heating are slowly being overcome as technology and policy are moving towards reducing the costs of using alternative fuels and increasing their prominence in society (National Research Council (U.S.), 1985). The rising costs of conventional fossil fuels also contribute to improving the feasibility of district heating systems. District heating’s ability to easily switch between fuels makes it incredibly adaptable to changing fuel prices. Further, there is a general trend of governments subsidizing more sustainable technologies (as exemplified by FITs). Another notable trend is the banning of landfills and increase in Waste-to-Energy plants which are prime candidates for cogeneration and district heating systems. Currently, Denmark, Switzerland, Austria, Sweden and Germany have landfills bans as well as decent district heating adoption (U.S. Environmental Protection Agency, 2012; Euroheat & Power, 2012). These advancements toward more sustainable technologies are bringing district heating to the cusp of more widespread implementation.

All the above reasons are why this thesis is focused on promoting the implementation of district heating systems. While long-term thinking and internalization are not easily plotted in a geographical sense, GIS can be used to reduce and remove barriers (such as high capital cost) to district heating. GIS is especially applicable as location is a critical aspect of infrastructure.

1.3 Technical Background

District energy is the production and distribution of heating and/or cooling services from a central facility (a district heating/cooling plant) to surrounding buildings. Hot water, cold water or steam is transferred to buildings via insulated underground pipes and heat exchangers in each building. Cogeneration or Combined Heat and Power (CHP) is a closely related technology but will not be explored further. The focus here is on district heating.

The advantages of district heating over individual furnaces/boilers are:

- Regular maintenance that improves operational efficiency and thus lower resource consumption and costs;
• More cost effective and easier to adopt new heating/cooling technologies or fuels resulting in lower fuel costs and reduced environmental impact;

• Servicing diverse heating loads resulting in more efficiently sized equipment with the same (if not better) dependability;

• Reduced space requirements for heating equipment within individual buildings; and

• Reduced risks related to on-site fuel delivery (International Energy Agency, 2009).

Given these advantages several countries in Europe have widely adopted district energy systems while Canada has yet to implement district energy as widely. Some challenges which exist include:

• The need to secure a high heating load in order to be economical;

• High capital cost and a long term investment horizon; and

• The public and professionals’ unfamiliarity with the technologies leading to perceived risks and construction delays (Canadian District Energy Association, 2007).

The goal is to address these concerns by utilizing geographical forms of analysis. One particular tool is GIS. GIS is software that operates on various computing platforms and harnesses data, shapes, points, lines and their locations. It merges cartography, statistical analysis and databases into one program frequently used by urban planners, utilities, transportation departments and scientists. Most GIS programs feature a layered graphical display of data (such as heating loads); data input and manipulation; geographical, statistical and network analyses; and custom algorithms and analyses (Foote & Lynch, 2009). A screenshot of a typical GIS program illustrates the user interface in figure 1.
1.4 Research Objectives

The goal of this study is to improve the implementation of district heating systems by utilizing GIS. This is accomplished by aiding designers and decision makers in the planning and implementation of these systems. District energy systems and their implementation are influenced by people/politics, infrastructure and resources. Thus, a geographical approach to visualization and analysis is taken in order to understand various perspectives and overcome challenges associated with the implementation of such systems. Further, graphic displays convey complex amounts of data in a simpler manner. This study focuses on district heating systems in Toronto, Canada and uses the city for a case study. Therefore, the more at-hand question is: how can the barriers of district heating be overcome through the use of geographical theory and tools?

Specific research objectives include the:

- Identification of current barriers to district heating;
- Analysis of current district heating feasibility practices;
- Collection of building heating data in Toronto;
• Application of geographical data analysis to considering multiple perspectives surrounding district heating analysis;

• Illustration of the advantages and disadvantages of said application; and

• Application of the general approach in broader contexts.

1.5 Organization

It has been established that the author’s underlying motivation for this thesis is to implement preference utilitarianism in decision making where the best solution is that which satisfies the most good (based on each person’s definition) for the most people. This motivation is expressed and applied to the areas of sustainability and district heating where long-term thinking and the internalization of impacts are profoundly influential. GIS is the primary method used to understand various perspectives of good and to overcome the barriers to district heating implementation. GIS can be leveraged to feature numerous forms of data and connect them through the common factor of location. This thesis specifically focuses at the current state of analyzing district heating projects, how GIS can be applied to such areas and the advantages and disadvantages of such applications with Toronto, Canada being used as a case study.

The remainder of the thesis involves a literature review in chapter 2, the Status of District Heating, in which the history, barriers, current feasibility studies and tools related to district heating analysis. The specific parameters, data sources and techniques to be used in the GIS model are explained in chapter 3, Methodology for Building the GIS Model. Results from the model are presented in chapter 4, GIS Model Results, with a more in depth discussion following in Chapter 5, Discussion of the Challenges and Opportunities. An overview of the work done is provided in chapter 6, Conclusion, with thoughts on the progress made, relating the topics back to the initial goals of a preferential utilitarian approach. Afterwards, suggestions for future work are presented in chapter 7, Research Opportunities.
Chapter 2
The Status of District Heating

What follows is a thorough assessment of the development of district heating systems, the barriers that exist to the implementation of such systems, how district heating projects are currently being assessed and what tools are being used for such assessments. This review illustrates the current landscape of district heating and enables insights into what contributions could be made to aid in its implementation.

2.1 District Heating Past and Present

District heating has existed for centuries with the first system implemented in the 1300s in France and the first commercial system implemented in New York in 1877 (Kilpatrick, 2010). Extensive district heating distribution systems have been developed in numerous cities in Europe with Czech Republic, Iceland, Finland, Denmark, Latvia, Lithuania, Slovakia and Sweden all serving over 30% of their citizen with district heating (Euroheat & Power, 2012). These systems developed over decades primarily through government incentives with the aim of reducing reliance on increasingly costly foreign energy and fuels (Manczyk & Leach, 2009; International Energy Agency, 2004).

The first district heating system in Canada was built in 1880 in London, Ontario and in 1924 the first commercial system in Canada was built in Winnipeg (Canadian District Energy Association, 2011). Canada currently heats 1.3% of its total floor space (or 27 million square meters) with district heating leaving considerable room for expansion (Canadian District Energy Association, 2009). Further, space heating is Canada’s second largest subsector of energy consumption at 893.2 PJ/year in 2009 (Natural Resources Canada, 2009). However, unlike the high district heating adopting countries of Europe, Canada has significant natural gas and other fuel resources at relatively low prices (International Energy Agency, 2011; National Energy Board, 2012;
Europe's Energy Portal, 2012). The presence of this abundant and cheap resource may result in less pressure for Canadians to adopt district heating systems.

Two surveys of district heating systems in Canada were performed in 2007 and 2009 by the Canadian District Energy Association to understand the state of the technology. They determined that ‘established’ (older than 14 years at the time of study) Canadian district heating plants had an average distribution network length of 10.3 kilometers per plant while newer plants have an average distribution network length of 4 kilometers per plant. Older district energy plants service about 673,000 square meters of floor space while newer plants average about 51,100 square meters. The fact that older systems were larger than newer ones could mean that district heating systems grow over time or it was a more desirable service in the past. The median size of district energy systems in Canada is around 15 MW. The current total capital investment in district energy systems in Canada is over $12 billion. These statistics provide a sense of what to expect in terms of size, cost and growth within district heating systems. One particularly application is to use the size and age characteristics in order to determine whether a proposed system should be optimized to serve the expected 673,000 square meters of floor space (or 10.3 km of distribution piping) in the longer term or focus on being optimized for the shorter term expectations (Canadian District Energy Association, 2007; Canadian District Energy Association, 2009).

Within Canada, Ontario is leading the provinces with 48 district heating plants and 42.9% of the district heating capacity (Canadian District Energy Association, 2007; Canadian District Energy Association, 2009). Of the 48 district energy plants in Ontario, 8 are operated by universities, 8 by private utilities and 32 by publically owned utilities. Despite being the leader in district energy capacity, Ontario still has significant room for growth. The Ontario Power Authority manages 968 MW of district energy contracts with a directive to increase this by 1000 MW (Duguid, 2010). This is contrasted with the total ‘technical’ district energy potential being estimated to be about 16,500 MW or about half of Ontario’s electricity supply (ICF Consulting, 2005; Casten, 2008). Ontario currently has a Combined Heat and Power Standard Offer Program in order to promote and support the development of cogeneration plants in Ontario. This program

1 Romania and Calgary had the lowest natural gas prices at $10.22/GJ and $11.42/GJ respectively. Sweden and Halifax has the highest consumer natural gas prices at $43.95/GJ and $21.23/GJ respectively.
guarantees the purchase of energy produced at a set price if the proposed project meets the required specifications (Ontario Power Authority, 2011).

Toronto is home to 11 district energy plants, more than any other municipality in Canada (Canadian District Energy Association, 2009). Toronto’s district energy history began in 1911 with the University of Toronto building its first system afforded through a provincial grant. The next project was implemented by Toronto Hydro in 1964. By 1982, district heating services in downtown Toronto were consolidated as the Toronto District Heating Corporation, a non-profit company. The Toronto District Heating Corporation rebranded itself as Enwave and was allowed to become a private and for-profit company in 2000. In 2004, Enwave began pumping cold water from the depths of Lake Ontario in order to expand the downtown Toronto district energy system to include cooling as well (Enwave Energy Corporation, 2011). Enwave currently services 3.7 million square meters of space with 40 km of piping connecting 140 buildings in downtown Toronto (Enwave Energy Corporation, 2011). Aside from the University of Toronto and Enwave systems there are currently district energy systems at Regent Park, the Baycrest Centre for Geriatric Care, the Centre for Addiction and Mental Health, York University and the Canadian National Exhibition (Canadian District Energy Association, 2009). Toronto has plans to implement systems in the East Bay Front and the Lower Don Lands (Shirley Hoy, 2007). In addition to Toronto’s recent district energy development, there have been projects recently implemented in the neighbouring municipalities of Markham, Mississauga and Hamilton.

It can be seen that district energy is well implemented in numerous European countries potentially due to less common fossil fuel resources. While Canada has a large potential for a similar widespread implementation, it may not suffer from the same pressures as its European counterparts due to its abundant and cost effective natural gas resources. Regardless, there has been considerable experience and interest in developing district heating systems in Canada with most development being in Toronto and cities nearby.

### 2.2 Studies of District Heating in Toronto

The Canadian Urban Institute (CUI), Genivar and the City of Toronto have performed studies on potential configurations, environmental impacts and areas of focus for district heating systems in Toronto.
A study conducted by CUI evaluated the potential monetary and GHG emissions savings for district energy systems in Canada in a report entitled *Advancing District Energy Development in Canada* (Canadian Urban Institute, 2007). The method used to select the areas for study consisted of four steps: identifying communities using census population growth, identifying candidate plant sites in high density areas using official plans, developing a land use profile for each site using census and utility data, and calculating the annual energy use intensity factor. In this report the development of district energy systems in three City of Toronto neighbourhoods (Scarborough Centre, North York Centre, and the Sheppard Corridor) are considered. The study finds that:

*... the development of combined heat and power (CHP) district energy systems in these three neighbourhoods would yield significant energy and greenhouse gas emissions reductions. The total annual energy reduction for these three communities is estimated to be approximately 4,100,000 gigajoules, corresponding to a reduction in greenhouse gas emissions of approximately 200,000 tonnes. This represents a combined 27 percent reduction for the three communities evaluated. An emission reduction of 200,000 tonnes is equal to a reduction of almost 1.5 percent of the City’s greenhouse gas emissions, current as of 2007*\(^2\) (City of Toronto, 2009).

For comparison, the GHG emission reduction per person is shown in figure 2 for the specific areas of study within Toronto, Mississauga\(^3\), Oakville, Barrie and Oshawa.

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\(^2\) It should be noted that as of 2007 the Government of Ontario has planned to phase out all coal-fired electricity by 2014 (Ontario Ministry of the Environment, 2012). This would drastically reduce the GHG savings claimed by CUI.

\(^3\) Mississauga’s large GHG reduction potential may be due to the presence of a large shopping centre (Square One) and government offices accompanied by low residential occupancy in the same area.
Figure 2 - CUI report estimates of GHG reduction per capita per year for certain areas in Ontario Municipalities.

In a report by Genivar, prefeasibility studies on 27 nodes in Toronto were performed with a more detailed feasibility analysis of the same nodes being suggested (Genivar, 2012). These nodes combined seek to meet the City’s criteria of achieving significant CO₂ emissions reductions (approximately 4 million tonnes), having 9-10% Return-On-Investment (ROI) and improving the energy reliability of the City. The preferred compositions of the nodes are as follows:

- Have high density with anchor clients⁴;
- Have communities which are supportive and designed for active travel modes;
- Have residents with a culture of energy management;
- Be located in an electrically constrained distribution region in Toronto;
- Have supply to natural gas and opportunities for alternative energies (waste heat, biogas, biomass, deep lake cooling etc.); and

---

⁴ Anchor clients are buildings with large heating loads which provide a continuous and financially attractive base load for the heating plant.
• Have special considerations which would make it suitable to district energy implementation (boilers which will be phased out, utility work in the near future and proximity to existing DES).

Toronto’s official sustainable energy plan also provides some direction for the city’s district energy future and suggests:

• Creating local district heating systems that cover high-density areas of Toronto;

• Taking advantage of early opportunities for neighbourhood thermal energy networks;

• Creating a long-term plan to interlink the local networks into a citywide structure;

• By 2030 District Energy Systems will become prevalent in Toronto and will be supplied increasingly by energy forms other than natural gas; and

• The implementation of distributed energy infrastructure in both existing and new neighbourhoods has the potential to significantly reduce the City’s energy consumption through deployment of a more efficient and flexible distribution network (City of Toronto, 2011).

These studies and reports show there is significant GHG reduction potential if district heating is implemented in Toronto. Further, the scope of the case study can be narrowed down to the 27 nodes within Toronto which have already been identified and where further detailed studies have been suggested. Lastly, Toronto’s official strategy provides a general but supportive direction for district heating development.

2.3 Barrier to District Heating Implementation

In order to understand how to increase the uptake of district heating projects there needs to be a collection and analysis of the challenges currently facing district heating. The issues cover economic, socio-political and environmental realms.

In terms of economics, the barriers revolve around the reliability and attractiveness of district heating business plans. The fabrication and installation of piping networks is often the largest capital cost of district heating system. While installing district heating systems in new
developments reduces this cost, new developments are typically low density resulting in higher distribution losses per connection and thus a lower ROI. High density areas often have shorter distribution networks with greater loads but the networks themselves are more expensive to install since they usually involve digging up existing roads and other infrastructure (Hans-Holger, 1993). Infrastructure costs aside, there is also risk involved in securing enough customers. Since most potential customers in a developed area will already have a heating system in place it may not make financial sense for them to connect to a district heating system until their heating system requires replacement. This can be addressed by understanding the fact that typical boiler systems have a lifespan of 25 years and connecting district heating systems to these buildings at the end replacement time.

Residents, businesses and developers are generally unaware and uneducated about district energy as a heating and cooling option (Canadian District Energy Association, 2007). Without the knowledge and push for district energy systems from the bottom up there is a lower possibility of implementation. Additionally, Canada’s district energy sector could benefit from more experts and contractors with the knowledge on how to design and implement district energy systems. This aspect may impact the rate, cost and perceived risk with designing, constructing and operating district energy projects.

With regards to politics, provinces regulate energy production and sale but have varying degrees of involvement in district energy. In Ontario, specific regulations do not exist for the construction of connection of these district energy systems as they do in other countries. This leaves the market open for future legislation which may alter the feasibility of such systems. Since district heating is often a long-term investment, a change in legislation or policy may cause the feasibility analyses to shift greatly, a risk not desired by investment or utility companies. While there is a lack of regulation around district energy, many utility companies are restricted to only selling electricity or natural gas (International Energy Agency, 2009; Northwest Clean Energy Application Center, 2010).

Although it could be considered a financial consideration, for district heating to compete with alternatives the cost of energy and its associated environmental impacts needs to be fully calculated (i.e., externalities should be internalized). District energy solutions would be much
more competitive if the increase in efficiency and reduction in GHG emissions was more appropriately valued.

Having identified numerous barriers to district heating implementation from across economics, politics, social and environmental realms, it is clear there is a plethora of challenges to overcome. Out of all these challenges, a geographical approach and GIS are probably most applicable to reducing costs through improved planning and construction. Specifically, GIS can be used to determine the most promising communities for district heating; quickly identify anchor buildings; more clearly estimate the heating loads; identify opportunities for coordinating construction with utilities; and optimize the plant location in order to minimize pipe costs and heating losses. These applications help reduce financial risk, the capital and operational cost barriers to district energy and create a more attractive proposal to consumers and investors. These applications are explained in chapter 3, Building the GIS Model.

2.4 District Heating Feasibility Studies

An investigation of numerous North American district heating pre-feasibility and feasibility studies is undertaken in order to gain insights on the format, process and focuses of current approaches. These insights help to guide the application of GIS to the current methods of cost assessments and other analyses associated with district heating implementation.

Feasibility studies have had a diverse range of scopes spanning from a single neighbourhood to an entire continent (in this case, Europe). Studies of an entire city are commonly broken down into individual studies of areas or neighbourhoods. This wide variety of scopes motivates one to develop a single tool or method which is applicable or adapts to the scale required.

A key aspect of district energy feasibility studies are heating load estimates. These are usually generated using existing utility data, building code standards (R-2000), energy efficiency standards (such as LEED) and/or building modeling software. Both annual and peak heating loads are calculated in order to determine plant size and configuration (such as back up and peaking boilers). Plant capacities are usually lower than the sum of the peak loads due to peaking occurring at different times between different types of users. The peak loads are multiplied by a ‘diversification factor’ (which usually ranges from .8 to .95) to account for such differences (International Energy Agency, 2005). A report to Ontario Power Authority uses a diversification
factor of .85 for Toronto (Compass Resource Management, 2010). Heating loads are usually averaged over the usable area within each building and account for factors such as building use, heating degree days and age of buildings. These averages are then used to estimate heating loads for buildings in general. In an investigation of 12 district heating feasibility studies heating load estimates ranged from 36.4 KWh/m$^2$ (for a study of London, Ontario) to 295 KWh/m$^2$ (for a study of Old Crow, Yukon) with the median value at 99.7 KWh/m$^2$. Considering only studies in cities with average annual temperatures within plus or minus five degrees of Toronto’s, the median value becomes 75.5KWh/m$^2$. Six of the same studies have a range of peak heating loads from 24 W/m$^2$ and 207 W/m$^2$. A study by FVB Energy Inc. for the City of Pickering estimates “for each MW of peak heating demand a typical residential unit in the GTA would consume approximately 2,500 MWh of heating energy per year” allowing for an approximate conversion to be made between the two values (FVB Energy Inc., 2007). Heating load estimates can now be performed using similar methods and a reasonable range of values have been established. A summary table of Energy Use Intensity examples is in Appendix A.

Once heating load estimates are established, the studies move onto calculating infrastructure costs. These are usually calculated for the distribution system, energy transfer stations and construction of the heating plant. Seven feasibility studies show distribution systems cost estimates ranging from $157/m to $2437/m of pipe. Piping costs are highly dependent soil conditions and their size. Five feasibility studies show energy transfer station cost estimates ranging from $20,000 to $227,000 each station. Five feasibility studies show heating plant cost estimates ranging from $150,000 to $5,900,000 per plant. This is highly dependent on the technology used and the capacity of the plant. The Canadian Urban Institute (CUI) modeled district energy costs and GHG reduction potentials using the CBIP Screening Tool and adjusted it to Calgary conditions (Natural Resources Canada, 2012). This resulted in a capital cost of $184/GJ of heating capacity (Canadian Urban Institute, 2008). Between the feasibility studies and CUI’s estimates, it is clear that infrastructure costs are highly dependent on type, capacity and local conditions. In addition to heating load estimates and infrastructure cost estimates, some studies produced: an estimate for the service cost to consumers, GHG emissions of district heating compared to business-as-usual, return on investment forecast, cash flow diagrams, local socio-economic impacts, fuel and heating technology comparisons, sensitivity analyses, proposed plant locations, and/or distribution system configurations.
While there are clear differences between studies and estimates on various aspects, this review has provided a feel for how studies are carried out and a reasonable range for values to be within. The current research being undertaken can now be designed to fit into how feasibility studies are currently being carried out.

2.5 RETScreen District Energy Project Analysis

In addition to current feasibility studies, there are also various tools and software platforms being used to perform cost and environmental impact analysis for district heating projects. RETScreen is an example of such software which provides general values based on parameters such as pipe size, location and heating load. RETScreen is a spreadsheet based energy project analysis tool developed and distributed for free by the government of Canada. RETScreen is used internationally and its district energy project analysis is used for guidance and comparison with the previous feasibility study findings.

Firstly, a location must be set in RETScreen as the program adjusts its heat and cost estimates based on the project’s location. The program then calculates heating and domestic hot water loads based on the heated area (in a cluster of buildings as defined by the user), the building’s characteristics (insulation, windows, etc.) and the number of heating degree days at the location (which already exists in a database in the program). A load duration curve is also produced using the heating degree days in a month. A more detailed description of the exact process can be found on their online e-textbook (RETScreen, 2009).

In figure 3 and 4, RETScreen provides values for peak heating loads ranging from 30 to 100 W/m² based on location, type of building and general quantity of insulation (Natural Resources Canada, 2012).
Figure 3 – RETScreen Heating Load Estimates Based on Location, Building Use and Amount of Insulation

<table>
<thead>
<tr>
<th>City</th>
<th>Regina</th>
<th>Ottawa</th>
<th>Halifax</th>
<th>Vancouver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Temperature</td>
<td>-36°C</td>
<td>-27°C</td>
<td>-18°C</td>
<td>-9°C</td>
</tr>
<tr>
<td>Insulation</td>
<td>Good</td>
<td>Med.</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Office</td>
<td>60</td>
<td>65</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>Retail</td>
<td>65</td>
<td>80</td>
<td>95</td>
<td>50</td>
</tr>
<tr>
<td>Restaurant</td>
<td>90</td>
<td>105</td>
<td>120</td>
<td>75</td>
</tr>
<tr>
<td>Warehouse</td>
<td>45</td>
<td>60</td>
<td>75</td>
<td>35</td>
</tr>
<tr>
<td>School</td>
<td>50</td>
<td>65</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Health/Medical</td>
<td>55</td>
<td>70</td>
<td>85</td>
<td>45</td>
</tr>
<tr>
<td>Hospital</td>
<td>100</td>
<td>115</td>
<td>130</td>
<td>90</td>
</tr>
<tr>
<td>Hotel</td>
<td>90</td>
<td>105</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Residential</td>
<td>65</td>
<td>80</td>
<td>95</td>
<td>55</td>
</tr>
<tr>
<td>Food/grocery</td>
<td>65</td>
<td>80</td>
<td>95</td>
<td>50</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>55</td>
<td>75</td>
<td>95</td>
<td>45</td>
</tr>
<tr>
<td>Average building</td>
<td>69</td>
<td>83</td>
<td>97</td>
<td>58</td>
</tr>
</tbody>
</table>

Figure 4 – RETScreen Heating Load Estimates Based on Design Temperature
RETScreen utilizes a formula (graphed in figure 5) which factors in the size of pipe in order to determine the appropriate cost. The costs include the pipe costs, land work (such as trenching and replacing sidewalks) and installation of preinsulated supply and return pipes (i.e., 2 pipes). The cost assumes a trench approximately 600 mm deep for the pipes and also estimates a 50-100 year life span. RETScreen warns that rocky terrain or installations in areas that have many old utility services (e.g., telephone, electricity, sewage, water, etc.) could substantially increase the calculated cost.

![figure 5 - RETScreen Pipe Cost Graph](image)

**Figure 5 - RETScreen Pipe Cost Graph**

RETScreen uses a similar method for energy transfer stations and boiler/plant costs. Instead of pipe diameter as the factor, the capacity (in KW or MW) of the energy transfer station and boiler is used instead. Smaller energy transfer stations are prefabricated which may account for the non-linear increase in cost at small capacities as shown in figure 6.
RETScreen is capable of providing pre-feasibility cost and heating data where more context specific data (such as actual utility consumption data) cannot be readily obtained. This reduces the need to gather data from (potentially restrictive) organizations such as utilities, consulting companies or municipalities. The use of RETScreen can significantly lower the bar for data needed by GIS software to be effective. With the use of RETScreen, building footprints and transportation networks can be used to calculate heating loads and piping costs.

2.6 GIS-Based District Energy Assessments

Currently, GIS is being used in various fields to plan and design networks, manage assets, manage operations and provide analysis to aid in decision making. GIS is applied in the fields of transportation, geology/geography, utilities and modeling energy resources. A study of current applications gives a sense of the breadth GIS is currently being used when applied to district heating.

In one study, GIS was applied to assess the potential for district heating expansion in Europe (Gils, 2012). The analysis uses heat demand data from each country and distributes it based on population, land use and number of consumers to provide a map of actual heat demand. The
process is diagramed in figure 7. The heat demand data is adjusted to the heating degree days estimated from the PRIMES 2005 scenario (Capros, 2002).

![Figure 7 - A diagram of the heat demand mapping process from Figure 1 in Gils, 2012](image)

A raster map of heat demand across Europe was generated with pixels/areas ranging from 0.27 km$^2$ to 0.74 km$^2$. Cells below a certain threshold of energy density are removed and their heat consumption combined with neighbouring cells. The study recognizes that due to the low resolving power of the model that certain district heating potentials are probably underestimated or not calculated. The study reveals the district heating potential within each country compared to the current amount of district energy generation but does not provide information on a more granular level. The study concludes that the model predicts a significant potential for district heating in Europe even with a 2% per year reduction in space heating demand.

GIS has also been used in an analysis of Germany’s district heating potential (Dorfner, 2011). A method that utilizes building geometry, building use and age was developed and used to estimate heat demand with 200 m by 200 m square zones as seen in figure 8. The program effectively generated a heat map which could be used for identifying areas in a city which could be targeted for energy efficiency improvements and district heating plans. The tool is self-admittedly unusable on an individual building level.
SOLUTION, a GIS based Energy Management System is in the process of being developed by the European Commission and is expected to be completed by 2013 (Concerto, 2012). This model seeks to provide information in a graphical format which aids in municipal decisions on energy projects. It aims to assess the success of different demonstration projects and the emission mitigation potential of a community wide application. Heating load estimates consider building footprint, year of construction, location, use, area, heating method and utility data. The preliminary report states, “GIS analysis can be highly efficient tool for district heat producing energy companies in search of potential expansion of the DH network”. The report uses case study areas broken down into 250 m by 250 m blocks, a slightly coarser resolution than Dorfner’s model. The process uses GIS and the ‘blocked’ heat loads to determine feasible plant location via three general steps:

1. Finding general areas with potential for a plant based on total heating fuel consumption.
2. Selection of a few blocks which demonstrate a high potential to be a district energy plant site based on various criteria.
3. A detailed analysis of the selected blocks to determine a final location suggestion.

(The preliminary report is not specific about the criteria to judge suitability.)

The current research shows the primary use GIS is to analyze areas/sectors of heating load. Some efforts are being taken to use GIS for determining plant locations. These generally leave a more detailed (such as on a building level) GIS analyses to be desired since it would improve accuracy and allow for precise forms of analysis.

2.7 Other Energy Assessments Relevant to District Energy

While previous GIS studies related to district energy are most relevant to this thesis, other geographical approaches to energy mapping are useful for understanding other approaches to similar issues.

2.7.1 Energy Mapping of New York City

The City of New York was the focus of a study used to estimate end uses of energy on each tax lot as can be seen in figure 9 (Howard, et al., 2012). The study used floor area, gas use, electricity use and fuel oil use from the mayor’s office which was collected it in 2009 from major utility companies. The study accounted for the weather that year which was the average for the 30 year period. The data was based on tax lot, which is estimated to have 14% less entries than actual buildings. Linear regression is used to interpolate heating values for tax lots without data. Eight types of building categories were used: residential family, residential multi-family, office, store, education, health, warehouse and other commercial. A visual map was created with heating and electricity load estimates based on end use. The map helped the team to suggest micro combined heat and power systems and other energy saving retrofits.
2.7.2 Energy Mapping in Ontario Municipalities

In a more local setting, the CUI’s Integrated Energy Mapping for Ontario Communities (IEMOC) aims to visualize the current and future energy consumption in various communities (Canadian Urban Institute, 2010). The goal is to provide communities in Ontario with information that could aid them in urban planning for lower energy consumption. Studies have been performed for the cities of Guelph, Hamilton, Barrie, London and Calgary. The studies state they may help to:

- Identify the energy and GHG emissions associated with the built environment and with transportation by working with data from local utilities and other sources;

- Evaluate the potential for energy and GHG reductions through the development of energy efficiency strategies, scenarios and by applying a cost-effective evaluation process; and

- Implement the preferred energy efficiency strategies as effectively as possible by identifying and enabling policies, program tools and supportive actions.

The program’s data results are meant to be used by local distribution companies, municipalities, regional governments and urban planners. Some outcomes include:
- The assessment of the energy and carbon reduction potential;
- Reviews of energy technologies and alternatives; and
- Energy demand maps from buildings and transportation.

The process involved calculating floor space based on building footprint and number of floors, distinguishing new buildings from old buildings, categorizing each building by type (low rise residential, high rise residential, commercial office, etc.) and determining the energy used by each building by multiplying its floor space by energy intensity factors (EIFs) which were derived from utility data and energy efficiency standards. The resulting graphic for Guelph is shown in figure 10. GHG emissions and costs were calculated from the total energy given local factors. This study is potentially the most relevant energy study to this thesis and provides a set of guidelines to follow in the energy mapping aspect.

Figure 10 - IEMOC energy intensity map for Guelph
2.7.3 District Energy System Analysis

In 1979, Public Works Canada created a program called District Energy System Analysis (DESA). The intent was to provide ‘preliminary engineering design and a financial/energy life cycle costing of specified district energy systems’ (Verma, 1979). There were seven modules in DESA:

- “Demand: determines the peak heating and cooling demand for each year;

- Network Sizing and Costing: determines the sizes of the unknown chilled water, hot water and steam mains in the distribution system and calculated the cost of the entire network year by year;

- Refuse Processing and Expenditure: determines the size of facilities such as transfer stations, shredder mills and landfill sites. Then the total cost is computed of processing, haulage, and disposal of the solid waste;

- Plant Sizing and Costing: determines the size and cost of the central plants;

- Financial Sensitivity: determines the present value of the entire district energy system taking escalation and discount rates as variable parameters;

- Differential Charge: determines the differential or tipping charge by comparing the net present values of two district energy systems - one with and one without a refuse incineration/pyrolysis system; and

- Energy: determines the total energy cost of a district energy system given the capital, operating and maintenance costs, and fuel requirements. The indirect energy required to manufacture a range of goods and machinery is derived from their dollars value in the market place”.

The user entered the building energy loads, load configurations, the type of plant desired and the location of the plant. DESA also allows the manipulation of input parameters enabling the comparison of various system configurations. The program appears to not be in common use anymore but does neatly organize and explain the common processes involved in analyzing district energy projects.
2.8 Chapter Synthesis

A review of the literature and current district energy landscape reveals that Toronto and its surrounding areas is a Canadian hub for district energy projects. There is significant potential for reducing energy resource consumption, GHG emissions and energy costs by expanding upon Toronto’s current district heating systems in addition to constructing new ones. Toronto’s district heating history involves a century of slow but consequential growth demonstrating that there is the ability, desire and expertise to develop Toronto’s district heating systems further. Toronto and its surrounding municipalities have exhibited an encouraging growth spurt of proposed and built district heating projects (about 6 within the last and next five years). Toronto’s Official Plan focuses on finding neighbourhoods with favourable conditions to district heating such as having a high density of anchor clients, redevelopment potential and a culture of energy management. This provides clear objectives for district energy development.

Present challenges to district heating in Canada can generally be summed up to increasing certainty within the industry. This means creating awareness amongst the general population, identifying financially viable projects and developing actual policies to structure the industry.

Current feasibility studies have primarily utilized GIS to identify and analyze potential district heating neighbourhoods by calculating the current and future heat loads. These heating loads are then used to calculate GHG reduction potentials and infrastructure costs. GIS has yet to be applied to other concerns of local governments, communities or district heating’s other challenges. Map data consists of heat loads and is not combined with other available map data to provide unique insights. GIS’ powerful analytical tools are also not being fully utilized for network and plant location optimization.

Referring back to the initial focus on preferential utilitarianism, it is evident that current feasibility studies focus on financial viability and environmental benefits. These are undoubtedly important but the consideration of other information and perspectives could prove useful for feasibility analysis and can be easily facilitated by the use of GIS. Even in studies which provide insights on other considerations, GIS’ data visualization capabilities have not been leveraged in order to communicate such information. GIS may also facilitate more accurate and reliable financial and environmental benefit calculations.
Overall, this literature review has revealed there is value in:

- A detailed analysis of Toronto’s heating loads;
- Using these heating loads and growth patterns to predict where district heating systems should be implemented;
- Overlaying data along with heating demand data to provide new perspectives on district heating potential; and
- Leveraging GIS’ powerful analytics to optimize certain district heating aspects.

The next chapter explains the approach taken to fully capture these opportunities.
Chapter 3
Methodology for Building the GIS Model

The literature review shows what is currently being done but more importantly what new advances could be made in order to help reduce and remove the barriers to district heating implementation. The research to be undertaken strives to use GIS as a flexible and effective means to meet current and future needs for district heating assessment. GIS’ data layering capabilities allow for the application of preference utilitarianism and its data visualization capabilities enable the effective communication of ideas and information such as large quantities of peak heating data.

The methods of this research demonstrate that through the use of GIS, heat mapping, heating load calculations, visualizations and analysis can be performed easily. From these methods planners, decision makers and investors can more reliably predict the revenue, costs and other considerations for district heating projects.

The GIS model uses a foundation of utility data and building footprints in order to estimate peak heating loads. The nodes used in the previously performed Genivar study narrows the areas of study to a select few of those intersections. Lastly, the model is fully built out in ArcGIS in order to utilize its visualization, data layering and analysis functions.

3.1 Research Practicality

In the pursuit of promoting district heating in Toronto, this research aims to utilize data, methods and tools which are broadly applicable and practical. Most data can be obtained publically and the methods are meant to be straight-forward, repeatable and require a sensible amount of time. However, it should be mentioned that many sources of data which would be useful are not easily obtainable or are not in a GIS format (this is elaborated upon in Chapter 5). The tools used (spreadsheet software and GIS software) should be readily available to most organizations performing geographical analysis with free versions also being available to anyone with access to
a computer and internet. The specific GIS software used is ArcGIS, the most popular GIS software on the market (Francica, 2011)\(^5\).

### 3.2 Heating Load Estimates

Much like current feasibility studies, the point of focus is to estimate heating loads in order to determine the financial feasibility and environmental benefits associated with the project. This is a must but given the use of GIS, this constraint also allows for a variety of other insights to be gained. In order to estimate peak building heating demand in the GIS model, 2009 utility data of 376 downtown Toronto buildings is collected from Enwave Energy Corporation. Many of the buildings currently use Enwave heating services so the figures are accepted to be generally accurate for district heating services. The data includes peak heating load, number of floors, building use, building area and year built.

Heating loads are greatly affected by the weather so for comparison, 2009’s coldest day was -22.2 degrees Celsius while the 30 year record lowest was -31.0 degrees Celsius in 1994 meaning the peak heating data is relatively conservative. Toronto’s 30 year average (from 1982 to 2012) heating degree days (HDD) is around 3600 while in 2009 it was around 3100 (Environment Canada, 2012).

These values are then used to calculate the peak heating energy required per year per square meter for each building type. The building types identified in the Enwave data included: commercial, institutional, residential, entertainment and hotel. Entertainment and hotel had 9 and 2 buildings respectively and are considered as commercial buildings in the GIS model.

In order to calculate the peak heating load in metric units we assume a temperature change of 136 degrees Celsius (191 degrees Celsius supply, 55 degrees Celsius return). Other quantities and a sample calculation (Equation 1) are illustrated below where \( M, \Delta H_{steam} \) and \( T_i \) refer to mass flow, energy transferred and the temperature in Kelvin respectively. Equations and values are taken from the CODATA Key Values for Thermodynamics and The Engineering Toolbox, respectively (Cox, 1989; The Engineering Toolbox, 2012).

\(^5\) A plethora of GIS software exists and a general comparison can be found at http://en.wikipedia.org/wiki/Comparison_of_geographic_information_systems_software
<table>
<thead>
<tr>
<th>Unit</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Heat Capacity of Liquid Water</td>
<td>$c_{pw}$</td>
<td>$4.187 \frac{kJ}{kg^{\circ}K}$</td>
</tr>
<tr>
<td>Specific Heat Capacity of Water Vapour (Steam)</td>
<td>$c_{ps}$</td>
<td>$1.996 \frac{kJ}{kg^{\circ}K}$</td>
</tr>
<tr>
<td>Specific Heat of Vaporization for Water</td>
<td>$\Delta H_{vap}$</td>
<td>$2257 \frac{kJ}{kg}$</td>
</tr>
</tbody>
</table>

Table 2 - Constants Used for the Conversion of Peak Loads to Metric Units

\[
\Delta H_{steam} = H_f - H_i + \Delta H_{vap}
\]

\[
= M \left[ c_{ps}(T_{191} - T_{100}) - c_{pw}(T_{100} - T_{55}) + \Delta H_{vap} \right]
\]

\[
= M \left[ 1.996 \frac{kJ}{kg^{\circ}K} (191^{\circ}K - 100^{\circ}K) - 4.187 \frac{kJ}{kg^{\circ}K} (100^{\circ}K - 55^{\circ}K) + 2257 \frac{kJ}{kg} \right]
\]

\[
= M \left( \frac{2627 kJ}{kg} \right)
\]

\[
= \left( \frac{0.2022 \text{ lb}}{h \cdot m^2} \right) \left( \frac{0.000126 \text{ h} \cdot \text{kg}}{s \cdot \text{lb}} \right) \left( \frac{2627 kJ}{kg} \right)
\]

\[
= \frac{0.06693 kJ}{s \cdot m^2}
\]

\[
= \frac{66.9 W}{m^2}
\]
### Building Type

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Mean Area (in m²)</th>
<th>Mean Peak Load (in PPH)</th>
<th>Number of Sites</th>
<th>Pounds Per Hour/m²</th>
<th>W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>27017</td>
<td>5464</td>
<td>72</td>
<td>.2022</td>
<td>66.9</td>
</tr>
<tr>
<td>Institutional</td>
<td>30969</td>
<td>20575</td>
<td>33</td>
<td>.6644</td>
<td>220</td>
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<tr>
<td>Residential</td>
<td>42758</td>
<td>9205</td>
<td>13</td>
<td>.2153</td>
<td>71.3</td>
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<td>Entertainment</td>
<td>30571</td>
<td>3912</td>
<td>9</td>
<td>.1280</td>
<td>42.4</td>
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<tr>
<td>Hotel</td>
<td>51802</td>
<td>10050</td>
<td>2</td>
<td>.1940</td>
<td>64.2</td>
</tr>
</tbody>
</table>

**Table 3 - Peak Heating Data Collected from Enwave**

These values are reasonable given the values used previously by district energy studies. They provide the basis for estimating heating loads in the GIS model to be built.

### 3.3 Node Choices

Mapping the entirety of the City of Toronto is expected to be more labourious and comprehensive than currently necessary since there are large low density sprawls which would not be a priority for district heating systems. The previous study performed by Genivar is used to narrow the scope down to only the areas already determined to have high potentials for district energy projects to be implemented.

The Genivar report concluded the nodes needed further investigation making the targeted case study relevant to future development of district heating. Nine of these nodes are shown in figure 11 and are chosen for further analysis based on:

- Not having nearby existing district heating plants (Downtown, Regent Park, the Canadian National Exhibition, University of Toronto, University of York, Portlands, West Don Lands, etc.);
● Potential for new development (population growth, development opportunities);\footnote{A map of buildings over 35m which have been proposed and which are under construction according to SkyScraperPage.com can be found in Figure 18 and Appendix B (Skyscraper Source Media, 2012)}
● Geographical spread across Toronto; and
● Being part of the Places to Grow plan\footnote{The plan identifies urban growth centres in Ontario which are the focus of strategic and sustainable urban planning and development} (Government of Ontario, 2008).

A list and description of the intersections chosen can be found in Appendix C.

![Figure 11 - A map of the 9 nodes chosen for detailed analysis.](image)

### 3.4 GIS Model

To create the actual model in the software a shapefile containing polygons representing the 2010 building footprints for the city of Toronto is obtained from the University of Toronto Maps and
Data Library. The building footprint data is the foundation on which other data is layered upon to enable an assortment of analyses to be performed. At each intersection under study, the building footprint polygons are reconciled with more recent satellite and aerial imagery from Bing Maps, Google Maps and OpenStreetMap to improve the accuracy of building area and peak heating load estimates. New buildings are drawn in with approximate area and location and previously existing buildings are removed. The building footprints layer contained an attribute table with the fields: ‘Area’ (building footprint areas in m²), ‘Type’ (building uses denoted by r for residential, c for commercial and i for institutional), ‘Floors’ (the number of floors in each building), ‘Peak_Load’, ‘X coordinate’ and ‘Y coordinate’. For each building the number of floors and type of use are manually entered from databases such as Google Maps, UrbanDB, OpenMaps and Bing Maps. This process is the most time consuming part of creating the model and took around two to three hours per intersection. For large subdivisions the building height and type is assumed to be constant. The total building areas are then calculated as the product of the number of floors and gross area of the building footprint. While the City of Toronto provides a zoning map (which would have been helpful for determining building type), there seems to be missing data for a few patches around Toronto which can be seen in figure 12 (City of Toronto, 2012).

![Figure 12](image)

**Figure 12** – The grey area shows a large portion of Yonge Street between Finch and Sheppard without zoning data.
Each building’s dominant use\(^8\) is then used to select the appropriate peak heating factor which is then multiplied by the building’s gross area in order to calculate the total peak load. Buildings which are equally mixed use had the average of the two heating load factors applied for their calculation. The heating load calculation is:

\[
H_i = F_i \times A_i \times P_i 
\]  \hspace{1cm} (2)

where \(H_i\) refers to the total peak heating load of building ‘\(i\)’, \(F_i\) refers to the number of floors in building ‘\(i\)’, \(A_i\) refers to the area (in m\(^2\)) of building ‘\(i\)’ and \(P_i\) refers to the peak heating load factor that corresponds with the use of building ‘\(i\)’.

Since building types vary, in order to calculate \(H_i\) in ArcGIS a short ‘If Statement’ is programmed into ArcGIS in the computing language of VB Script. A sample of the code can be found below in figure 13 with the full code found in Appendix D.

```
Dim loadcalc
If [Type] = "r" Then
    loadcalc = [Floors] * [Area]*71.3
ElseIf [Type] = "c" Then
    loadcalc = [Floors] * [Area]*66.9
    ...
Else
    loadcalc = 0
End If
```

**Figure 13 - VB Script Code for ArcGIS**

The ‘feature-to-point’ tool is used to convert the polygons to points at their centroids. The ‘Add XY Coordinates’ tool is used to attribute location data to each point. A 500m (or 750m in some cases, depending on the original Genivar study) radius buffer polygon is created at each intersection. The polygon is intersected with the building polygons (any buildings in contact with the buffer are included and not cut off) and point shapes to create a new layer with only buildings at the intersection of focus included. The model now has the basic data (heating loads and

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\(^8\) Dominant in this case means the majority of the floors of the building are used for this purpose. For example, a condominium with 30 floors of residential and 2 floors of retail would have the residential building type and peak heating factor applied.
location) needed for district energy analysis. This data can then be shared and exported to various formats for analysis.

3.5 Analysis Techniques

The analysis performed consists of those typically found in current feasibility reports but also new visualizations for conveying data effectively and the superimposition of available and relevant GIS based data. ArcGIS can export its attribution tables (height, type, area etc.) as spreadsheets to facilitate various data analyses more easily. ArcGIS’s files can also be imported for analysis by other GIS software as well. These analyses only represent a small portion of the total applications GIS has in improving district heating implementation in Toronto.

3.5.1 Heating Loads

Heating loads are the backbone of district energy analysis because they are used to predict the revenue and costs for a district heating system. In this study, the peak heating load for various scenarios is calculated and summarized. The scenarios are: all the buildings, the top ten heating load buildings, the top three heating load buildings, all commercial and institutional buildings, and all residential type building. This data can then be used to determine the capacity of the district heating plant. Supplementing this information with heating degree days and the heat load distribution between building types allows for annual heating loads, a diversification factor, scheduling of heating services and the configuration of the boiler plants (base load, peaking load) to be estimated. These types of analyses are typical for current feasibility studies but other types are demonstrated in Chapter 5, Discussion of the Challenges and Opportunities.

3.5.2 Heating Load Visualizations

In order to improve the communication of such massive amounts of data GIS programs can create visualizations using colour, shapes, size and other graphical representations.

Peak heating load data can be divided into user definable quantities and then be visualized using a spectrum of colours or intensity of colours as seen in figure 14. Peak heating load can also be represented by proportionally sized shapes (larger shapes for higher loads, smaller shapes for lower loads). This type of visualization is particularly useful for quickly grasping an understanding of where the highest loads are and thus ascertaining the potential anchor buildings within an area.
Figure 14 - Colour Intensity Visualization of the Yonge Street and Empress Avenue Intersection. The darker the building the higher peak heating load estimated.

The use of spatial analysis tools within ArcGIS allow for some interesting and useful visualizations. One particular tool, which can be seen in figure 15, is an Inverse Distance Weighing interpolation. While we do not actually want to interpolate peak heating loads between buildings, the visualization provides a ‘landscape’ of peak heating load similar to a topographic map. This visualization helps convey where heating loads are concentrated and provides a sense of where it may be more effective or less effective to place a plant.
3.5.3 Proximity to Schools

GIS’ ability to overlay various forms of data allows the user to consider various issues and perspectives. One such local issue that occurred in 2012 was the resistance of local residents to gas fired power plant. Part of their concern was the proximity to housing and schools (Town of Oakville, 2012). This resulted in at least $40 million of extra costs (Ontario Power Authority, 2012). ArcGIS can aid in avoiding such costly changes by leveraging its data visualization abilities.

A shapefile containing Toronto District School Board schools can be imported into the current map with buffer zones created around the schools (figure 16). This helps planners visualize where it may be sensitive to build a district heating plant. However, this may compete with locating a thermally efficient plant since schools generally act as good anchor buildings.
Figure 16 - A 500m buffer made around the schools (symbolized by stars) in the Yonge Street and Empress Avenue area shows where residents may be sensitive to a district heating plant.

3.5.4 On-going Construction

The City of Toronto maintains a map of planned and ongoing infrastructure projects in a website named ‘INview’ (City of Toronto, 2013). The map, as seen in figure 17, can show road resurfacing, road reconstruction, sidewalk construction, watermain replacements, sewer replacements and other infrastructure construction. Overlaying this data provides valuable awareness on if there are opportunities to coordinate construction schedules (and thus reduce costs), where there are moratoriums on construction, what additional easements may be necessary for new pipes and where contracts for construction can be merged. Unfortunately, this data is not publically available in a GIS format.
Figure 17 - INview map of the Yonge and Empress intersection showing watermain replacement (blue line with white dots), a moratorium on construction (black and white checkered line) and Toronto Hydro projects (green line with yellow triangles)

3.5.5 Estimating Future Potential

An important aspect to consider when deciding an area’s district heating potential is its development trends. District heating plants take several years to plan, build and bring to operation meaning their surrounding area could have undergone impactful changes since the system’s inception. These changes can make a difference in how the system is planned (e.g., where distribution pipes are laid and the plant location) and its feasibility. A neighbourhood with a growing number of high heating load buildings would improve the feasibility while a neighbourhood that is deteriorating and losing density would negatively impact the feasibility of a district heating system. New buildings also provide an opportunity for immediate customers if approached before they on their own heating system. Figure 18 shows a map of proposed (blue markers) and under-construction (green markers) buildings in Toronto above 35m (or 12 floors) in height (Skyscraper Source Media, 2012). The map gives a sense of where growth is happening and how much. The pink circles show where the current intersections under study are. Having this information influences the decision to invest in an area’s district heating system.
Figure 18 - Proposed (Blue) and under construction (Green) buildings over 35m in Toronto from SkyScraperPage.com with the intersections under investigation in pink circles.

3.5.6 Plant Location Optimization

The location data obtained through GIS can now be used to suggest a plant location that minimizes the heating losses (and thus increase efficiency) through the distribution network. In Norway’s district heating system, these distribution losses are around 10% of the total energy generated (Norwegian Water Resources and Energy Directorate, 2009). The location is optimized based on being the shortest straight-line distance to the highest loads. This ‘shortest distance’ of piping is only true if we assume a grid-like pattern for roads (which distribution pipes are usually built under) in which case their straight line distances would be proportional to the distribution network length. This is generally, but not always, true.

The optimal locations suggested are based on either all the buildings in the area of study or also the 10 highest heating load buildings. The optimized plant locations are determined by
calculating the shortest distance to the above mentioned scenarios. This is done by identifying the appropriate buildings (all or top 10), weighing each by its relative peak load compared to the other buildings in the area of study and then applying this weight to each building’s respective location coordinates. In other words:

\[ w_i = \frac{H_i}{\sum_0^n H_i} \]  \hspace{1cm} (3)

\[ X = \sum_0^i (x_i \times w_i) \]  \hspace{1cm} (4)

\[ Y = \sum_0^i (y_i \times w_i) \]  \hspace{1cm} (5)

where \( w_i \) refers to the weight associated with each building \( i \), \( n \) refers to the total number of buildings in the intersection of study, \( X \) refers to the optimal plant location longitude, \( Y \) refers to the optimal plant location latitude, \( x_i \) refers to the building longitude and \( y_i \) refers to the building latitude. The result for the Kipling and Bloor intersection can be seen in figure 19.
3.6 Summary

The research methods presented show how GIS and a geographical approach in general to district heating can be developed from local data and effectively used to consider an assortment of information in order to encourage district energy implementation. The methods outlined show how GIS can be used to fulfill the needs of current feasibility studies but also go beyond this and consider other aspects with ease.

The GIS model uses actual heating load data from hundreds of downtown Toronto buildings. This large sample size of local data ultimately produces relevant average values to be applied across all Toronto buildings. These values also fall within the range of values used in previous studies further establishing their suitability.

The approach focuses the study to a group of intersections based on potential growth and geographical breadth. This concentrates resources and effort on the areas which are most promising for district heating and avoids putting resources into analyzing low district heating potential areas.
In addition to the building footprints and average heating values obtained, the model required manual entry of the building type and the number of floors in each building. This obstacle was surmounted by using various online mapping and building data resources such as Google Maps. Combining all the data allowed a peak heating load to be calculated for each building within the areas of study.

The model’s location specific peak heating loads allow it to perform analyses which inform decision makers and planners of the potential heating load to be served by a district heating system in each area. Additionally, information is obtained on which buildings have the highest loads (i.e. anchor buildings) and where those buildings are located with an easy method to visualize all this information. Additional contextual information such as planned construction, school locations and future high-rise development is brought into the model in order to capture a diverse set of considerations and to further enhance the ability to understand district heating potential. Identifying anchor buildings, determining opportunities for coordinating construction and determining the best location for the plant are just some of the examples of what is capable given the data and resources available.

The model effectively calculates and utilizes peak heating loads and supplementary geographical data in order to provide insight into an area’s district heating potential. What follows are the outputs from the methods illustrated in this chapter.
Chapter 4
GIS Model Results

It is critical that results and data are communicated well in order to be useful. Accordingly, the results for the methods described previously are presented in order to be relevant and comparable. The peak heating load data results are used to compare the intersections on different levels and draw insights on which may be best for which types of implementation. How attractive an intersection is to district heating is evaluated on the basis of estimated heating load since higher loads generally mean higher revenue potential and higher potential for environmental impact reduction. The visuals on each intersection’s results demonstrate the ability of GIS to communicate data. Other forms of analysis are touched upon but further elaborated on in Chapter 5, Discussion of the Challenges and Opportunities.

4.1 Floor Area Estimates

One of the primary methods to assessing whether an area is attractive for district heating implementation is the amount of building floor area that exists. Obviously, the more floor area there is the more heating required and thus the greater financial and environmental opportunity.

A comparison of the current building floor space between the GIS model and Genivar’s report provides a baseline on which to judge the model’s reasonableness by. This comparison shows there are many similarities but also drastic differences in estimates depending on the location and type of floor space.

In terms of residential floor space, the GIS Model estimates more than twice as much at the Yonge and Empress intersection and more than seven times the residential floor space at the Yonge and Sheppard intersection. The Genivar study estimates more than five times as much residential floor space at the Leslie and Sheppard intersection. At all other intersections estimates differ by 22% or less of the averaged value between the two studies. These statistics are conveyed in figure 20 below.
The GIS model estimates almost twice as much commercial/institutional floor space at the Yonge and Empress intersection. The Genivar study estimates more than twice as much commercial/institutional floor space at the Norseman and Kipling intersection and more than three times as much floor space at the Leslie and Sheppard intersection. The Genivar study also estimates 61% and 45% more floor space than the average values at the Bloor and Kipling intersection and McCowan and Ellesmere intersections, respectively. Yonge and Eglinton, Yonge and Sheppard and Thorncliffe and Overlea’s commercial floor space estimates differ by 14%, 0% and 21% of the average estimate respectively as exemplified in figure 21.
Figure 21 - Total Commercial/Institutional Building Area Comparison

Since residential and commercial peak heating load factors are relatively similar. In a comparison of total floor space estimated by both methods the GIS model estimates twice as much floor space for the Yonge and Empress and Yonge and Sheppard intersections. The Genivar study estimates more than twice as much floor space at the Norseman and Kipling intersection and more than five times as much floor space at the Leslie and Sheppard intersection. All other total area estimates differ by 30% or less.

It is significant that four out of the nine intersections studied show noticeable discrepancies with neither method consistently estimating more or less as can be seen in figure 22. This raises questions which would require a larger subset of work to done since the details and methods of the Genivar study are largely unknown. Some potential explanations could be that Genivar’s estimates included planned construction or it was based upon another metric other than an actual physical count of the space. Unfortunately, the unexplained methodology does not aid in understanding how these discrepancies have come about. The need for a transparent and accountable method may be the most important takeaway from this comparison (although perhaps the methods are kept secret for competitive reasons).
4.2 Area Comparisons to Other Databases

A building from each intersection is selected to be compared (in terms of area estimated) with other data (such as real estate listings and corporate websites). The purpose of the comparison is to see how well the estimates align with other values. The buildings selected are usually of the commercial type since those are the more likely to have other data sources on gross area.

The findings show that the GIS model estimates more floor space for eight of the nine buildings analyzed. An inspection of the results unveils that the other data sources are sometime incomplete and that the use of building footprints in the GIS model has some shortfalls. Only published gross leasable floor area (instead of total floor area) is obtainable for some of the properties analyzed (mainly malls). Gross leasable floor area only considers space available for rent and does not include all areas (such as hallways and maintenance facilities) within the building. This results in an incompatible comparison. The other noticeable issue is that the GIS

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9 A full list of each building, its alternative area estimate and source can be found in Appendix E
model multiplies the building footprint with the number of floors in order to obtain the total building area whereas in reality, the floors above ground level could have drastically different areas. A hypothetical situation of this is diagramed in figure 23. Buildings rarely increase floor area with height so this observation shows that the GIS model most likely overestimates building areas. A more thorough comparison between more buildings could provide a factor to correct for this discrepancy.

![Figure 23 - An example building (left). The same example building showing the darker extra floor space the GIS model would include (right).](image)

### 4.3 Heating Loads

What follows floor area estimations are calculations to determine the current actual heating loads that the district heating plant will be supplying if implemented. These provide more specific results which take into consideration the usage of the building. The results in figure 24 show that the largest peak loads are at the Yonge and Eglinton, Yonge and Sheppard and Yonge and Empress intersections. These intersections could be connected through a corridor of district heating along Yonge Street since Toronto’s energy plan suggested a citywide network. The Leslie and Sheppard; McCowan and Ellesmere; and Thorncliffe and Overlea intersections have the highest proportion of their total loads within the top ten buildings. It could be financially attractive to create smaller but more concentrated district heating systems in these areas. Peak
heating load data at each intersection provides an idea of the plant sizes required in addition to potential plant expansions in the future.

**Figure 24 - Total, Top 10 and Top 3 Peak Building Heating Loads**

Fully utilizing the building level details we can visualize the loads at a given intersection through a distribution graph. As shown in the distribution graph of figure 25 for the intersection of Thorncliffe and Overlea, there are 17 buildings above the 1 MW threshold. Conversely, in figure 26, the intersection of Yonge and Eglinton shows 34 buildings over 1 MW in peak heating (and many more buildings in general). Knowing how many buildings are at a certain threshold of heating load helps planners and decision makers to consider which buildings have the highest ROI and how to plan various phases of a district heating system. Peak load distribution graphs for other intersections can be found in Appendix F.
The preceding statistics can now be easily summarized into a profile, as seen in figure 27, for each location. This provides a convenient snapshot of heating, area, and building types to urban planners and decision makers. This is yet another example of how building level data and GIS can be used to achieve a more detailed understanding of each intersection. This level of detail opens up new realms of considerations and analyses which are examined in Chapter 5. Profiles for other intersections can be found in Appendix G.
<table>
<thead>
<tr>
<th>Allen and Lawrence</th>
<th>Peak Load in MW</th>
<th>Area in 1000s of m²</th>
<th>Number of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>55.7</td>
<td>721</td>
<td>1260</td>
</tr>
<tr>
<td>Top 10</td>
<td>16.6</td>
<td>181</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>7.8</td>
<td>115</td>
<td>3</td>
</tr>
<tr>
<td>Total Residential</td>
<td>39.5</td>
<td>558</td>
<td>1240</td>
</tr>
<tr>
<td>Total Commercial</td>
<td>8.6</td>
<td>129</td>
<td>8</td>
</tr>
<tr>
<td>Total Institutional</td>
<td>7.6</td>
<td>34</td>
<td>8</td>
</tr>
<tr>
<td>Total Check</td>
<td>56</td>
<td>721</td>
<td>1260</td>
</tr>
</tbody>
</table>

Figure 27 - Location Profile for the Allen and Lawrence Intersection

4.4 Optimized Locations

Another application of GIS is to minimize pipe length and distribution losses. This helps reduce both capital and operating expenses which reduce risk and increase economic viability.

Location optimization is performed for two scenarios: all buildings and the top 10 highest loads. The results show the largest distance between suggested plant locations is 237 m at the Allen and Lawrence intersection (figure 28) while the shortest is at the Leslie and Sheppard intersection (figure 29) at 67 m. A comparison of the two suggested locations can be used to assess what type of system may be best suited for each intersection. Suggestions that are close together could mean expanding the system in most directions would produce similar load capacities. Suggestions far from each other could mean a smaller more concentrated system would be more effective. Numbers alone only provide hints and a more thorough look at the actual intersection’s configurations would provide better context for decision making.

A closer inspection of what currently exists at the optimized locations shows both realistic and impractical suggestions. The suggested locations at the Allen and Lawrence intersections are at existing structures (Lawrence Square, a mall, and Allen Road, a major transportation arterial). The suggested plant locations at Leslie and Sheppard are near or on green fields. While the original goal is to improve efficiency through less heat loss during distribution, it appears that exact suggested locations may not always be feasible for highly developed areas due to existing infrastructure. However, the suggestion does provide an idea of where to place the plant near to in order to reduce transmission losses. Optimized location maps for all intersections are available in Appendix H.
Overall, these suggestions give a solid answer to planners and decision makers on where the most efficient plant location would be. The flexibility of the data obtained also allows for the
plant location to be optimized for any number of buildings under study. GIS and this method is capable of suggesting a location based on all buildings over 1 MW in peak heating load or on a cluster of 100 residential low-rise buildings on the north-west corner of the intersection.

4.5 Data Visualizations

The application of GIS software to visualizing data has been explored and it has shown to be capable of simple graphical representations of data which may prove useful in conveying vast quantities of data in a concise form. These visualizations could prove useful in presentations, public consultations and technical reports. Examples using dot sizes and dark/lightness to represent heating loads are shown below in figure 30 and 31, respectively.

![Figure 30](image)

**Figure 30 -** Dots represent buildings at the Allen and Lawrence intersection with the smallest dot denoting a peak load of 1 PPH or less and the largest dot denoting a peak load of 10,000 PPH or more.
Figure 31 - A representation of Allen and Lawrence intersection using shading to denote peak load. The lightest shade polygon represents a peak heating load from 0 to 4000 PPH and the darkest from 21,000 to 64,000 PPH.

These visualizations specifically address the issue of awareness amongst professionals, communities and politicians. It is a bit abstract to discuss tonnes of carbon dioxide reduction and megawatts of power saved. However, these graphical representations can show where energy is being consumed, what each building’s impact is compared to others and what are the largest opportunities for improvement are at a glance.

4.6 Future District Heating Potential and Other Data

Data layering allows for the consideration of any perspective that can have a location attributed to it. This provides GIS with the flexibility that’s only hindered by the availability of data and the user’s creativity. Data can be in either vector or raster form. The three types of data considered in this study are development trends, on-going construction and proximity to schools.

Thorncliffe and Overlea’s top 10 buildings loads are second only to the Yonge and Empress intersection despite being fourth in total load. A closer examination of the proposed and under
construction buildings over 35 m shows Thorncliffe and Overlea has no future development. This provides developers, planners and decision makers with insight into how the areas may look once the district heating plant is in operation and thus would influence their decision to construction a district heating system in the first place as well as the configuration of the system should it get the go ahead. Out of all the intersections, figure 32 shows Yonge and Eglinton seems to hold the most development.

![Proposed and Under Construction Buildings Over 35 m Tall](image)

**Figure 32 - Proposed and Under Construction Buildings Over 35 m Tall**

While the on-going construction data is not in GIS form it still provides useful information during the planning and construction stages for reducing construction costs. Since the installation of the distribution system is a major cost in district heating projects, a coordination of construction services with those that are already planned (such as cuts into the road) can help improve the ROI of a project and reduce any stoppages in services (such as blocked roads).

Knowing the proximity to schools is useful during planning and public consultations phases of projects since residents may express concerns of safety. These concerns have been shown to produce strong community opposition which would reduce the likelihood of the project being successful. The previously stated case of a power plant in Oakville cost $40 million to relocate.
Preventing community opposition and improving community acceptance and awareness are beneficial for reducing the costs and risks currently associated with district heating projects.

Both sets of data digress from calculating heating loads and illustrate the ability of location based data and GIS software to be applied throughout different stages to reduce the costs and risks associated with district energy projects. GIS software also allows for the data to be continuously added onto a single GIS project file improving the organization of data.

![Image](image.png)

**Figure 33** - All the GIS format visualizations (colour intensity, dot size, topographic map, proximity to schools and optimized locations) simultaneously for the Yonge and Empress intersection.

### 4.7 Summary

The results show that GIS software can be applied to support the implementation of district heating systems. GIS software allows users to input heating data, perform calculations, compare data sets, analyze results and generate data visualizations. All of the capabilities can be applied to reducing costs, reducing risks and making improvements at various stages of a district heating project.
While there are similarities, the discrepancies in area estimates between Genivar’s report and the GIS model have demonstrated the need for more transparent methodologies to accompany results. Without knowledge of how results were calculated, explanations are speculative and inconclusive. An explanation of the methodology used would improve the understanding and legitimacy of the results.

The intersections of Yonge and Eglinton; Yonge and Sheppard; and Yonge and Empress have the largest peak heating loads and future growth among the intersections explored. These intersections may hold the largest potential for greenhouse gas emission reduction and the best financial case for district heating projects. The Leslie and Sheppard; McCowan and Ellesmere; and Thorncliffe and Overlea intersections contain much of their heating load within a few buildings. These could be attractive areas for investment since fewer connections are required to capture a significant portion of the load.

Peak heating data and individual building level heating load data can be used to create distribution graphs and profiles for each intersection, providing detailed statistics for planning plant configurations, plant sizing and potential staged expansions of the district heating network in an area.

Location data has enabled recommendations on an optimal plant location to be made, although, in most cases the exact location may be on existing infrastructure and may not be feasible. The suggested location still provides planners and decision makers with an idea of where it may be most efficient to locate a plant.

It has been demonstrated the GIS software is apt at creating basic visualizations for data. The control over various layers of data allows for any location-based information to be overlaid and considered as necessary. The consideration of safety to a community and the coordination of construction are some examples of this application. Data layering in general allows for the flexibility to consider many concerns which are raised throughout the project’s life.

Overall, the results show GIS and geographical techniques are capable of considering multiple perspectives; organizing and presenting information; provide more reliable results; determine future development; and help to reduce barriers to district heating implementation. GIS has been shown to improve current feasibility studies for district heating by allowing a more detailed
analysis to be performed within reasonable time and effort. What follows is a conversation about these results, the contributions made and how the methods in general could be applied more broadly.
Chapter 5
Discussion of the Challenges and Opportunities

So far an opportunity to improve district heating implementation has been identified, a method has been developed, and the method is applied to select intersections in Toronto. But how well does the method fulfill on the original goals of making district heating a more viable option in Toronto? How well do the results help accomplish the original goals? The answers to these questions are discussed by identifying the weaknesses in the method and the results as well as examining what impacts they have had on the original objectives related to improving district energy feasibility in Toronto.

5.1 Limitations and Challenges to the Methodology

The issues related to the methodology primarily revolve around ease-of-use. The considerations include the practicality of obtaining the data necessary for effective use; the human and financial resources required to utilize the method; and the effort required to accomplish the goals through the use of the software. Each of these aspects could prove to be a barrier in receiving and actually using the proposed approach.

5.1.1 Data Availability

GIS is capable of presenting any perspective as long as it can be location-based, available in a format understood by GIS and accessible. Lacking these three prerequisites presents a challenge to the usefulness of GIS. However, current trends in technology (such as GPS enabled smartphones) are encouraging more data to be available and more of it to include location information.

Location is fundamental to GIS and data which is not location specific is unusable in this context. For example, a survey demonstrating a certain percentage of people supporting district heating cannot be taken into consideration with GIS. If the survey also included the respondents’ place of residence then that could be considered by GIS and aid in development of district heating projects. Fortunately, GPS enabled mobile devices and web apps that mine location-
based data are becoming more prominent and making data acquisition much easier. These technologies can and should be leveraged to gather data for GIS and overcome this barrier.

Once this data is available it also needs to be in a format readable by GIS software. Each GIS program can read different file formats which leads to capability and availability issues. There are several dozens of raster and vector file formats available for dozens of GIS programs. Each file format can differ in terms of file size, capabilities (such as being able to include topographic information) and compatibility. Fortunately, the Open Geospatial Consortium (OGS) is striving to standardize data formats and there are online resources that can convert between some (but not all) formats\(^\text{10}\).

Lastly, the data needs to be accessible. Some location based data may be inaccessible due to privacy concerns. Other data could have been costly to gather and thus cost money to access. Unavailable or costly data inhibits GIS’ potential applications or increases the barriers to them. OGS and many other organizations are striving for more open and accessible data.

Overcoming these challenges of availability and compatibility would greatly reduce the obstacles that exist and enable GIS to be as flexible as the data that is available. A list of GIS free and accessible data sources can be found in Appendix I.

### 5.1.2 Managing Coordinate Systems

Data can have different, incorrect or missing coordinate systems information which may cause issues with using it properly. ArcGIS can align different coordinate systems automatically but incorrectly labeled or missing coordinate system data requires problem solving on the user’s side. The data could state an incorrect coordinate system or use a different unit of measure. This could lead to misaligned data causing less accurate perceptions and conclusions to be made. Missing coordinate system information could result in a time consuming process to determine the correct system or the data being unused if the correct system cannot be determined. It would be prudent for any data collection that does occur to be properly documented and to be in a consistent coordinate system. This would improve the compatibility of the data and increase the usefulness of any conclusions made from observations of the data.

\(^{10}\) One such resource is [http://converter.mygeodata.eu/](http://converter.mygeodata.eu/).
5.1.3 Software Cost and Accessibility

The cost of software, hardware and human resources may reduce the attractiveness of using GIS as a means to improve district heating assessments. However, other methods for energy and GIS analysis use similar techniques with similar disadvantages.

While there are free versions of GIS software, ArcGIS is the industry standard and requires considerable resources. A standard ArcGIS desktop license costs $1500 USD not including extensions such as spatial analysis, network analysis and data interoperability which cost $2500 USD each for single-use licenses. Concurrent licenses with extensions may total over $10,000 USD, a cost certainly worthy of consideration.

The software’s minimum system requirements are low compared to current computing standards but it has been the author’s experience that up-to-date hardware would provide faster data entry, faster analysis and smoother operation in general. In addition to hardware and software requirements, the time needed to train personnel to use the software or the need to hire an expert may be cause for consideration.

These significant resources are certainly a challenge to this methodology but hopefully it can be seen that there are greater benefits in reduced cost throughout the lifetime of the district heating project.

5.1.4 Third-Party Data Management and Analysis Tools

Some spreadsheet and database analysis programs are more flexible and capable than ArcGIS’ in-house capabilities. However, the use of third-party programs (such as Microsoft Excel or another GIS program) results in a fragmented and less streamlined process.

ArcGIS stores attribution table data in an easy to access database file that can be read by many spreadsheet or database programs. ArcGIS’s graphing capabilities are not as flexible or customizable as programs dedicated to such tasks. These two factors promote the use of third-party software, such as Microsoft Excel, with more functionality such as graph types and stylistic elements.

Unfortunately, the functionality and capabilities of third-party software cause the data and process to be segmented. Data needs to be exported and any edits to the data need to be done
carefully if the changes are to appear back in the GIS attribution table. Improving the graphing capabilities of ArcGIS would be a step forward in making it the only program needed for analysis.

5.2 Limitations of the Results

The products of the GIS model exhibit both advantages and disadvantages due to the general nature of the method taken. The use of general peak heating load factors and estimations allows for flexibility and broader applicability at the expense of precision. The themes of flexibility and broader applications are explored through the data used, the results arrived at and the conclusions that could be drawn from these results.

5.2.1 Obtained Data

The data obtained and used in the GIS model is limited in scope and specificity. The diversity of building types and attributes are not fully taken into account in calculating the peak heating loads. This results in a poorer fit between the actual building characteristics and the peak heating load factor which then leads to less precise estimates and conclusions.

The Enwave data used to determine peak heating load factors was mostly taken from downtown Toronto high-rise buildings and may not necessarily represent low-rise buildings of the same use. Further, the building types are potentially over-simplified to only including residential, commercial and institutional. This omits building, such as hospitals or factories, which may have vastly different peak heating loads. Heating load factors gathered from a more diverse set of buildings and categorized into more building types may have improved the accuracy of the peak heating load estimates.

Further, the building footprints take into consideration areas beyond just the usable interior space and thus may result in higher heating loads being estimated for each building. The building footprints also include structures which may not require heating such as garages. If these buildings are not properly addressed they could result in an overestimation of the number of buildings and their heating loads.
There are opportunities for peak heating loads to be inaccurate to a certain degree in the current model. A more accurate model could be obtained if data on floor space (perhaps from property tax assessments) and specific heat consumption (perhaps from utility bills) could be obtained. On the other hand, individual building data also varies and it should be noted that there really is no perfect method with each having its own advantages and disadvantages. General heating values also allow the assessment of newly construction and proposed buildings which don’t have utility data yet. The difficulty in obtaining specific building data has resulted in a more accessible method to be developed.

5.2.2 Data Input and Calculations

Having a widely applicable methodology enables users to evaluate whether an area or building has district heating potential without having to obtain precise data. As with any approximation there are drawbacks which need to be considered when performing such evaluations. The weaknesses of peak heating load factors, building areas and other aspects are made evident so that users can gain a complete understanding of what to account for in making conclusions about the district heating feasibility in each area.

Building height and use types are manually entered requiring up to two to three hours per intersection depending on the complexity and density. This is not an insignificant amount of time and does raise the cost of using this method. A method to automate this process (or obtain the necessary data in the first place) would be extremely valuable.

The conversion of peak heating load factors from imperial units to metric units used assumed supply and return temperatures which may not be the exact temperatures Enwave uses in its system. A confirmation of these values would improve the estimates although the supply and return temperatures may vary in practice anyways.

The use of floors to calculate total heating load for each building results in two potential inaccuracies. Firstly, buildings with different floor heights could require a different amount of heating than the factor accounts for. Secondly, for some buildings, the shape of the building changes with elevation. These two factors could potentially be accounted for but come at a cost of time and effort. Similar to the previous issues, these could be addressed with actual utility data and gross floor spaces from property tax assessments.
One final issue is the fact that the building’s dominant use is the use considered. For example, some mixed use buildings (such as condominiums with ground level retail) are considered to be purely residential for simplification purposes. This example would influence the heating load calculations more and more as more and more condominiums of this type grow. Not only does this influence the peak load estimated but also potentially the distribution system since some commercial establishments may require high supply temperatures.

In general, the data input required enables this method to be more accessible but also more time consuming then if the data were already obtainable. As with any estimation, there are generalizations which may lead to less accurate results. With so many buildings in each area of study, the aggregated discrepancies that arise from floor area, floor height and building type estimates could amount to a significant impact in total peak heating load estimate.

5.2.3 Analysis

The goal of comparing the GIS model to Genivar’s report in terms of gross floor space is to see if there are similarities and if either method provided a reasonable estimate relative to the other. The results showed there are some intersections with dramatically different results. The GIS model estimates far more total space at the Yonge and Empress and Yonge and Sheppard intersections while Genivar’s study estimates more at the Norseman and Kipling and Leslie and Sheppard intersections. Since there is a three year gap between when the estimates were made these discrepancies could arise from the construction or demolition of buildings in areas with high growth or decline. Other speculations are difficult to come by and conclude since Genivar’s data sources and methods are not readily accessible in the scope of this project. This makes it a challenge to validate Genivar’s numbers but the GIS model is thorough and clear about which buildings are accounted for and how the calculations were made.

In terms of the comparisons made between intersections, these results provide a ‘birds-eye’ view of the intersection and could be made useful with more contextual information. The distribution graphs and peak heating load comparisons only inform as far as how much load there is at the intersection. These quantitative results provide no indication of whether the most attractive buildings in an area may actually connect to the district heating network if it was built. This could potentially be addressed by knowing the building’s age and the typical lifecycle of a boiler or furnace (about 25 years). The graphs and charts should also be combined with the map data in
order to understand how close the buildings are to each other, where they are in relation to each other and where they are in relation to a potential plant site.

The quantitative data provides an idea of which intersections and which buildings may be attractive but should be combined with other data to provide the context needed to answer planning and decision making questions. Planners and decision makers are looking to find out if there is enough heating load in an area to sustain a plant, if the buildings are willing to connect to a district heating system and how much it would cost to connect.

5.3 Significance of the Results

The goal of this research is to reduce the barriers to district heating implementation through the applications of GIS. The outcome has been a district heating potential assessment of nine different areas of interest around Toronto. This fulfills the site identification step which works towards actual implementation of district heating systems. Planners and decision makers now have reliable data sources, calculations, analysis and visualizations that help them identify which intersections to pursue further with more thorough assessments or proposals.

One impact of the research carried out is the identification and synthesis of data and data sources useful for estimating Toronto’s heating loads. Data has been obtained on peak heating load factors, locations of schools, building footprints, zoning and construction projects. Not all data is available in a GIS format thus attributes such as building use are manually entered for over 4400 buildings. As the data is now entered within a GIS format file, future changes to the intersections studied (such as construction or demolition of buildings) can be easily accounted for. Having data sources and actual data performs one of the first steps towards district heating assessment. Future assessments no longer need to spend resources and acquire the data. This removes the resources barriers to assessment making it easier and more likely to implement district heating in Toronto particularly for the intersections within the scope of this study.

The floor area comparison with Genivar’s study has brought up the importance of being explicit with the data sources and methods used. Without such knowledge, the resulting data cannot be scrutinized or sufficiently understood. This lack of transparency points to a need for district heating studies (or any study) to be more transparent with results or at least describe their methods (perhaps at the expense of brevity). Providing a description of the methods would allow
readers to have a deeper understanding of the study and also lend it credibility. A more credible assessment leads to more trustworthy results and confidence in implementing a district heating system.

Through a comparison of the heating loads at each intersection it is now clear which have the most heating loads and which have a high concentration of large heating load buildings. This has helped to explicitly clarify which intersections in Toronto provide the best district heating opportunity in terms of potential financial and environmental benefit. The maps displaying proposed and under construction buildings over 35 m in height provide the added perspective of development potential. Using this information along with the maps for each intersection, a more detailed proposal with cost estimates, distribution network schemes and plant configurations can now be made. The comparison has moved district heating several steps closer to implementation in the areas studied and also improve the understanding of where to implement district heating plants afterwards.

The use of visualizations enables average people to see and understand peak heating loads in an area and for experts to gain a sense of what the infrastructure will be for a district heating system. Through the maps produced, the general public can now see which buildings have the highest heating loads and where they are in relation to each other. This perspective is simple and can be used to communicate how a district heating plant could benefit an area which further addresses the previously identified issue of awareness. From an expert’s point a view, they can now see which buildings to connect, how the distribution network may be laid out and where it may be best to place a plant. These are helpful in advancing the district heating assessments from numbers to an actual proposal and thus move it one step closer to construction and implementation.

The products of this study can be summed up to be moving district heating one step closer to widespread implementation in Toronto. Through the acquisition, comparison, estimation and visualization of heating data around Toronto, planners and decision makers can now work towards proposals detailing plant sizes, distribution networks, revenues and costs.
5.4 Impacts of the Methodology

The methodology developed focuses on reducing the barriers to district heating implementation in Toronto by providing more detailed information, leveraging how we use data and focusing on the usefulness of location. The methodology developed here primarily differs from those previously developed by going beyond the basic heating load calculations. The methodology takes advantage of location data and uses it to address other issues related to district heating such as construction coordination and the proximity to high heating load structures. These approaches can have applications to numerous areas but perhaps the most obvious is to other municipal services and infrastructure.

Heating data for individual buildings has enabled better ways of understanding which areas in Toronto are most feasible for district heating. Aggregated heating data for an area did not provide the granularity needed to fully understand an intersection’s potential for district heating since the number of buildings that might actually be willing and worth connecting to a district heating system could not be inferred. In general, more specific data helped to provide better context for decision making. Now imagine the possibilities given a unified database with a profile for each building in Toronto that included information such as property value, water consumption, electricity consumption, construction date, number of occupants, access to cable television, access to internet and so on. These are just examples of data that most likely already exist and do not include what could be collected. This type of information can improve how we develop a city by enabling more context appropriate solutions to be proposed.

The ability to layer data with GIS enhances the ability to organize, manipulate, use and view information. This ability allowed district heating plants to easily consider their proximity to schools, a potentially sensitive community issue. The ease of being able to compare, contrast and combine data can be seen to have other applications to how a city is developed. For example, perhaps it would be possible to assess a city councillor’s platform and how well they did in the previous election to inform planners and decision makers about where certain city services or certain infrastructure improvements would be most needed and best supported. The ability to compare, contrast and connect data is only limited by the amount of obtainable data and the user’s creativity in employing it.
Finally, combining the emphasis of location with the two previously discussed focuses completes the picture on how the methodology can be applied more broadly. Now planners can identify where the opportunities for improvement exist, what is causing them and how to fully take advantage of them. For instance, if data showed that older houses are associated with consuming more energy for heating then an incentive for energy efficiency retrofits can be targeted towards neighbourhoods with older homes. Governments could also use this approach to target areas that have high growth and low household income with more support resources. Developers could similarly seek out south-facing detached homes and high income households with solar panel incentives. The potential uses for such an approach is practically indefinite.

It can be seen that detailed data that is location focused and well organized can lead to many applications within infrastructure and most likely beyond.

5.5 Contributions Made

The research identifies the challenges associated with district heating, addresses them through the use of GIS and assesses the potential of district heating in various locations across Toronto. The literature review is used to understand the current landscape of district heating assessments and district heating barriers. From this, the methodology is created such that GIS is used to enhance the current method of analysis and also consider data not conventionally used. GIS software also enabled the graphical representation of a tremendous amount of data in a helpful and orderly manner.

The literature review summarizes the history of Canada, Ontario and Toronto’s district heating development. Additionally, it reveals that district energy projects are currently being assessed primarily based on heating loads, feasibility and environmental impacts. The barriers that exist for district energy projects primarily revolve around improving its cost effectiveness, improving awareness and the lack of a governmental policy. GIS has been used to create energy maps that consider areas and not on a building-by-building level. The resulting conclusion is that GIS can be used to improve the precision and reliability of results for district energy reports and projects as a whole by expanding beyond the current considerations and providing a more detailed analysis.
Given this challenge, data has been collected and a method of approach has been developed to easily and effectively assess the energy uses for a large area in a detailed manner while also enabling the consideration of many other factors. Peak heating loads for around 4400 buildings in Toronto were modeled contributing a significant body of data. This building level detail has spurred more transparent results, the ability to perform new forms of analysis and the ability to compare different intersections. Alongside these functions, the method is also able to accommodate the dynamic changing nature of cities since the data can also be easily manipulated. This has been applied to nine different intersections within the City of Toronto demonstrating the ease and effectiveness of the method. Additionally, new information besides the conventional heating loads has been utilized to present various other considerations to district heating project assessment.

The research has identified opportunities for improvement, acquired the data necessary, and developed a method that reduces some of the barriers to district heating particularly through the improvement of district heating project assessments. These advancements have helped to identify the areas in Toronto with the most district heating potential and also increase the level of reliability in these assessments.
Chapter 6
Conclusion

The motivation for this thesis is to expand the breadth of considerations used in decision making (in general) while improving upon the level of communicability. This ethos is applied to the area of sustainability and more specifically, district heating systems in Toronto.

The review of the literature exposed that Canada currently heats 1.3% of its space with district heating while some European countries heat over 30% of their floor space through district heating. Toronto contained more district heating plants than any other municipality providing a good base of expertise and appetite. A study of some neighbourhoods in Toronto in 2007 by the Canadian Urban Institute showed the implementation of district heating could reduce GHG emissions by about two tonnes per capita. Current district heating project assessments had a narrow approach primarily focusing on calculating heating loads from which financial and environmental considerations could be made. Financial and environmental considerations are significant to the success and evaluation of a district heating system but it is believed that such assessments could be much more thorough and also consider other aspects such as local concerns surrounding health and safety. The exploration of concerns of district heating planners, operators and decision makers showed that they felt an improvement in the financial case for district heating systems would greatly improve their adoption (among a plethora of other concerns). An understanding of the current state of district heating leads to an approach which targets the specific opportunities for improvement. The approach uses geography and GIS in order to consider and fit together these different pieces.

The first step involved acquiring the geographical data needed to facilitate a more thorough heat use analysis and allowed for the consideration of other influential factors. This resulted in obtaining building outlines, uses/types and heights for specific intersections of interest in the city of Toronto; peak heating load factors; a map of construction around the city of Toronto; and locations of Toronto District School Board schools. Building outlines were obtained from the Maps and Data Library at the University of Toronto for the entire City of Toronto. Peak heating load data was obtained by Enwave from 376 downtown Toronto buildings resulting in
commercial, residential and institutional average peak heating values to be 66.9 W/m², 71.3 W/m² and 220 W/m², respectively. These values were reasonable in comparison to values found in previous studies. The number of floors and type of building was manually entered from map databases such as Google Maps. This data is used to assess nine intersections identified within Toronto. The peaking heating load for about 4400 buildings in Toronto was modeled adding a significant amount of information in addition to the creation of new approach to district heating feasibility analysis.

Not only did the data and GIS enable the organization and layering of various types of information, but it also enabled a precise level of understanding. Having heating load data on a building-by-building basis improved credibility and allowed for a more in depth analysis. It is now possible to know the highest heating load buildings in an area; how close to each other they were; what the total number of buildings in an area were; how many buildings of each type existed; and the total heating load in the area. Other statistics such as the average heating load per building and the number of buildings that had heating loads above a given threshold are easily obtainable. These added benefits help district heating systems to be well planned, have more reliable financial analyses and improved communicability. The geographical approach and use of geographical software allowed for simple graphical representations of heating load data which otherwise would be daunting to take in.

The intersections with the largest total peak heating loads were Yonge and Empress; Yonge and Eglinton; and Yonge and Sheppard with about 96 MW, 95 MW and 92 MW, respectively. Interestingly, the intersection of Thorncliffe and Overlea had the second highest cumulative loads within its top 10 heating load buildings. A comparison between Yonge and Empress and Thorncliffe and Overlea buildings showed that Thorncliffe and Overlea was inferior as Yonge and Empress had more buildings in general but also more buildings with loads above 1 MW. An assessment of proposed and under construction buildings over 35 m in height at each intersection showed Yonge and Eglinton with 11 proposed and five under construction, the most out of any intersection. In contrast, Thorncliffe and Overlea had none in either category. The model allows for this type of in depth and specific analysis to be performed. The improved understanding of each area provides designers and decision makers with information critical to the feasibility analysis and potential design of a district heating system. The model improves upon the current approach to feasibility studies.
Throughout the research there are a few noted limitations. The greatest limitation to the methods used is, undoubtedly, the availability of data. Building types and heights are not conveniently available in a GIS format and thus manual entry is required. The availability of GIS formatted building type and height would enable a city wide assessment of heating loads in minutes. The ability to handle other considerations would also be enhanced by the availability of location based data. For example, the ability to integrate with the skyscraper database at SkyscraperPage.com would be useful for assessing high district heating potential areas in Toronto. Secondly, the building footprints used could not consider changes in floor area as height increased or multi-purposed buildings. Lastly, it could be argued that the software used, ArcGIS, proves to be a barrier since it can be costly, require training and (based on the author’s experience) sometimes prone to malfunction. These limitations show the opportunities available for improvement.

Overall, the pursuit of considering multiple perspectives has produced a method that has advanced district heating implementation by providing an approach to thoroughly and more reliably assess district heating potential. This includes the compilation of pertinent data and an assessment of nine different intersections in Toronto modeling the peak heating loads for approximately 4400 buildings. The research not only pushes for further district heating development but also aids its implementation through a practical approach.
Chapter 7
Research Opportunities

As this methodology developed there have been numerous thoughts on what other applications could grow out of it. These opportunities include refining the method and analyses; expanding the approach to other fields; and making location-based data more accessible.

The potential applications of GIS to district heating have only been touched upon leaving many other applications in site assessment and system design unarticulated. Like most applications, the cruxes of these are defined by the data available. Within these applications the focus is on optimizing efficiency and financial gain.

In addition, there could be a broader application of the three central themes of this thesis: the importance of location and location-based data; the collection and organization of said data; and the consideration of multiple perspectives. Only a very narrow application of these themes is used in this thesis but many more are possible.

Online data and mobile devices are already being leveraged to determine how people feel about certain issues, how water systems are managed, how to manage electricity consumption, where maintenance is needed around the city and the state of traffic on road networks. It is imaginable that the contents of social media status updates and locations of ‘check-ins’ could play a significant role in how we design cities, where we place services and what kind of infrastructure is prioritized in the future. GIS programs are expected to play a key part in organizing and visualizing maps of this data and also evolve as needed.

Specific applications of broader and more advanced uses for GIS and this methodology are explained below.

7.1 District Heating System Design

The location of the plant, configuration of the distribution network and configuration of the heat exchangers could be aided by the use of GIS given the applicable information. The plant location is only optimized to minimize the distribution losses but could be based on other factors such as cost of the space, the health impacts on people and the proximity to fuel. The configuration of the
plant’s boilers can also be determined if the base load and peak loads’ quantities and schedules can be determined. These can be estimated from the typical usage associated with each building type. The distribution network could be configured for phased implementation based on the knowledge of future development or could be configured to avoid difficult soil conditions and existing infrastructure. A financial analysis can be done to determine if buildings are worth connecting to depending on their load, the cost of the distribution network and the cost of the heat exchanger. These examples and more show how GIS can be further applied to design district heating systems.

7.2 Calculating and Visualizing District Heating System Impacts

Given current and future financial and energy use data, GIS could be utilized to demonstrate the resulting impacts of implementing a district heating system. Differences in fuel costs, infrastructure costs, GHG emissions and local air quality could be calculated and then shown via GIS. This further enhances the ability for GIS to aid in decision making and understanding the impacts of district heating projects.

7.3 Lifecycle Application to District Energy Projects

The method described in this thesis could gain significantly from being implemented on a real world project. The use of GIS from start to finish of a district heating project would most likely illuminate new uses, refine the current methods and provide an idea of the tangible benefits. These could amount to numerous changes and improvements in the methodology that make it much more applicable to real world implementation and thus more useful overall.

7.4 Building Analysis Software Integration

The heating data calculated uses general values and provides an estimate which would be improved through the integration of a building analysis tool. GIS could be used to obtain the values needed by a program like RETScreen to produce a heating load and heating schedule for each building. This data can then be fed back into the GIS model for visualization and other regional analyses. This would provide an even better level of detail and reliability for the model.
7.5 Weighted Location Optimization

The current method suggested plant locations based on being closest to the highest loads. Alternatively, a model could be created with GIS software that weighed each consideration (pipe length, proximity to schools, available locations, etc.) and suggested a location optimized for each specific concern. This would have similar advantages and drawbacks the rational decision making process.

7.6 Application to Promoting Awareness

One of the cited barriers to district heating is awareness of its existence and benefits to politicians, designers and the public. Devising a geographically centered method to improve the awareness would prove to be very beneficial for overcoming this barrier. An improved level of awareness among industry, the public and businesses would create a bottom-up push for more district heating services and thus increase the number and extent of district heating projects implemented.

7.7 Application to Municipal Decision Making

GIS, municipal infrastructure data and demographic data can be harnessed to smartly develop the infrastructure and services within a city. Infrastructure age, condition, repairs, uses and needs could all be tracked on a GIS database to help planners and decision makers prioritize various infrastructure projects. The oldest watermains could be targeted for replacement, well-travelled roads could be the focus for higher capacity transit and inefficient homes could be incentivized for energy efficiency retrofits. This could also be applied to city services such as employment services in low-income neighbourhoods and police services in high crime areas. No doubt, geographically methods are already being applied to these areas but the possibilities are seemingly endless.

7.8 Improving Data Availability and Standardization

One area of potential development is the push for more publically available and standardized forms of location-based data. For example, utility data for each building would be extremely valuable for calculating the actual heating used (instead of having to estimate it) but the process to access such information is bureaucratic and time consuming. As mentioned previously, mobile
devices are already leading the ability to accomplish this. This would enable geographical methods to be much more potent as the amount of data would be more easily usable. Further, an amalgamation of digital data for the city of Toronto (or any city for that matter) would make it more convenient since it is currently spread between multiple sources in multiple formats.

7.9 Summary

A diverse set of opportunities to promote district heating through the use of geography and GIS is abundant. Data could be more accessible, methods could be more thorough and new uses could certainly be thought of. It is unfortunate that district heating’s benefits remains largely untapped in most of the world but within that lays the potential for technology, people and businesses to take it up and seize the opportunity.
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http://www.retscreen.net/ang/heating_project_load_and_energy_calculation.php


## Appendices

### 9.1 Appendix A – Energy Use Intensity Factors

<table>
<thead>
<tr>
<th>Source</th>
<th>Project Location</th>
<th>Date of Study</th>
<th>Average Annual Load (kWh/m²)</th>
<th>Peak Load (W/m²)</th>
<th>Heat Load Estimate Source</th>
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<tbody>
<tr>
<td>Community Energy Association</td>
<td>Kelowna</td>
<td>1-Jan-10</td>
<td>48.79</td>
<td>102.24</td>
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<td>CDEA</td>
<td>Okotoks</td>
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<td>117.9</td>
<td>207</td>
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<td>CDEA</td>
<td>St Paul</td>
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<td>104.86</td>
<td>66</td>
<td></td>
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<td>WYG</td>
<td>Cork Docklands</td>
<td>1-Mar-09</td>
<td>100</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>FVB</td>
<td>Corner Brook, Newfoundland</td>
<td>9-Sep-08</td>
<td>109</td>
<td>70</td>
<td>Existing Utility Data</td>
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<tr>
<td>Strack and Associates</td>
<td>London, ON</td>
<td>1-Aug-07</td>
<td>34.1</td>
<td></td>
<td>Transys</td>
</tr>
<tr>
<td>Compass Resource Management</td>
<td>North Vancouver</td>
<td>1-Sep-09</td>
<td>61.1</td>
<td></td>
<td></td>
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<td>FVB</td>
<td>Old Crow, Yukon</td>
<td>2-Aug-01</td>
<td>295</td>
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<td>FVB</td>
<td>Pickering</td>
<td>1-Jan-07</td>
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<td></td>
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<td>Affiliated Engineers Inc.</td>
<td>Seattle</td>
<td>22-Sep-11</td>
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<td></td>
<td></td>
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<td>Keen Engineering</td>
<td>Whistler</td>
<td>24-Dec-04</td>
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<td>ASHRAE, ASPE, LEED Silver, MNEBC</td>
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<td>Yellowknife</td>
<td>1-Dec-09</td>
<td>175</td>
<td></td>
<td>Existing Utility Data</td>
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*Table 4 - Energy Use Intensity Factors from Current District Heating Studies*
9.2 Appendix B – SkyScraperPage.com Maps

Figure 34 - Proposed Buildings Over 35m in Height from SkyScraperPage.com

Figure 35 - Under Construction Buildings Over 35m in Height from SkyScraperPage.com
## 9.3 Appendix C – City of Toronto Ward Profiles

<table>
<thead>
<tr>
<th>Intersection</th>
<th>City Ward</th>
<th>Population (2006), Change from 2001-2006</th>
<th>Highest Level Transit</th>
<th>Major Loads</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen Road and Lawrence</td>
<td>Lawrence Heights</td>
<td>60,545, 3.1%(^{11})</td>
<td>Subway (Lawrence West Station)</td>
<td>Two large shopping malls (Yorkdale Mall (130,000m(^2)), Lawrence Square (63,000m(^2))</td>
<td>Significant amount of public housing, 1208 units with 5,500 units to be added(^{12}). Plan for significant revitalization in place(^{13})(^{14})(^{15})</td>
</tr>
<tr>
<td>Bloor and Kipling</td>
<td>Etobicoke-Lakeshore</td>
<td>57,260, 3.0%</td>
<td>Subway (Kipling)</td>
<td></td>
<td>Recent transportation</td>
</tr>
</tbody>
</table>

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\(^{12}\) "Lawrence Heights makeover could be jeopardized - The Globe and ..." 14 Sep. 2012


\(^{15}\) "Infrastructure Master Plan - City of Toronto." 2011. 14 Sep. 2012
| Neighbourhoods                        | Survey Area          | Combined Population | Station | Infrastructure
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>(Etobicoke City Centre)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kipling and Norseman</td>
<td>Etobicoke-Lakeshore</td>
<td>57,260, 3.0%</td>
<td>Subway (Kipling Station)</td>
<td>Recent transportation infrastructure revitalization (Six Points)</td>
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<tr>
<td>Leslie and Sheppard</td>
<td>Willowdale</td>
<td>58,805, 5.8% 16</td>
<td>Subway (Bessarion Station)</td>
<td>Shopping complex: Bayview Village Shopping Centre (41,000m²)</td>
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<td>Markham and Ellesmere</td>
<td>Scarborough Centre</td>
<td>63,310, 7.5%</td>
<td>Subway (Scarborough Town Centre)</td>
<td>Several government offices, Scarborough Town Centre (121,000m²)</td>
</tr>
<tr>
<td>Yonge and Eglinton</td>
<td>Eglinton and Lawrence/St. Paul</td>
<td>Combined population 111,695,</td>
<td>Subway (Eglinton Station)</td>
<td>High-rise commercial and numerous large</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ward</th>
<th>Neighbourhood</th>
<th>Population</th>
<th>Percent</th>
<th>Transport</th>
<th>Description</th>
<th>Future Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>McCowan and Ellesmere</td>
<td>Scarborough Centre</td>
<td>63,310</td>
<td>7.5%</td>
<td>Subway (Scarborough Town Centre)</td>
<td>Governmental offices, Scarborough Town Centre (121,000m²)</td>
<td>Future Light Rail Expansion</td>
</tr>
<tr>
<td>Thorncliffe Park Drive and Overlea Boulevard</td>
<td>Don Valley West</td>
<td>60,585</td>
<td>1.2%</td>
<td>Bus</td>
<td>Two, 44 floor apartment buildings</td>
<td></td>
</tr>
<tr>
<td>Yonge and Empress</td>
<td>Willowdale</td>
<td>79,435</td>
<td>29%</td>
<td>Subway (North York Centre Station)</td>
<td>Empress Walk, 22,000 m² of commercial space with 745 condo units above, North York Civic Centre</td>
<td>Regional Transit Hub</td>
</tr>
</tbody>
</table>

Table 5 - City of Toronto Ward Profiles

9.4 Appendix D – VB Script Code

```vbscript
Dim loadcalc

If [Type] = "r" Then
    loadcalc = [Floors] * [Area]/.2153
ElseIf [Type] = "c" Then
    loadcalc = [Floors] * [Area]/.2022
ElseIf [Type] = "c + r" Then
```
loadcalc = [Floors] * [Area]/.2088

ElseIf [Type] = "r + c" Then

loadcalc = [Floors] * [Area]/.2088

ElseIf [Type] = "i" Then

loadcalc = [Floors] * [Area]/.6644

Else

loadcalc = 0

End If

Figure 36 - Full VB Script Code Used in ArcGIS
### Appendix E – Alternative Area Comparisons

<table>
<thead>
<tr>
<th>Building Address</th>
<th>GIS Area Estimate (in m²)</th>
<th>Alternative Area Estimate (in m²)</th>
<th>% Overestimated (Underestimated)</th>
<th>Alternative Source</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Sheppard Avenue West (Nestle Building)</td>
<td>46000</td>
<td>38100</td>
<td>21%</td>
<td>Space Database (<a href="http://goo.gl/3zfFQ">http://goo.gl/3zfFQ</a>)</td>
<td>The GIS Model estimated 22 floors while the alternative source stated 21 floors.</td>
</tr>
<tr>
<td>5000 Yonge Street (Transamerica Tower)</td>
<td>76400</td>
<td>50100</td>
<td>50%</td>
<td>Adamson Associates and Architects (<a href="http://goo.gl/R7b52">http://goo.gl/R7b52</a>)</td>
<td>A portion of the building footprint is not 21 stories as the model estimates</td>
</tr>
<tr>
<td>700 Lawrence Avenue West (Lawrence Mall)</td>
<td>48600</td>
<td>63100</td>
<td>(23%)</td>
<td>Lawrence Square Shopping Centre (<a href="http://goo.gl/1U2BH">http://goo.gl/1U2BH</a>)</td>
<td></td>
</tr>
<tr>
<td>45 Overlea Boulevard (East York Town)</td>
<td>48100</td>
<td>38000</td>
<td>26.6%</td>
<td>City of Toronto (<a href="http://goo.gl/46HgP">http://goo.gl/46HgP</a>)</td>
<td>‘Gross Leasable Area’</td>
</tr>
<tr>
<td>Building</td>
<td>Ground Floor</td>
<td>Lower Ground</td>
<td>Percentage</td>
<td>Owner/Operator (URL)</td>
<td>Notes</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------</td>
<td>--------------</td>
<td>------------</td>
<td>----------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>5353 Dundas Street West</td>
<td>32400</td>
<td>19800</td>
<td>63.1%</td>
<td>Manulife Real Estate Funds (<a href="http://goo.gl/TzEeG">http://goo.gl/TzEeG</a>)</td>
<td>Much of the building footprint is not 6 stories as the model estimates</td>
</tr>
<tr>
<td>1019 Sheppard Avenue</td>
<td>19200</td>
<td>14700</td>
<td>30.8%</td>
<td>City of Toronto (<a href="http://goo.gl/FF4NM">http://goo.gl/FF4NM</a>)</td>
<td></td>
</tr>
<tr>
<td>Scarborough Town Centre</td>
<td>147000</td>
<td>122000</td>
<td>20.3%</td>
<td>Scarborough Town Centre (<a href="http://goo.gl/eWNhb">http://goo.gl/eWNhb</a>)</td>
<td>‘Gross Leasable Area’</td>
</tr>
<tr>
<td>777 Kipling Avenue</td>
<td>5000</td>
<td>4650</td>
<td>7.8%</td>
<td>Cinespace (<a href="http://goo.gl/PjTz3">http://goo.gl/PjTz3</a>)</td>
<td></td>
</tr>
<tr>
<td>2323 Yonge St.</td>
<td>7470</td>
<td>7380</td>
<td>1.2%</td>
<td>Colliers (<a href="http://goo.gl/XCmaH">http://goo.gl/XCmaH</a>)</td>
<td>‘Gross Leasable Area’</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>430170</strong></td>
<td><strong>357830</strong></td>
<td><strong>20.2%</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9.6 Appendix F – Peak Load Distribution Graphs

Distribution of Peak Heating Loads at Allen and Lawrence

Approximate Peak Load in Megawatts

Number of Buildings

Distribution of Peak Heating Loads at Bloor and Kipling

Approximate Peak Load in Megawatts

Number of Buildings

Distribution of Peak Heating Loads at Kipling and Norseman

Approximate Peak Load in Megawatts

Number of Buildings
Distribution of Peak Heating Loads at Leslie and Sheppard

Distribution of Peak Heating Loads at McCowan and Ellesmere

Distribution of Peak Heating Loads at Thorncliffe and Overlea

Distribution of Peak Heating Loads at Yonge and Empress
Distribution of Peak Heating Loads at Yonge and Sheppard

Distribution of Annual Heating Loads at Yonge and Eglinton
### 9.7 Appendix G – Intersection Profiles

<table>
<thead>
<tr>
<th>Allen and Lawrence</th>
<th>Peak Load in MW</th>
<th>Area in 1000s of m²</th>
<th>Number of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>55.7</td>
<td>721</td>
<td>1260</td>
</tr>
<tr>
<td>Top 10</td>
<td>16.6</td>
<td>181</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>7.8</td>
<td>115</td>
<td>3</td>
</tr>
<tr>
<td>Total Residential</td>
<td>39.5</td>
<td>558</td>
<td>1240</td>
</tr>
<tr>
<td>Total Commercial</td>
<td>8.6</td>
<td>129</td>
<td>8</td>
</tr>
<tr>
<td>Total Institutional</td>
<td>7.6</td>
<td>34</td>
<td>8</td>
</tr>
<tr>
<td>Total Check</td>
<td>56</td>
<td>721</td>
<td>1260</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kipling and Norseman</th>
<th>Peak Load in MW</th>
<th>Area in 1000s of m²</th>
<th>Number of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>33.9</td>
<td>507</td>
<td>323</td>
</tr>
<tr>
<td>Top 10</td>
<td>13.2</td>
<td>197</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>5.7</td>
<td>86</td>
<td>3</td>
</tr>
<tr>
<td>Total Residential</td>
<td>0.6</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Total Commercial</td>
<td>33.3</td>
<td>498</td>
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</tr>
<tr>
<td>Total Institutional</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Total Check</td>
<td>34</td>
<td>507</td>
<td>321</td>
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<table>
<thead>
<tr>
<th>Thorncliffe and Overlea</th>
<th>Peak Load in MW</th>
<th>Area in 1000s of m²</th>
<th>Number of Buildings</th>
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<tbody>
<tr>
<td>Total</td>
<td>79.3</td>
<td>912</td>
<td>108</td>
</tr>
<tr>
<td>Top 10</td>
<td>45.3</td>
<td>164</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>20.6</td>
<td>81</td>
<td>3</td>
</tr>
<tr>
<td>Total Residential</td>
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<td>664</td>
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<tr>
<td>Total Commercial</td>
<td>9.7</td>
<td>145</td>
<td>46</td>
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<tr>
<td>Total Institutional</td>
<td>22.3</td>
<td>101</td>
<td>8</td>
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<tr>
<td>Total Check</td>
<td>79</td>
<td>910</td>
<td>104</td>
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<tr>
<td>Location</td>
<td>Peak Load in MW</td>
<td>Area in 1000s of m²</td>
<td>Number of Buildings</td>
</tr>
<tr>
<td>-----------------</td>
<td>-----------------</td>
<td>---------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td><strong>Bloor and Kipling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>16.8</td>
<td>205</td>
<td>354</td>
</tr>
<tr>
<td>Top 10</td>
<td>7.5</td>
<td>77</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>4.3</td>
<td>52</td>
<td>3</td>
</tr>
<tr>
<td>Total Residential</td>
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<td>152</td>
<td>300</td>
</tr>
<tr>
<td>Total Commercial</td>
<td>2.5</td>
<td>37</td>
<td>35</td>
</tr>
<tr>
<td>Total Institutional</td>
<td>3.5</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Total Check</td>
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<td>205</td>
<td>341</td>
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<td><strong>Yonge and Empress</strong></td>
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</tr>
<tr>
<td>Total</td>
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<td>1160</td>
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<td>45.2</td>
<td>633</td>
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<tr>
<td>Total Check</td>
<td>96</td>
<td>1160</td>
<td>376</td>
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<tr>
<td><strong>Leslie and Sheppard</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>26.4</td>
<td>237</td>
<td>161</td>
</tr>
<tr>
<td>Top 10</td>
<td>20.9</td>
<td>164</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>14.6</td>
<td>93</td>
<td>3</td>
</tr>
<tr>
<td>Total Residential</td>
<td>3.8</td>
<td>53</td>
<td>133</td>
</tr>
<tr>
<td>Total Commercial</td>
<td>5.8</td>
<td>87</td>
<td>16</td>
</tr>
<tr>
<td>Total Institutional</td>
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<td>77</td>
<td>11</td>
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<td>160</td>
</tr>
<tr>
<td><strong>Yonge and Sheppard</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>91.5</td>
<td>1230</td>
<td>539</td>
</tr>
<tr>
<td>Top 10</td>
<td>36.2</td>
<td>358</td>
<td>10</td>
</tr>
<tr>
<td>Top 3</td>
<td>15.1</td>
<td>91</td>
<td>3</td>
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<td>732</td>
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</tr>
<tr>
<td>Total Commercial</td>
<td>30.8</td>
<td>461</td>
<td>60</td>
</tr>
<tr>
<td>Total Institutional</td>
<td>8.5</td>
<td>39</td>
<td>5</td>
</tr>
<tr>
<td>Total Check</td>
<td>92</td>
<td>1230</td>
<td>539</td>
</tr>
<tr>
<td>McCowan and Ellesmere</td>
<td>Peak Load in MW</td>
<td>Area in 1000s of m²</td>
<td>Number of Buildings</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Total</td>
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<td>608</td>
<td>516</td>
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<td>334</td>
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<td>9.6</td>
<td>143</td>
<td>59</td>
</tr>
<tr>
<td>Total Institutional</td>
<td>14.9</td>
<td>68</td>
<td>27</td>
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<tr>
<td>Total Check</td>
<td>48</td>
<td>545</td>
<td>515</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Yonge and Eglinton</th>
<th>Peak Load in MW</th>
<th>Area in 1000s of m²</th>
<th>Number of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>94.4</td>
<td>1260</td>
<td>800</td>
</tr>
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<td>Top 10</td>
<td>26.7</td>
<td>343</td>
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</tr>
<tr>
<td>Top 3</td>
<td>10.7</td>
<td>153</td>
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<td>749</td>
<td>648</td>
</tr>
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<td>447</td>
<td>126</td>
</tr>
<tr>
<td>Total Institutional</td>
<td>11.2</td>
<td>51</td>
<td>26</td>
</tr>
<tr>
<td>Total Check</td>
<td>94</td>
<td>1250</td>
<td>800</td>
</tr>
</tbody>
</table>
9.8 Appendix H – Optimized Locations

Figure 37 - Optimal Locations for the Allen Road and Lawrence (left) and Kipling and Dundas (right) intersections.
Figure 38 - Optimal Locations for McCowan and Ellesmere (left) and Kipling and Norseman (right) intersections
Figure 39 - Optimal Locations for Thorncliffe and Overlea (left) and Yonge and Empress (right) intersections
Figure 40 - Optimal Locations for Yonge and Sheppard (left) and Yonge and Eglinton (right) intersections
### 9.9 Appendix I – GIS Data Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Toronto Maps and Data Library</td>
<td>Various; Toronto and Canada</td>
<td><a href="http://goo.gl/7P2V5">http://goo.gl/7P2V5</a></td>
</tr>
<tr>
<td>Open Toronto</td>
<td>Toronto, Transportation, Wards, BIAs, Parks, Municipal Service Locations,</td>
<td><a href="http://goo.gl/TKCh4">http://goo.gl/TKCh4</a></td>
</tr>
<tr>
<td>GeoBase</td>
<td>Canada, Transportation, Natural Resources, Geology</td>
<td><a href="http://goo.gl/vtxiZ">http://goo.gl/vtxiZ</a></td>
</tr>
<tr>
<td>T.O. INview</td>
<td>Toronto, Wards, Construction</td>
<td><a href="http://goo.gl/cefXs">http://goo.gl/cefXs</a></td>
</tr>
</tbody>
</table>