Simulation Analysis for Integrating District Heating into An Existing Residential Neighbourhood in British Columbia

Raymond Boulter
Community Energy Specialist
Natural Resources Canada - CanmetENERGY

Natural Resources Canada
Ressources naturelles Canada

Executive Summary

From an energy efficiency perspective, this analysis investigated the applicability of integrating district heating into an established residential neighbourhood of relatively low energy density in British Columbia.

Using TERMIS simulation software and expected heating load profiles for homes in the study area, the impact of various system parameters, such as supply temperature, consumer delta-T value, and consumer connection rate, were analysed against the annual system delivery heat loss.

The quantifiable results highlight the importance of high connectivity, high consumer delta-T values, and low supply temperatures on reducing the overall system heat loss in this type of application.

Preamble

This analysis represents a theoretical investigation of the potential energy performance of integrating a district heating (DH) system into an existing urban residential study area, factoring estimated energy demands, street layouts, and property densities.

Any relations between system performance and variable inputs should only be used in the context of the study area in question. Results should not be interpreted to represent generalized outcomes applicable to another location.

This analysis is not meant to be an optimization model for pipe routing and sizing, or general system control for the modeled system.

The study is system fuel source agnostic. It is not the intent to conduct a fuel scenario analysis.

No personal information of individual property owners was collected or used in the analyses. Energy consumption of individual households was estimated from modeled representative home archetypes using known construction properties of homes in the local area. The property plan year of individual homes was used as an estimate of building age of the study area houses.

Minor variances in consumption values between different model scenarios may be present due to rounding.

Introduction

Background:

- Empirical data for residential DH system performance is not widely available, but demand for such information by utilities and municipalities is increasing.
- Utilities and municipalities must decide upon what types of new infrastructure could be investigated to best meet energy supply options for new developments, or for established areas with aging infrastructure.

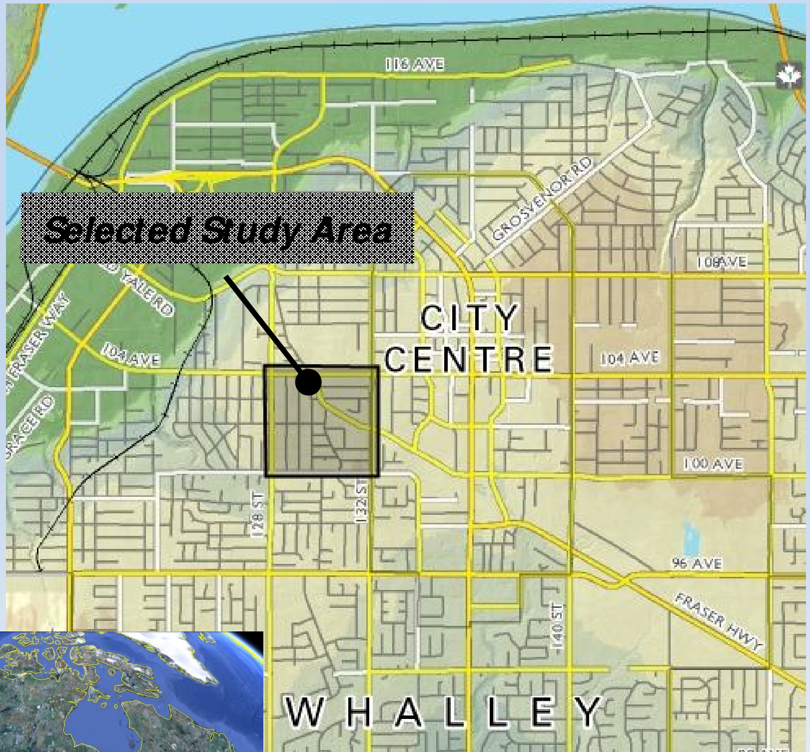
Project Scope:

- Select an existing urban residential neighbourhood and estimate the thermal energy demand of area.
- Develop a district heating model for the study area, factoring property and street configurations and estimated household energy consumption characteristics.
- Use the model to determine the magnitude of system delivery efficiency factoring different system design conditions and customer connection rates.

Potential Outcome:

- Results could aid decision makers to determine what system attributes would be required to compete against ‘business as usual’ (BAU) scenarios or with alternative technology options.

Study Area Selection



City of Surrey COSMOS image

Google image

A residential neighbourhood in Surrey, British Columbia was selected as the project study area.

The City of Surrey was chosen due to recent municipal interest in investigating district energy (DE) opportunities. Feasibility studies have been undertaken to examine how and where DE could be applied within the city. One of the high priority areas of note has been the City Centre commercial area.

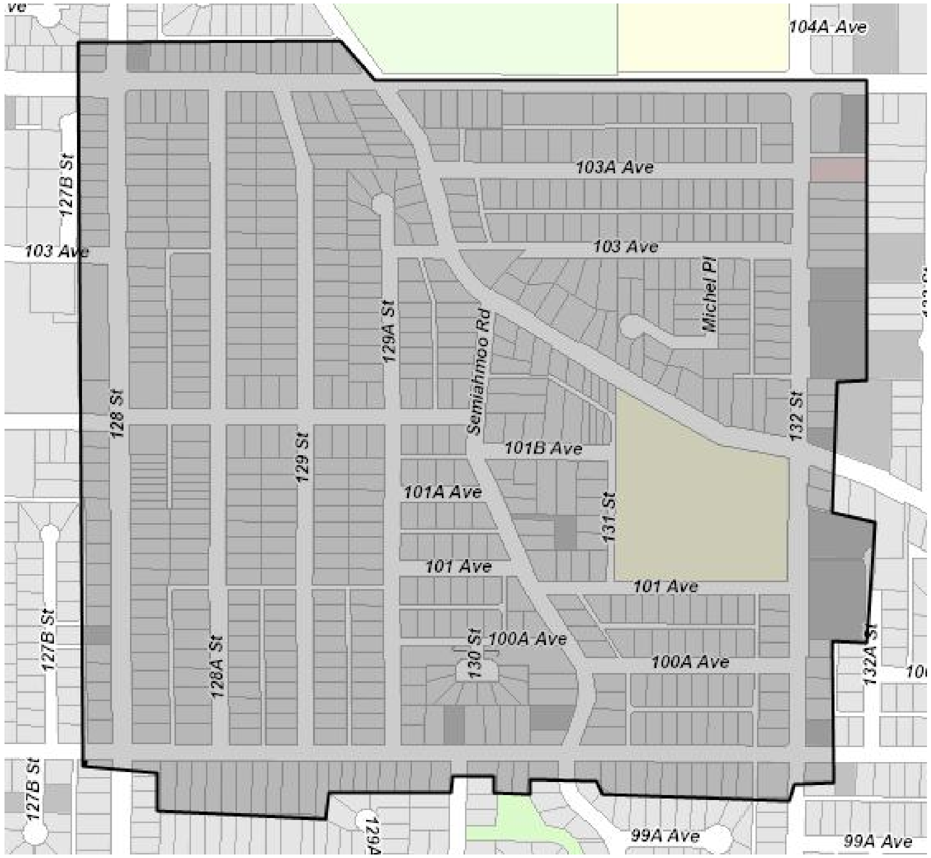
The study area is bounded by 128 St. to the west, 132 St. to the east, 100 Ave. to the south and 104 Ave. to the north, and is approximately 815m x 815m (66 ha, 164 acres in area). The City Centre commercial area lies approximately 400m east of the study area.

In examining potential DH system configurations, it has been assumed that the heating plant serving a DH system for the study area would be located in the City Centre.

Study Area Information

The study area includes 564 residential buildings, the majority of which are single detached houses. To simplify this analysis, all homes have been assumed to be individual single detached houses.

The general street layout includes typical grid property configurations as well as some 'loop and curl' street patterns, common in most urban and suburban areas.



City of Surrey COSMOS image

Alleys exist between properties in some areas, which could be an opportunity for pipe routing and could result in reduced traffic disruptions during installation.

There are two schools in the area, as well as a fire station, all which could be good candidates for district heating substation locations if required.

Housing Archetypes: Characteristics

To determine an estimate for the current thermal energy demand of the homes in the study area, an analysis was conducted using Natural Resources Canada ecoENERGY Retrofit – Homes (formerly EnerGuide for Houses (EGH)) records within the same postal code FSA as the study area. Physical characteristic data was compiled for six representative house archetypes in the area. Energy simulations were then completed for each archetype using HOT2000 software applying default values for house temperatures, schedules, and internal gains. The simulation results for each housing type were then applied to the study area properties to establish an overall energy profile that could be used for the district heating analysis.

NRCan Energuide for Houses (EGH) Average Data for Postal Code V3T

Archetype	01: Pre 1946	02: 1946-60	03: 1961-77	04: 1978-83	05: 1984-95	06: Post 1995
Number of Samples	5	77	89	31	18	3
Year	1940	1956	1970	1980	1988	2000
Area (m^2)	132	173	184	189	210	402
RSI Ceiling	3.3	3.6	3.3	4.2	4.9	6.4
RSI Walls	1.4	1.5	1.7	1.8	2.1	1.9
RSI Foundation	0.3	0.8	0.8	0.9	0.7	1.4
Furnace type	Continuous pilot	Continuous pilot	Continuous pilot	Continuous pilot	Continuous pilot	Induced draft
Furnace Efficiency	78%	78%	78%	78%	78%	80%
DHW type	Conventional tank w. pilot	Conventional tank w. pilot	Conventional tank w. pilot	Conventional tank w. pilot	Conventional tank w. pilot	Conventional tank w. pilot
DHW efficiency	55%	55%	55%	55%	55%	55%

* ecoEnergy, EnerGuide, and HOT2000 are official marks of Natural Resources Canada

Housing Archetypes: Assumptions

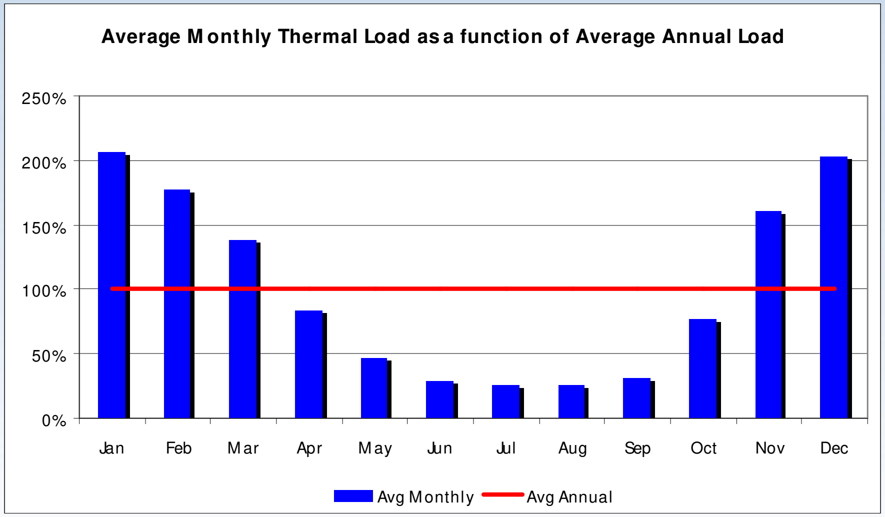
Several key assumptions were made for simulating each housing archetype to determine individual heating characteristics with HOT2000 software:

- Homes were modeled to be single storey
- An aspect ratio of 1.5 was used, applied against average archetype floor area to define footprint dimensions
- Orientation is predominately East - West
- Each house has two large windows in the front and back, one window on each side, and two basement windows on each side. Default values for sizing and thermal properties were used.
- No cooling systems were considered
- No ventilation systems were considered
- Average EGH sample data was used for wall, ceiling, and foundation RSI values.
- Air leakage was modeled as the average HOT2000 default value (4.5 ACH)
- All models represent a pre-retrofit situation

Housing Archetypes: Energy

The housing modeling analysis produced the following energy characteristics for each housing archetype:

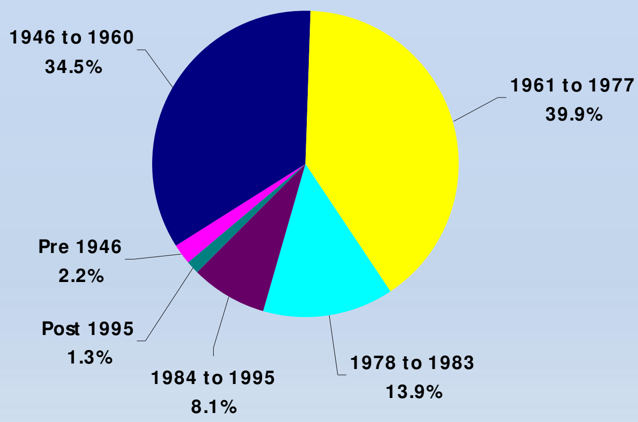
HOT2000 Simulation Results for EGH Archetypes						
Archetype	*01: Pre 1946*	*02: 1946-60*	*03: 1961-77*	*04: 1978-83*	*05: 1984-95*	*06: Post 1995*
Annual Heating (kWh)	10,685	11,134	11,591	10,250	10,893	19,168
Annual DHW (kWh)	4,273	4,259	4,259	4,256	4,263	4,256
Annual Thermal Energy (kWh)	14,958	15,393	15,849	14,505	15,156	23,424
Design Heat Loss (kW)	7.3	7.7	7.7	7.3	7.3	11.4
Peak Avg hourly DHW (kW)	3.1	3.1	3.1	3.1	3.1	3.1
Peak Design Load (kW)	10.3	10.8	10.8	10.3	10.3	14.4
Design Load @75% Diversity Factor (kW)	7.7	8.1	8.1	7.7	7.7	10.8
Properties in Study Area	1	400	119	12	12	20



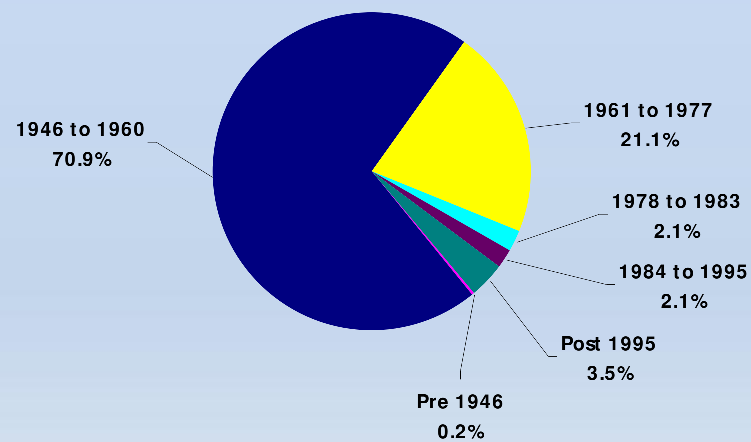
Annual thermal energy consumptions used in conjunction with monthly load profile in the DH model

Study Area Energy

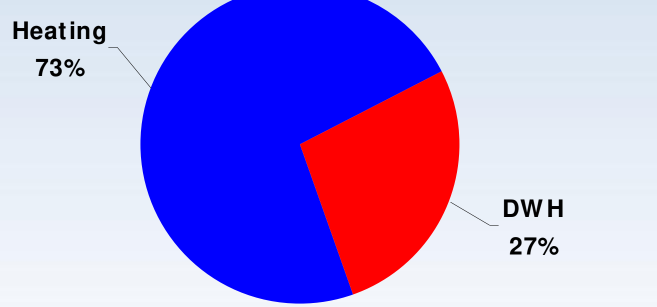
Housing Age Distribution for EGH Sample Data (Postal Code V3T)



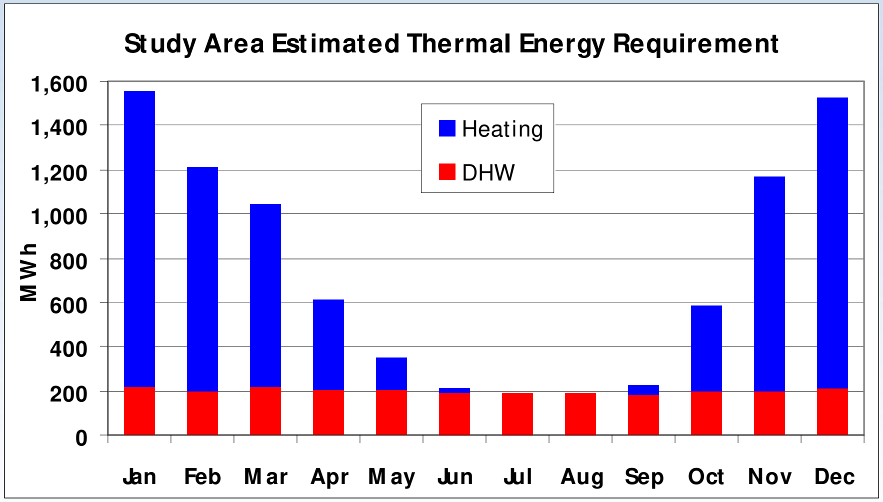
Housing Age Distribution for Study Area



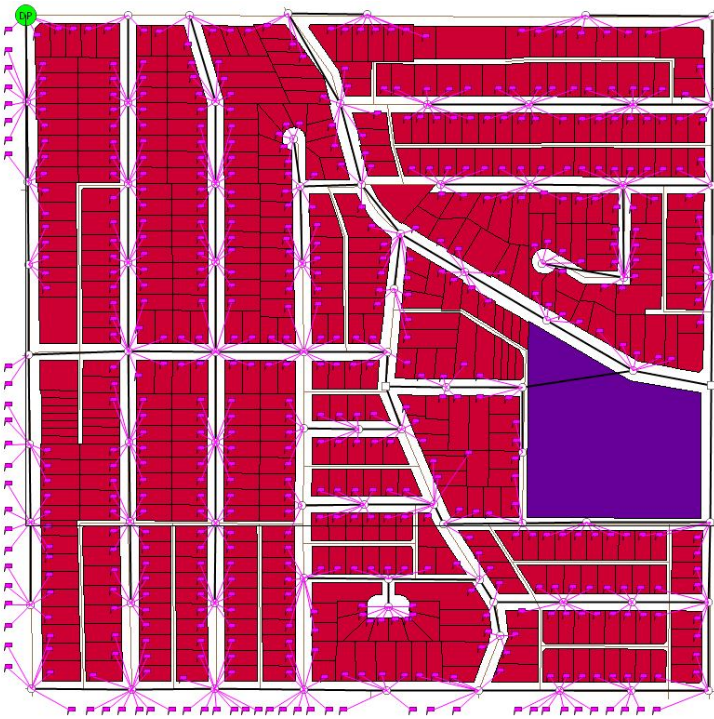
Study Area Annual Thermal Energy Breakdown



Study Area Estimated Thermal Energy Consumption:
8,883 MWh/yr



Model Development



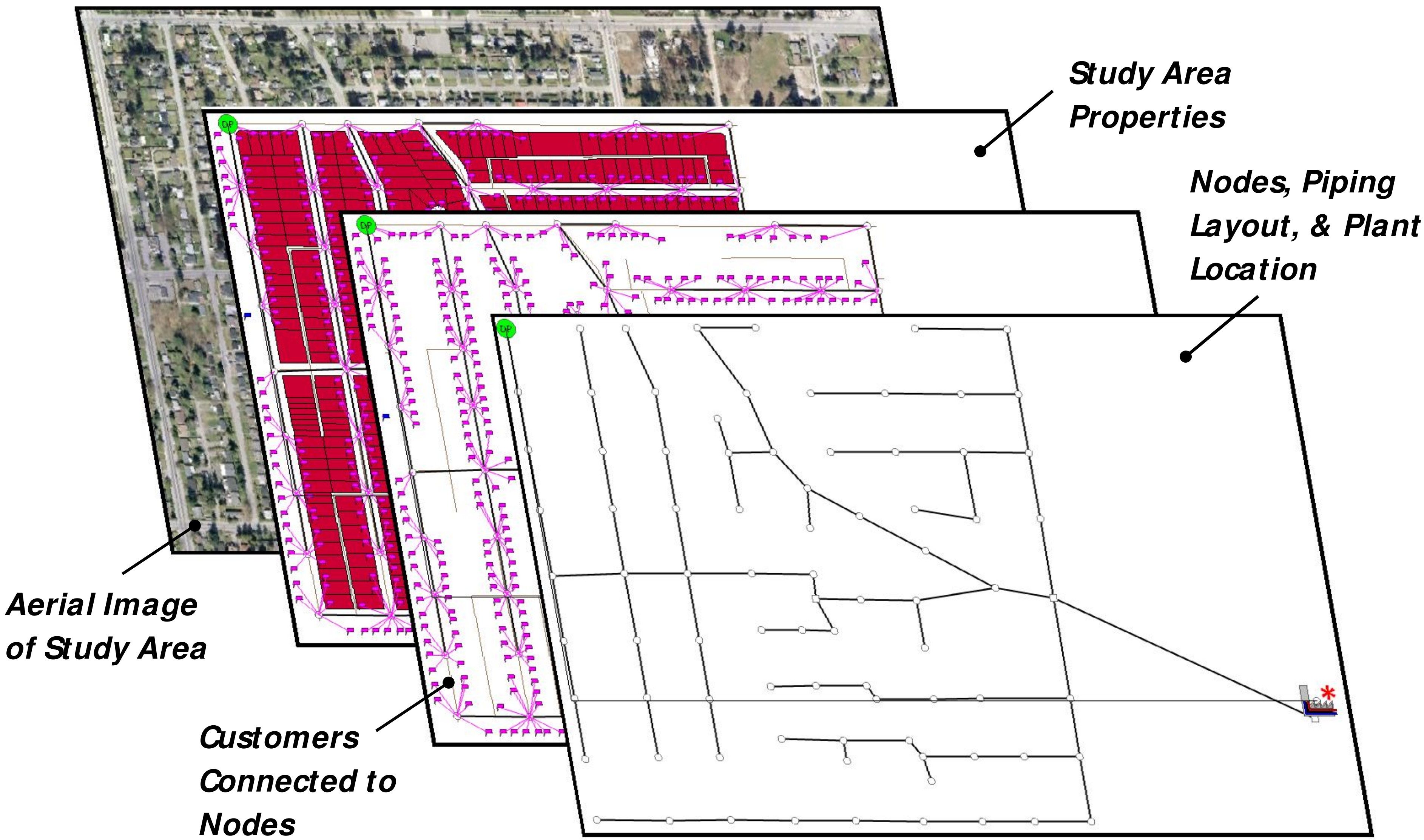
TERMIS model image

Using general GIS data received from the City of Surrey for properties in the study area, the spatial distribution of property age and associated thermal energy profiles were compiled.

A district heating model for the study area was created using TERMIS software, integrating the anticipated distribution piping route for the selected heating plant location.

Estimated thermal energy data was entered and individual consumers were integrated with nodes in the model to enable scenario analysis.

District Heating Model Images



Pipe Dimensioning Criteria

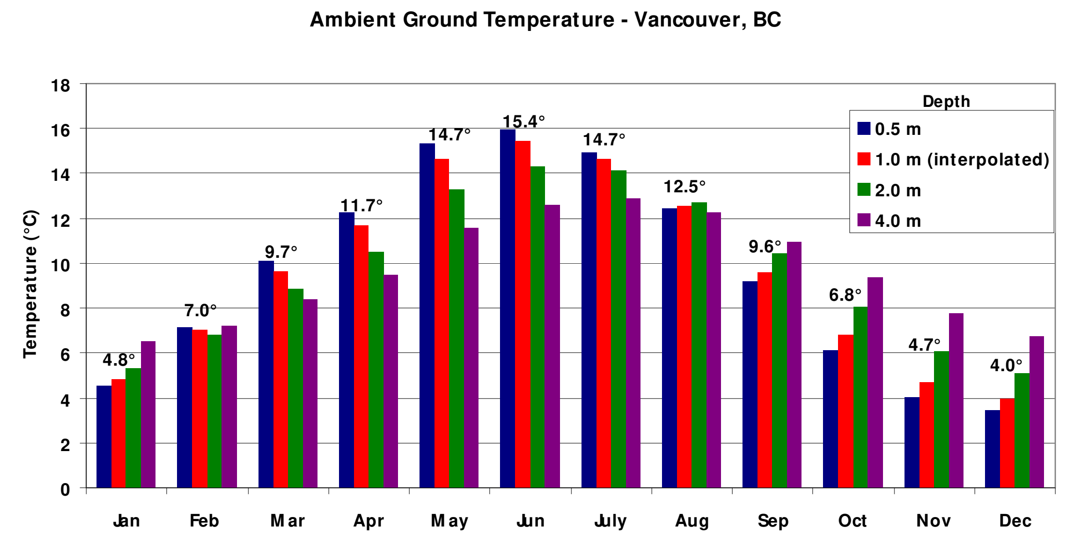
Heating loads used for pipe sizing were determined as the sum of the design heat loss for each house archetype and the peak average hourly DHW heating load, with an applied diversity factor of 75%. This relatively low diversity factor has been chosen due to the high quantity of customers in the analysis and expected variances in how each individual house is operated. The ambient temperature value at 1.0 m depth for January (4.8°C) was used for pipe dimensioning, corresponding to the period of peak heating load.

Three sets of pipe dimensioning calculations were completed using TERMIS, factoring average customer ΔT's of 20°C, 30°C, and 40°C, all with a connection rate of 100%, and meeting the following dimensioning criteria at peak conditions:

Max. Velocity: 3.5 m/s

Max. Pressure Gradient: 250 Pa/m

Each scenario simulation performed thereafter utilized the appropriately dimensioned distribution piping based upon scenario ΔT.



Values taken from EnergyPlus weather data files for Vancouver: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata/4_north_and_central_america_wmo_region_4/3_canada/CAN_BC_Vancouver.718920_CWEC.epw

Pipe Dimensioning Results

Factoring design customer loads and dimensioning criteria, the breakdown of system distribution piping by size for each condition resulted as follows:

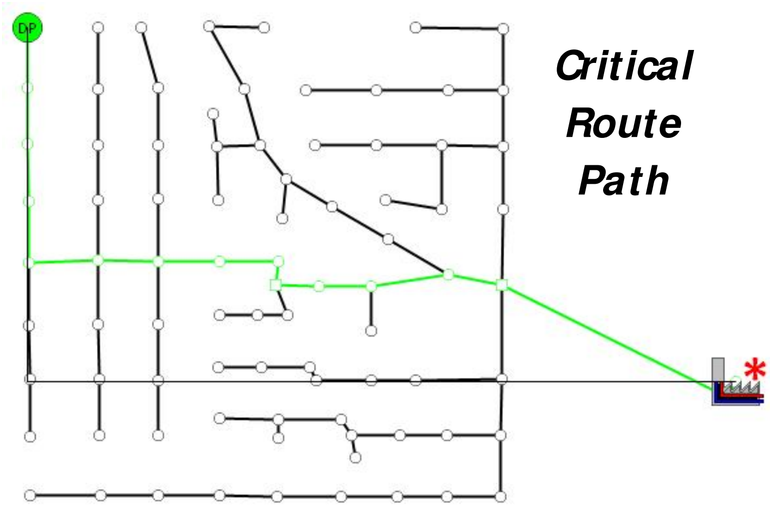
	ΔTav = 20°C	ΔTav = 30°C	ΔTav = 40°C
Pipe Size	Trench Length (m)	Trench Length (m)	Trench Length (m)
NW025	-	99	99
NW032	99	-	292
NW040	-	292	518
NW050	810	1,090	1,087
NW065	777	1,105	1,338
NW080	996	1,166	1,330
NW100	1,768	1,863	1,654
NW125	1,756	1,217	643
NW150	757	235	364
NW200	364	806	641
NW250	641	95	471
NW300	-	471	-
NW350	471	-	-
Total (m)	8,438		

TERMIS Database
Pipe Types

Type	Diameter mm	Heat Coefficient W/m/K	Roughness mm
NW018	16.0	0.14	0.02
NW020	21.7	0.14	0.06
NW028	24.0	0.18	0.02
NW025	28.5	0.18	0.06
NW032	36.8	0.19	0.02
NW040	42.7	0.21	0.06
NW050	54.7	0.24	0.06
NW065	69.9	0.29	0.06
NW080	82.5	0.3	0.06
NW100	106.9	0.31	0.06
NW125	132.5	0.37	0.06
NW150	160.1	0.43	0.06
NW200	209.1	0.47	0.06
NW250	262.0	0.46	0.06
NW300	311.7	0.53	0.06
NW350	343.4	0.52	0.06
NW400	444.6	0.74	0.06
NW500	495.4	0.71	0.06
NW600	593.6	0.72	0.06

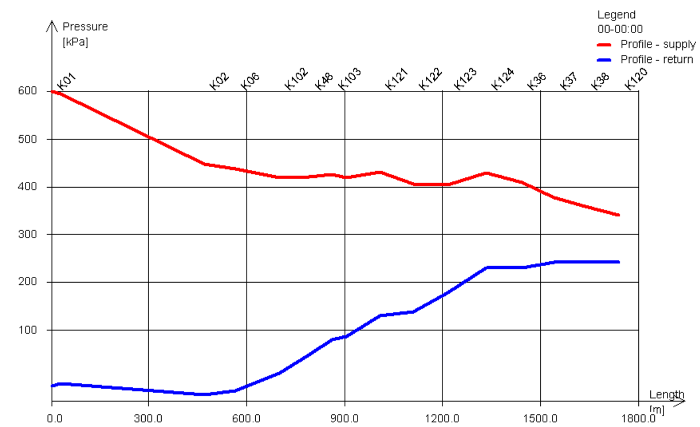
All piping was modeled as single supply and return lines using the default pipe properties from the TERMIS pipe database

Model Images – Design Conditions

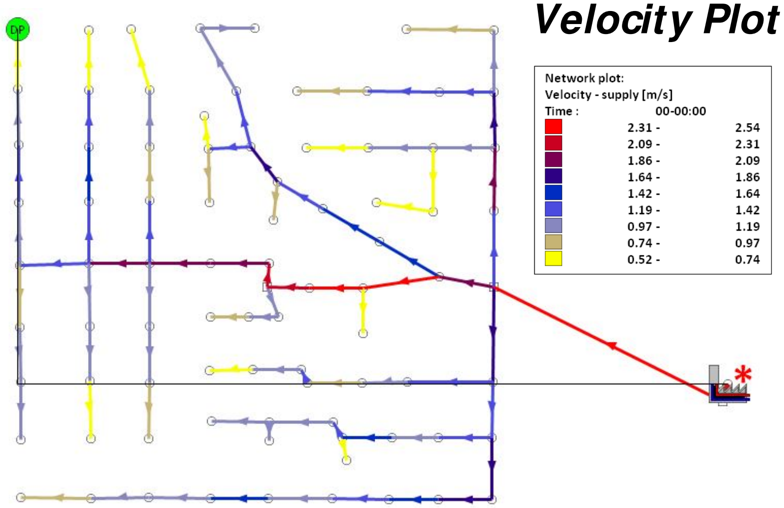


Critical Route Path

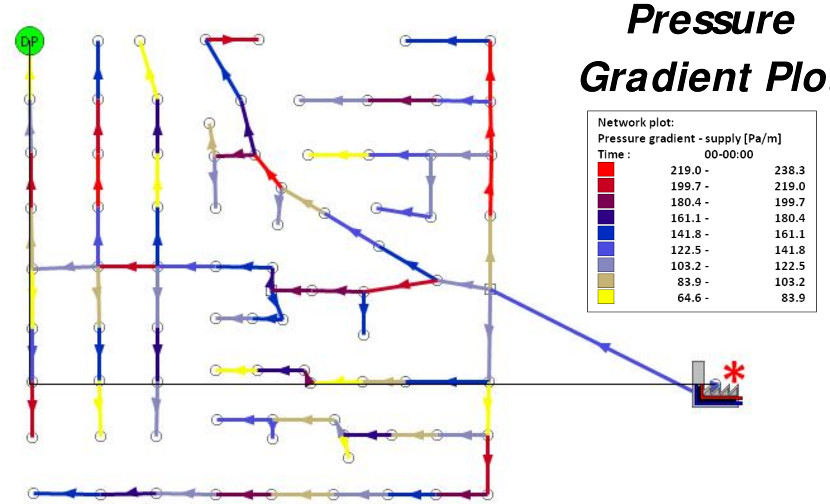
Critical Route Pressure Profile



Velocity Plot



Pressure Gradient Plot



Simulation Scenario Model

Using the '*Annual Cost Simulation*' feature in TERMIS, approximately 100 simulations were performed factoring scenarios of different household connection rates, supply temperatures, average customer ΔT's, and customer thermal loads to produce results for analysis.

Household Connection Rates:

- 50%, 60%, 70%, 80%, 90%, 100% (Randomly generated)

System Supply Temperatures

- Constant supplies of 90°C, 80°C, and 70°C, as well as a 90°C "Reset" scenario, operating at 90°C in winter, 70°C in summer, and 80°C in the shoulder seasons

Customer ΔTav:

- 20°C, 30°C, & 40°C

Customer Loads:

- 100% - Representing the modeled loads from the EGH archetype analysis
- 75% - Representing a decrease in customer thermal load due to widespread house energy retrofits or over-estimation of the EGH archetype models
- 125% - Representing an increase in customer thermal load due to infill or underestimation of the EGH archetype models

The TERMIS '*Annual Cost Simulation'* completes a series of steady-state simulations, (defined as monthly simulations for this analysis) over a one year period, each factoring different loads, supply temperatures, and ambient ground temperatures.

Service Piping

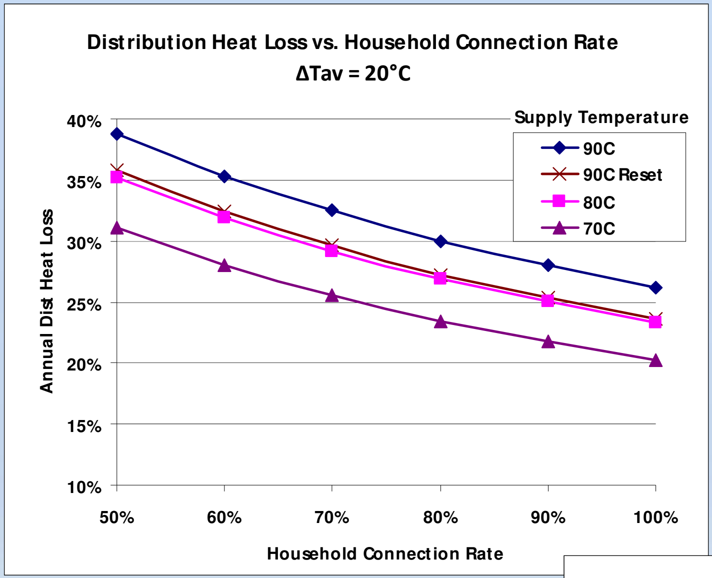
Due to limitations in the maximum allowable number of nodes that could be used with the current software licence, individual house service piping was not modeled with the main distribution system simulations. Heat losses associated with service pipes were estimated from separate simulation scenarios of modeling individual house connections, assuming standard 20 mm diameter pipe with an average trench length of 20 m, for each of the supply temperature and average ΔT scenarios.

Using the 'Annual Cost Simulation' analysis, TERMIS generates results based upon average monthly steady state conditions. For the service piping simulations, the results produced higher than expected heat loss due to resultant constant, low velocity flow rates, which are not necessarily representative of actual household operation.

For this reason, losses associated with service piping have not been included in this analysis.

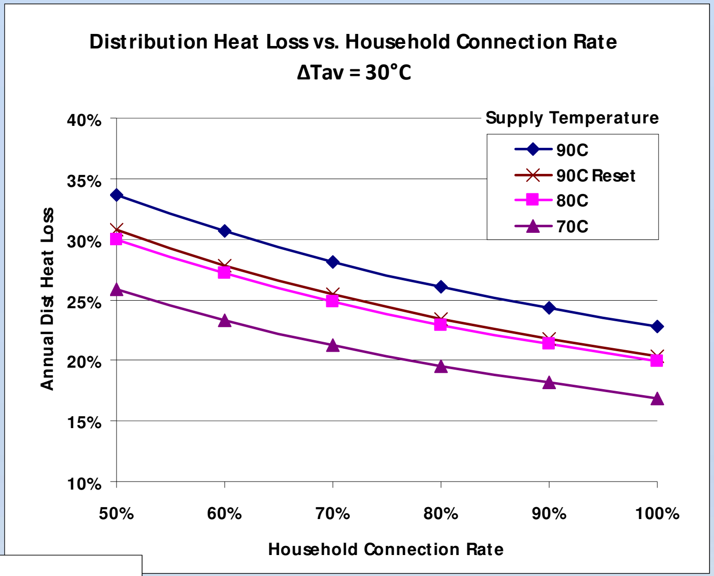
Future analysis may include the incorporation of hourly time series analyses to produce finer and more representative heating demand profiles for individual houses, which should generate more representative service piping heat loss calculations.

Model Results – Distribution Losses



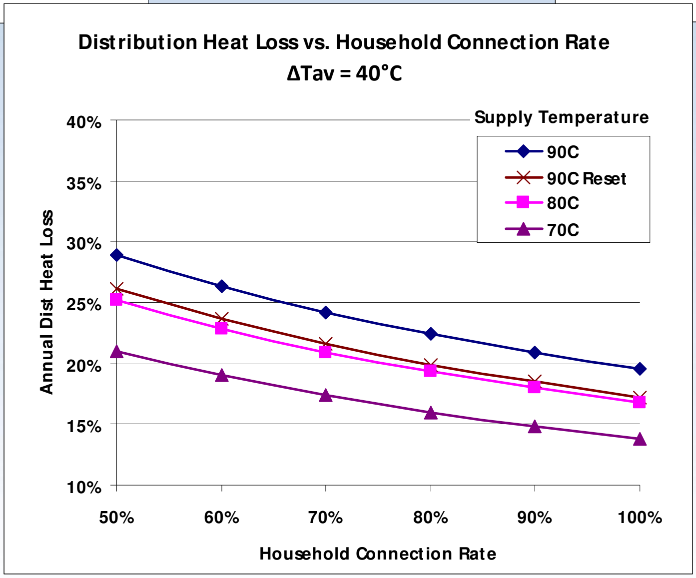
Connection Rate:

1% increase in connection rate yields ~0.2% decrease in annual heat loss



Supply Temperature:

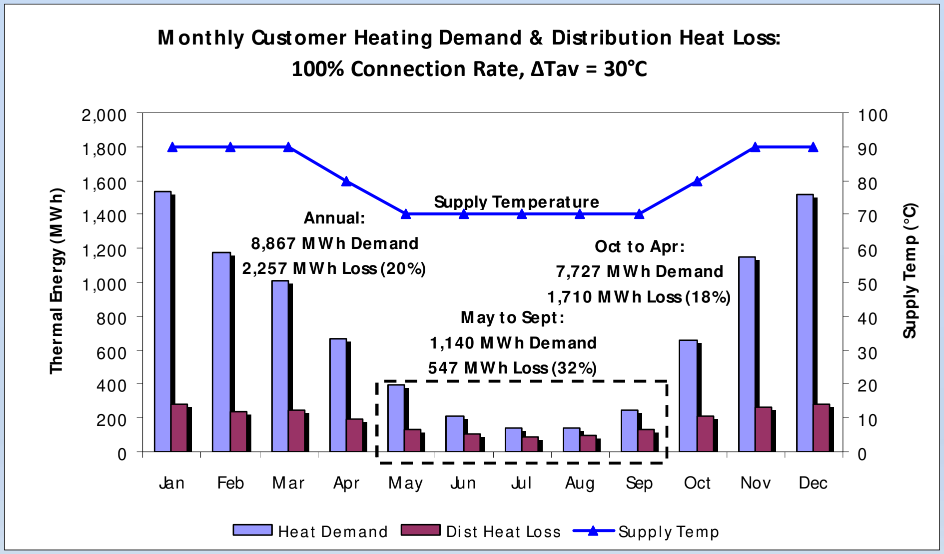
1°C decrease in supply temperature yields ~0.3% decrease in annual heat loss

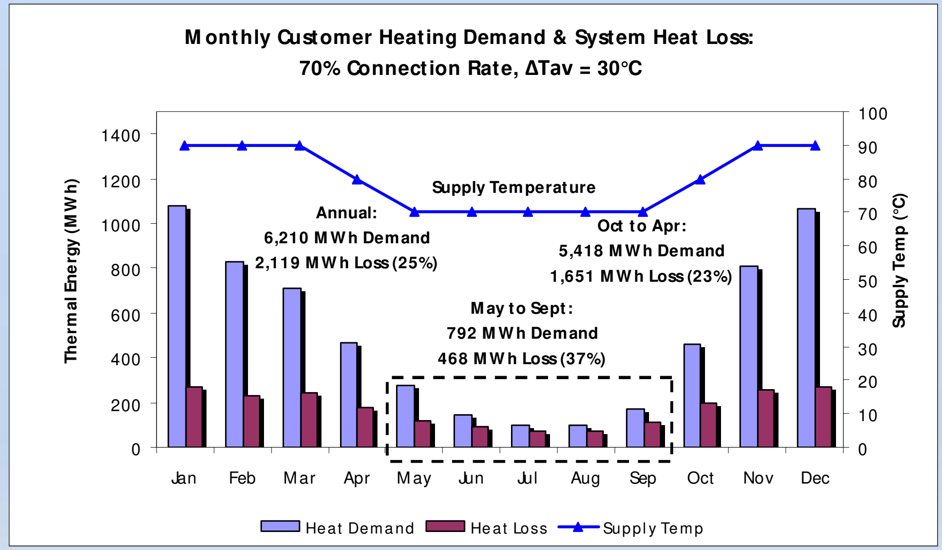


Customer ΔT:

1°C increase in customer ΔT yields ~0.3% to ~0.5% decrease in annual heat loss

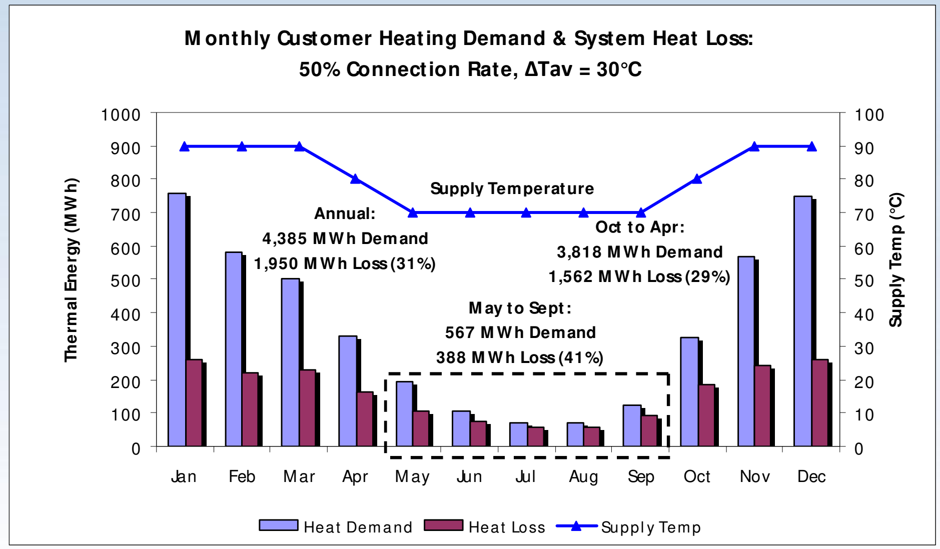
Monthly Profile Results





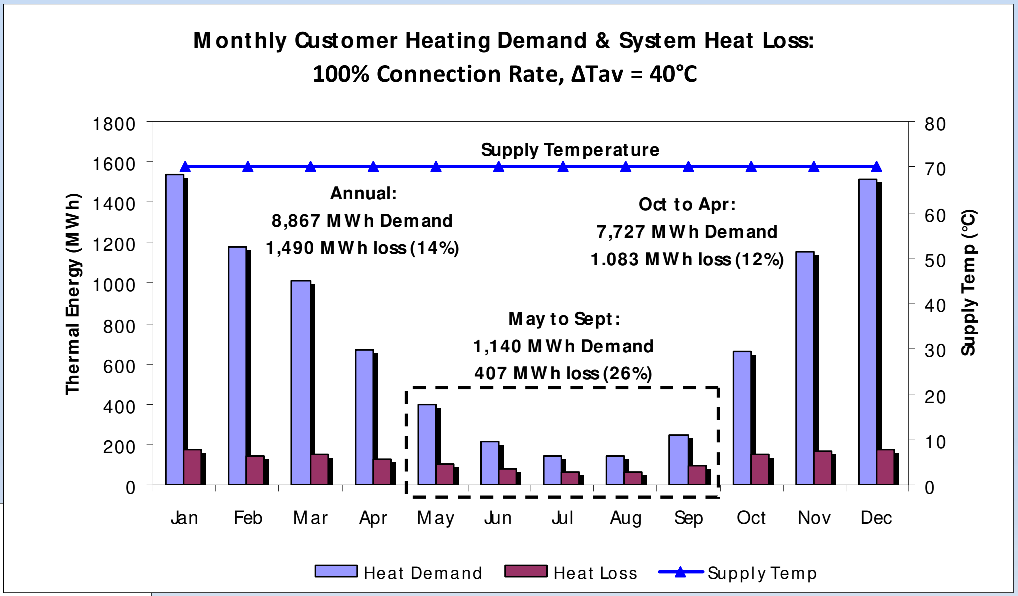
These graphics compare the result of having designed the DH system for 100% connection rate and then having fewer than expected homes connect.

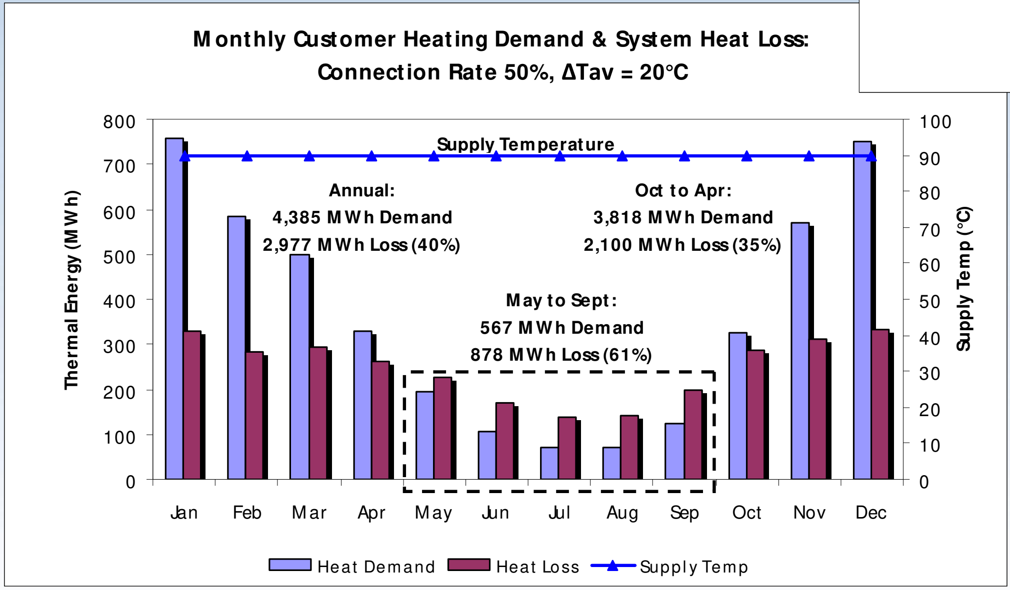
The significant difference in annual distribution heat loss highlights the importance of high connection rates in maximizing delivery efficiency.



Range of Model Results

These graphics represent the best and worst case scenarios modeled in terms of annual heat loss to highlight the vast differences in observed delivery performance at different supply temperatures, connection rates, and customer ΔT's.





Significant improvement in delivery efficiency is achieved through minimizing supply temperature, and maximizing the customer connection rate and customer ΔT.

Required BOS Efficiency

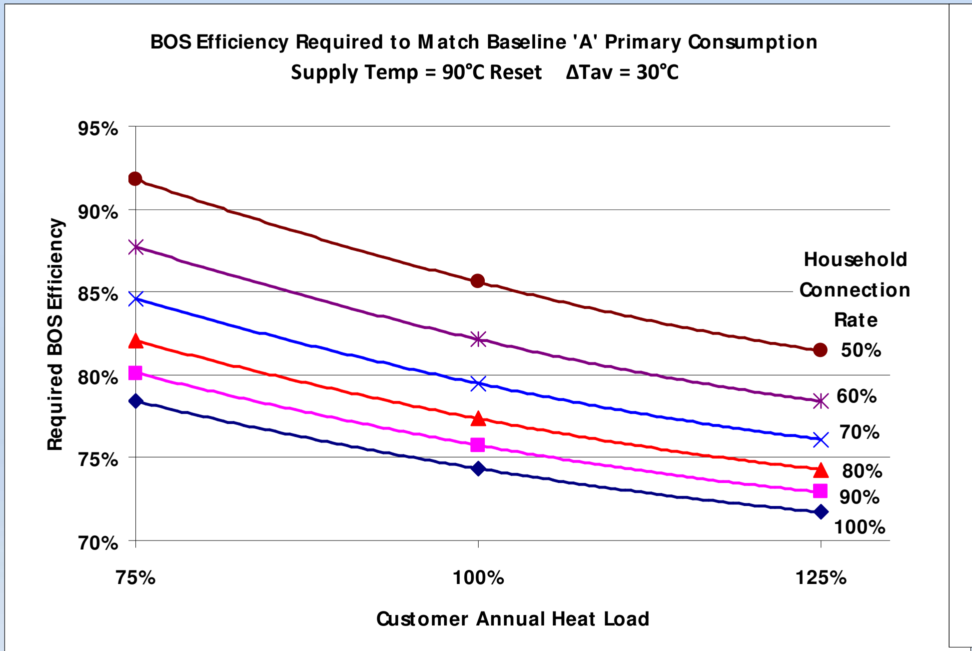
The TERMIS simulations quantified the distribution heat loss for each of the district heating system operation scenarios. Using those results, 'balance of system' (BOS) efficiency values were calculated to determine the required DH system performance needed to at least match the primary energy consumption of the study area factoring two baseline scenarios for houses having individual heating systems in the study area.

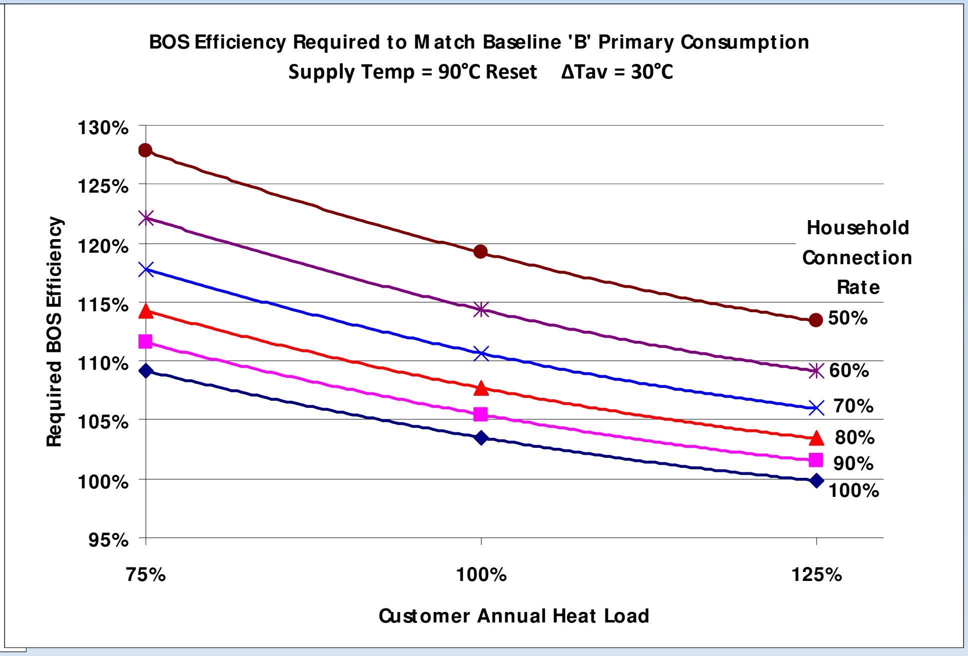
	Baseline 'A'	*Baseline 'B'*
Furnace Type	Standard, Continuous Pilot	Condensing
Steady State Efficiency	78%	94%
Seasonal Efficiency	61%	94%
DHW Type	Conventional Tank w. Pilot	Conventional Tank w. Spark Ignition
Energy Factor	0.55	0.62
Study Area Annual Primary Consumption (MWh)	14,964	10,747

The calculated BOS efficiency would include the combined energy performance of the heating plant, service piping, and all other system components influencing thermal delivery to the houses.

These baseline scenarios represent best and worst case possibilities for DH competitiveness against existing individual natural gas heating. Assuming all houses in the study area currently use natural gas for space and water heating, the likely real scenario would fall somewhere between the two baseline conditions.

Required BOS Efficiency





These results indicate that for a best case scenario, comparing the modeled DH system against the Baseline A situation, a minimum BOS efficiency of 74% would be needed in order to match the business as usual primary energy consumption of the study area.

Comparison of applying the DH system with Baseline B indicates the BOS efficiency would need to be greater than 100% for all scenarios as modeled.

Based upon these results, improving the primary energy consumption of the study area through integration of a DH system would be challenging. However, these results do represent a 'non-optimized' system with respect to distribution piping layout, piping type, and plant location.

Preliminary Costing

Using information received for typical installed costing[1], an estimate for the distribution piping capital cost was compiled for each pipe sizing scenario.

It has been assumed that all distribution piping is installed regardless of the rate of customer connection.

Estimated Installed Distribution Pipe Cost

Pipe Size	ΔTav = 20°C		ΔTav = 30°C		ΔTav = 40°C	
	Trench Length (m)	Estimated Trench Cost	Trench Length (m)	Estimated Trench Cost	Trench Length (m)	Estimated Trench Cost
NW025	-	-	99	$49,000	99	$49,000
NW032	99	$52,000	-	-	292	$154,000
NW040	-	-	292	$164,000	518	$290,000
NW050	810	$486,000	1,090	$654,000	1,087	$652,000
NW065	777	$513,000	1,105	$729,000	1,338	$883,000
NW080	996	$717,000	1,166	$840,000	1,330	$958,000
NW100	1,768	$1,415,000	1,863	$1,490,000	1,654	$1,324,000
NW125	1,756	$1,580,000	1,217	$1,096,000	643	$579,000
NW150	757	$757,000	235	$235,000	364	$364,000
NW200	364	$437,000	806	$967,000	641	$769,000
NW250	641	$897,000	95	$133,000	471	$660,000
NW300	-	-	471	$754,000	-	-
NW350	471	$848,000	-	-	-	-
		$7,702,000		***$7,111,000***		***$6,682,000***

Customer service piping has been assumed to be twin DN020 pre-insulated PEX pipe for all house connections.

Assuming the estimated pipe cost[2] received represents one-third of the total installed cost, an estimate of the service piping installed cost by customer connection rate was compiled as shown.

Estimated Service Piping Cost (DN020)

Connection Rate	Trench Length (m)	Estimated Installed Cost
100%	11,280	$859,000
90%	10,152	$773,000
80%	9,024	$687,000
70%	7,896	$601,000
60%	6,768	$515,000
50%	5,640	$429,000

1. Wiggin, M., Office of Greening Government Operations, PWGSC, personal correspondence, May 2011.
2. Issa, Z., Urecon Pre-Insulated Pipe, personal correspondence, April 2011.

Preliminary Unit Costing

Combining distribution and service pipe cost estimates against customer connection rate for the study area yields the following:

Installed Piping Capital Cost per Customer		Customer Connection Rate					
		100%	90%	80%	70%	60%	50%
Design	20	$15,179	$16,683	$18,601	$21,020	$24,311	$28,833
Customer	30	$14,131	$15,520	$17,290	$19,524	$22,562	$26,738
ΔT_{av}	40	$13,371	$14,675	$16,339	$18,438	$21,293	$25,216

Design **ΔT**

1°C increase in design ΔT yields ~0.6% decrease in capital cost per customer

It is noted that the shown cost estimates do not include the heating plant and all associated infrastructure, or considerations for household heating system retrofitting needed to integrate the DH supply at the house level.

Expanded financial analysis will be completed should improved estimates for installed component costing become available.

***Connection Rate*:**

1% increase in connection rate yields ~0.9% decrease in capital cost per customer

General Observations

- High distribution heat loss, especially in the summer, was evident in the analysis, highlighting the need to investigate improved system design characteristics for this type of application, such as alternative piping technologies, alternative heating plant locations, or possibly distributed storage.
- These potential system design improvements coupled with:
  - Maximized customer connection rates
  - Maximized customer ΔT's
  - Minimized system supply temperatures

  are necessary elements for improving the overall energy consumption of the study area.
- Preliminary costing estimates highlight the challenge of achieving financial viability. Maximizing the customer connection rate is a key factor to minimized unit capital costs.

Next Steps

Potential further analysis with the study area DH model include:

- Hourly Demand Analyses:
  - Integration of hourly demand analysis and the effect on system performance
- System Optimization:
  - Investigate the effect of integrating twin piping for most distribution and all service piping on annual heat loss
  - Investigate the effect of integrating thermal storage into the system
  - Conduct the analysis factoring alternative plant locations
- Additional System Loading:
  - Investigate the effect of adding additional loads, such as the school facilities in the study area, on the projected system performance
- Financial Analyses:
  - Completion of financial analysis as improved costing values become available

Acknowledgements

Financial support of this project has been provided through the Program of Energy Research and Development (PERD), a federal, interdepartmental program operated by Natural Resources Canada (NRCan). PERD funds research and development designed to ensure a sustainable energy future for Canada in the best interests of both our economy and our environment.

Special thanks are extended to personnel with the GIS Section and Engineering – Utilities department at the City of Surrey for supplying property data and planning information required for this analysis, as well as to the Support department of 7Technologies for providing software support.

Contact Information

Natural Resources Canada / Ressources naturelles Canada

Raymond Boulter

Community Energy Specialist

Natural Resources Canada - CanmetENERGY

Housing, Buildings, Communities and Simulation Group

580 Booth Street, 13-D4-4

Ottawa, ON Canada K1A 0E4

Telephone: (613) 943-0951

E-mail: Raymond.Boulter@NRCan-RNCan.gc.ca

Web: http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca